Transportation Geotechnics 5 (2015) 68–85

Contents lists available at ScienceDirect

Transportation Geotechnics

journal homepage: www.elsevier.com/locate/trgeo

The influence of water content on the Dynamic Cone Penetration Index of a lateritic soil stabilized with various percentages of a quarry by-product

Samuel Innocent Kofi Ampadu [a,*], Gilbert Jones Yao Fiadjoe [b]

[a] Kwame Nkrumah University of Science and Technology, College of Engineering, Kumasi, Ghana
[b] Kwame Nkrumah University of Science and Technology, Civil Engineering Department, College of Engineering, KNUST, Kumasi, Ghana

ARTICLE INFO

Article history:
Received 23 June 2015
Revised 30 September 2015
Accepted 30 September 2015
Available online 23 October 2015

Keywords:
Lateritic soil
Dynamic Cone Penetration Index
Water content
Relative compaction
Water Content Change
Fines Content

ABSTRACT

Laterites and lateritic soils have been a source of good pavement material in tropical countries for a long time. However, increasingly it is becoming difficult to find lateritic material that meets the required specification within economic haulage distances of roads under construction. This has necessitated, among other things, the need for stabilization of lateritic soils of high fines content with quarry by-products. The use of such marginal material however requires that they be properly compacted in order to improve their engineering properties. For low volume roads there is the need for simple, rapid and economical methods of compaction quality control. This study builds upon previous ones on using the Dynamic Cone Penetrometer (DCP) for compaction verification and seeks to account for post-compaction water content changes. The use of the DCP for compaction verification starts with the establishment of a correlation between the Dynamic Cone Penetration Index (DPI) and the relative level of compaction. However, the DPI is sensitive to water content changes even at constant dry density. The objective of this study is to investigate how the DPI of a lateritic soil determined at the optimum moisture content changes when the water content varies and the fines content reduces. The results show that small changes in water content can lead to significant effects on DPI.

Introduction

Background

The processes of formation of laterites and lateritic soils start with the chemical weathering of the parent rock in-situ followed by the leaching out of silica and bases (Lyon, 1971; Gidigasu 1972; Gidigasu, 1976). The resulting material is deficient in silica, but rich in the sesquioxides of iron and aluminium and contains substantial amounts of clay minerals. Depending on the relative proportions of aluminium and iron oxides which is related to drainage and topography, the colour may range from reddish to brownish-red on well-drained upper slopes with a higher concentration of aluminium salts to brown and yellowish-brown on middle slopes with a higher iron salts concentration (Brammer, 1962). The material usually develops a bonded structure (Kemp and Pierce, 1995).

Laterites and lateritic soils abound in countries with tropical climate where they have been used successfully as an excellent road pavement material for a long time. However, as a non-renewable natural resource, such good quality lateritic gravel is becoming increasingly difficult to find within economic haulage distances of road works.

* Corresponding author.
E-mail addresses: sikampadu@yahoo.co.uk, skampadu.coe@knust.edu.gh (S.I.K. Ampadu), gijoyafia@ymail.com (G.J.Y. Fiadjoe).

http://dx.doi.org/10.1016/j.trgeo.2015.09.007
2214-3912/

Many of the countries that face this pavement material constraint also face huge road network rehabilitation needs and therefore have low budgets available especially for low volume roads. Under the conditions of low budgets and difficulty of finding suitable pavement material, the usual approach is to relax the specifications or to attempt to improve the marginal pavement material or both. One method of improving marginal pavement material is to mechanically stabilize the material with sand or quarry by-product when these are readily available. Such stabilized lateritic soil is also used as backfill for culverts and also as hardcore filling for construction of on-grade slabs.

