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Technical Note

Influence of delayed compaction on the compressibility and hydraulic conductivity of soil–lime mixtures

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ABSTRACT

Conflicting recommendations and opinions can be found in literature concerning the effects of a delayed compaction of lime-stabilized soils. This study was carried out to evaluate such effects on a clayey soil (CH) with 5% of quicklime and hydrated lime. One-dimensional consolidation and hydraulic conductivity tests were carried out on samples compacted soon after lime addition and after 48 h. Analysis of results, helped by scanning electron microscopy and mercury intrusion porosimetry, shows that, for the tested soil, delayed compaction causes a reduction of the dry unit weight up to 11% with hydrated lime and to 18% with quicklime and a greater compressibility of the mixtures at high pressures (at 800 kPa the compression index of samples compacted with delay is doubled relative to that of the immediately compacted ones). However, pozzolanic reaction was found to progress with curing time, even in the case of delayed compaction. The hydraulic conductivity is not significantly modified by a delayed compaction; it is strongly affected by the wetting conditions of curing in the case of hydrated lime. In general, a prompt compaction is always recommendable after addition of hydrated lime whereas the use of quicklime mitigates the influence of a delayed compaction.

1. Introduction

Availability of natural high-quality soil to be used as construction material is more and more limited for environmental and economic reasons; in particular, soils are non-renewable resources and, as such, they should be recycled as much as possible.

Properties of fine grained soils can be improved by adding lime as a stabilizing agent in order to obtain proper mechanical characteristics for earthen structures (e.g. dikes, road embankments). A combination of lime and other stabilizing agents (e.g. cement kiln dust, high alkali and slag cements, fly ashes) can improve geotechnical properties of dredged sediments too, making them favorable for large fill applications and subgrade improvement applications at costs equivalent to or less than conventional construction materials (Grubb et al., 2010).

In fact, lime addition eliminates high costs due to both supplying suitable soils (purchase of high quality material from quarries and its transportation) and transportation and disposal of the unsuitable in situ soil. Typically, in road design, the soil available from trenches along the route is often used after its improvement by adding lime (quick or hydrated) (Winterkorn and Pamukcu, 1991; Greaves, 1996).

The successful use of compacted fine soil–lime mixtures requires a careful preliminary laboratory testing on the soil to be used and on the soil–lime mix in order to identify the best soil–binder proportion. Moreover, proper laboratory testing should be set up in order to consider the influence on the mixture performance of the environmental factors occurring during construction. One of them is a possible compaction delay after lime adding and mixing.

During construction, a time lag may elapse between soil–lime mixing and compaction due to hitches or technical breaks for logistic reasons. In reviewing literature, conflicting recommendations and opinions can be found concerning the influence of delayed compaction: studies developed by the Louisiana Department of Transport in the early sixties pointed out that a delay longer than 48 h involves a lower strength of the soil–lime mixtures (Taylor and Arman, 1960), Mitchell and Hooper (1961) found that a 24 hour delayed compaction reduced the dry unit weight and the long-term strength (then confirmed by the Dumbleton's studies (1962)), whereas the swelling was found to increase. More recently, some authors recommend compaction to be performed immediately after addition of lime (Winterkorn and Pamukcu, 1991; Osinubi, 1998; Osinubi and Naiwu, 2006) while others advise a wait of few days (mellowing period) in order to obtain a higher quality material (Bhattacharia et al., 2003). The suggested delay should depend on the grain size of soil to be stabilized and on the wet or dry condition of lime addition (TRB, 1987; Holt and Freer-Hewish, 1996).

The aim of the study is to evaluate the effects of a delayed compaction on a clayey soil stabilized with lime. The mechanical and hydraulic performances of samples compacted immediately after mixing or allowing a 48 hour delay were compared, both with hydrated lime and with quicklime, at a percentage of 5%.

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Table 1
Main soil characteristics.

Properties	Value
Sand (<2 mm%)	16
Fine (<0.075 mm,%)	84
Clay (<0.002 mm,%)	44
Liquid limit (%)	62
Plasticity limit (%)	30
USCS class	CH
ICL[a] (hydrated lime)	4
ICL[a] (quicklime)	2

[a] ICL = initial consumption of lime ASTM C977-00.

2. Soil–lime reactions and their effects

When lime is added to a clay soil, different reactions occur causing immediate and long term changes to the soil. These reactions, widely described in literature (TRB, 1987; Winterkorn and Pamukcu, 1991; Boardman et al., 2001; Bhattacharia et al., 2003; Di Sante et al., 2014) depend upon the type of soil and lime mixed. Briefly, if quicklime is added to a soil–water system, its hydration (highly exothermic) occurs at first, forming hydrated lime, $Ca(OH)_2$. As a result soil workability is improved for any type of soil, due to dewatering.

