CBR Characteristics and Behaviors of Black Cotton Soil on Sedimentary Formation

[1] Akinola Johnson OLAREWAJU and Ayodeji Solomon ADEBESIN

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

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

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, low permeability, among others. The black cotton (expansive) soil was obtained from a borrow pit on the sedimentary formation at Idogo in Yewa South Local Government, Ogun State, South-Western Nigeria. The borrow site lies within the coordinates 6º 50' 6" N and 2º 58' 42" N. 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 sedimentary formation to determine the suitability of the natural expansive soil for use as sub-grade, sub-base or base materials. 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: *Sedimentary Formation, California Bearing-Ratio, Pavement, Strength*

Introduction

The natural layer or native soil upon which road is built is regarded as sub-grade and this naturally occurring material is regarded as a soil layer upon which an embankment is built. The sub-grade strength is therefore very important parameter that determines the thickness of the road pavement structure. Sub-grade strength is measured with the California Bearing Ratio (CBR) test which is also dependent on the soil composition. Road accident is usually caused by bad roads as a result of wrong application of constructional materials especially laterite and black cotton soil as sub-base and base material by construction companies (Oke et al. 2009). For a material to be used as either a base course or sub-base course depends on its strength in transmitting the axle-load to the sub-soil and or sub-grade. The characteristics and durability of any constructional material is a function of its efficiency in response to the load applied on it. The mineralogical composition of the lateritic soil and black cotton soil have an influence on the geotechnical parameters such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity, CBR, petro graphic properties (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Olarewaju and Afolabi, 2022; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008).

Background Study

An engineering definition of black cotton soil is a dark grey or black soil with a high content of clay usually over 50% in which montmorrilonite is the dominant clay mineral and are commonly expansive. Tropical black clays are formed residually by weathering and two groups of parent rock materials have been associated with the formation of expansive soils. The first group comprises sedimentary rock of volcanic origin while the second groups of parent materials are basic igneous rocks (Singh et al. 2018). Expansive soils are seen mostly as tropical black clay soils also known as black cotton soils which are produced from the breakdown of basic igneous rocks, where seasonal variation of weather is extreme. Sedimentary rocks are produced by the weathering of preexisting rocks and the subsequent transportation and deposition of the weathering products. Weathering refers to the various processes of physical disintegration and chemical decomposition that occur when rocks at Earth's surface are exposed to the atmosphere and the hydrosphere. These processes produce soil, unconsolidated rock detritus, and components dissolved in groundwater and runoff. Erosion is the process by which weathering products are transported away from the weathering site, either as solid material or as dissolved components, eventually to be deposited as sediment. Any unconsolidated deposit of solid weathered material constitutes sediment. It can form as a result of deposition of grains from moving bodies of water or wind, from the melting of glacial ice, and from the down slope slumping of rock and soil masses in response to gravity, as well as by precipitation of the dissolved products of weathering under the conditions of low temperature and pressure that prevail at or near the surface of the earth. The solutions to roads and highways on black cotton soil deposit on sedimentary formation must be long-term, sustainable, and cost effective, from local access roads to major urban and rural strategic routes. The design of highways, roads, and streets requires a delicate balance between the physical demands of a project, the realities of constraints faced by owners and operators, and the need for the design to recognize the setting of the asset in the environment. From feasibility studies to planning, design, procurement, construction supervision, and post-construction assessments, engineering expertise is required to ensure optimal efficiency and safety, while minimizing costs and environmental impacts (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; Knappet and Craig, 2012; O'Flaherty, 2002; Oke et al. 2009; Olarewaju and Afolabi, 2022; Sherwood, 1993; Singh et al. 2008; Zhu and Liu, 2008).

Methodology

The black cotton (expansive) soil was obtained from a borrow pit on the sedimentary formation at Idogo in Yewa South Local Government, Ogun State, South-Western Nigeria. The borrow site (Figure 1) lies within the coordinates 6º 50' 6" N and 2º 58' 42" N. 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 sedimentary formation) to determine the suitability of the expansive soil for use as sub-grade, sub-base or base materials (BS1377, 1990; Craig, 1987; Joseph, 1981; Knappet and Craig, 2012).

