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Physico-mechanical Properties of Some Major Weak Soils in Nigeria

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ABSTRACT

The paper presents an overview of the physico-mechanical properties of some major weak soils in Nigerian. The study focuses on the physico-mechanical properties of vertisols (black cotton soil) of the North-east region, Sokoto soft clay shale of the North-west region and organic clay of the South-west region of Nigeria as reported in different literatures and their corresponding influence on the engineering behavior of the soils as regards geotechnical practices in relation to the types of foundations of buildings used on them. In light of the findings, the physico-mechanical properties of these weak soils cover wide ranges.

KEYWORDS: Weak soils; physico-mechanical properties; foundations.

INTRODUCTION

The engineering properties of Nigerian soils have been shown to fall into the category of tropically weathered soils in line with other areas in tropical region (Ola, 1980). Due to large volumetric change, severe cracking when dried, low bearing capacity when wet as well as low permeability, weak soils, generally poses major problem to foundations, especially if these unique properties are not taken into considerations during choice, design and subsequent construction of the foundations. These can lead to failure of the entire structure.

In geotechnical engineering, soils with properties that cannot be safely and economically used for the construction of civil engineering structures without adopting some stabilization measures are referred to as weak or problematic soils. The engineering properties of these soils must be extensively investigated by geotechnical engineers, in order to recommend appropriate foundation type depending on among other factors like the structural loads, environmental loads as well the use to which the intending structure would be put.

When designing a building or other structure on land, engineers take into consideration the

structural properties of the ground that supports their project. Adequate knowledge of ground conditions is very important for analyses, design and construction of geotechnical systems. Project delays, failures and cost over-run are the result of inadequate and inappropriate soil investigations. Geotechnical soil investigation is an integral component of any civil engineering project. It provides the necessary information for design, construction as well as for environmental assessment of the intended project (Tomlinson and Boorman, 2001). Site investigation generally provide among others, the following basic information (Bowles, 1997):

1. Information to determine the type of foundation required (shallow or deep);
2. Information to allow the geotechnical consultant to make a recommendation on the allowable load bearing capacity of the foundation.
3. Sufficient data/laboratory tests to make settlement predictions.

Armed with basic physico-mechanical properties of soil on which a foundation is to be sited, geotechnical engineer is able to make his choice of foundation, taking into consideration first, safety and the economy. Physico-mechanical properties of weak soils in Nigeria cover wide ranges, especially with different seasons. This singular behavior of these types of soils poses challenges to designers as regards the type of foundation to adequately use for a particular structure on them.

Many researchers (Ola, 1978; 1980; 1983-a; 1983-b; 1987; Farrington, 1983; Ajayi, 1983; Madedor and Lal, 1985; Madedor and Adeleke, 1987; Adesunloye, 1987; Omange et al, 1988; Omange and Aitsebaomo, 1989; Nwaiwu and Nuhu, 2006; Osinubi and Stephen, 2007; Osinubi et al, 2009; Okafor and Okonkwo, 2009; Oritola and Moses, 2010) have worked on properties of weak soils in Nigeria. While the compendium on the geotechnical properties of major problem soils of Nigeria, compiled by Abolarinwa (2010), can be handy while dealing with these soil as road bases, this work presents an overview of the basic physico-mechanical properties of some Nigerian weak soils that is intended to serve as guiding parameters for the preliminary choice and design of foundations for buildings and other structures.

THE GEOLOGY AND GEOMORPHOLOGY OF NIGERIA

Nigeria is one of the West African countries located within the tropical region of the world. The country is geologically bounded on the south by the gulf of Guinea and on the north by the southern edge of the Sahara desert. The climate is typified by hot tropical condition, which is humid in the south and semi-arid in the north. Seasonal rainfall results from the influence of the wet south westerly monsoon winds from the sea and the hot dry dusty north east trade wind from the Sahara, known locally as the hamattan. The geomorphology and the quaternary history of Nigeria have evolved under the remarkable changes brought about by the intensity and periodicity of rainfall in the past. Wetter periods have been termed pluvial and drier periods are termed inter-pluvial. The geology of Nigeria is dominated by sedimentary and crystalline basement complex formations which occur in almost equal proportions all over the country (Durotoye, 1983; Rahaman and Malomo, 1983; McCurry, 1989; Shitta, 2007) (fig. 1). The sediment is mainly Upper Cretaceous to recent in age while the Basement Complex rocks are thought to be Precambrian.

The characteristic landforms on the crystalline rock Basement Complex and the Younger Granites of the Jos Plateau are the extensive dissected pedi-plains above which rise prominent steep sided residual hills. These hills range in height from a few meters to over 600m.

