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A. J. OLAREWAJU & R. R. AFOLABI
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# California Bearing-Ratio Characteristics and Behaviors of Black Cotton Soil on Basement Complex of Part of South-Western Nigeria

[1] Akinola Johnson OLAREWAJU and Rapheal Rafiu AFOLABI

Civil Engineering Department, Faculty of Engineering,
Federal University, Oye, Ekiti State, Nigeria.

E-mail: [1] akinolajolarewaju@gmail.com

**Abstract:** *Road construction as a viable means for economic advancement of any country requires much attention. The attention for this is in different facet and the mode of construction as well as cost of construction affects the quality and size of the road to be constructed. Developing nation with verse arable land and inter lands needs enough quality roads to link the rural areas with the urban areas where mainly agricultural activities are done in large scale. 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. In line with BS 1377 (1990) and other relevant codes, California Bearing-Ratio (CBR) tests were conducted on the materials of black cotton (on basement complex) to determine the suitability of the expansive soil for use as sub-grade, sub-base or base materials in road construction. It is evidently clear from the results that the CBR value of the soil is low and could be classified as poor soil. Even though the soil could be used as sub-grade, and in order to reduce the overall construction cost of highways, it will still be required that soil be stabilized with any of the locally available stabilized agents or materials.*

**Keywords:** *California Bearing Ratio, Sub-grade, Sub-base, Base Course, Pavement*

## Introduction

Roads traverse over different terrains and both competent and problematic sub-grade soils may be traversed. It has been noted to be difficult and sometimes impractical to re-route some road course because of the occurrence of poor sub-grade materials. Weak or problematic sub-grade materials eventually cause the deformation of the roads pavement structure as a result of their inability to support heavy vehicular loads (Zhu and Liu, 2008). Therefore, such unwarranted materials along the road corridor may require some improvements or reinforcements to enhance its usage. However, due to increasing population and industrialization throughout the world, there are various forms of waste and by-products being generated on daily basis that could be tested for their soil improvements properties. Few of such waste materials tested with positive results include blast furnace slag, saw dust, rice husk ash, cement kiln dust, bottom ash and fly ash. The engineering benefits obtained from using these industrial wastes to improve soils include reducing their thermal conductivity, decreasing weight of constructional materials, increasing tensile and compressive strength, restricting swelling tendencies and reducing soil brittleness (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008). Black cotton soil contains a high amount of clay and it is known to have low bearing capacity, low permeability, and high volume change. Due to these properties, black cotton soil is not used for the construction and building of civil engineering structures without stabilization. Road construction as a viable means for economic advancement of any country requires much attention. The attention for this is in different facet and the mode of construction as well as cost of construction affects the quality and size of the road to be constructed. Nigeria being a developing nation with verse arable land and inter lands needs enough quality roads to link the rural areas with the urban areas where mainly agricultural activities are done in large scale. For the produce to get to the urban centers where the end users and industries are located, the road network needs to be well constructed and articulated. Aside its importance in the agricultural sector, in urban centers, good roads help to reduce travel time and the wear and tie on vehicles. The construction of road at lower cost using black cotton soil is our focus rather than total replacement of the available soil (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008).

## Background Study

Properties of black cotton soil such as plasticity, compressibility and permeability can be altered by the addition of stabilizing agents but the main interest is usually in finding a means of increasing soil strength and resistance of softening water. Soil stabilization may be brought in three ways, by bonding the soil particles together, by water proofing them, or by combining and waterproofing. Bonding agents stabilize soils by cementing the particles together so that the effect of water on the structure is lessened. The effectiveness of this type of stabilizer depends on the strength of the stabilized matrix, on whether a bond is formed between the soil and the matrix and on whether individual particles or agglomerations of particles are bonded together. These stabilizing agents do not waterproof a soil, although a soil that has been successfully bonded together will absorb less water than untreated material owing to the reduced ability of the bonded soil to swell (Sherwood, 1993). The principle of a waterproofing agent is to maintain the soil at a low moisture content at which it has adequate strength for its purpose. In actual fact the water in the stabilized soil and the efficiency of the stabilizers in this group depends on how much the permeability of the soil is reduced. Very slight or no cementing action is obtained from these materials and, unlike the process of bonding, the degree of stabilization does not increase the stabilizer content but attains a maximum which is usually reached with less than 2 percent of stabilizer by weight of soil. Stabilizing agents that display both a bonding and a waterproofing effect are uncommon, although the two effects can be achieved together by using a mixture of a bonding and a waterproofing agent (Sherwood, 1993). The CBR test is essentially a laboratory test but in some instances the test is carried out on the soil in-situ. The laboratory CBR test consists essentially of preparing a sample of soil in a cylindrical steel mould and then forcing a cylindrical steel plunger, of nominal diameter 50 mm, into the sample at a controlled rate, whilst measuring the force required to penetrate the sample. CBR values may vary from less than 1% on soft clays such as black cotton soil to over 150% on dense crushed rock samples. Preparation of remoulded samples for the CBR test can be made in several ways. However, commonly used methods are static compression and dynamic compaction by using 2.5 or 4.5 kg rammer and using vibrating hammer (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008).

