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Quantification of the effects of nitrates, phosphates and chlorides on soil stabilization with lime and cement

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ABSTRACT

Despite the scant quantitative data available in the literature, it has been hypothesized that some chemical compounds can have deleterious effects on soil stabilization with lime and cements (e.g., nitrates, phosphates and chlorides). This study intends to assess their influence on soil stabilization quantitatively. An original experimental procedure was followed. Selected soils were mixed with a potential deleterious compound at a concentration representative of what can be found in the field. The performance of the different mixtures in terms of soil stabilization was then assessed by performing mechanical tests on samples submitted to several curing conditions (temperature and humidity). The results showed that the tested compounds are likely to alter the soil stabilization processes and thus lower the mechanical performance of the stabilized soil. The results also showed that it is not possible to determine a single threshold value for the compounds considered because their influence on soil stabilization is also a function of the nature of the soil (silt or fine sand), the type of cement (CEM I or CEM II) and the curing conditions.

1. Introduction

Soil stabilization with lime and cement is a commonly used technique in earthworks, and it has been under continuous development since its introduction in the middle of the past century. Currently, environmental issues are leading to an evolution of the socio-economic context of earthworks. One of the most remarkable changes is the requirement to exclusively use the soils located directly in the land reservation of a project to build the infrastructure. In certain situations, the achievement of that objective imposes the use of soils with very low engineering properties that are unsuitable for making different parts of the structure, such as the capping layer and subbase, with the required performance. In these cases, soil stabilization becomes essential to improve the engineering properties of these materials. However, soil stabilization faces a number of limitations, especially when the soil contains a significant amount of chemical compounds that may alter the effects of the lime and cement. In France, about two million tons of soil per year is recognized as unsuitable for soil stabilization with lime and cement, and the presence of some detrimental chemical compounds has been highlighted to explain these failures.

The most widely known compounds to alter soil stabilization with lime and cement are sulfates (e.g., Mitchell, 1986; Hunter, 1988) and organic matter (e.g., Kuno et al., 1989; Tremblay, 1998). However, several cases of soil stabilization failure have been reported by practitioners with no sulfates or organic matter identified in the soil to be stabilized. In these cases, other compounds are sometimes considered to explain these failures like those contained in agricultural fertilizers (nitrates and phosphates) or chlorides in the vicinity of sea coasts (e.g., LCPC-SETRA, 2000). However, there are very few data available in the literature on the actual effects of these compounds on soil stabilization. In this context, it is not possible to conclude whether or not the presence of agricultural fertilizers (nitrates and phosphates) or chlorides in a soil can explain soil stabilization failures. In addition, if these compounds are likely to alter soil stabilization, it is necessary to determine the concentration threshold beyond which a compound may have a negative impact on the effectiveness of soil stabilization with lime and cements. Moreover, it is known that the curing conditions influence the physico-chemical processes of soil stabilization and, therefore, the mechanical performance and the swelling of the stabilized soil. In the case of sulfate-bearing soils stabilized with lime, considerable variations of the swelling have been demonstrated by Wang et al. (2003) and Harris et al. (2004) as a function of the curing conditions (relative humidity and temperature).

This study intended to assess quantitatively the influence of some potential deleterious compounds on the mechanical performance of a

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soil stabilized with cement and lime. The results permitted to study the possibility to determine a concentration threshold beyond which each compound alters the soil stabilization processes. Besides, several experimental procedures are available to determine the performance of a stabilized soil in the laboratory (LCPC-SETRA, 2000). They are based on several curing conditions (temperature and humidity) and different mechanical parameters to be tested (tensile strength, compressive strength, etc.). These different procedures were followed, to highlight the combined influences of temperature, curing time and humidity on the effects of the tested potential deleterious compounds.

Working with a natural soil could cause difficulties in determining the individual effects of a given chemical compound on soil stabilization (e.g., Cabane, 2005). Thus, an original procedure was used in this study. Suitable soils for stabilization were mixed with one chemical compound at a given concentration. The mechanical behavior of this mixture was then determined and compared to the performance of the stabilized soil without any added chemical compounds. Several experimental procedures, derived from French standards available to assess the performance of stabilized soils, were followed. The combination of these results demonstrated the actual effect of each compound quantitatively.