About half of the total area of Nigeria is covered by sedimentary rocks (fig. 1). Products of weathering in Nigeria are generally grouped into four main basic groups: the Ferruginous soils, the

Ferrallitic soils, the weakly developed soils, and the vertisols (black cotton soil), which is localized to the North-eastern part of the country (Malomo, 1983). The characteristic landforms consist of extensive dissected flat to very gentle sloping plains of a lower pediment level above which rise remnants of flat lateritic capped hills of a higher pediment level. The lateritic capped hills, dissecting the flat plains are of various heights, with height up to 300m been recorded (Durotoye, 1983).

Residual hills are obviously the resistant remains left after the weathering and erosion of surrounding rocks under humid tropical conditions, and there is a remarkable tendency for them to concentrate on the interfluves of large rivers. Rocks with high residual hill forming potentials are the Older Granites, the Younger Granite, and the Quartzite.

Dissected relatively flat to very gentle sloping plains are characteristic landforms on areas or regions dominated by weak soils.

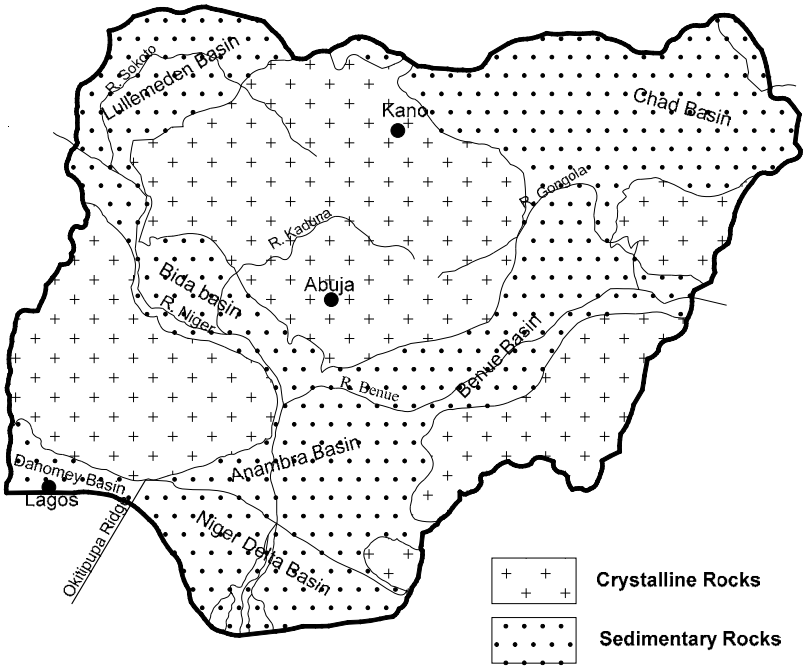

Figure 1: Geological formation of Nigeria

WEAK SOILS IN NIGERIA

In Nigeria, Weak soils are generally associated with soils formed on sedimentary basement complex. Products of weathering in Nigeria are generally grouped into four main basic groups: the Ferruginous soils, the Ferrallitic soils, the weakly developed soils, and the Vertisols (black cotton soils), which is localized to the North-eastern part of the country (Malomo, 1983).

Weak soils mostly encountered in Nigeria among others include: the vertisols (black cotton soils), which is mostly found in the Chad basin and some part of Benue basin, especially in Numan and Guyuk area of north-eastern region of Nigeria; the soft clay shale, which is mostly found in the Lullemeden basin of north-western region of Nigeria; and the group of weakly developed soils, which

include the peat and organic clay, prominent in the Dahomey basin of the south-west, and soft sedimentary deposits of the Niger-delta basin in the south-southern region of the country (fig. 1). The soft sedimentary deposits of the Niger-delta basin are not discussed in this paper.

Vertisols (Black Cotton Soils)

Vertisols are heavy black clays associated with calcium rich parent rocks found in the relatively dry savannah climate. They are also known as black cotton soils. Characteristically they have a black upper horizon. The black color is due to the presence of black color humus-clay complex. They are characteristically very soft when wet and very hard when dried. Work by Malomo (1983) show the organic matter content of these soils to be characteristically low (usually below 5%). They have a heavy texture and a dominant montmorillonite clay fraction. They are highly plastic, expand considerably on wetting and shrink on drying.

The engineering properties of vertisols are dominated by its small particle sizes and the presence of montmorillonite clay mineral. These properties impose low permeability, high plasticity, expansiveness and shrinkages on the soils. The black cotton soils of North-eastern Nigeria, up to the Chad basin areas fall into this category (Ola, 1978). The basic physico-mechanical properties of these type of soils ranges between: Natural Moisture Content (NMC) = 8-40 %; Liquid Limit (LL) = 70-93 %; Plastic Limit (PL) = 21-31 %; Plasticity Index (PI) = 47-72 %; Cohesion (c) = 120-220 κPa; Angle of internal friction (ϕ) = 4-12°; Linear Shrinkage (LS) = 11-21 %; Specific Gravity (G_s) = 2.50-2.56; Free swell = 50-140 %; swelling pressure = 120…130 κPa; Bulk unit weight (γ_b) = 19-21 κN/m^3; Void ratio (e) = 0.35-1.3; Degree of saturation (S_r) = 0.5-1; Modulus of deformation (E) = 7-18 MPa. They are usually classified as CH on Unified Soil Classification Systems (Ola, 1983-b, 1987; Abolarinwa, 2010).

