The Influence of Cementitious Materials and Admixture on Ground Improvement Strength Using the Jumbo-Jet Special Grouting Method

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Abstract

For ground improvement projects in Taiwan, the jumbo-jet special grouting method is often adopted in consideration of the maturity of construction technology and the project economy. The type of cementitious materials used in this method and the presence or absence of bentonite affects its strength although this is often ignored in the engineering circle in Taiwan. This study aims to address this issue by conducting a series of laboratory experiments under simulated site conditions. The findings are expected to have a positive impact on Taiwan's engineering circle.

1. Introduction

In the shield method, the ground improvement construction method is often applied in the start and terminus shafts and the cross passage, and the improved soil structure is penetrated by shield machines.[1)] To avoid excessive wear and tear on the shield machines, the strength of the ground improvement should not be too high.[2)] Situations in which the ground improvement has poor quality and the groundwater is rich or the stratum is weak are prone to produce an imbalance in soil-water pressure.[3)] Subsequently, spring water may arise in the interface between the shaft and the ground improvement, or the structure may be destroyed. This may further lead to settlement of the surrounding ground and damage to adjacent above-ground structures and underground objects.[4)]

Taking the Mass Rapid Transit projects in Taiwan as an example, many construction safety accidents occurred when the shield machines arrived at the terminus shaft and exited the shaft, and these were mainly caused by poor ground improvement. Some arose due to the excessive unconfined compression strength of the ground improvement, which led to construction problems related to difficulties in excavating the shield machines. This delayed project progress, increased construction costs, and caused inconvenience and harm to the public.[5)]

Ordinary portland cement and slag cement are common cementitious materials for ground improvement in shield tunnel projects. The usage amount of cementitious materials should be controlled within an appropriate range based on considerations of economy, safety, and constructability so as to control the unconfined compression strength of the ground improvement.[6)] The optimum mix-proportion is set to be the unconfined compression test aged 28 days (qu = 5~7.5 MPa).[7)] The jumbo-jet special grouting method is not a replacement

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method. The original ground soil would be partially mixed with the ground improvement, so the ground improvement strength will be affected by the soil properties. Additionally, the type of cementitious material and the presence or absence of bentonite also affects its strength. All of the above-mentioned issues are often neglected in the engineering circle.[8]

This study aims to analyze the above issues by fabricating a series of cylindrical specimens indoors with different mix-proportions via simulating the field conditions, and to discuss the influence of soil types, cementitious materials, and bentonite on the strength. It is expected that the results can be used as a reference in the engineering circle.

2. Experimental method

2.1 Mix-proportion combination

A total of five types of soil (SW: well-graded sand, SP: badly graded sand, SM: silty sand, ML: silt, CL: clay) and three kinds of soil percentages (0, 10, and 20%) were produced for this study. The mix-proportions of the A, B, and C series are shown in Table 1.[9] There were 33 types of mix-proportions, namely, A1 to A11, B1 to B11, and C1 to C11. These 33 types of mix-proportions employed four kinds of combinations of cementitious materials and admixtures: bentonite-added ordinary portland cement, bentonite-added slag cement, bentonite-free ordinary portland cement, and bentonite-free slag cement.

Table 1 Content of mix-proportion

	A series mix-proportion (kg/m^3)	B series mix-proportion (kg/m^3)	C series mix-proportion (kg/m^3)
Cementitious materials	500	400	350
Bentonite	25	27	28
Water	0,10,20% (831,731,631)	0,10,20% (831,731,631)	0,10,20% (831,731,631)
Kind of soil	SW, SP, SM, ML, CL	SW, SP, SM, ML, CL	SW, SP, SM, ML, CL
Soil percent	0,10,20% (0,180,360)	0,10,20% (0,180,360)	0,10,20% (0,180,360)

2.2 Trial mix of specimens

A total of 12 cylindrical specimens with a diameter of 5 cm and a height of 10 cm were made in each mix-proportion, and three specimens were taken on the 7th day, 28th day, 91st day, and 180th day for the unconfined compression tests.[10] There were a total of 1,584 specimens made from the 33 mix-proportions and four types of combinations of cementitious materials and admixtures.