A key requirement of using lateritic soils with marginal properties for road pavement construction is to ensure that the material is well compacted. Several methods are available for compaction quality control monitoring. However, among many developing countries the sand replacement method (ASTM D 1556-01, BS 1377-90) is still the most commonly used. In this method, the dry density of the compacted layer is determined intermittently during the course of compaction and the value of the dry density achieved in the field is compared with the maximum dry density obtained in the laboratory using the specified standard. However, this method presents the practical difficulty of having to determine the compaction water content of the material on site. This difficulty is resolved by using any of the approximate but rapid methods such as the Speedy Moisture Tester (ASTM D 4944-89) and the Microwave Oven Method (ASTM D 4643-91). For low volume road construction, many of which occur in remote areas, there is the need for even simpler and rapid methods of compaction quality control.

The Dynamic Cone Penetrometer (DCP) equipment is perhaps best known for its use in pavement strength evaluation where it has been correlated with various pavement design parameters such as the California Bearing Ratio (CBR) and the elastic modulus back-calculated from the falling weight deflectometer tests (Kleyn et al., 1982; Livneh, 1987a,b, Newcomb et al., 1996; Chen et al., 2001; Ampadu and Okang, 2011). The DCP has also been proposed for estimating the bearing capacity of shallow foundations (Sowers and Hedges, 1966; Sanglerat, 1972; Ampadu and Ditze-Awuku, 2009). A standard has even been established for DCP in shallow pavement applications (ASTM D6951-03). However, the DCP has also been proposed as a simple tool that can be used to provide rapid compaction verification (Chaigneau et al., 2000; Gabr et al., 2001; Ampadu and Arthur, 2006) and to predict the dry density achieved in lateritic base layers in-situ (Jjuuko et al., 2015).

In the DCP test, a standard weight is used to drive a standard cone through the soil and the penetration achieved is measured against the number of blows of the standard weight. The penetration in millimeters achieved per blow of the standard weight is known as the Dynamic Cone Penetration Index (DPI). The DPI is a measure of the resistance of the soil to the penetration and most of the different applications of the DCP correlate the DPI with the particular soil parameter under investigation. When the DCP is used for compaction verification, a calibration is first established between the DPI and the relative level of compaction ($\rho_d/(\rho_d)_{max}$) at the optimum moisture content (w_{opt}) for the pavement material. Whenever the material source changes a new calibration becomes necessary. However, because the DPI is sensitive to the water content of the compacted material, its value changes when the compacted pavement layer dries out or when the material becomes wet even though the dry density and therefore the relative compaction achieved remains unchanged. In fact, it is for this reason that compaction verification is recommended to be done immediately after compaction (Siekmeier et al., 1998). Whereas the effect of density, as expressed in the relative level of compaction, has been well documented, no attempt appears to have been made to quantify the effect of water content change on DPI. However, in order to be able to successfully apply the DCP for compaction verification even when the post-compaction water content changes, the relationship between the DPI and water content at constant levels of compaction need to be established.

Purpose and scope

This study therefore seeks to investigate how the DPI determined at the optimum water content, changes with post-construction water content changes for a lateritic pavement material and how this varies with the fines content of the material. A lateritic sandy clay material was stabilized with different percentages of a quarry product to give a material whose fines content varies from about 45% to about 6% with corresponding plasticity index values varying from 34 to non-plastic. The material was then moisture conditioned at different levels of compaction between 90% and 100%. Then in-mould DCP tests were performed on the moisture conditioned samples. The detailed procedures are described and the results are presented and discussed.

Materials and methods

The Dynamic Cone Penetrometer

The characteristics of the DCP equipment used in this investigation are shown in Table 1. The equipment consists basically of a 60°, 20-mm-base diameter cone at the end of a 16 mm diameter rod. The rod is driven vertically into the soil by blows from an 8-kg hammer dropped over a height of 575 mm, to strike an anvil. The DCP therefore imparts a theoretical driving energy per blow per unit cone area of 144 kN-m/m^2. The effect of shaft friction is neglected because the rod diameters are slightly smaller than the cone. During the test for each blow the penetration is recorded. The cumulative number of blows is then plotted against the total penetration and the slope of the line of best fit is defined as the DCP penetration index (DPI) (in millimeters per blow). The DPI is not a direct measure of soil property but rather it is an index which is based on the soil response to the dynamic impact loading. The DCP equipment used in this investigation therefore meets the specification of ASTM D6951-03.