Figure 1: Back cotton soil on sedimentary formation (Idogo, Ogun State, Nigeria)

Results and Discussion

The results of force on plunger for top and bottom against penetration for 4% to 16% test water content in black cotton soil on sedimentary formation are graphically presented in Figures 2 to 8 respectively, while the results of average CBR values are graphically presented in Figure 9.

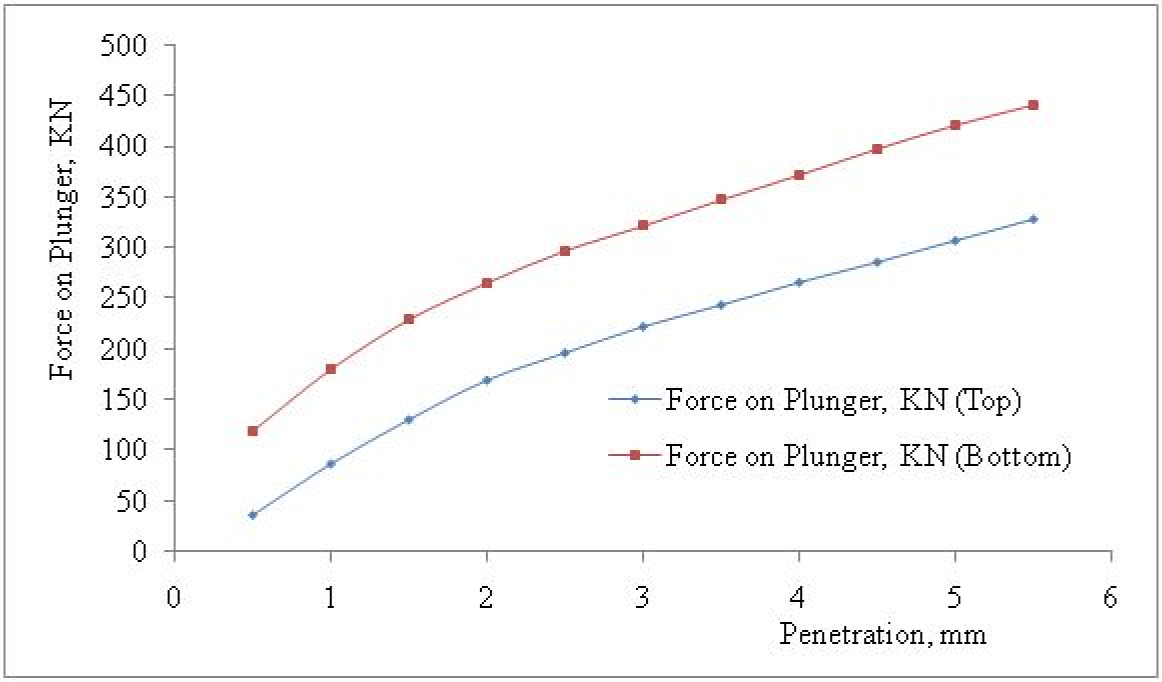

Figure 2: Results of force on plunger for top and bottom against penetration for 4% moisture content in black cotton soil on sedimentary formation

