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Design and parametric study of a pavement foundation layer made of cement-treated fine-grained lateritic soil

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Abstract

This study deals with the application of experimental results to the design of a roadway structure. It firstly addresses the design of a layer of pavement foundation made of cement-treated fine-grained lateritic soil, using the American empirical and the French mechanistic-empirical methods developed by AASHTO (American Association of State Highway and Transportation Officials) and LCPC (Central Laboratory of Roads and Bridges), respectively. Then, a comparison is made of the results obtained by these two pavement design methods with those provided by the CEBTP (Experimental Center for Research and Studies in Building and Public Works) pavement design manual for tropical countries. It is observed that there is very little difference between the thicknesses of the pavement layers (D) obtained by the LCPC mechanistic-empirical method of pavement design and the AASHTO empirical pavement design method. However, the pavement thicknesses (D) obtained by the LCPC pavement design method are lower than those obtained by the AASHTO pavement design method in the order of 8%, thereby reducing the input of a significant amount of lateritic soil at the worksite. It is further observed that the thicknesses (D) obtained by the LCPC and AASHTO pavement design methods are 1–1.9 times lower than those provided in the CEBTP pavement design manual, used for several decades in the tropics. This considerable decrease in the cement-treated fine grained lateritic soil required for the pavement body is both economically profitable for project managers and beneficial for the environment. Regression relationships were proposed based on the key parameters, namely, resilient modulus M_R, modulus of elasticity E, layer coefficient a_i and structural number SN. They provide strong relationships that yield good linear correlations.

Keywords: AASHTO empirical method of pavement design; LCPC mechanistic-empirical method of pavement design; CEBTP empirical method of pavement design; Parametric study; Cement-treated fine-grained lateritic soil; Cement content; Base layer; Subbase layer

1. Introduction

In almost all tropical and subtropical areas where residual lateritic soils abound, soil-cement mixing (chemical stabilization) is the widely used technic to improve the engineering properties of poor laterites (Kamtchueng et al., 2015; Donrak et al., 2016; Phummiphan et al., 2016a,b; Suebsuk et al., 2017). Soil-cement mixing has also been used with success for many geotechnical engineering applications in sub-Saharan Africa, such as pavement structures, roadways (the construction of highway embankments), building foundations, channel and reservoir linings, irrigation systems, water lines and sewer lines, to avoid the damage due to the settlement of soft soil or to the swelling action (heave) of expansive soils (Bagarre, 1990; Joel and Agbede, 2010; Mengue et al., 2017).

Under the effect of external stresses (environmental, loading conditions, etc.), the pavement structures are subjected to complex phenomena (mechanical, thermal, physical and chemical) that often appear in a coupled manner (Ambassa et al., 2013). Given the complexity of the observed problems, design methods are developed based

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on empirical rules drawn from observations in the service behavior of pavement structures or experimental sections. These methods have limitations which are most visible with new types of structures and configurations for traffic that is constantly changing (Sadek et al., 2009). The development of more rational design methods became necessary, and this need led to the development and application in the 1970s of rational methods based on mechanistic-empirical rules.

In sub-Saharan and Equatorial Africa, the design of pavement structures continues to be based on an empirical approach (CEBTP, 1984; Mengue et al., 2017). However, it is recognized that this technique leads to over-dimensioning which entails high construction costs (Mengue et al., 2015). For these reasons, the mechanistic-empirical or rational approach is becoming more and more common for use in pavement designs.

This study focuses on the application of experimental results to the design of pavement foundation layers made of a fine-grained lateritic soil treated with cement at different dosages (3%, 6% and 9% by dry weight of soil). The objectives of this research were to obtain the thickness of the pavement foundation (both the subbase and the base layers), as a function of the cement content (optimum cement dosage), and the thickness of the roadbed (platform) from two design approaches. The American empirical method of pavement design of the AASHTO (American Association of State Highway and Transportation Officials) and the French mechanistic-empirical method of pavement design of the LCPC (Central Laboratory of Roads and Bridges), implemented in ALIZE-LCPC Software 1.3, are used for this purpose, namely, to design a pavement foundation made of cement-treated fine-grained lateritic soil. The results are compared with the standard results provided in the CEBTP (Experimental Center for Research and Studies in Building and Public Works) pavement design manual for tropical countries.

