Compaction Behaviors of Black Cotton Soil on Basement Complex and Sedimentary Formation of Part of South-Western Nigeria

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Abstract: *Expansive soils are one of those kinds of soils whose volume change takes place while it comes in contact with water. It expands during the rainy season due to intake of water and shrinks during dry season. The wetting and drying process of a sub-grade layer composed of black cotton soil result into failure of pavements in form of settlement and cracking. Therefore, prior to construction of a road on such sub-grade, it is important either to remove the existing soil and replace it with a non-expansive soil or to improve the engineering properties of the existing soil by stabilization using additives such as egg shell powder and palm kernel shell which is source locally 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 7º24'45" and latitude 3º18'34". Another 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. In line with BS 1377 (1990) and other relevant codes, compaction tests were conducted on the black cotton soils on basement complex and sedimentary formation for the determination of maximum dry density, bulk density and optimum moisture content of the natural soils. From the results, the bulk and dry densities of black cotton soil on the sedimentary formation are higher than that of basement complex while the later required more test water content to achieve the maximum bulk and dry densities. The optimum moisture content of basement complex is higher than that of sedimentary formation. It could be seen from the results that the type of formation played a prominent role in their behaviors to the compactive efforts.*

Keywords: *Black Cotton Soil; Basement Complex; Sedimentary Formation; Dry Density; Optimum Moisture Content.*

Introduction

Black cotton soil is clay-rich soil that contains lime, iron, carbonate, magnesium, and a small amount of organic matter along with nitrogen, phosphorous, etc. in small quantities. It has a low bearing capacity, high moisture-absorbing power, low shear strength and high plasticity value. There is need for additional technique for its stability and to improve the strength of soil at the same time lowering the construction costs by the use of locally available material. Stabilization is mainly of three types namely physical, mechanical, and chemical. Mechanical stabilization is necessary after the adoption of either physical or chemical stabilization. Reinforcement is meant to hold the soil particles by way of friction and cohesion with the admixtures and mere physical stabilization cannot be relied on; hence, materials are mixed with soil, which performs both physical and chemical stabilization. Soil stabilization is widely employed for modifying the geotechnical properties of a soil to improve the engineering properties thereby increasing the strength of the soil, which in turn also reduce the construction cost. Black cotton soils are very poor and undependable sub-grade material for road project. The soils are very hard when dry but lose its strength completely when wet and thus become a global problem that poses several challenges to civil engineering projects. The soil absorbs water heavily during rainy season which results into swelling and softening of the soil, it loses its strength and becomes easily compressible, shrinks and cracks during the dry season, however, as a result of this, road built on black cotton soil experience early failure particularly in pavement with heavy traffic. In many situations, soils cannot be used directly as road pavement layers, foundation layers and as a construction material; hence the properties of those soils should be altered. Prior to construction of a road on such sub-grade, it is important either to remove the existing soil and replace it with a non-expansive soil or to improve the engineering properties of the existing soil by stabilization using additives such as egg shell powder and palm kernel shell which is source locally. Stabilization of the expansive soil can be of great value in improving the strength and/or bearing capacity of soil through controlled compaction test. Different methods are available to stabilize the soil and the method should be first analyzed in the laboratory before applying it on the field (BS1377, 1990; Chen.1975; Craig, 1987; Jones and Hockey, 1964; Joseph, 1981; Nelson and Miller, 1992; Ola, 1983; Radhey, 1998).

