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Analysis of strength development in cement-stabilized silty clay from microstructural considerations

Suksun Horpibulsuk [a,*], Runglawan Rachan [b], Avirut Chinkulkijniwat [a], Yuttana Raksachon [c], Apichat Suddeepong [c]

[a] Construction Technology Research Unit, School of Civil Engineering, Suranaree University of Technology, 111 University Avenue, Muang District, Nakhon Ratchasima 30000, Thailand
[b] Department of Civil Engineering, Mahanakorn University of Technology, 51 Cheum-Sampan Rd., Nong Chok, Bangkok 10530, Thailand
[c] School of Civil Engineering, Suranaree University of Technology, 111 University Avenue, Muang District, Nakhon Ratchasima 30000, Thailand

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ABSTRACT

This paper analyzes the strength development in cement-stabilized silty clay based on microstructural considerations. A qualitative and quantitative study on the microstructure is carried out using a scanning electron microscope, mercury intrusion pore size distribution measurements, and thermal gravity analysis. Three influential factors in this investigation are water content, curing time, and cement content. Cement stabilization improves the soil structure by increasing inter-cluster cementation bonding and reducing the pore space. As the cement content increases for a given water content, three zones of improvement are observed: active, inert and deterioration zones. The active zone is the most effective for stabilization where the cementitious products increase with cement content and fill the pore space. In the active zone, the effective mixing state is achieved when the water content is 1.2 times the optimum water content. In this state, the strength is the greatest because of the highest quantity of cementitious products. In the short stabilization period, the volume of large pores (larger than 0.1 μm) increases because of the input of coarser particles (unhydrated cement particles) while the volume of small pores (smaller than 0.1 μm) decreases because of the solidification of the cement gel (hydrated cement). With time, the large pores are filled with the cementitious products; thus, the small pore volume increases, and the total pore volume decreases. This causes the strength development over time.

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1. Introduction

Soil in northeast Thailand generally consists of two layers. The upper layer (varying from 0 to 3 m thickness) is wind-blown and has been deposited over several decades. It is clayey sand or silty clay with low to moderate strength ($12 < N < 20$, where N is the standard penetration number). This upper soil is problematic because it is sensitive to changes in water content [1]. Its collapse behavior as a result of wetting is illustrated by Kohgo et al. [2]; and Kohgo and Horpibulsuk [3]. The lower layer is residual soil that is weathered from claystone and consists of clay, silt, and sand [4]. It possesses very high strength (generally $N > 30$) and very low compressibility. One of the most common soil improvement techniques for upper soil is to compact the in situ soil (in relatively a dry state) mixed with cement slurry. This technique is economical because cement is readily available at a reasonable cost in Thailand. Moreover, adequate strength can be achieved in a short time.

Stabilization begins by mixing the soil in a relatively dry state with cement and water specified for compaction. The soil, in the presence of moisture and a cementing agent becomes a modified soil, i.e., particles group together because of physical–chemical interactions among soil, cement and water. Because this occurs at the particle level, it is not possible to get a homogeneous mass with the desired strength. Compaction is needed to make soil particles slip over each other and move into a densely packed state. In this state, the soil particles can be welded by chemical (cementation) bonds and become an engineering material.

The effects of some influential factors, i.e., water content, cement content, curing time, and compaction energy on the engineering characteristics of cement-stabilized soils have been extensively researched [5–20]. However, these previous investigations have mainly focused on the mechanical behavior: the microstructural study is limited. It is vital to understand the changes in engineering properties that result from changes in the influential factors.

Models of the microstructure of fine-grained soils have been developed and modified since 1953 by geotechnical engineers to help understand soil behavior. Lambe's model is the first conceptual model, which considers clay particles to be single platelets.

* Corresponding author. Tel.: +66 44 22 4322, +66 89 767 5759; fax: +66 44 22 4607.
E-mail addresses: suksun@g.sut.ac.th, suksun@yahoo.com (S. Horpibulsuk), runglawa@gmail.com (R. Rachan), avirut@sut.ac.th (A. Chinkulkijniwat).

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Since Lambe developed his theory, there have been significant improvements in microstructure observation techniques, leading towards complete description of the microstructure of fine-grained soils in relation to their engineering behavior such as the works reported by Gillott [21] and Collins and McGown [22]. Aylmore and Quirk [23]; Olsen [24]; and Nagaraj et al. [25] have revealed that the basic element of the microstructure of natural clay is not the single platelet but domains composed of various aggregated platelets.

Because cement and clay interacts with water, when clay is mixed with cement and water, clay and cement particles group together into large clay–cement clusters [26]. The cement gel is stable in the intra-aggregate and inter-aggregate pores because of the attractive forces (caused by physicochemical forces), and the capillary forces between the clay–cement clusters and the cement gel, respectively.

Abduljauwad [27] observed the microstructure changes of stabilized soils using scanning electron microscopes (SEMs). Keshawarz and Dutta [28] reported that the particles of uncemented soil appear as a blocky arrangement of loosely packed particles while the cemented soil has an abundance of tobermorite crystals. Previous works focusing on clay mineralogy [27,29–32] used X-ray diffraction techniques to investigate the mineralogical changes and to identify the reaction products formed when lime is added to clay soils.