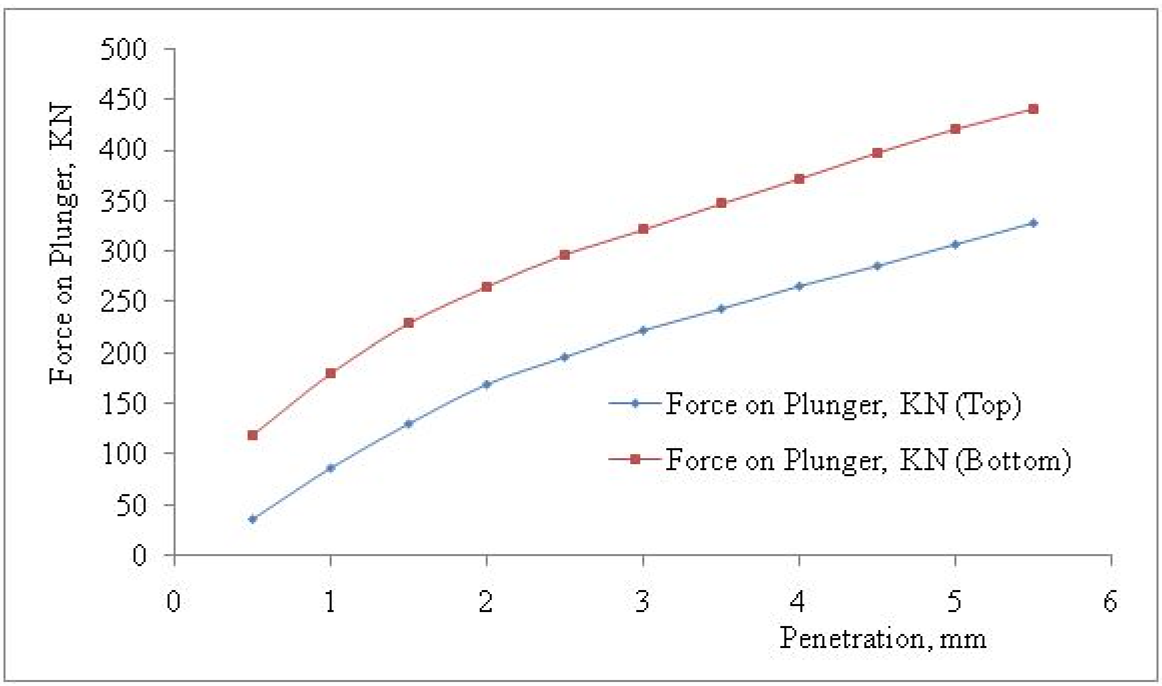

Figure 3: Results of force on plunger for top and bottom against penetration for 6% moisture content in black cotton soil on sedimentary formation