2.3 Types of cementitious materials

The cementitious materials adopted in this study were divided into two types; the first is ordinary portland cement (hereinafter referred to as OPC) and the second is slag cement (hereinafter referred to as SC). The standard of physical and chemical properties for OPC and SC are shown in Table 2.[11]

Table 2 Standards of physical and chemical properties for SC and OPC

Inspection Item			Certification	
			SC	OPC
Physical test	Fineness by air permeability test (%)		≥450	≥280
	Density		≥2.85	≥3.15
	Time of setting	Initial setting (min.)	≥150	≥60
		Final setting (min.)	≤600	≤600
	Autoclave test	Expansion (%)	≤0.80	≤0.80
	Air content of mortar (%)		≤12.0	≤12.0
Chemical analysis	LOI (loss on ignition) (%)		≤3.0	≤3.0
	MgO (magnesium oxide) (%)		–	≤6.0
	SO_3 (sulfur trioxide) (%)		≥3.0	≥3.0

3. Research Results Analysis

The unconfined compression strength of bentonite-added OPC and bentonite-added SC with A, B, and C series of mix-proportions at the ages of 7, 28, 91, and 180 days are shown in Figures 1 to 3.

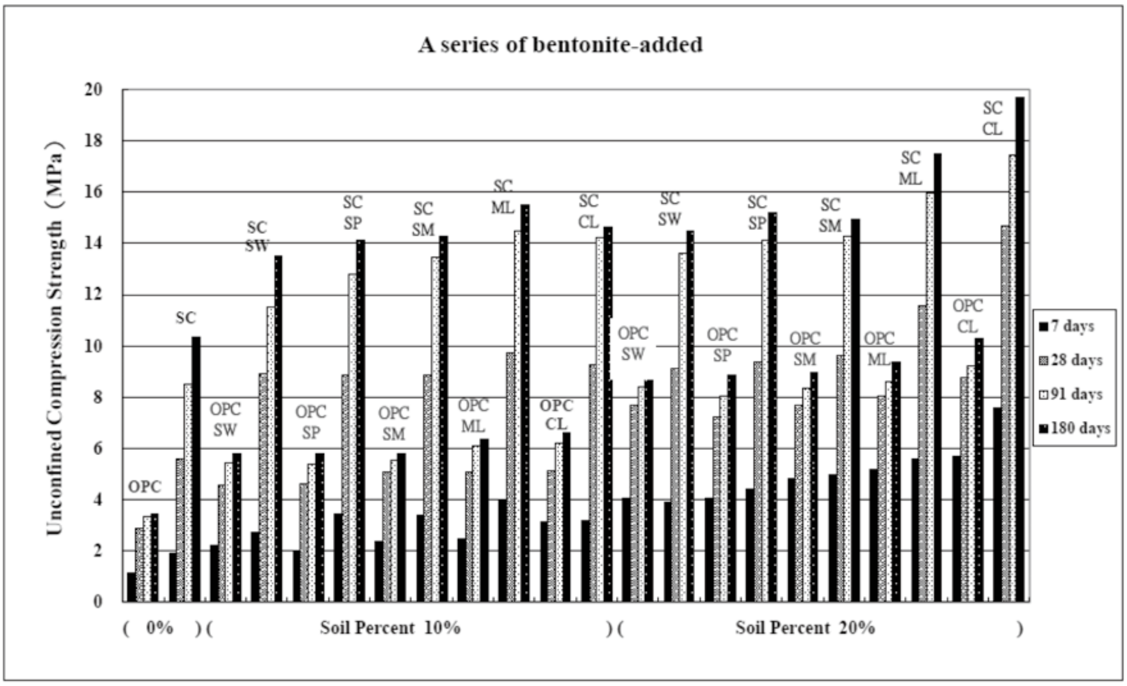

Figure 1 Unconfined compression strength (A series of bentonite-added)