## 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 (Figure 1) 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. In line with BS 1377 (1990) and other relevant codes, California Bearing-Ratio (CBR) tests were conducted on the materials of black cotton (on basement complex) to determine the suitability of the expansive soil for use as sub-grade, sub-base or base materials (Joseph 1981; Craig, 1987; BS 1377, 1990).


Figure 1: Back cotton soil on basement complex (Igbo-Ora, Oyo State, Nigeria)

## Results and Discussion

The results of force on plunger for top and bottom against penetration for 4% to 20% moisture content in black cotton soil on basement complex are graphically presented in Figures 2 to 10 respectively, while the results of average CBR values are graphically presented in Figure 11.

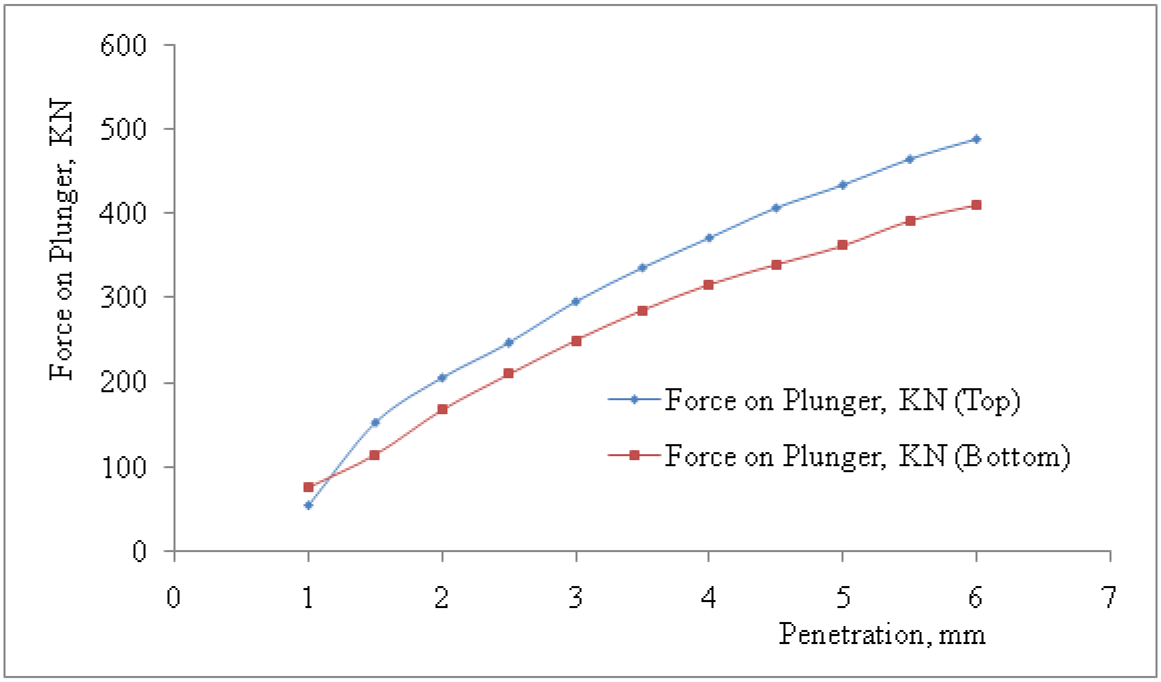


Figure 2: Results of force on plunger for top and bottom against penetration for 4% moisture content in black cotton soil on basement complex

