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Research paper

Comparison of the effect of mixing methods (dry vs. wet) on mechanical and hydraulic properties of treated soil with cement or lime

Mohammad S. Pakbaz [a], Mohsen Farzi [b]

[a] Department of Civil Engineering, Shahid Chamran Univ., Ahwaz, Iran
[b] Shahid Chamran Univ., Ahwaz, Iran

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ABSTRACT

Where difficult foundation soils are encountered in civil engineering projects, deep soil mixing method is a choice as a solution to deal with the problem. In this soil improvement method, cement or lime in slurry form (wet method) or in dry powder (dry method) is mixed with the in situ soil. To the knowledge of the authors no comparison between cement and lime treated soil using wet or dry method has been made for saturated soils. In this research saturated bentonite-sand mixtures were treated with 2, 4, 6, 8 and 10% by dry mass of cement, lime and cement–lime using both wet and dry methods. Treated soil samples after curing periods of 7, 14 and 28-days were tested in unconfined compression strength and consolidation. The results of unconfined compression tests indicated that the strength of wet cement treated samples was higher than dry cement treated samples and this was opposite for lime treated samples. The results of consolidation tests in terms of the e–logσ'_v relationship indicated that they were in general, function of the type and the amount of the admixture and the curing time. Compression index decreased with amount of additive in contrast with previous finding for cement treated samples of a low plastic clay soil. Lime treated samples showed higher elastic modulus than cement treated samples and dry treated samples in general showed higher elastic modulus than wet treated samples.

1. Introduction

Soil mixtures with the Portland cement and with lime have differences and similarities. This is because these additives have different chemical constituents. Lime besides other impurities mainly consists of calcium oxide (CaO) known as dehydrated lime or calcium hydroxide [$Ca(OH)_2$] known as hydrated lime. Whereas, the primary constituents of the Portland cement are tri-calcium silicates in the form of 3CaO, SiO_2 (C_3S), bi-calcium silicate in the form of 2CaO, SiO_2 (C_2S) and tri-calcium aluminates in the form of 3CaO, Al_2O_3 (C_3A).

According to Mitchell and Soga (2005), when lime or cement is mixed with soil and water, the pH increases to about 12.4, causing the dissolution of both silica (SiO_2) and alumina (Al_2O_3) from the soil into a highly alkaline environment. These compounds can then combine with lime (dissociated into Ca^{++} and OH^-) to form calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). The strength of lime-treated soils is dependent primarily on the dissolved SiO_2 and Al_2O_3 available as well as on the existing amounts of Ca^{++} and OH^- (Consoli et al., 2011). When, the ions Ca^{++} and OH^- are completely consumed, the pH of the soil mix would drop and the end of pozzolanic reactions is reached unless the amount of lime is higher than the minimum amount necessary to reach the maximum pH of 12.4. The higher the amount of lime and the amount of SiO_2 and Al_2O_3 available from the soil the larger the strength reached by the soil–lime mixture (Ingles and Metcalf, 1972). According to Mitchell (1981), lime contents of 3–8% by weight of dry soil are typical for the improvement of fine-grained soils. It is generally known that lime is particularly suitable to improve heavy clays and the pozzolanic reaction in soil–lime is a slow process (Feng et al., 2001). The flocculation of soil particles at low lime content below about 3% by dry weight was accounted for the changes in soil properties (Locat et al., 1996).

The improvement of the cement-treated soil on the other hand is due to primary hydration reaction of cement constituents with soil water and secondary pozzolanic reaction of hydrated lime produced during primary hydration reaction with Sio_2 and Al_2O_3 dissociated from the soil in alkaline environment (pH > 12.4) created upon hydration of cement constituents (Mitchell, 1981; Feng et al., 2001). The products of primary hydration are comprised of hydrated calcium silicates (C_2SH_x, $C_3S_2H_x$), calcium aluminates (C_3AH_x) and hydrated lime [$Ca(OH)_2$] and the product of secondary pozzolanic reaction is additional calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) (Chew et al., 2004; Kamnuzzaman et al., 2009).

Evaluation of soil mixing in the field and in the laboratory has been done before by many researchers around the world (Bergado et al., 1996; Locat et al., 1996; Feng et al., 2001; Chew et al., 2004; Lee et al., 2005; Shen et al., 2008; Kamnuzzaman et al., 2009; Duraisamy et al., 2009; Jongpradist et al., 2011; Consoli et al., 2011 and Pakbaz and

E-mail addresses: Pakbaz_m@scu.ac.ir (M.S. Pakbaz), Mohsen.Farzi@gmail.com (M. Farzi).

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Table 1
Chemical composition of lime.

Composition	Content (%)
SiO2	0.7
$Al_2O_3 + Fe_2O_3$	1.3
L.O.I	26.4
CaO	71.1
MgO	0.5

Alipour, 2012). In these research activities the cement or lime was introduced to the soil either in the form of slurry (wet method of mixing) or in the form of powder (dry method of mixing). Also in the field both dry and wet applications are used (Islam and Hashim, 2004). A comparison between wet and dry method of mixing for both cement and lime treated soils with high initial water content has not been done so far. In this study, the behavior of the soil samples with the initial high water content treated with lime, cement and lime–cement in different percentages using dry and wet methods is examined and compared.

