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Weathering of a lime-treated clayey soil by drying and wetting cycles

Guillaume Stoltz [a,b,*], Olivier Cuisinier [a,1], Farimah Masrouri [a,2]

[a] Université de Lorraine, LEMTA, rue du Doyen Roubault N°40, Vandoeuvre lès Nancy 54501, France
[b] Irstea, HBAN Unit, 1 rue Pierre-Gilles de Gennes, CS 10030, Antony 92761, France

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ABSTRACT

Lime treatment induces several time-dependent physico-chemical processes (cation exchange, pozzolanic reactions, etc.) that result in the bonding of soil particles. This treatment can reduce the swelling properties of clays and improve their strength. Nevertheless, these positive effects of lime-treatment could be altered by weathering in the very long term. In this paper, the effects of successive drying/wetting cycles on the hydro-mechanical properties of a lime-treated clayey soil are considered.

Quicklime-treated samples were subjected to successive controlled-suction (osmotic technique) drying/wetting cycles; and also severe hydric cycles corresponding to an alternation of oven drying and saturation. The effect of quicklime dosage and curing time were considered. The results show a progressive increase of the swelling properties of the material and a progressive loss of strength with increasing number of drying/wetting cycles. The extent of the degradation is directly related to the amount of added quicklime and the amplitude of the suction cycles. Mercury intrusion porosimetry tests show that successive cycles lead to a progressive change of the micro-fabric, thus explaining partly the degradation of macroscopic properties.

This study shows that weathering by successive drying/wetting cycles is likely to significantly alter the properties of a lime-treated soil, thus weathering effects should be accounted for the long term design of treated soil structure.

1. Introduction

Swelling/shrinkage of expansive soils due to moisture content changes may cause damages to structures (e.g., Jones and Holtz, 1973; Chen, 1975). Many studies attempted to depict the couplings between variations in water content and the resulting modifications in volume, mechanical properties, or fabric of expansive soils, compacted or in a natural state (e.g., Push, 1982; Gens and Alonso, 1992; Simms and Yanful, 2002), with a special attention to the influence of drying/wetting cycles (Day, 1994; Al-Homoud et al., 1995; Alonso et al., 1999; Cuisinier and Masrouri, 2005). Successive drying/wetting cycles may result in progressive accumulation of irreversible strains, (Chu and Mou, 1973; Alonso et al., 2005; Nowamooz and Masrouri, 2009) leading to alteration of the mechanical behaviour.

Among the potential techniques likely to reduce the impact of drying/wetting cycles on expansive soils, lime treatment would be of interest. Indeed, it induces several time-dependent physico-chemical processes (cation exchange, pozzolanic reactions, etc.) that result in the improvement of soil behaviour (Diamond and Kinter, 1965; Eades and Grim, 1966). In particular, it is known to reduce the swelling potential of expansive soils (Ashraf and Walker, 1963; Transportation Research Board, 1987; Basma and Tuncer, 1991; Nalbantoglu and Tuncer, 2001). Nevertheless, some authors have shown that the effects of lime treatment could be partially withdrawn by exposure to climatic conditions, like freezing and thawing (Thompson and Dempsey, 1969), or water circulation (De Bel et al., 2005; Le Runigo et al., 2009). In the case of lime treated expansive soils, a key question is the impact of successive drying and wetting periods. Gutschick (1978) and Kelley (1988), from field investigations of lime stabilised roads and earthfills, showed qualitatively that the alternation of dry/wet periods could be detrimental to the efficiency of lime treatment in the long term. Some experiments conducted on samples reconstituted in the laboratory were also reported in the literature. Khattab (2002) concluded that after a few number of wetting/drying cycles, the swelling potential of a lime-treated bentonite was of the same order of magnitude as the untreated bentonite. Guney et al. (2007) showed that the beneficial effect of lime stabilisation in controlling the swelling potential of lime-treated samples is partially lost, after having been exposed to several cycles of wetting and drying. These studies tend to indicate that such cycles can alter the effects of lime treatment on swelling potential of clays. However, in these laboratory studies, the samples were subjected to cycles between saturation (samples exposed to free water) and very low relative humidity associated to temperatures higher than 40 °C. These

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* Corresponding author at: Irstea, HBAN Unit, 1 rue Pierre-Gilles de Gennes, CS 10030, Antony 92761, France. Tel.: +33 1 40 96 60 48; fax: +33 1 40 96 61 99.

E-mail addresses: Guillaume.Stoltz@irstea.fr (G. Stoltz), Olivier.Cuisinier@univ-lorraine.fr (O. Cuisinier), Farimah.Masrouri@univ-lorraine.fr (F. Masrouri).

[1] Tel.: +33 3 83 59 63 41; fax: +33 3 83 59 63 00.

[2] Tel.: +33 3 83 59 63 04; fax: +33 3 83 59 63 00.

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experimental conditions are severe compared to field conditions. Very few studies tested lime-treated samples subjected to successive wetting/drying cycles with more realistic water content variations. Cuisinier and Deneele (2008) performed suction-controlled oedometer tests on samples from an embankment three years after the construction. They concluded that the lime treatment efficiency could decrease with time due to successive wetting/drying cycles. Lastly, Tang et al. (2011) showed that successive wetting/drying cycles could lower the stiffness of a silty soil treated with 3% of quicklime.