From a parametric study, the correlations and mathematical relations between different parameters of cement-treated material, such as the resilient modulus (M_R), the modulus of elasticity (E), the layer coefficient (a_i) and the structural number (SN), are proposed.

2. Materials and test methods

2.1. Soil sample and cement

The raw sample, taken from Zoétélé in the Southern part of Cameroon was composed almost exclusively of silica ($SiO_2 = 36.47\%$), iron ($Fe_2O_3 = 29.13\%$) and alumina ($Al_2O_3 = 19.34\%$). The other elements (Ti, Mn, Na, Ca, K and P) were negligible, while alkali and alkaline earth cations were totally absent. The S/R ratio, defined according to the SiO_2 content, the Al_2O_3 content and the Fe_2O_3 content, was used to determine the type of lateritic soil. This ratio is defined by the following relationship (Bagarre, 1990):

$$\frac{S}{R} = \frac{S_iO_2}{R_sO_3} \quad \text{with} \quad R_sO_3 = Fe_2O_3 + Al_2O_3 \tag{1}$$

in which S/R is the Sesquioxyde Ratio. The Sesquioxide Ratio ($S/R = 0.69 < 1.33$) shows that the raw sample would be a real laterite (Bagarre, 1990). The relatively high iron oxide content (29.13%) partly explains the red color of the raw sample.

The lateritic soil used in this study is a fine-grained soil. The particle size distribution of the lateritic soil used in this study (Fig. 1) shows that the sample consists of 18.8 wt% of gravel, 32.4 wt% of sand, 14 wt% of silt and 34 wt% of clay. Table 1 presents a summary of the geotechnical properties of the soil.

The selected cement in this study is a compound Portland cement (CEM II / BM 32.5 N) whose main constituents are Portland clinker, limestone, granulated blast furnace slag and siliceous fly ash. The clinker content is between 65 and 79%.

2.2. Cement-treated soil

The studied mixtures consisted of cement (up to 9 wt%), fine-grained lateritic soil and water. For samples preparation, the above mentioned materials were oven-dried at 50° C for 24 h, manually mixed, for preventing the grain size change, and stored in hermetic plastic bags in order to ovoid moisture contamination. The optimum moisture contents (OMC) of the treated and untreated lateritic soil were determined according to NF P94-093 (1999) standard. These OMC were used for preparing the specimens for the Californian bearing ratio, unconfined compressive strength and indirect tensile strength tests carried out according to NF P94-078 (1997), NF EN 13286-41 (2003), NF EN 13286-42 (2003) and NF EN 13286-43 (2003) standards, respectively.

These laboratory tests allow the determination of the soaked California bearing ratio (I_{CBR}), unconfined compression strength (UCS), tensile strength (TS) and modulus of elasticity (E). These parameters are used both as indices to quantify oil improvement following treatment as well as to determine the suitability of the material to be used in pavement foundations and as experimental input data.

For each mixture of cement and water given, five specimens were designed and tested. Repeatability was estimated from the standard deviation (s) by the following formula:

$$S = \sqrt{\frac{\sum_1^n (X_i - \bar{X})^2}{n-1}} \tag{2}$$

where X_i is the i^{th} value based on a series of n measurements of a sample, X is the average value for the set of n measurements and n is the number of measurements.

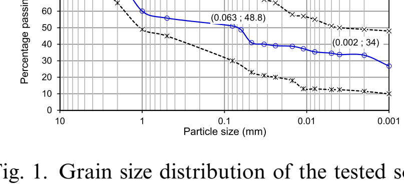

Fig. 1. Grain size distribution of the tested soil.

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