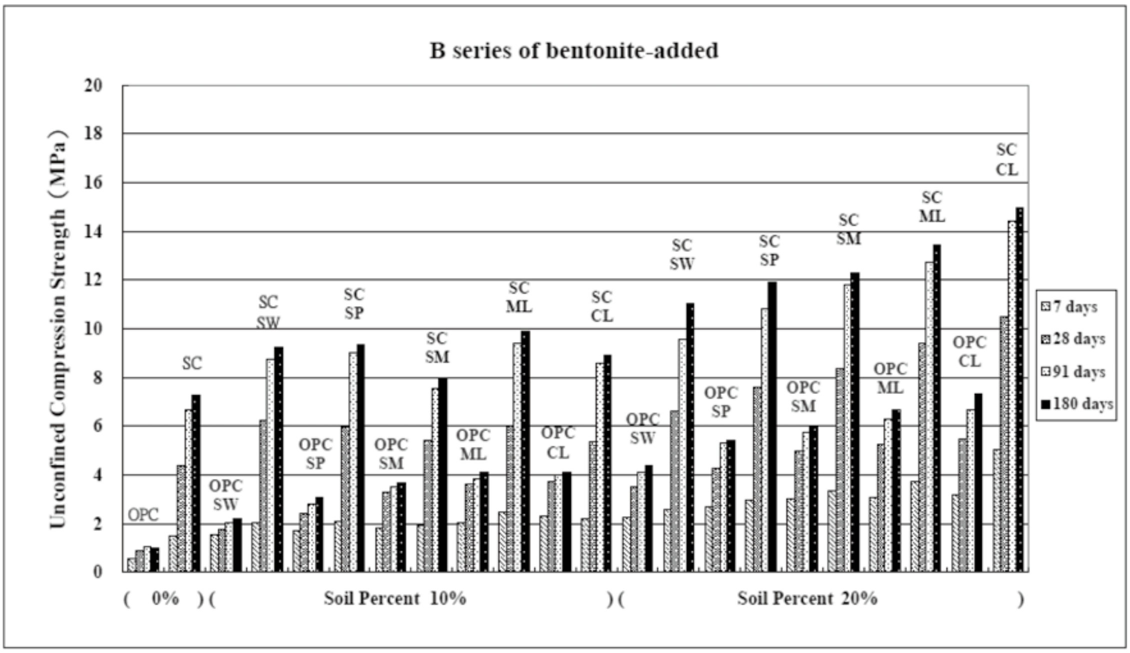

Figure 2 Unconfined compression strength (B series of bentonite-added)

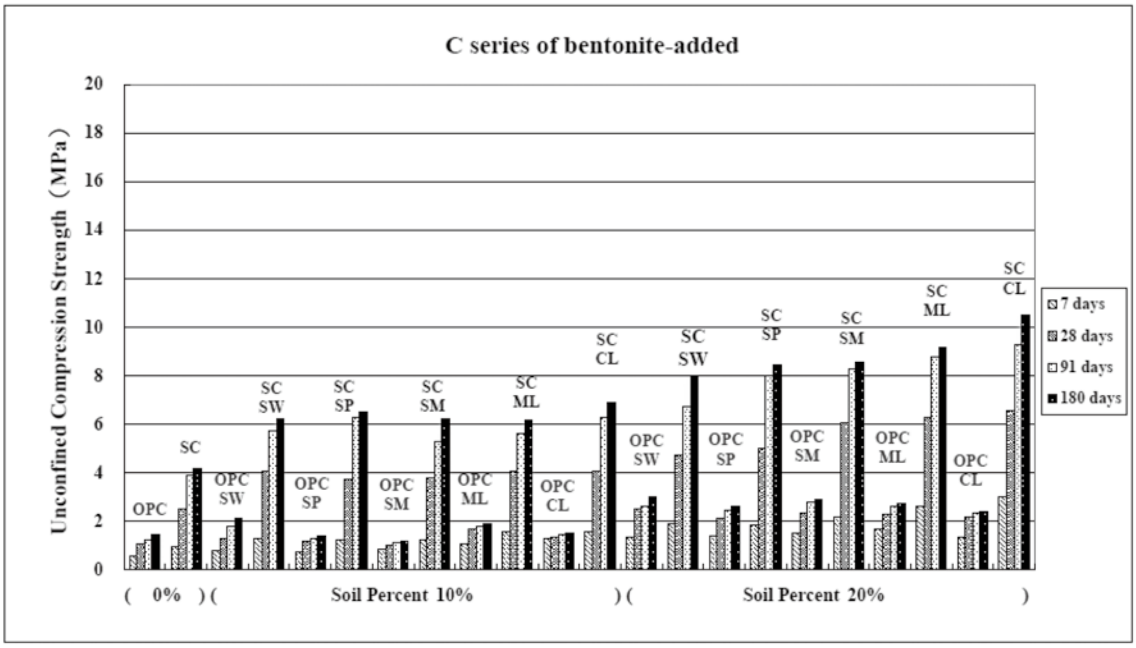

Figure 3 Unconfined compression strength (C series of bentonite-added)

(1) At any mix-proportion, the unconfined compression strength of SC was higher than that of OPC, and the strength development was faster in the later period (91 and 180 days).