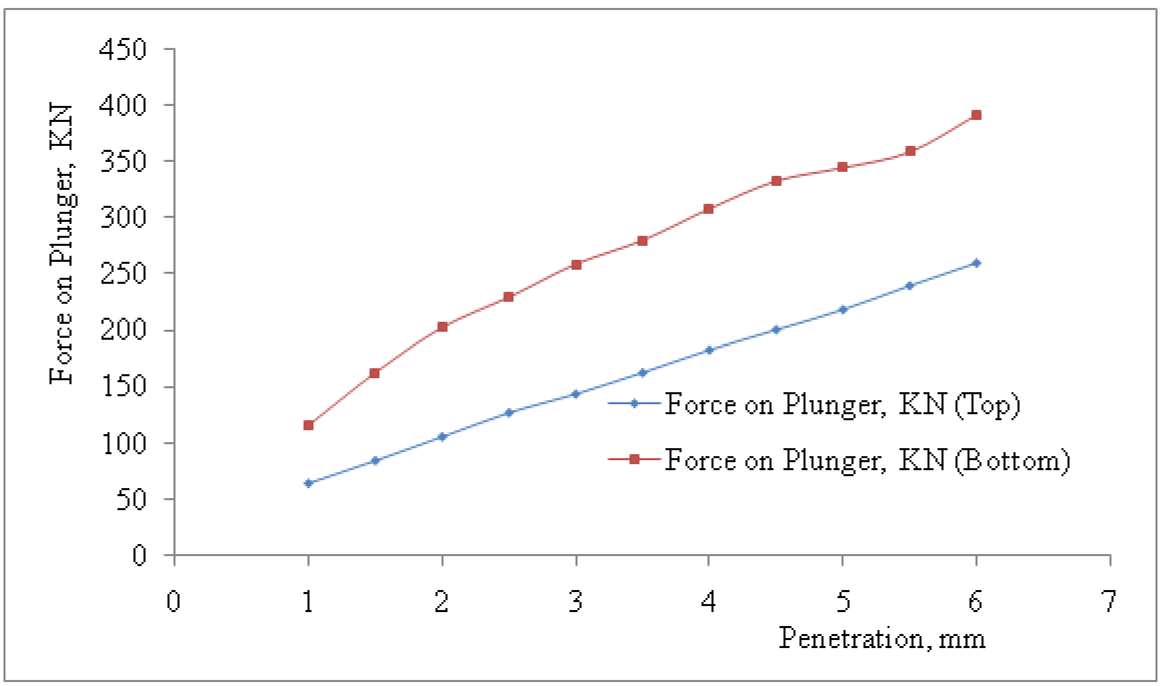


Figure 3: Results of force on plunger for top and bottom against penetration for 6% moisture content in black cotton soil on basement complex

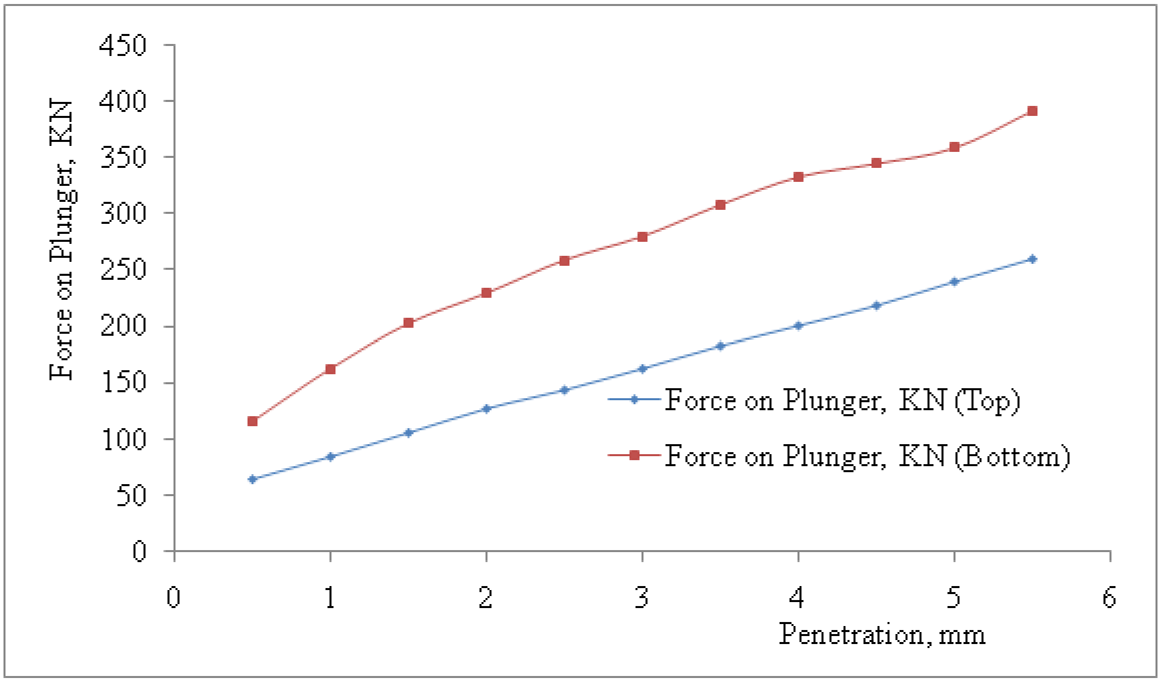


Figure 4: Results of force on plunger for top and bottom against penetration for 8% moisture content in black cotton soil on basement complex

