NBRRI

NIBRRI RESEARCH PAPERS

NO. 1.

ENGINEERING PROPERTIES OF BLACK COTTON SOILS OF NIGERIA AND RELATED PAVEMENT DESIGN

NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE

FOREWARD

NBRRI Research Paper No. 1 is the first publication arising from the Institute's research programme in which the main subgrade soils and road construction materials of Nigeria are to be investigated. It is intended in this programme to undertake a systematic study of the main subgrade soils occurring in Nigeria.

The main feature of the programme is to take a wide representation of samples of the soil type under study from the field. These are subjected to classification tests for liquid limit, plastic limit and particle size, and strength tests of compaction and california bearing ratio. From the analysis of the results of these tests, it is possible to define in bold outlines the engineering classification and properties of the soil with regard to the design and construction of roads. In addition, considerations are given to measures which can help in improving the strength properties of the soil by means of mechanical and chemical stabilisation techniques. The Institute believes that this kind of field and laboratory study of road construction materials is an invaluable aid to road planners, designers and contractors who can obtain, even before they engage in field activities, fairly accurate assessment of the engineering properties of the soils to be encountered and used on the site.

In the choice of areas and types of soil, priority has been given to problem soils and widely occurring soils. Thus it was decided to begin with the problem black cotton soils occurring widely in North Eastern part of Nigeria. The results of that investigation are described in this report. It is hoped that highway engineers will benefit tremendously from this publication.

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1. BACKGROUND INFORMATION:

1.1 Origin and Distribution of Black Cotton Soils in Nigeria:

The black cotton soils are dark coloured expansive clays, characterised by the phenomena of swelling on absorption of water and shrinkage on drying. These characteristics make them highly problematic as foundations for both building and road structures. Such soils are common products of tropical weathering and are encountered in several parts of the world.

In general, the black cotton soils derive their origin from basic igneous rocks such as basalts, rich in feldspars and mafic minerals such as montmorillonites. In Nigeria, these soils are found predominantly in the North-Eastern region of the country, lying within the Chad Basin and partly within the Benue trough (Figure 1). It is believed that these soils derive their origin in Nigeria, from basalts of the upper Benue trough which cover several hundred square kilometers extending North and East of the Jos Plateau, and from quarternary sediments of lacustrine origin from the Chad Basin consisting mainly of shales, clays and sandy sediments.

Black cotton soils generally occur in poorly drained areas, with alternating wet and dry seasons and with an annual rainfall generally less than 120cm. Such physiographical features and climatic conditions are typified in the Chad Basin where sediments were deposited as the old lake expanded and shrank during the alternating wet and dry periods. Other conditions conducive to their formation include the cumulative effects of leaching, alkaline environment and retention of calcium and magnesium in the soil.

Bulk of the black cotton soil deposits in Nigeria are found in the North-Eastern States of Borno, Gongola and Bauchi. These soils generally occur in discontinuous stretches as superficial deposits usually not more than 2 metres in thickness, overlain or underlain by sandy sediments. Typical shrinkage cracks on the surface of a Black Cotton soil deposit in Nigeria are shown in photo 1. Typical sandy sediments underlying a black cotton soil deposit are shown in photo 2.

1.2 Clay Mineralogy and Swelling Mechanism:

It is considered necessary for a road engineer to have at least a basic understanding of the mechanism responsible for the swelling and shrinkage phenomena in Black Cotton soils, so that proper precautions are taken at the design stage. This mechanism of swelling and shrinkage can best be explained by the mineralogical and chemical structure of the black cotton soils.

Out of the various clay minerals viz., kaolinite, halloysite, montmorillonite and illite, it is the montmorillonite mineral which is the most common in expansive clays or the black cotton soils. The basic unit for a montmorillonite is shown in Figure 2(a). It consists of a gibbsite sheet between two silica sheets. The gibbsite sheet (with an octahedral structural unit) may include atoms of aluminium, iron, magnesium or a combination of these. The silicon atoms in a silica sheet (with a tetrahedral structural unit) may interchange with, say, aluminium atoms of the gibbsite sheet. These structural changes termed as isomorphous changes, result in a net negative charge on the clay mineral.

The cations in water like sodium, potassium, or calcium are attracted to the negatively charged clay plates and, therefore, are in a continuous state of interchange. The bond between the montmorillonite units, stacked in the manner as shown in Figure 2(b) is relatively weak, depending on the type of exchangeable ion. Due to this weakness in the bond between montmorillonite units, it is possible for water to penetrate in-between these units and cause their "separation". Such a separation of these plates results in "swelling" of the clay mass. A road pavement constructed over an expansive block cotton soil subgrade generally shows poor performance as a result of swelling caused by the ingress of water from the road side shoulders and from the ground water table, Figure 2(c). To reduce this tendency of swelling, the black cotton soils are generally "stabilized" by additives like lime and cement. These additives, or stabilizers, in essence, replace the active sodium by the less active calcium ions.

1.3 Road Damage in Black Cotton Soil Areas:

In practically all countries of the world, where black cotton soils are encountered, the roads constructed over such subgrade soils show unsatisfactory performance, unless proper precautions are taken at the design stage. The problem of poor performance, resulting in greatly enhanced maintenance costs can be attributed to the undesirable engineering characteristics of such soils by way of swelling on absorption of water and shrinkage on drying. On absorption of water, the subgrade gets considerably softened and its shear strength or bearing capacity reduces considerably. Such a situation results in the road pavement getting deformed and the surface becoming "wavy". If a black cotton soil subgrade absorbs water, but is not allowed to "swell" because of vertical confinement, it exerts a vertical upward swell pressure. Similarly, laterally confined black cotton soils exert swell pressure in the lateral direction also. In actual field conditions, there can be different amounts of swelling in the vertical and lateral directions depending upon the degree of confinement in these directions. Generally, the development of vertical and lateral swell pressures is accompanied by reduction in shear strength on absorption of water.

It is interesting to observe that there are certain common features in the types of distress in a road pavement in Black Cotton soil areas in different parts of the world. This, apparently, is due to similar engineering characteristics of black cotton soils in regard to swelling and shrinkage with changes in moisture content and the development of vertical and lateral swell pressures. Some of the common types of pavement distress observed on selected roads in Nigeria are briefly described below:

(i) Longitudinal cracks running more or less parallel to the centre-line of the road are commonly observed. Such cracks are generally observed near the shoulders (Photo 3). Sometimes, these longitudinal cracks appear near the centre-line also. Many a time, uneven deformations over the width of the road accompany the appearance of longitudinal cracks.

(ii) Localised pavement failures in the form of excessive deformations leading to cracking and crumbling of the upper layer are due to inadequate bearing capacity of the road subgrade and sub-bases. Photos 4 and 5 show typical failures of this nature.