(2) For the unconfined compression strength of those with the soil percentage of 20% at any mix-proportion, the finer the particles, the higher the strength.

The unconfined compression strength of bentonite-free OPC and bentonite-free SC with

A, B, and C series of mix-proportions at the ages of 7, 28, 91, and 180 days are shown in Figures 4 to 6.

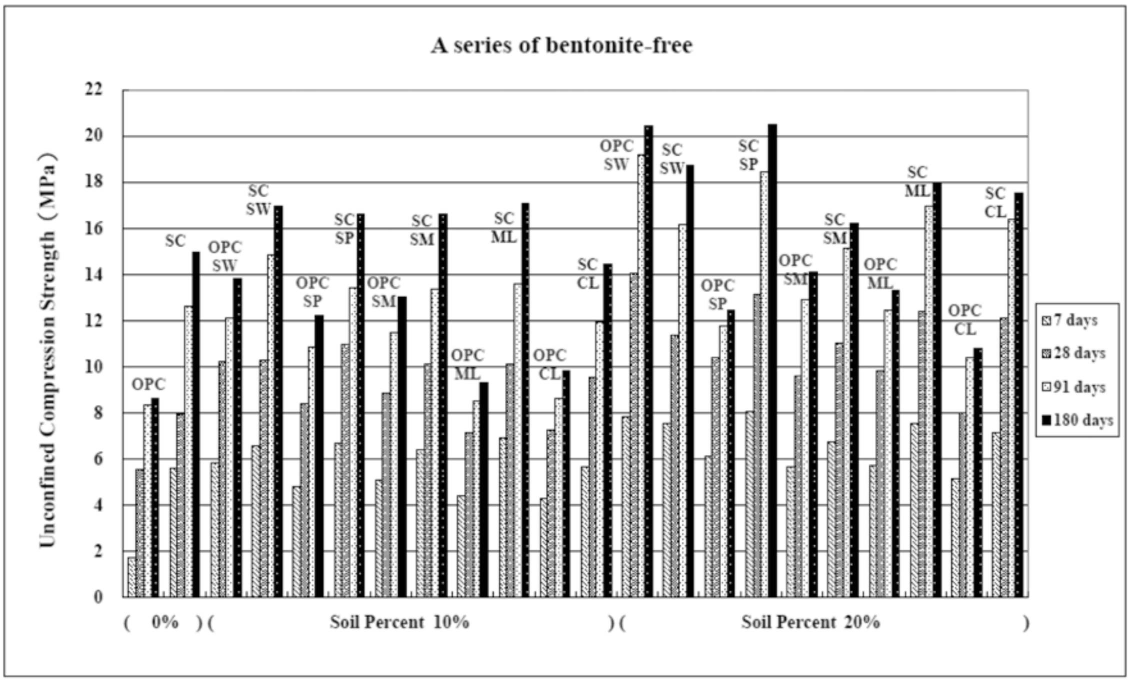

Figure 4 Unconfined compression strength (A series of bentonite-free)