Shrinking and swelling characteristics of the soils is the main determining factor for choice of foundation. Foundations are designed to ballast the swelling pressure of the soil. This is sometimes difficult to achieved, especially with light structures, which are typical of buildings in this part of the country. Modification of the foundation soil and sand columns can be used to reduce the swelling and shrinking behavior of the soils. Bored piles, designed to resist both drag and uplift forces are also considered good option in these types of soils.

Sokoto Soft Clay Shale

The engineering properties of Sokoto soft clay shale are dominated by its small particle sizes and high clay content, consisting mostly of attapulgite, which consist essentially of chains of the montmorillonite type lattice that are stacked at every other layer, forming tunnels (Ola, 1983-a). Work on this soil by Ola (1980), shows that the soil is highly structure sensitive. These properties impose the low permeability (although, higher than black cotton soil), expansiveness and shrinkages on the soils. The zero cohesion value of this clay suggests that they are normally consolidated clay. The basic physico-mechanical properties of these type of soils ranges between: Natural Moisture Content (NMC) = 10-40 %; Liquid Limit (LL) = 170-250 %; Plastic Limit (PL) = 7-10 %; Plasticity Index (PI) = 163-240 %; Cohesion (c) = 0 κPa; Angle of internal friction (ϕ) = 16-30°; Linear Shrinkage (LS) = 18-24 %; Specific Gravity (G_s) = 2.42-2.55; swelling pressure = 145-240 κPa; Bulk unit weight (γ_b) = 14-17 κN/m^3; Void ratio (e) 0.4-1.3; Degree of saturation (S_r) = 0.5-1.0; Compressive index (C_c) = 0.19-0.25. They are usually classified as CH on Unified Soil Classification Systems (Ola, 1983-a).

The principles applied in the choice and design of foundation on black cotton soil of the North-

eastern region can be handy while dealing with Sokoto soft clay shale.

South-west Organic Clay

The engineering properties of peaty clay of Lagos are dominated by high organic content, relatively high porosity, compressibility and low overburden pressure. Bulk densities of this soil vary widely depending on composition and depth. Their natural moisture content is generally just below the liquid limit, and in some cases above liquid limit (Farrington, 1983). Work by Ajayi (1983) and Farrington (1983), shows that the basic physico-mechanical properties of these type of soils ranges between: Natural Moisture Content (NMC) = 50-250 %; Liquid Limit (LL) = 75-250 %; Plastic Limit (PL) = 30-175 %; Plasticity Index (PI) = 20-120 %; Cohesion (c) = 3-200 κPa; Angle of internal friction (ϕ) = 0-7°; Specific Gravity (G_s) = 2.20-2.68; Bulk unit weight (γ_b) = 24.0-28 κN/m^3; Void ratio (e) 0.5-2.20; Degree of saturation (S_r) = 0.5-1.0; Coefficient of consolidation (C_v) = 0.3-10 m^2/year; Coefficient of volume compressibility (M_v) = 0.04-0.32 m^2/MN. They are usually classified as OL to OH on Unified Soil Classification Systems.

Settlement characteristics are the main determining factor in the choice of foundation on these types of soils. Foundations on these soils are designed to spread structural loads to the barest minimum to check excessive settlement. This is sometimes difficult to achieve with shallow foundations, especially with heavy structures. Modification of the foundation soil and sand columns can be used to reduce the excessive settlement behaviors of the soils. Piles, designed to resist drag forces are considered better option in these types of soils.

CONCLUSIONS

-The physico-mechanical properties of weak soils in Nigeria, covers wide ranges.

-Vertisols (black cotton soils) have physico-mechanical properties which impact high swelling and shrinkage potentials to the soils. These properties, which are also not to a lesser degree exhibited by the Sokoto soft clay shale, determine the type of foundations and construction methods/measures employed on the soils.

-The south-west organic clay has physico-mechanical properties which impact high compressibility to the soils. These properties determine the type of foundations and construction methods/measures employed on the soils. Foundations on these soils are design to limit compressibility (excessive settlement) problem to the barest minimum.

-The findings of this work can be used as a guide for the preliminary choice and design of foundations on these soils. For detailed design, detailed study will be required to ascertain exact required design parameters.

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