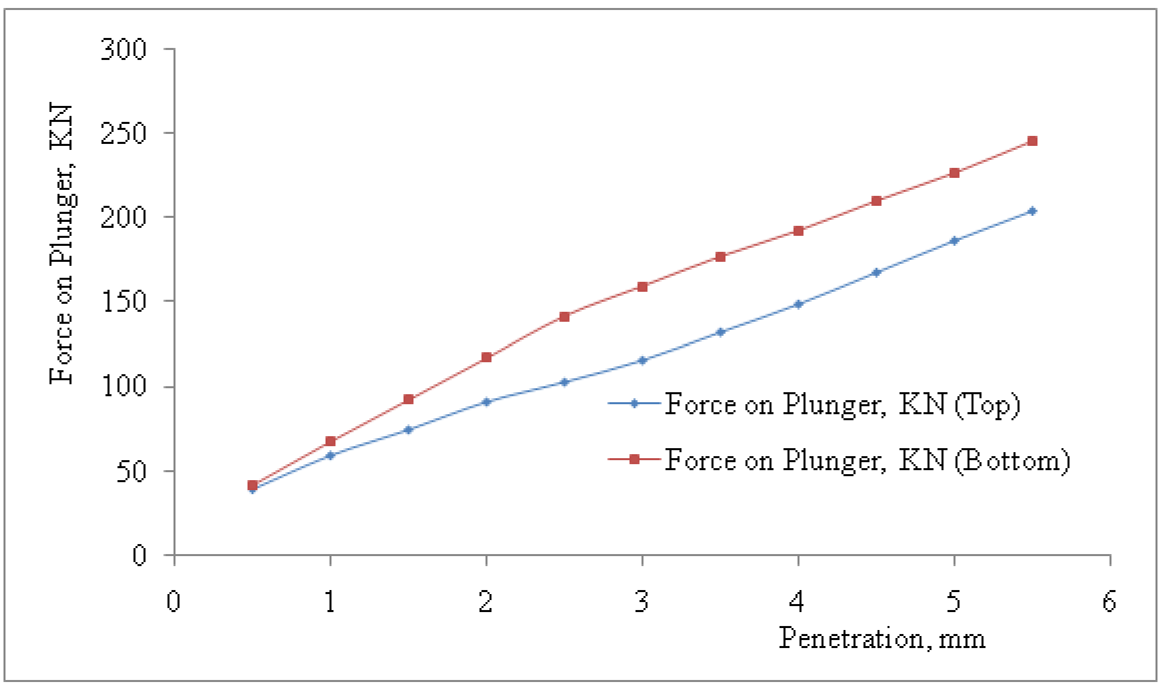


Figure 5: Results of force on plunger for top and bottom against penetration for 10% moisture content in black cotton soil on basement complex

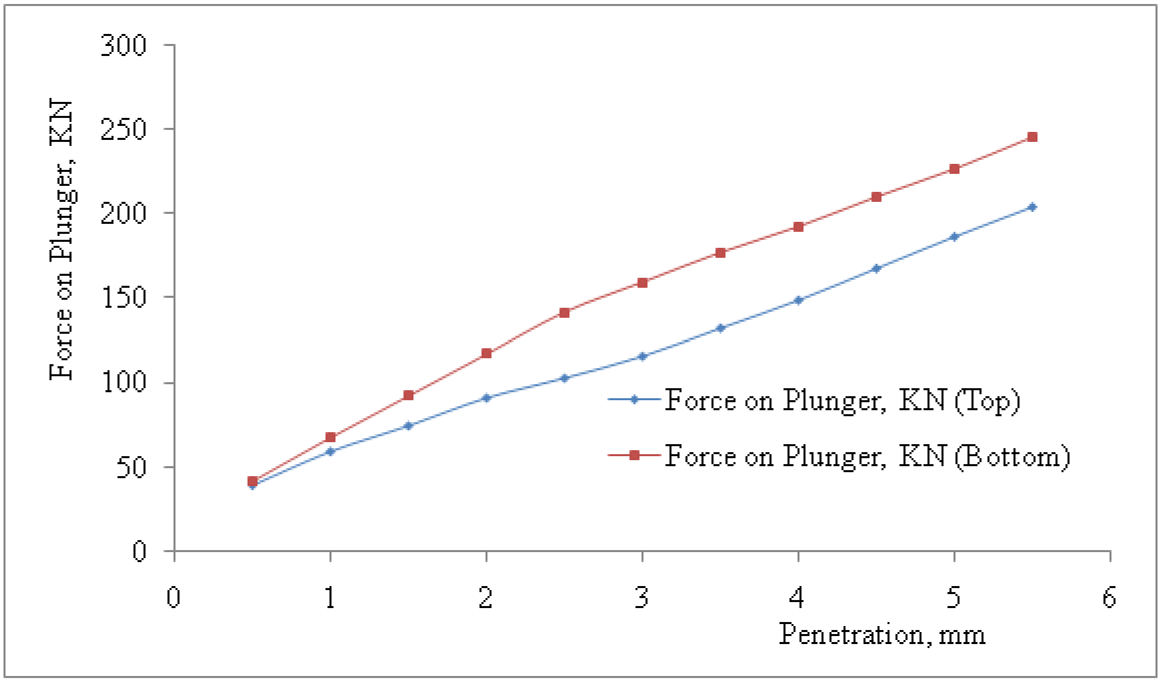


Figure 6: Results of force on plunger for top and bottom against penetration for 12% moisture content in black cotton soil on basement complex