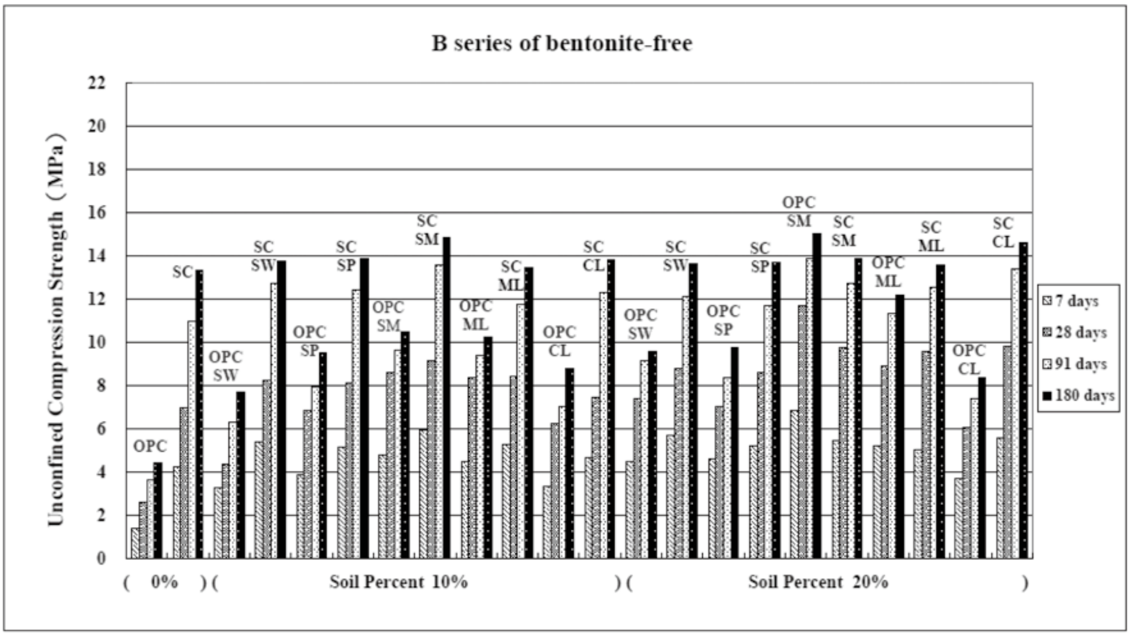

Figure 5 Unconfined compression strength (B series of bentonite-free)

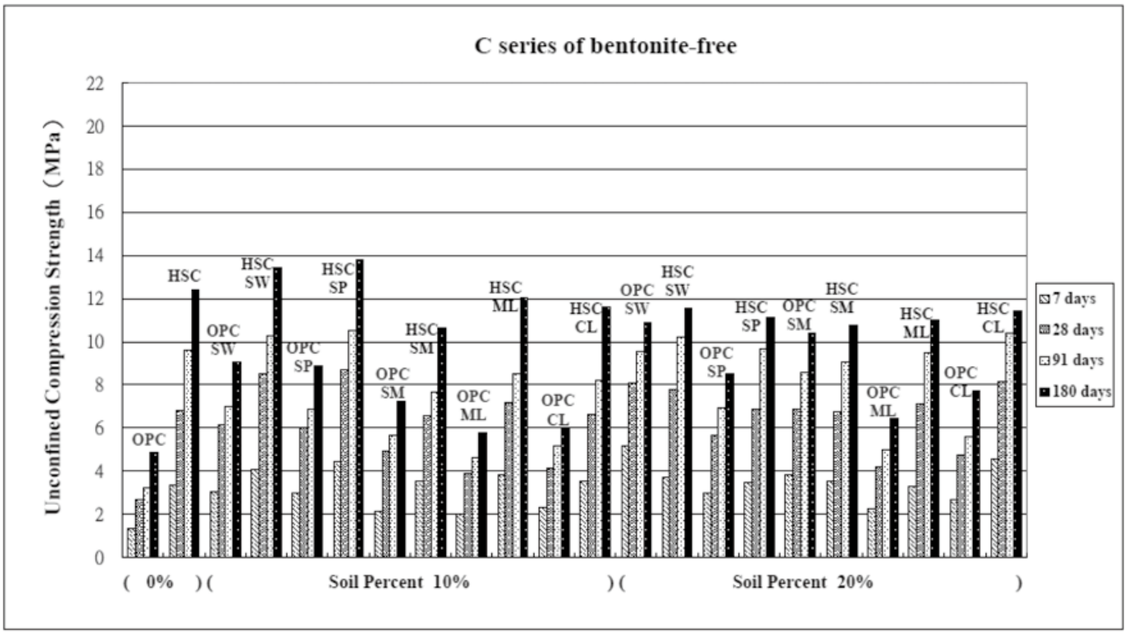

Figure 6 Unconfined compression strength (C series of bentonite-free)

(1) At any mix-proportion aged over 28 days, the unconfined compression strength of SC was higher than that of OPC.

(2) The long-term strength (91 and 180 days) of sandy soils with larger particles was higher than the unconfined compression strength of cohesive soil with finer particles.

Using the OPC as the cementitious material with A, B, and C series of mix-proportions at the ages of 7, 28, 91, and 180 days, and taking the ratio of bentonite-free strength / bentonite-added strength as the Y-coordinate, the results of the specimens are shown in Figures 7 to 9.