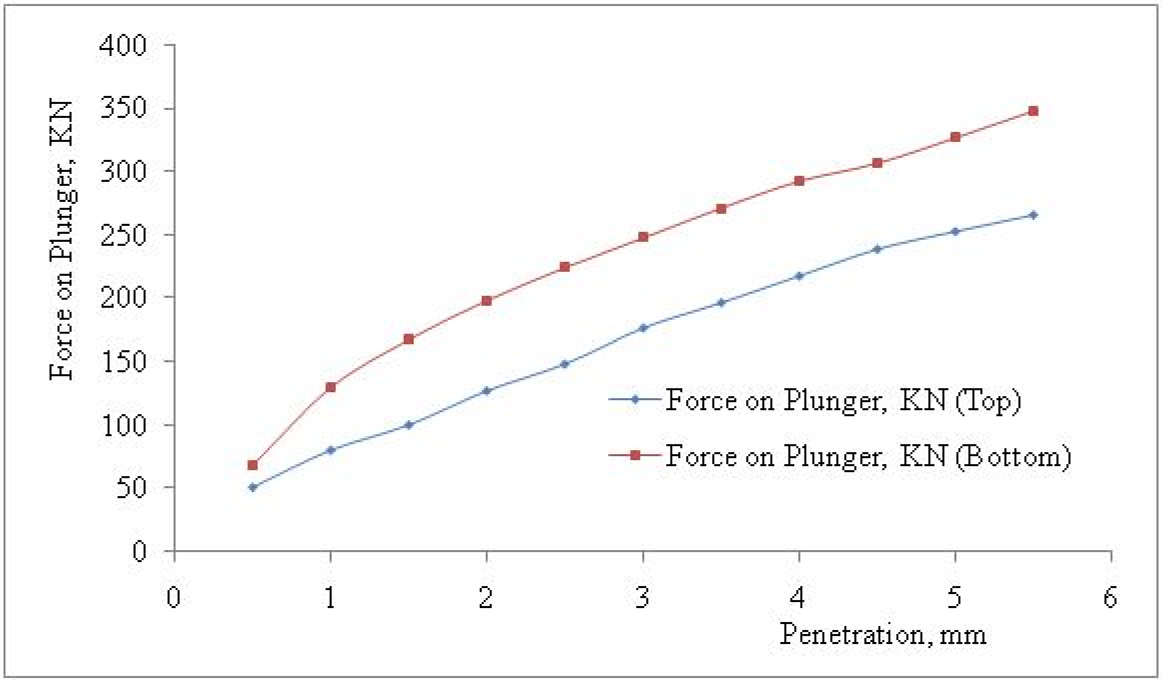

Figure 4: Results of force on plunger for top and bottom against penetration for 8% moisture content in black cotton soil on sedimentary formation

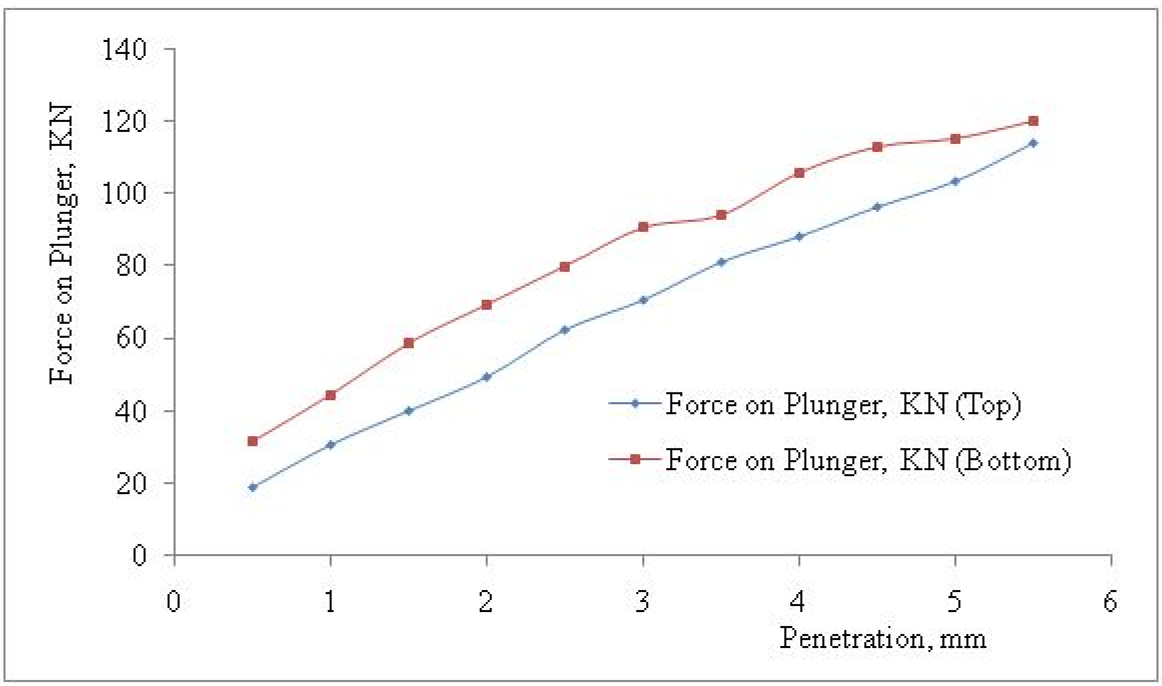

Figure 5: Results of force on plunger for top and bottom against penetration for 10% moisture content in black cotton soil on sedimentary formation

