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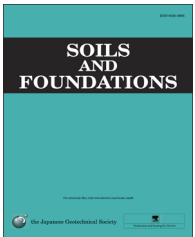


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Effect of cation exchange capacity of soil on stabilized soil strength

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Abstract

While a certain correlation between the cation exchange capacity (CEC) of the soil and the strength of the cement stabilized soil has been reported, the mechanism remains unclear. In this research, a set of soil samples with different CECs were stabilized with different proportions of cement and calcium hydroxide (Ca(OH)₂, CH). The influence of soil CEC on the strength of the stabilized soil was investigated by analyzing the CH saturation in the pore solution and measuring the strength of the stabilized soil specimens. It is revealed that cation exchange in the soil can reduce the CH saturation of the stabilized soil. If the CEC of the soil is too high, the CH in the pore solution of the stabilized soil cannot reach the saturation level, and further cation exchange would then consume the Ca²⁺ ions which should be originally used to generate calcium silicate hydrate, thus result in the poor strength of the stabilized soil.

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Keywords: Stabilized soil; Strength; Cation exchange capacity; Pore solution; CH saturation

1. Introduction

Cement stabilized soil is a kind of treatment technique which has been broadly used in subgrade stabilization (Arman et al., 1990; Kawasaki et al., 1983; Nishimura et al., 2012; Reuben, 2003; Taheri et al., 2012; Zhou and Ye, 2008). It is well known that soil's physical characters, such as water content, porosity, and clay content, have great influence on the strength of cement stabilized soil (Anagnostopoulos and Chatziangelou, 2008; Kawasaki et al., 1978). However, it is noticed that the strength of the stabilized soils made with same cement content, and even the strength of soils with similar

physical properties, differs greatly (Huang, 1997). Therefore, there must be other factors besides the physical properties of the soil which cause the difference in the strength of stabilized soils. Croft and Nettleton (1962) reported that cement could hydrate normally in clay minerals, kaolinite and illite consumed little calcium hydroxide (Ca(OH)₂, CH) and the strength of the stabilized soil made of the soil mainly composed of them was higher, while montmorillonite consumed more CH and the strength of the stabilized soil made of the soil mainly composed of it was lower. Cui et al. (2011) reported that the higher the montmorillonite content in bentonite, the higher was the soil's cation exchange capacity (CEC). Saitoh and Suzuki (1986) reported that cement hydration mainly produced the calcium silicate hydrate (C–S–H) and CH. The soil could absorb CH until it reached saturation point. Then the pozzolanic reaction occurred between the remaining CH and the soil to generate additional C–S–H, which determined the strength difference of the cement stabilized soils made from different soils. However,

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this theory does not satisfactorily explain the phenomenon mentioned above. Nakatsukasa (1986) reported that other cations absorbed by the soil could exchange with Ca^{2+} , and there was certain correlation between CEC and the strength of the cement stabilized soil. This study offered the test phenomenon, but did not explain the mechanism. Kawamura et al. (1971) studied the relationship between soil CEC and the stabilized strength of the cement stabilized soil, and proposed that the C–S–H with different lime–silicate ratios could be formed in the cement stabilized soils which were made from the soil samples with different CECs, and led to the strength difference among the cement stabilized soils. No experimental evidence, however, can prove that the C–S–H with different lime–silicate ratios can lead to a significant strength difference in the cement stabilized soils. Huang and Zhou (1994) proposed that because the CH in stabilized soils might be under-saturated, the further consumption of Ca^{2+} and OH^- ions by the soil decreases the amount of C–S–H generated by the cement. This explains why an equal amount of cement would not produce equal amount of hydrates in the stabilized soils made from soils with different absorption capacities of the ions, but resulted in a strength difference of the stabilized soils. However, the factors which affected the CH saturation were not clarified (the ratio of CH concentration in the pore solution to the saturated concentration is expressed as the CH saturation index (SI) in this study) for the stabilized soils, or how they affected the strength of the stabilized soils.

