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# Physicochemical and consolidation properties of compacted lateritic soil treated with cement

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## Abstract

The consolidation of a fine-grained lateritic soil, treated with compound Portland cement (CEMII/BM 32.5 N) up to 9% by weight of the dry soil and prepared at three different molding water contents ($\omega_{DRY}$, OMC, and $\omega_{WET}$), was investigated by means of a one-dimensional consolidation test. The physicochemical and microstructural properties of the compacted lateritic soil-cement mixture were investigated using Raman spectroscopy, polarized light microscopy (PLM), scanning electron microscopy (SEM), and pH measurement. The results show that cement admixtures resulted in the formation of tobermorite, afwillite, ettringite, portlandite, and calcite. However, tobermorite and afwilite, which are calcium silicate hydrates (CSH) whose mechanisms of formation are the pozzolanic and alkali silica reactions, appear from 6% added cement. The fixing point of the pH (12.4) is also obtained from 6% added cement. It is the threshold value at which the material begins to develop an adequate mechanical performance. In general, as the content of cement in the soil is increased, the yield stress increases from 1 to 3 times in comparison to untreated soil. For effective vertical stresses smaller than the cement-induced yield stress, the primary consolidation process for specimens treated with cement is 2–7 times faster than that for specimens not treated with cement, while for effective vertical stresses higher than the cement-induced yield stress, the primary consolidation process for specimens treated with cement is about 0.5–1.5 times faster than that for specimens not treated with cement. Permeability and secondary compression are reduced 1–9 times and 2–11 times that of the untreated samples, respectively. These changes are attributed to the creation of chemical bonds and aggregation that accompany the addition of cement. The results also show that it would be desirable for soil samples to be prepared at the dry side of optimum ($\omega_{DRY}$) when the optimum moisture content (OMC) is not reached at the site. These results indicate that significant and desirable changes in soil behavior can be achieved when the soil is admixed with CEM II/BM 32.5 N cement, thus providing the possibility of using the tested lateritic soil in road construction.

*Keywords:* Lateritic soil; Cement mixes; Microstructure; Consolidation behavior

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## 1. Introduction

Until recently, in many parts of the world, especially in tropical and subtropical regions, gravelly soils have been used for highway geotechnic, primarily in roadway structures (Mesbah et al., 1999). With the evolution of knowledge, needs, and the recent consideration of environmental constraints, fine-grained lateritic soils are increasingly used in road construction to reduce costs. From a geotechnical perspective, fine-grained lateritic soils (silt or clays) are generally associated with high compressibility, high rates of creep, and sometimes lower permeability characteristics, which increase the risk of inadmissible

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settlements and/or foundation failure. As a result, construction on these soils poses significant challenges to geotechnical engineers. The viability of civil engineering works consisting of lateritic soils is proven to be dependent on the chemical and mineralogical compositions as well as the mechanical characteristics of these raw materials (Idrissa, 1994).

Several methods are generally used to modify and improve the geotechnical properties of these problematic soils. The methods include densifying treatments (such as compaction or preloading), pore water pressure reduction techniques (such as dewatering or electro-osmosis), the bonding of soil particles (by ground freezing, grouting, and chemical stabilization), and the use of reinforcing elements such as geotextiles and stone columns (Ismaiel, 2006; Bobet et al., 2011). In almost all tropical and subtropical areas where residual lateritic soils abound, soil-cement mixing (chemical stabilization) is the method widely used to improve the engineering properties of poor laterites (Kazemian and Huat, 2009; Oyediran and Kalejaiye, 2011). Soil-cement mixing (cement stabilization) 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 damage due to the settlement of soft soil or to the swelling action (heave) of expansive soils (Bagarre, 1990; Joel and Agbede, 2010).

Although today there are high quality data on the engineering properties of treated lateritic soils, little attention is paid to the investigation of their microstructures or to the one-dimensional consolidation behavior (primary consolidation and secondary consolidation) of treated fine-grained lateritic soils (Millogo et al., 2008; Li et al., 2012). In addition, in almost all of the above-mentioned works, the authors limited themselves to preparing their samples only at the optimum moisture content. However, it is difficult to reach the optimum moisture content on site; this is why it is desirable to vary the molding water content in order to approach the best condition of the reality at the site (CEBTP, 1984). Compound Portland cements (CEM II) were only rarely used as stabilizers in these previous studies.

This paper presents a series of experimental studies on the feasibility of using local lateritic soil treated with cement in road construction. In this study, a compound Portland cement (CEM II/BM 32.5 N) produced in Northern France was added at various weight proportions, to a fine-grained lateritic soil prepared at different molding water contents. Geotechnical and microscopic testing of the soil samples were performed to assess the characteristics of the materials before and after the cement addition. The tests included Raman spectroscopy, polarized light microscopy (PLM), scanning electron microscopy (SEM), pH measurement, compaction tests, workability tests, and one-dimensional consolidation. The potential use of this amended material for road construction is discussed.

## 2. Materials and test methods

### 2.1. Materials

The soil samples used for this study were obtained from a borrow pit at Zoétele, in the Southern part of Cameroon (located between latitudes 11° 45′ and 11° 55′N and longitudes 3° 05′ and 3° 10′E) using the method of disturbed sampling (Fig. 1). The first 0.60 m of soil was removed to get rid of the organic soil layer. Laterite was then taken from the A horizon whose thickness was approximately 2.5 m. The soil samples were sealed in bags and then transported to the laboratory. Previous geological and pedological studies show that the samples taken belong to the group of ferralitic tropical soils derived from acid igneous and metamorphic rocks (Tchameni, 1997). The mineralogical and chemical compositions of the concerned lateritic soil are summarized in Table 1. As can be seen in this table, the raw sample is mainly composed of quartz, kaolinite, goethite, hematite, gibbsite, and traces of feldspar (oligoclase). These mineral phases are those commonly present in laterites (Millogo et al., 2008). Nevertheless, the absence of swelling clay species, such as smectites, is noted. The sample is 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) are negligible, while alkali and alkaline earth cations are 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 (Autret, 1980):

$$\frac{S}{R} = \frac{SiO_2}{R_SO_3} \quad \text{with} \quad R_SO_3 = Fe_2O_3 + Al_2O_3 \tag{1}$$

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 (Autret, 1980; Bagarre, 1990). The relatively high iron oxide content (29.13%) partly explains the red color of the raw sample.

The particle size distribution of the lateritic soil used in this study (Fig. 2) 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. The values of some geotechnical properties (determined according to the French standards) of the sample are gathered in Table 2. It is a reddish lateritic soil, classified as a fine-grained soil (A-7-5) in the AASHTO (American Association of State Highway and Transportation Officials) soil classification system (AASHTO 1986), inorganic silts (MH) in the USCS (Unified Soil Classification System) soil classification (ASTM 1992), and sandy clay or silt (A2) in the GTR (French “Guide des Terrassements Routiers”) soil classification (GTR 1992). According to CEBTP (1984) and Bagarre (1990), the geotechnical properties of the studied sample

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