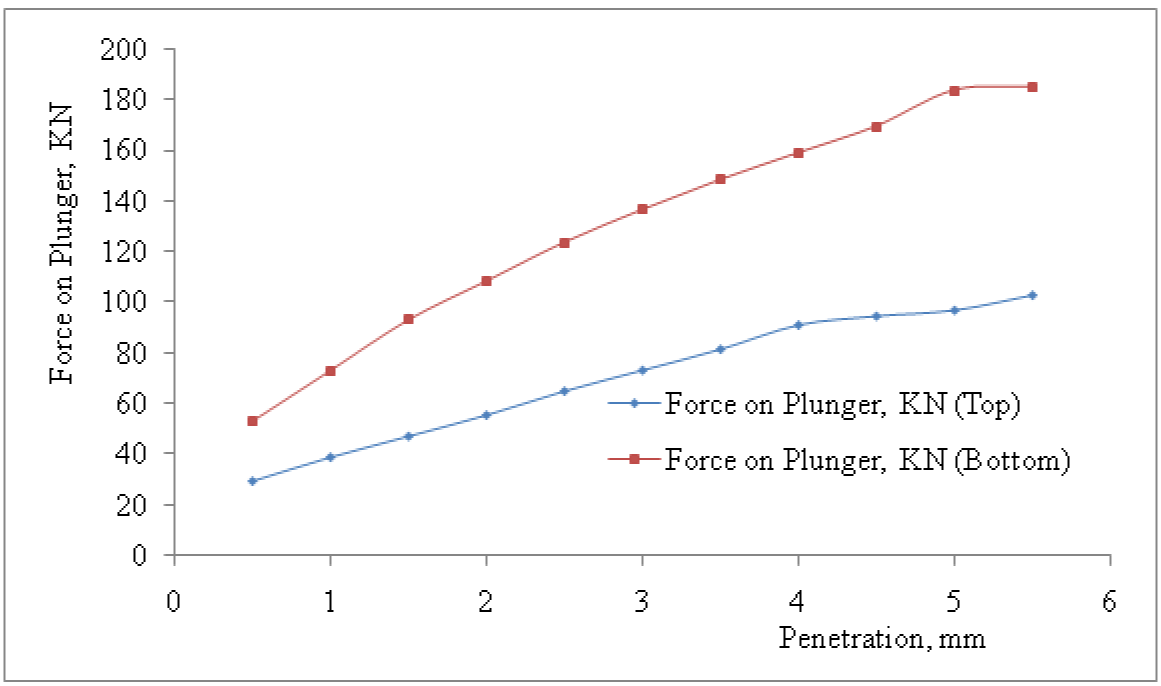


Figure 7: Results of force on plunger for top and bottom against penetration for 14% moisture content in black cotton soil on basement complex