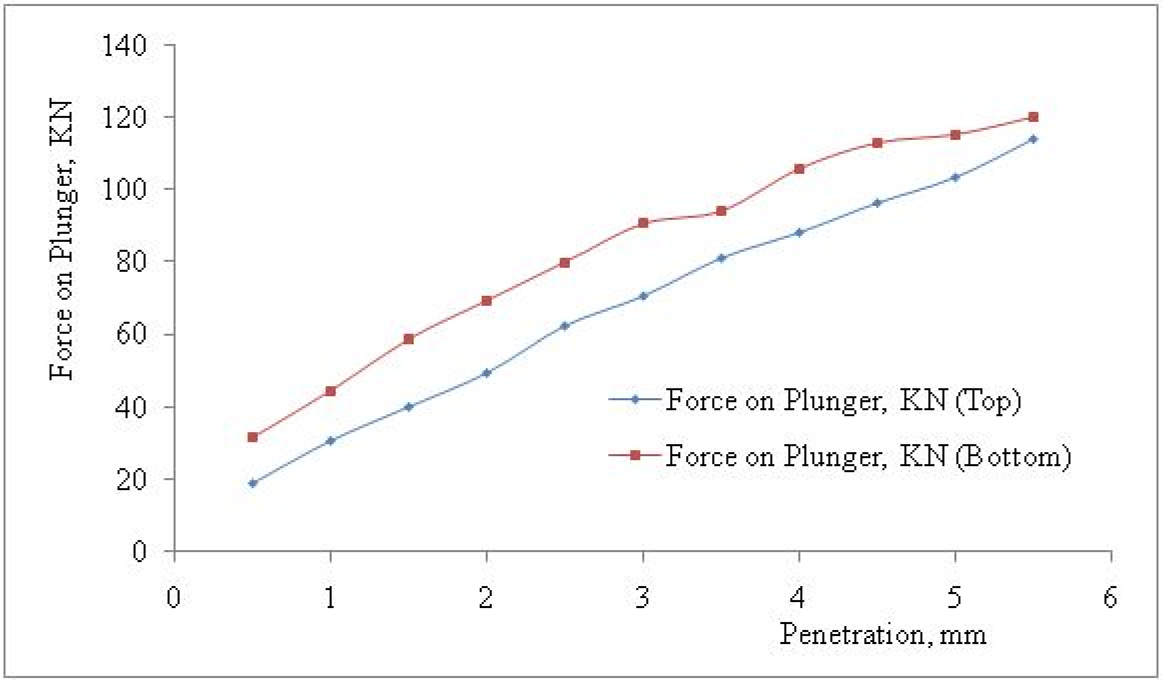

Figure 6: Results of force on plunger for top and bottom against penetration for 12% moisture content in black cotton soil on sedimentary formation