Even though available researches exists on microstructure of cement-stabilized clay, they mainly focus on particular water content and curing time and do not cover all microstructural tests. This paper attempts to investigate the microstructural changes in cement-stabilized silty clay to explain the different strength development according to the influential factors, i.e., cement content, clay water content and curing time. Two sets of cemented samples were prepared for this study: samples with cement content C = 0–10% (practical range) and C > 10%. In the first set, the investigation illustrates the role of the influential factors on the strength and microstructure development and determines the effective mixing state in the practical range. The second set is used to further understand the strength and microstructure development with cement to facilitate the determination of proper quantity of cement to be stabilized. The unconfined compressive strength was used as a practical indicator to investigate the strength development. The microstructural analyses were performed in this paper using a scanning electron microscope, mercury intrusion porosimetry, and thermal gravity tests.

Table 1
Chemical composition of ordinary Portland cement and silty clay.

Chemical composition (%)	Portland cement	Silty clay
SiO_2	20.90	20.10
Al_2O_3	4.76	7.55
Fe_2O_3	3.41	32.89
Cao	65.41	26.15
MgO	1.25	0.47
SO_3	2.71	4.92
Na_2O	0.24	ND
K_2O	0.35	3.17
LOI	0.96	3.44

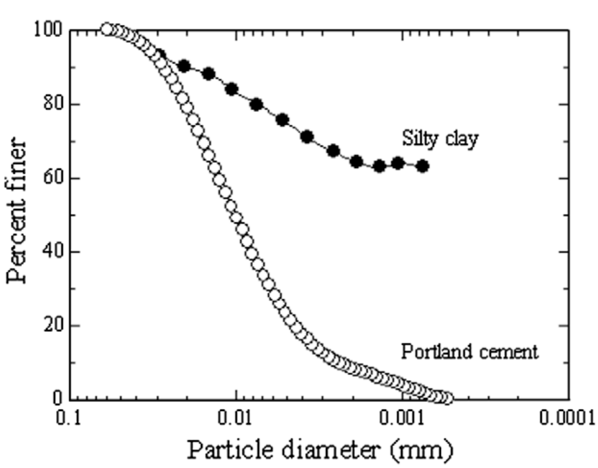

Fig. 1. Grain size distributions of Portland cement and silty clay.

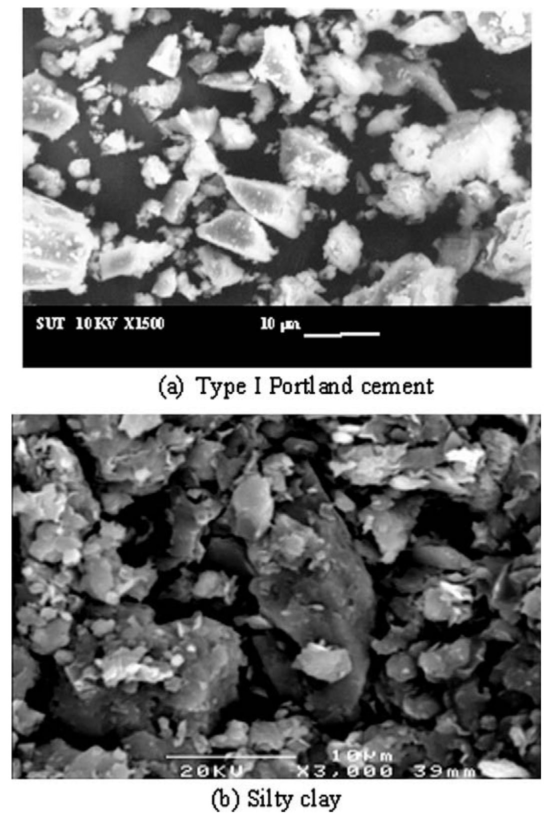

Fig. 2. SEM photos of cement and natural clay.

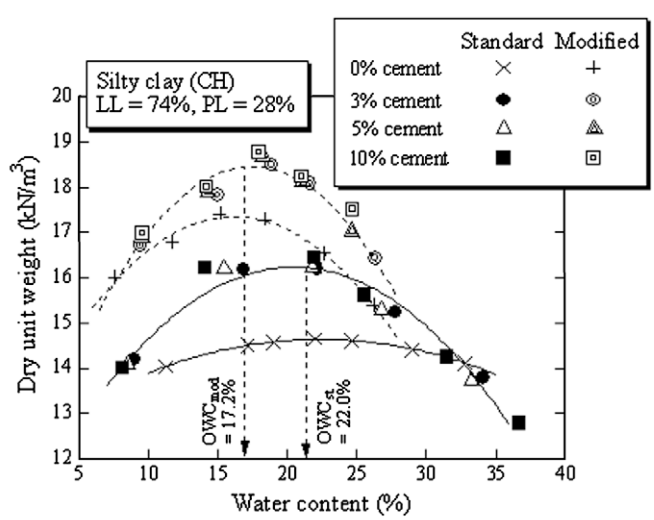

Fig. 3. Plot of dry unit weight versus water content of the uncemented and the cemented samples compacted under standard and modified Proctor energies.

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