Hydrated lime is a strong base, therefore, in the pore water of soil, it dissociates into Ca^{++} and OH^{-}. In clayey soils this dissociation results in a sequence of reactions. The first one is an immediate ion exchange of calcium ions for the existing cations at the negative charge sites on the clay particle surface (the number of exchange sites increases with pH). The ion exchange causes aggregation of mineral particles and reduction of plasticity index (Hussain and Dash, 2010) therefore a further improvement in workability occurs. The reaction mechanisms described so far produce the so called "lime modified soils".

The long-term changes in soil properties are brought about by pozzolanic reactions that occur between calcium ions and the silica or alumina of the lattices of clay minerals (many researchers have different opinions about where reactions occur: in solution or at the surface or at the edges of the clay particles (Diamond and Kinter, 1966; Eades and Grim, 1966; Stocker, 1972)). These reactions produce improvements

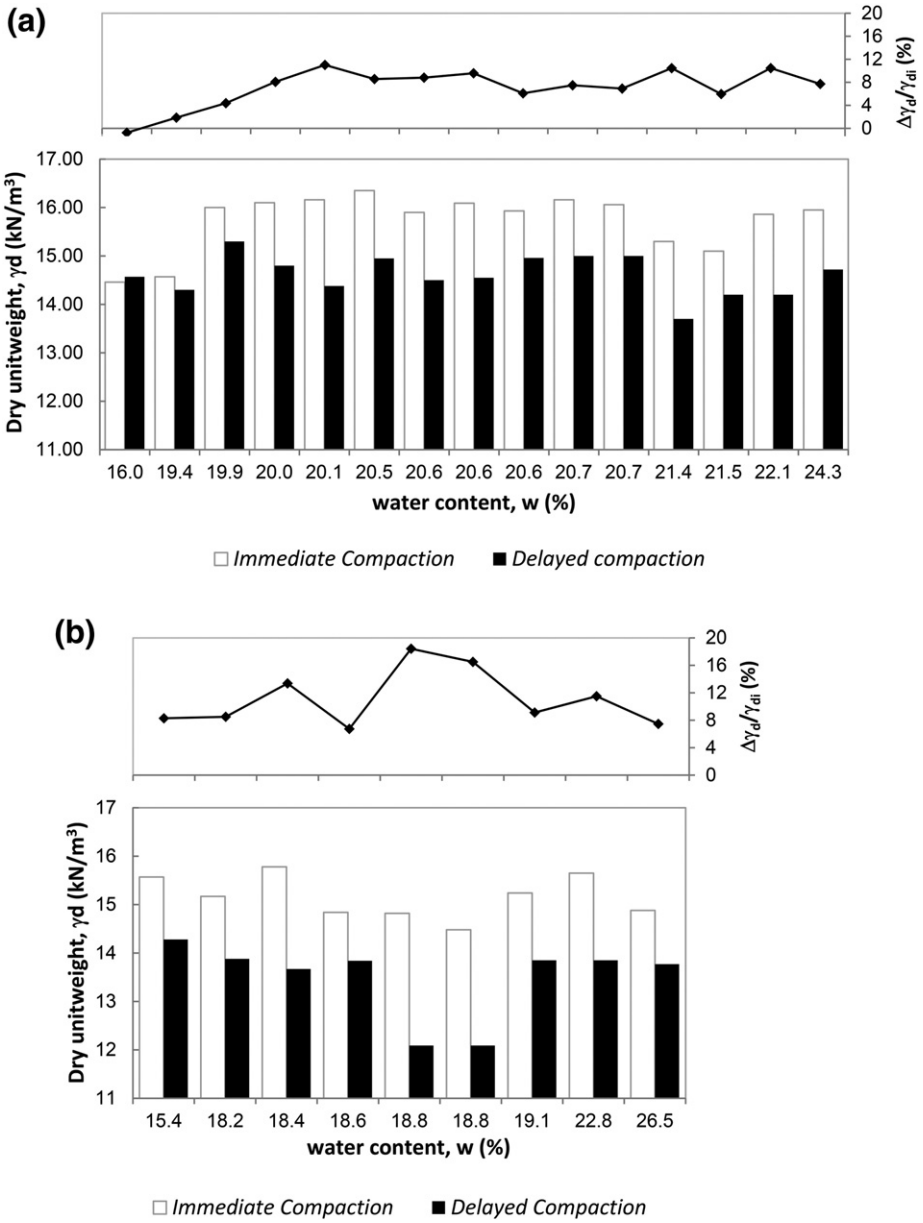

Fig. 1. Dry unit weight values and relative reduction for immediate and 48 h delayed compaction for hydrated lime stabilization (a) and for quicklime stabilization (b).