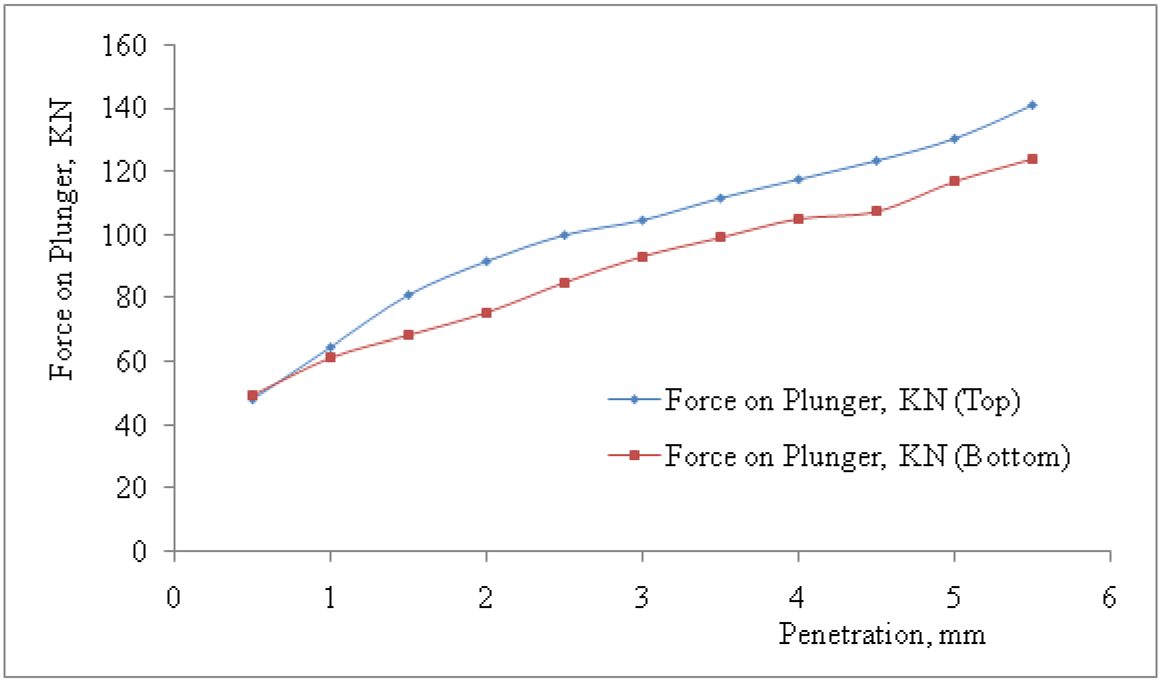


Figure 8: Results of force on plunger for top and bottom against penetration for 16% moisture content in black cotton soil on basement complex

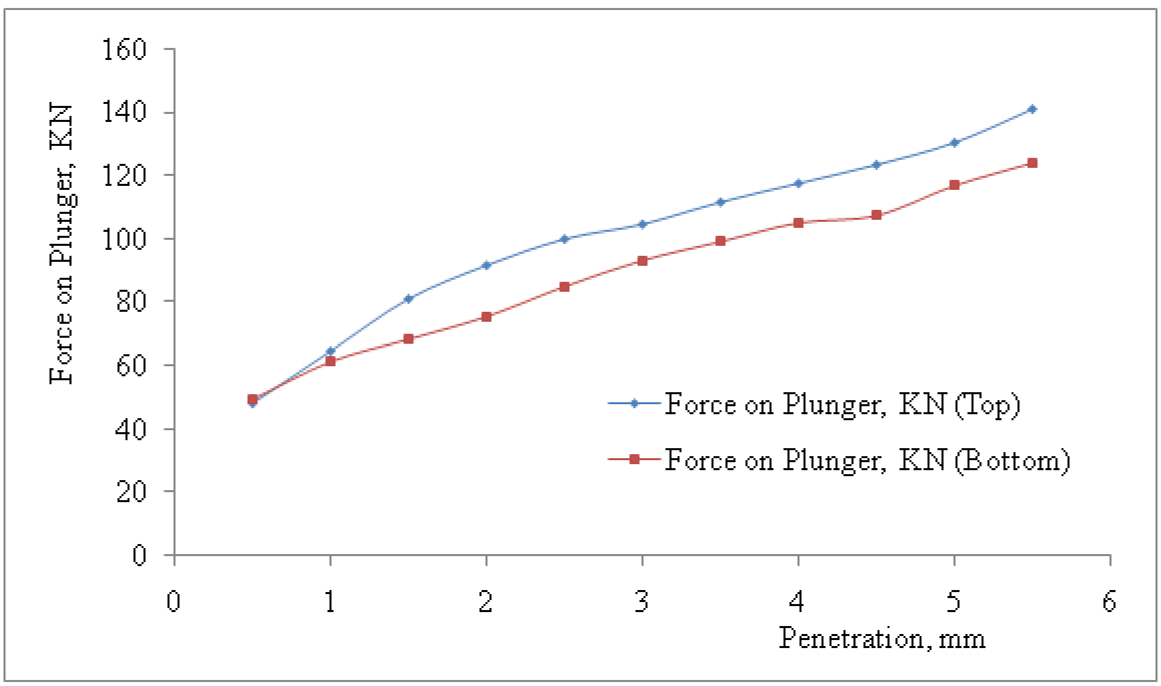


Figure 9: Results of force on plunger for top and bottom against penetration for 18% moisture content in black cotton soil on basement complex