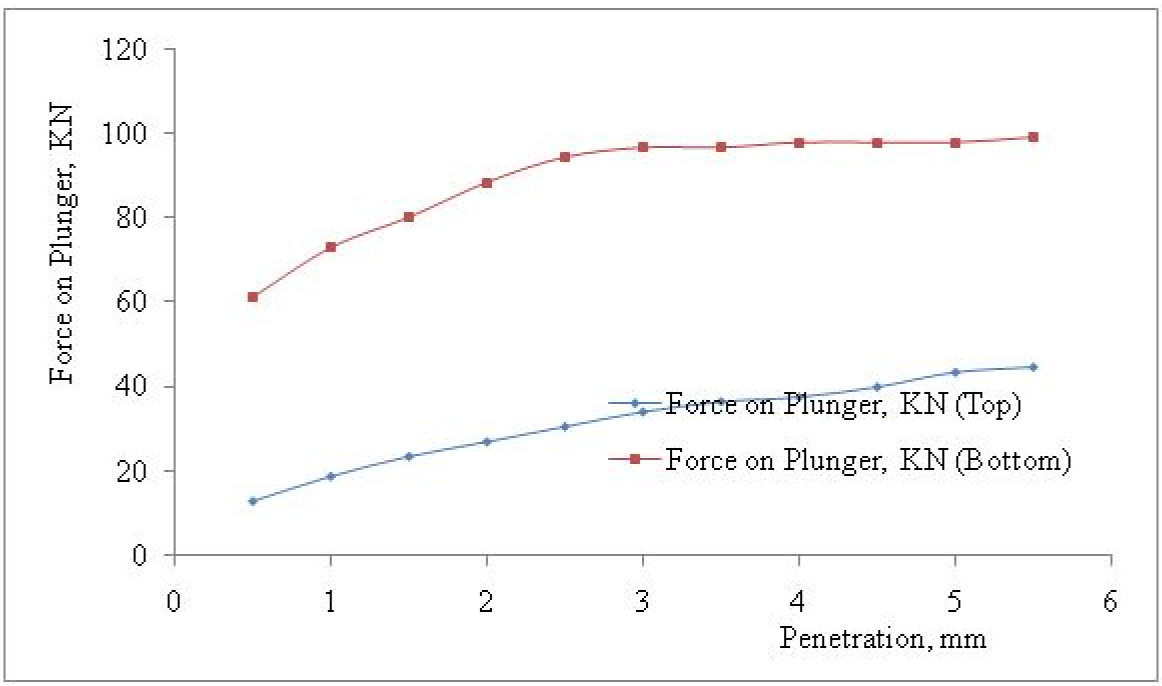

Figure 7: Results of force on plunger for top and bottom against penetration for 14% moisture content in black cotton soil on sedimentary formation

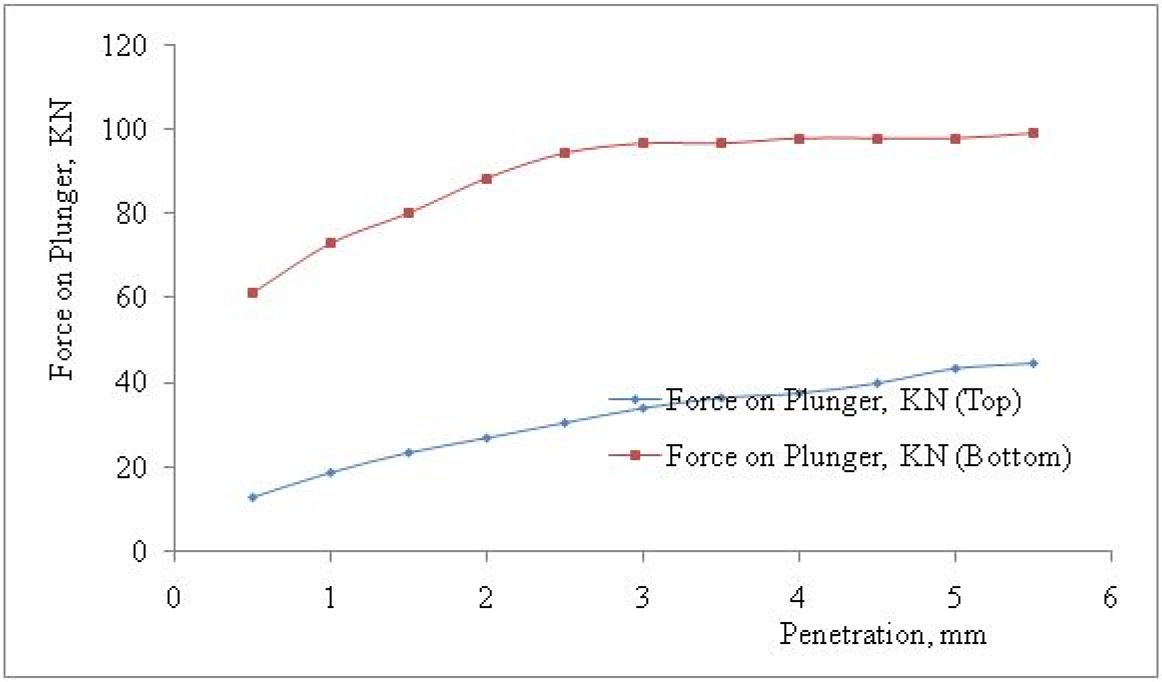

Figure 8: Results of force on plunger for top and bottom against penetration for 16% moisture content in black cotton soil on sedimentary formation