Two agricultural fertilizers were selected for testing: ammonium nitrate ($(NH_4)_2NO_3$) and potassium phosphate (K_3PO_4). Their use is widespread, and their potential effects on soil stabilization are still unknown. The chosen chloride was sodium chloride (NaCl). Although a comprehensive literature review of their effects on the soil stabilization processes is already available, sulfate compounds were also considered in this study because sulfates would give a qualitative comparison point to assess the impact of the other compounds on soil stabilization.

2. Materials

2.1. Tested soils

Two soils were selected in the framework of this study, a fine sand and a silt. The main difference between these soils was the presence of clayey particles in the silt (Le Borgne, 2010). The main properties of the two soils selected for this study are given in Table 1. The first soil, "limon Val d'Europe" (LVE), was sampled in the East of Paris. According to the AASHTO soil classification system, it can be classified as a silty soil (A.4). The second soil, Bouër sand (BS), was taken from the western part of the Paris Basin, and it can be classified as a fine sand (A.3).

The chemical analysis confirmed that these two soils do not contain any chemical substance that could be considered as potentially deleterious compounds for soil stabilization. The amount of organic matter, on a dry-weight basis, is 0.21% for the LVE silt and 0.07% for the BS sand. The main difference between the two selected soils is their grading, with a significant amount of particles smaller than 2 μm in the LVE silt. A mineralogical analysis showed that these fine particles are mainly composed of kaolinite (Le Runigo et al., 2009).

Table 1
Main identification properties of silty soil.

	Magny le Hongre silt (LVE)	Boüer sand (BS)
Dmax (mm)	5	1
<2 mm (%)	99.9	100.0
<80 μm (%)	94.6	5.2
Liquid limit (%)	36.5	Non plastic
Plasticity index (%)	15.7	Non plastic
Specific density (Mg m^{-3})	2.70	2.61

2.2. Chemical compounds

A key factor in these experiments was the amount of each chemical compound to add to a soil sample. The strategy adopted was to select two concentrations for each compound. The first one, a low value, was the mean value of the concentration of that compound found in soils in France. The second concentration, a high value, was the maximum concentration that has been reported in France. The selected values (Table 2) were determined with the help of the soil database of the French Institute for Agricultural Researches (INRA, 2007). They are derived from measurements in the first meter of the soil profile. In the case of chlorides, the high concentration corresponds to soils in the vicinity of a sea coast. The low concentration of chlorides was taken as the mean concentration of chlorides in the soils in France. For sulfates, the two concentrations correspond to the amount of sulfates found in the northern part of France.

2.3. Lime and cement

The quicklime selected has a high content of free lime, greater than 91%. Cements are highly variable in terms of their composition because they can include several secondary constituents. To minimize the interactions between these secondary constituents and the added chemical compounds, cements with as few secondary constituents as possible were selected. The first selected type of cement was pure Portland cement (CEM I 52.5 N) with more than 95% clinker, and the second one (CEM II 32,5 R) was a cement based on pure Portland cement (70% of clinker) containing limestone as a secondary constituent.

The amount and the type of cement were adapted as a function of the nature of the soil. In the case of the LVE silt, a pretreatment with 1.5% of lime was systematically performed before the addition of 6% of the desired cement. The BS sand was only stabilized with 6% cement. These dosages are of common practice in France for these types of soil (LCPC-SETRA, 2000). Under these conditions, the unconfined compressive strength (UCS) after 180 h of curing at constant water content of the LVE silt and of the BS sand is given in Table 3. All dosages are expressed on the dry-weight basis of the soil.

3. Experimental procedures

3.1. Blending of soil and chemical compounds

The preparation of the mixture of the soil and the desired chemical compound is a critical issue. To obtain homogeneous samples, we adapted a mixing procedure from the international standard ISO 11268 (1993). The procedure used in the present study followed these steps:

1. The chemical compound was dissolved in distilled water.
2. The soil and the solution were thoroughly mixed with a mechanical mixer for a few minutes.
3. A fifteen-day equilibration period was required in an airtight container and at 20 °C.
4. The soil was mixed again, and the water content was subsequently determined.

Table 2
Concentration of the chemical compounds (g per kg of dry soil).

	Low concentration [LC]	High concentration [HC]
$CaSO_4$, 2 H_2O	0.62	6.2
NH_4 NO_3	0.16	1.5
KPO_4	0.29	0.85
NaCl	0.06	1.2