2. Materials

The soil that was used in this study consisted of a mixture of 60% commercial bentonite ($w_l = 255\%$, $I_p = 122\%$) used in drilling and 40% local wind blown sand ($D_{10} = 0.074$ mm, $D_{60} = 0.2$ mm, $C_U = 2.4$). The reason for using sand in the mixture was to reduce the time for primary consolidation of soil samples in the laboratory. The time for 90% consolidation (t_{90}) untreated mixture varied between 30 and 600 min depending on the stress level. The end of primary consolidation for untreated bentonite without sand was not measured. Liquid limit and plastic limit of the soil mixture were 132 and 70% respectively. All the samples prepared with initial water content equal to the base soil liquid limit. The reason for selecting initial water content of all samples as the liquid limit of the mixture was to have similar initial condition. It is realized that in practice during wet method application higher initial water content than during dry method application before setting time may be achieved. The cement that was used was type II cement manufactured in Karoon factory in Khuzestan. The lime that was used was of non-hydrated type and had chemical composition as shown in Table 1.

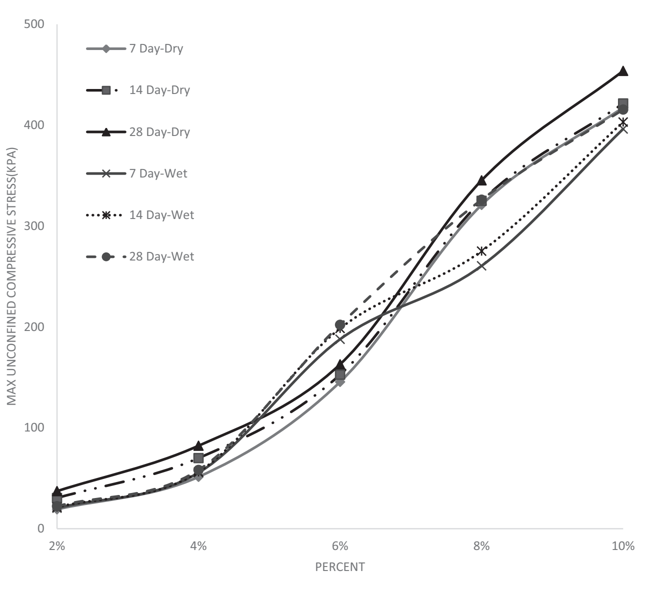

Fig. 1. Relationship between max unconfined compressive stress percent lime dry and wet.

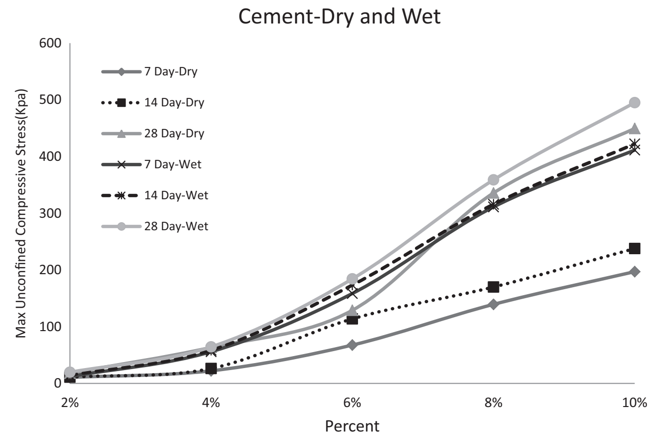

Fig. 2. Relationship between max unconfined compressive stress, percent cement dry and wet.

2.1. Sample preparation

All unconfined compression and consolidation test specimens were prepared in the pvc molds of 5 cm in diameter and 16 cm in height. After curing of samples, specimens for consolidation tests were cut and prepared from original cured samples using wire saw (diameter = 5 cm height = 3 cm). The remainder of samples (height = 13 cm) were prepared and used in unconfined compression tests. In order to eliminate any sample disturbance during the removal of the samples from the molds, the molds were cut longitudinally into two halves and the two halves were then taped back together stiffly before placing the soil samples into them. Before placing the soil samples into the molds, the bottom of the molds were sealed tightly with a thick plastic. In order to prevent the soil from sticking to the molds a plastic lining was placed inside the molds.

The soil samples after proper mixing were placed into the molds with spatula in four stages. In each stage, after placing the soil into the mold to a height of about 4 cm, the mold was tapped 40 times against the surface of the table from a height of about 10 cm. This was done in order to ensure removal of any air bubble trapped within the samples. The samples were then sealed and wrapped with a thick plastic and placed into a water tab for curing.

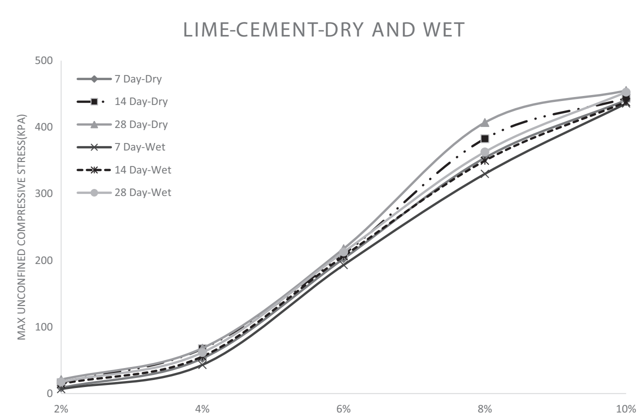

Fig. 3. Relationship between max unconfined compressive stress, percent lime + cement dry and wet.