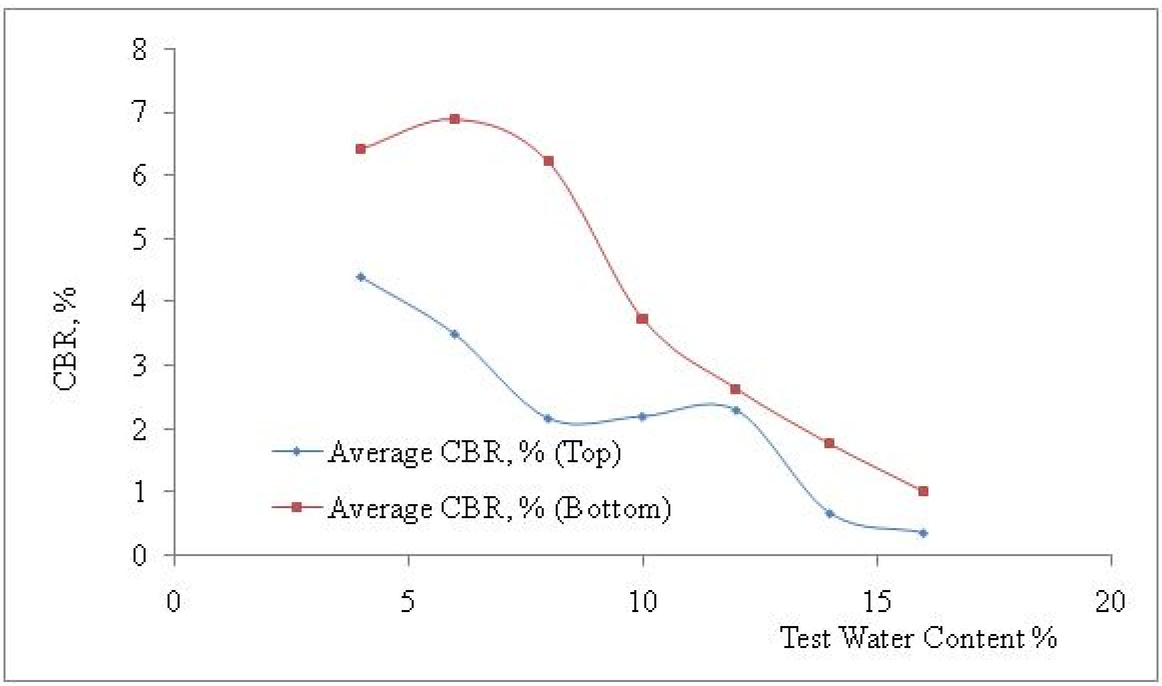

Figure 9: Results of average CBR for top and bottom against test water content in black cotton soil on sedimentary formation

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. 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. 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

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

To get the unit loads at penetrations of 2.5mm and 5.0mm, the measured load (values) are multiplied by 0.003 and 100 (Equation 1). 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. From the results presented in Figure 9, the average CBR varies from 0.36% to 4.4% for the top while that of the base (bottom) varies from 1.01% to 6.4% which could classified as poor or low. The test moisture content stopped at 16% which is lower than that of basement complex which stopped at 20%. 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), and may require special treatment (like stabilization) during construction. The sub-base itself should have a CBR of not less than 30%. Stabilization of soil can be seen as the process of blending and mixing materials with soil to improve certain properties of the soil. The process may include the blending of soils to achieve a required gradation or the mixing of commercially available additives that may alter gradation, texture or act as a binder for cementation of the soil. 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; Oke et al. 2009; Olarewaju and Afolabi, 2022; 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 Content (OMC) is lower than that of basement complex. 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 (Bell and Culshaw, 2001; BS1377, 1990; Chen 1975; Craig, 1987; Joseph, 1981; 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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