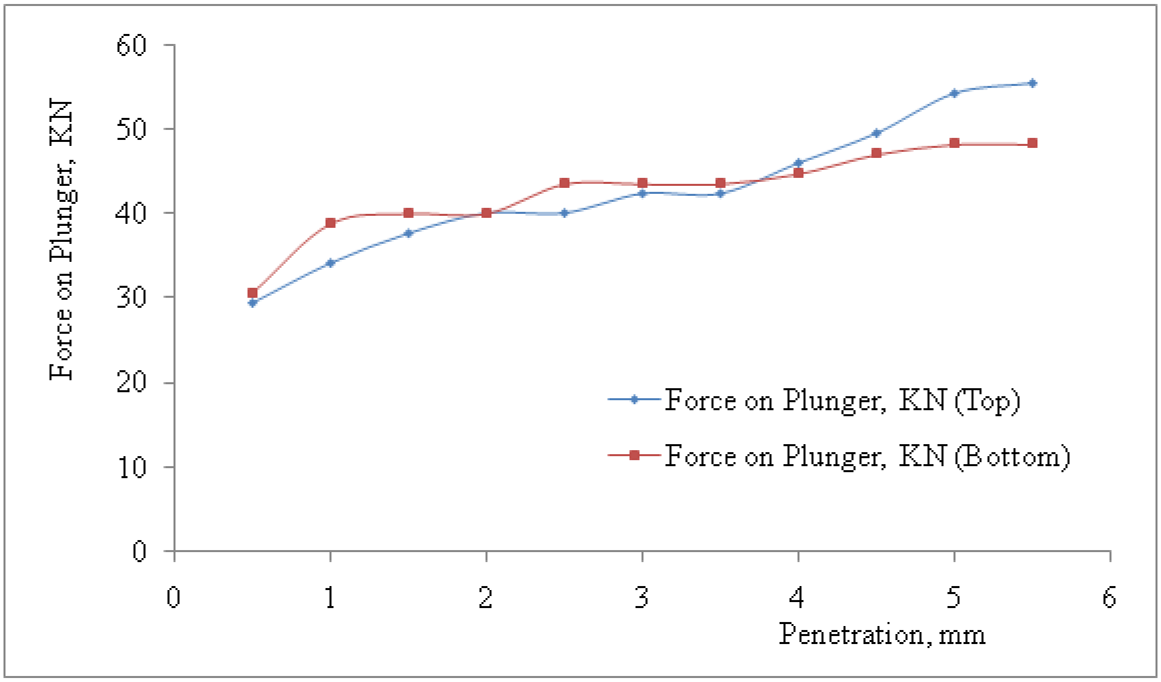


Figure 10: Results of force on plunger for top and bottom against penetration for 20% moisture content in black cotton soil on basement complex

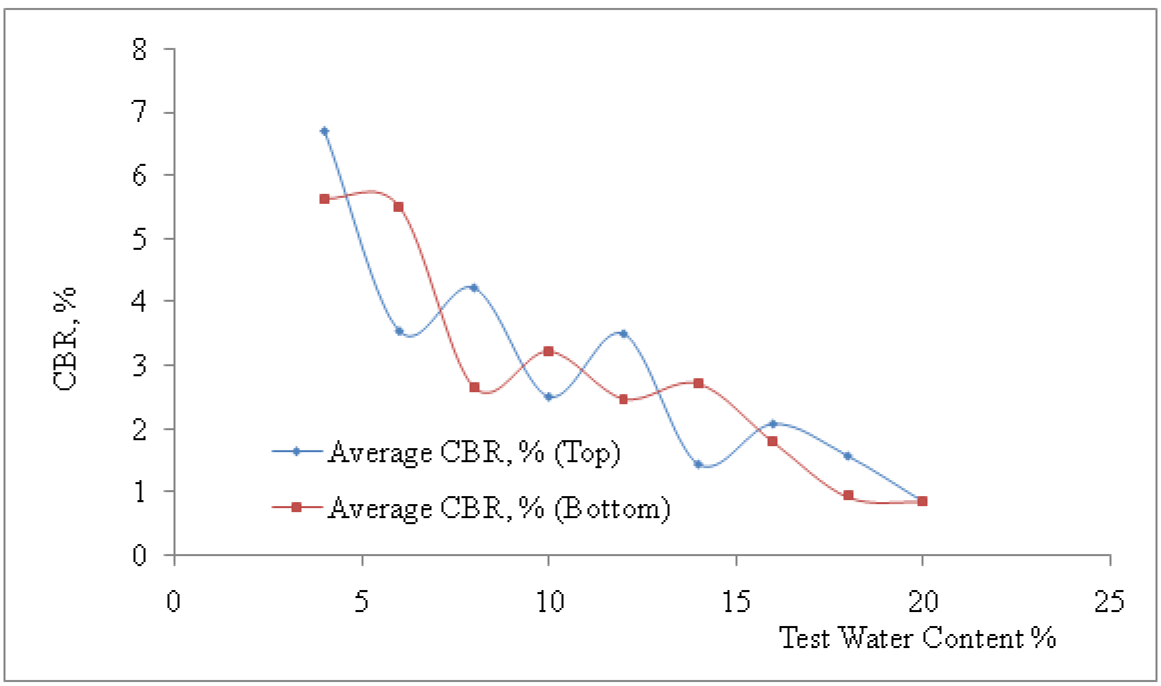


Figure 11: Results of average CBR for top and bottom against test water content in black cotton soil on basement complex