Background Study

The major principles of soil stabilization are to evaluate the soil properties, to decide lacking property of soil, choosing the effective method for stabilization and designing the stabilized soil mix sample. Gradation of the soil is also a very important property which is considered where the soil may be well-graded and is desirable as it has less number of voids or uniformly graded which could sounds stable but has more voids thus. It is therefore important to mix different types of soil together to improve the soil strength properties because it is very expensive to replace the problematic soil completely during construction. Advantages of soil stabilization are effective utilization of locally available soils and other suitable stabilizing agents. It is more economical both in terms of cost and energy to increase the bearing capacity of the soil and to provide more stability to the soil as embankment construction material leading to increase in workability and durability. Soil stabilization is done to reduce the permeability of the soil thus preventing water from entering into the soil layers (BS1377, 1990; Chen.1975; Craig, 1987; Jones and Hockey, 1964; Joseph, 1981; Nelson and Miller, 1992; Ola, 1983; Radhey, 1998). Soil stabilization is used in many sectors of the construction industry, roads, airport runways, building sites, etc. based on both economic and service life considerations. Stabilization of soil can be done by adding additives or without additives, the following are major methods of soil stabilization: soil cement stabilization is an intimate mix of soil, cement and water, compacted to form a strong base course and to increase compressive strength of the soil layer. Soil cement can be used as a sub-base or base course for all types of pavements. Soil-lime has been widely used as a modifier or a binder for high plastic soils which imparts binding action even for granular soils. Bitumen stabilized layer may be used as sub-base or base course for all the roads in which the basic principles are water proofing and binding of soil components which enhances its strength and the most commonly used materials are cut back and emulsion. Lime fly ash stabilization can be used for construction of embankments, rigid and semi rigid pavements and major constituents of fly ash are oxides of silica, aluminum, iron, calcium and magnesium. Fly ash properties vary widely and it has to be characterized before it is used for stabilization of soil layer. Mechanical stabilization is suitable for low volume roads which involve the correct proportioning of aggregates and soil which are adequately compacted to get mechanically stable layer. Compaction is one of the types of mechanical stabilization of soil to determine the moisture-density relationships for a given compactive efforts on black cotton soils on basement complex and sedimentary formation as well as load carrying capacity of the soil by improving the shear strength (BS1377, 1990; Chen.1975; Craig, 1987; Jones and Hockey, 1964; Joseph, 1981; Nelson and Miller, 1992; Ola, 1983; Radhey, 1998).

Methodology

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 7º24'45" and latitude 3º18'34". Another 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. In line with BS 1377 (1990) and other relevant codes, compaction tests were conducted on the black cotton soils on basement complex (Figure 1a) and sedimentary formation (Figure 1b) for the determination of maximum dry density, bulk density and optimum moisture content of the natural soils (Joseph, 1981; Ola, 1983; Craig, 1987; BS 1377, 1990).


a


b

Figure 1: Black cotton soil on (a) Basement Complex (b) Sedimentary Formation

Results and Discussion

The results of moisture content and bulk density for Igbo-Ora (Basement Complex), moisture content and dry density for Igbo-Ora (Basement Complex), moisture content and bulk density for Idogo (Sedimentary Formation) and moisture content and dry density for Idogo (Sedimentary Formation) are presented in Tables 1 to 4 respectively

Table 1: Moisture Content and Bulk Density - Igbo-Ora (Basement Complex)

Test water content (%)	14	16	18	20	22
Bulk density (Kg/m^3)	1855	1968	1998	1942	1895

Table 2: Determination of moisture content and dry density - Igbo-Ora (Basement Complex)

	Determination of moisture content									
Moisture can no	Ora1	Ora2	Ora3	Ora4	Ora5	Ora6	Ora7	Ora8	Ora9	Ora10
Test water content (%)	14		16		18		20		22	
Average percentage moisture content (%)	21.2		24.5		27.2		34.0		37.4	
Dry density (Kg/m^3)	1531		1580		1571		1450		1379	

Table 3: Moisture Content and Bulk Density - Idogo (Sedimentary Formation)

Test water content (%)	8	10	12	14	16
Bulk density (Kg/m^3)	1911	1926	2075	2055	2047

Table 4: Determination of moisture content and dry density - Idogo (Sedimentary Formation)

Moisture can no	Ido1	Ido2	Ido3	Ido4	Ido5	Ido6	Ido7	Ido8	Ido9	Ido10
Test water content (%)	8		10		12		14		16	
Percentage moisture content (%)	12.8		14.7		17.0		20.9		22.3	
Dry density (Kg/m^3)	1693		1679		1774		1700		1674	

From the results presented in Tables 1 and 2, the maximum bulk density for black cotton soil on basement complex is 1998 kg/m^3 at 18% test water content. At the same test water content, the maximum dry density is 1571 kg/m^3 at 27.2% moisture content. In addition to this, from the results presented in Tables 3 and 4, the maximum bulk density for black cotton soil on sedimentary formation is 2075 kg/m^3 at test water content of 12%. At the same test water content, the maximum dry density is 1774 kg/m^3 at 17% moisture content. From the results, the bulk and dry densities of black cotton soil on the sedimentary formation are higher than that of basement complex while the later required more test water content to achieve the maximum bulk and dry densities. The optimum moisture content of basement complex is higher than that of sedimentary formation. It could be seen from the results that the type of formation played a prominent role in their behaviors to the compactive efforts. Efforts are still ongoing to determine the relevant consolidation parameters and settlement indices of the eggshell powder palm kernel shell stabilized black cotton soils on basement complex and sedimentary formation.