When the effects of hydric stresses on a lime-treated soil are investigated, one major issue is the reasons that could explain the alteration of the soil behaviour. This implies the analysis of the physico-mechanical processes at micro-scale. In the above refereed studies, no authors have investigated such mechanisms even if it is crucial to know if some minerals from lime hydration were washed away due to water exchange. Regarding this question, Le Runigo et al. (2009) investigated the effect of long term leaching on the physical properties of a silty soil treated with two dosages of lime. After 150 days of leaching, they concluded that there was likely some dissolved portlandite and cementitious compounds but they supposed that there was simultaneously a competition between dissolution and precipitation processes. Finally, their study evidenced that the weathering processes of lime-treated materials at micro-scale are very complex.

In this context, a study was undertaken to assess the long term hydro-mechanical properties of a quicklime-treated expansive clayey soil subjected to cyclic suction variations. Osmotic suction-controlled oedometers were used to determine the shrinkage/swelling behaviour of soils subjected to drying/wetting cycles in the range of suctions comprised between about 8 MPa–0 MPa (suction range discussed in Section 2.2.2). To evaluate the effect of the cycle amplitude, severe hydric cycles corresponding to an alternation of oven drying and saturation were performed. At the end of the cycles, the mechanical properties were measured and compared to those of the intact specimens. The effect of quicklime dosage (i.e. 2% and 5% quicklime) and curing time (i.e. 0, 28 and 180 days), corresponding to the time during which the lime-treated samples were stored before the imposition of the cycles, were considered. Moreover, to study the effect of drying/wetting cycles on the soil fabric, pore size distribution (PSD) was investigated by mercury intrusion (MIP) tests. To interpret the quicklime-treated soil fabric after hydric cycles, the study of Stoltz et al. (2012) that examines the effect on both wetting and drying paths on the quicklime-treated soil fabric will be considered. At last, by coupling macroscopic aspects with fabric changes, the weathering process of lime-treated clayey soil was discussed.

2. Materials and methods

2.1. Tested materials

The studied soil was an expansive clayey soil sampled in the eastern part of France (Table 1). This soil is an inorganic clay of high plasticity (CH group symbol) according to the Unified Soil Classification System. The clayey fraction (<2 μm) analysed by X-ray diffraction shows that it was mainly composed of smectite and muscovite minerals with a small quantity of chlorite. The lime used in this study contained 94% quicklime (CaO). The Atterberg limits of the lime-treated soil evidenced a significant increase of the liquid and plastic limits, which is typical with this kind of clayey soil.

Table 1
Main geotechnical properties of the clayey soil in this study.

Properties	Natural soil	Soil treated with 2% of CaO (1 h of curing)	Soil treated with 5% of CaO (1 h of curing)
Geotechnical			
Passing sieve 80 μm (%)	90	–	–
Clay size content (<2 μm) (%)	70	–	–
Specific gravity Gs (−)	2.675	–	–
Liquid limit (%)	71	107	103
Plastic limit (%)	29	46	48
Plasticity index (%)	42	61	55

For the sample preparation, the water content of the clayey soil was adjusted to reach the optimum water content of compaction which depended on the considered quicklime content (Table 2). After a storage period of 24 h to homogenise the moisture content, the soil and the quicklime were mixed thoroughly. The mixture was left 1 h in an airtight container before compaction to allow the development of immediate reactions between the quicklime and soil particles. Then, the mixture was statically compacted in a mould to the target dry density (Table 2). When a curing period prior to testing was required, the compacted samples were wrapped in plastic sheets to prevent any water loss and kept at 20 ± 1.5 °C.

2.2. Experimental techniques

Three types of oedometer tests were used: constant rate of strain CRS test to follow the kinetic of the increasing mechanical performances of lime-treated soils; standard oedometer test to assess the mechanical performances of lime-treated soils at high effective stresses and osmotic oedometer tests including wetting/drying cycles.

2.2.1. Mechanical tests

In this study the effect of quicklime treatment on the tested samples was evaluated through oedometer tests with the determination of swelling potential and yield stress. To monitor the variation of yield stress as a function of time, CRS oedometer tests were carried out in a modified Rowe cell on lime-treated samples for various quicklime dosages comprised between 0 and 5% and various curing times comprised between 1 h and 360 days. The initial height of the samples was $H_0 = 1.9 \pm 0.10$ cm and the diameter was equal to 7.6 cm. The CRS test consists in compressing at constant rate of vertical strain a fully saturated sample placed in an oedometric cell. The progressive loading applied to the sample results in an increase of total vertical stress σ_v and pore water pressure u_b at the base of the sample whilst drainage takes place at the top. Following Wissa et al., 1971, who suggested that the soil can be supposed to be a linear material provided that the rate of strain is slow enough to keep the ratio u_b/σ_v less than 0.05, it is possible to relate the void ratio to an average effective stress. In this case, the average effective stress is given by the following equation:

$$\sigma_v\prime = \sigma_v - 2/3u_b \tag{1}$$

where σ_v is the total vertical applied stress and u_b is the pore pressure measured at the base of the specimen. To meet this ratio of 0.05, a rate of vertical strain of 0.07%/min was suitable for the CRS tests on the studied quicklime-treated materials.

In this study, CRS tests lasted less than 5 h. It was therefore possible to monitor accurately the variation with time of yield stress of the tested lime-treated materials even with very short curing time (i.e. 1 h, 1 day).

Table 2
Compaction characteristics under normal Proctor energy of the quicklime-treated samples.

Quicklime content (% CaO dry weight)	0.0	0.5	1.0	1.5	2.0	5.0
Maximum dry density ρ_{di} (Mg·m^{-3})	1.45	1.43	1.40	1.37	1.34	1.20
Optimum water content w_i (%)	26.5	27.0	28.0	30.0	32.0	37.0