In this research, a set of soil samples with different CECs were selected. The stabilized soil specimens were made by mixing the soil samples with different amounts of cement and CH. The influence of soil CEC on the CH saturation in the pore solution and in turn on the strength of the stabilized soil specimens was investigated by analyzing the pore solution of the specimens and measuring the strength of the specimens.

2. Materials and methods

2.1. Materials

Ordinary 32.5 Portland cement (PC, based on the standard *Common Portland Cement*, GB175-1999), the analytic reagent CH, and distilled water were used in this test. The soil samples T₁, T₂, T₃, T₄, and T₅ had significant differences in their CEC content, and were made by mixing kaoline (GT), Na texture montmorillonite (NT) and the silt soil (FT) with particle sizes between 0.1 mm and 0.074 mm. Table 1 provides details of the mixing proportions as well as the physical properties and CEC content of the soil samples. The physical properties of the soil samples T₁, T₂, T₃, T₄, and T₅ were measured based on *Standard for Soil Test Method* (GB/T50123-1999). The determination of soil samples' CEC was conducted by the Chemical Testing Center of China University of Geosciences (Beijing, China) based on the standard *Cation exchange capacity of soils (sodium acetate)* (US EPA Method 9081). The main procedures were as follows: (1) 4 g air-dried soil sample was put into a centrifuge tube; (2) 33 mL of 1 mol/L sodium acetate solution was added to the centrifuge tube, then

Table 1
Mixing proportion and characteristics of testing soil samples.

Soil samples	Mixing proportion (%)			Physical characteristics					CEC (mol/kg)
	GT	NT	FT	ρ (g cm ⁻³)	ω (%)	n (%)	ω_L (%)	ω_P (%)	
T ₁	0	87.5	12.51	1.53	92.50	52.15	101.34	40.23	86
T ₂	30	60.0	0.0	1.54	81.00	52.38	92.32	38.64	65
T ₃	50	42.5	7.5	1.55	72.50	53.05	85.51	35.36	48
T ₄	70	24.5	5.5	1.57	60.00	53.49	79.24	32.48	32
T ₅	100	0	0	1.52	52.50	50.50	60.29	27.23	4

GT: kaoline; NT: Na texture montmorillonite; FT: silt soil whose particle size was between 0.1 mm and 0.074 mm. ρ : wet density; ω : water content; n : porosity; ω_L : liquid limit; ω_P : plastic limit.

the tube was vibrated for 5 min, and then the centrifuge was operated for 5 min at a speed of 4000 r/min; (3) the excess sodium acetate solution in the centrifuge tube was removed; (4) procedures (2) and (3) were repeated more than 3 times; (5) 25 mL of isopropyl alcohol with purity of 99% was put to the centrifuge tube, which was then vibrated for 5 min, followed by 5 min in the centrifuge at a speed of 4000 r/min; (6) the excess of isopropyl alcohol in the centrifuge tube was removed; (7) procedures (5) and (6) were repeated more than 3 times; (8) 25 mL of 1 mol/L ammonium acetate solution was put into a centrifuge tube, which was then vibrated for 5 min, followed by 5 min in the centrifuge at a speed of 4000 r/min; (9) the excess solution was transferred into a 100 mL volumetric flask; (10) procedures (8) and (9) were repeated more than 2 times; (11) 1 mol/L ammonium acetate solution was added to the volumetric flask until the volume of solution reach 100 mL, and then the concentration of Na^+ in the solution in the volumetric flask was measured by means of atomic absorption spectrometry.

The value of the CEC was calculated by the following formula:

$$\text{CEC} = \frac{cV}{23mK \times 10} \quad (1)$$

where c is the concentration of Na^+ in the solution in the volumetric flask, V is the volume of the volumetric flask, m is the mass of the soil sample, and K = the coefficient of the soil sample transformed from air-dried to oven-dried, K is 0.87 in this study.

2.2. Test methods

The mixing apparatus was a SJ-160 mortar mixer (based on the standard *Mortar mixers for testing*, JG/T 3033-1996). The specimen was prepared as follows (based on the standard *Test Methods of Materials Stabilized with Inorganic Binders for Highway Engineering* (JTG E51-2009):

- (1) The cement, CH, and distilled water was weighed according to the component proportion of the stabilizer, and all

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