Soil compaction is generally the cheapest method of soil stabilization available and is used to improve the undesirable physical properties of a soil to achieve the desired shear strength, structure and void ratio. There are many methods of stabilizing soil using chemicals such as lime, cement, lime-flyash, admixtures, phosphoric acid compounds, but these methods are usually more expensive and may utilize compaction methods in addition to the admixture since its incorporation into the soil mass may disturb the soil considerably. Compaction achieve soil stabilization through the input of energy into the soil by impact method, which is achieved in the laboratory using standard compaction test but in the field using nothing comparable. Using kneading action method, which is achieved in the laboratory, using Havard miniature apparatus (Hveen method) but in the field, using sheep foot roller and wobble wheel. In the case of vibration method which is achieved in the laboratory using vibratory table but in the field using vibratory rollers. Finally, using static (or dynamic) compression method which is achieved in the laboratory, using compression machine but in the field using smooth wheel rollers (BS1377, 1990; Chen.1975; Craig, 1987; Jones and Hockey, 1964; Joseph, 1981; Nelson and Miller, 1992; Ola, 1983; Radhey, 1998). Generally compaction efforts imparts to the soil an increase in shear strength since this is a function of density, an increase in swell potential, an increase in density, a decrease in shrinkage, decrease in permeability and decease in compressibility. From the list of soil properties affected by compaction, it can be seen that there is more to the problem of specifying compaction than merely requiring compaction to increase the density. It is also important to consider the side effects; fortunately this is not as serious as might be expected at first in view of the method of stipulating compaction which is often used. This comes about in specifying the type of soil to be used, that is, limiting the type of soil to which compaction criteria are applied on a given project to eliminate, for example, volume-change problems like black cotton soils. It is now recognized that the structure of the resulting soil mass (especially when fine-grained soils are present) is intimately associated with the compaction process and the water content at which the mass is compacted. This concept is extremely important for compacting the clay cores of dams (as one example), where settlement could cause cracks in the core. It has been found that the dispersed soil structure obtained by compacting these soils on the wet side of optimum results in a soil which has a somewhat lower shear strength but which can undergo large deformation without failure (cracking) and the resulting large leakage and/or actual dam failure (BS1377, 1990; Chen.1975; Craig, 1987; Jones and Hockey, 1964; Joseph, 1981; Nelson and Miller, 1992; Ola, 1983; Radhey, 1998). Compaction of the soil on the wet side of optimum also reduces the permeability, as compared with compacting the soil on the dry side of the optimum. Conversely, the flocculated structure resulting from compacting a clayey soil on the dry side of the optimum is less susceptible to shrinkage but is more susceptible to swell. The ultimate strength of soils with flocculated structures is higher at low strains than is the strength of soils with dispersed structure, i. e. the soil tends to brittle failure. The residual strength of the compacted on the dry side of optimum is nearly the same as the ultimate strength of soil compacted on the wet side of optimum. Thus, for highway works, where low strain beneath the pavement are desirable, the soil should be compacted at a water content from dry of optimum to optimum. The soil shell surrounding the clay core of an earth dam should be also compacted to produce a flocculated structure since strength is more important than seepage. The clay core, on the other hand should be compacted to produce a dispersed structure since large settlement are possible and soil would need to be able to tolerate these large strains without cracking with a resulting piping/seepage failure. From the above discussion, it is evident that compaction criteria should be based on a consideration of soil structure, strength, permeability, etc. as design properties needed rather than simply obtaining a compaction curve in the laboratory and requiring that the soil be compacted to some percent relative compaction although in many case especially where density (and settlement control) is the only needed property this does produce a satisfactory product. It could be seen that there is no field compaction counterpart to the laboratory impact method of soil compaction (BS1377, 1990; Chen.1975; Craig, 1987; Jones and Hockey, 1964; Joseph, 1981; Nelson and Miller, 1992; Ola, 1983; Radhey, 1998).

Conclusion

Compaction behaviors of black cotton soil on basement complex and sedimentary formation have been investigated. From the results, the bulk and dry densities of black cotton soil on the sedimentary formation are higher than that of basement complex while the later required more test water content to achieve the maximum bulk and dry densities. The optimum moisture content of basement complex is higher than that of sedimentary formation. It could be seen from the results that the type of formation played a prominent role in their behaviors to the compactive efforts.

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