The strength of the sub-grade is the main factor in determining the thickness of the pavement although its susceptibility to frost must also be considered. The sub-grade strength is expressed in terms of its California Bearing-Ratio. The CBR is simply the resistance to a penetration of 2.54mm of a standard cylindrical plunger of 49.6mm diameter, expressed as a percentage of the known resistance of the plunger to various penetrations in crushed aggregate, notably 13.6KN at 2.5mm penetration and 20.4KN at 5.00mm penetration. CBR is a method used to evaluate the relative quality of sub-grade, sub-base and base soils for pavements. This test was developed by California Division of Highways in 1929 as a means of classifying the suitability of a soil for use as sub-grade or base course material in highway construction. During World War II, the U.S. Corps of Engineers adopted the test for use in airfield construction. The CBR test measures the shearing resistance of a soil under controlled moisture and density conditions. The test yields a bearing-ratio number and this number is not a constant for a given soils but applies only for the tested state of the soil. In passing, the test can be performed in the field or in-place/in-situ soil (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008). The CBR number is obtained as the ratio of the unit load required to effect a certain depth of penetration of the penetrating piston into a compacted specimen of soil at some water content and density to the saturated unit load required to obtain the same depth of penetration on a standard sample of crushed stone. In equation form, this is

$$CBR = \frac{test\ unit\ load}{standard\ unit\ load}\ 100 \text{ percent} \qquad \text{Equation 1}$$

To get the unit loads at penetrations of 2.5mm and 5.0mm, the measured load (values) are multiplied by 0.003 and 100. These unit loads could then be divided by standard unit load of 13.6 and 20.4 for 2.5mm penetration and 5.0mm penetration respectively. The value of 0.003 is the factor from the manufacturer of the CBR machine and different CBR machine with different factors. From this equation, it could be seen that the CBR number is a percentage of the standard unit load. In practice, the percentage symbol is dropped and the ratio is simply noted as a number such as 3, 45, 98. The CBR number is usually based on the load ratio for a penetration of 2.5mm. If, however, the CBR value at a penetration of 5mm is larger, the test should be repeated. If a second test yield also a larger CBR number at 5.0mm penetration, the CBR for 5.0mm should be used. The CBR number is used to rate the performance of soils primarily for use as bases and sub-grades beneath pavements or roads and airfields. For instance, if the CBR value is between 0 and 3, the general rating of the soil is very poor and such soil could be used as sub-grade but if the CBR value is between within 3 and 7, the general rating of the soil is between poor and fair and such soil could also be used as sub-grade (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008). In addition to this, if the CBR value is between 7 and 20, the general rating of the soil is fair and such soil could be used as sub-base. Furthermore, if the CBR value is between 20 and 50, the general rating of the soil is good and such soil could be used as base and sub-base. Finally, if the CBR value is greater than 50, the general rating of the soil is excellent and such soil could be used as base material. Many paving-design procedures are published in which one enters a chart with CBR number and read directly the thickness of sub-grade, base course, and/or flexible pavement thickness based on expected wheel loads. Sometimes the CBR is converted to a sub-grade modulus (also using charts) before entering the paving design charts. The relationship between the CBR so obtained and the thickness of pavement required is entirely empirical. Design charts have been compiled based on experience given the thickness of the construction required for a particular value of CBR, and particular condition of loading. If the CBR of the sub-grade is less than 2%, then thickness of the sub-base is determine by adding 150mm to the thickness required with a sub-grade CBR of 2%. This may not be sufficient for local soft spot (such as the presence of black cotton soil on either basement complex or sedimentary formation), and may require special treatment (like stabilization) during construction. The sub-base itself should have a CBR of not less than 30% (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008).

## Conclusion

California Bearing-Ratio (CBR) characteristics and behaviors of black cotton soil on basement complex have been investigated. The test water content required to achieve Maximum Dry Density (MDD) and Optimum Moisture Cont (OMC) is higher than that of sedimentary formation. It is evidently clear from the results that the CBR value of the soil is low and could be classified as poor soil. Even though the soil could be used as sub-grade, and in order to reduce the overall construction cost of highways, it will still be required that soil be stabilized with any of the locally available stabilized agents or materials. Soil stabilization is the alteration of properties of an existing soil to meet the specified engineering requirements especially the strength properties which are taken to mean the requirements for use in the various layers of road pavements. The main properties that may be required to be altered by stabilization include strength which increases the strength and thus stability and bearing capacity. In addition to this is the volume stability which controls the swell-shrink characteristics caused by moisture changes. Durability increase the resistance to erosion, weathering or traffic usage and permeability reduce the passage of water through the stabilized soil (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Kameswara, 1998; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008).

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