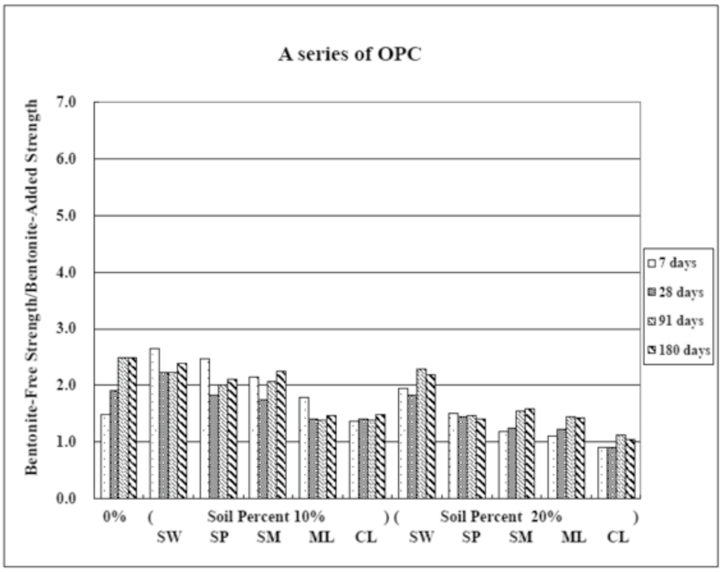

Figure 7 Bentonite-free strength / Bentonite-added strength (A series of OPC)

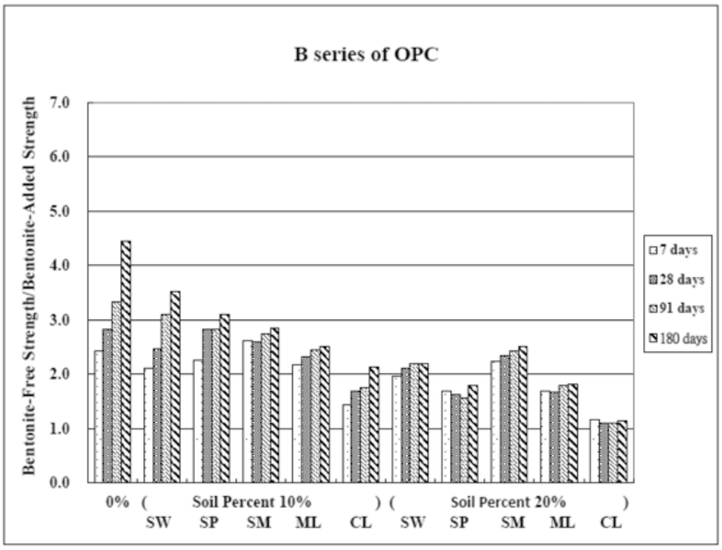

Figure 8 Bentonite-free strength / Bentonite-added strength (B series of OPC)

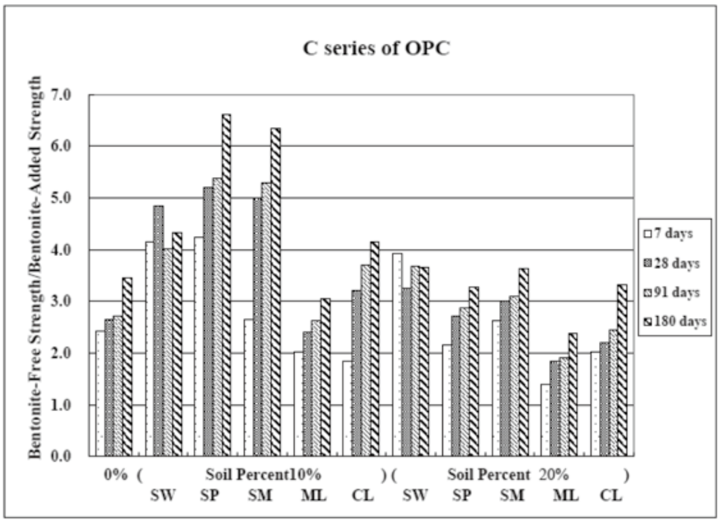

Figure 9 Bentonite-free strength / Bentonite-added strength (C series of OPC)

(1) The less cementitious material was used, the greater the ratio was, and the greater the influence of the added bentonite on the unconfined compression strength was. That is, the addition of bentonite led to a large decrease in strength.

(2) For the mix-proportions of A and B series with any rate of soil content, the ratio lowered as the soil particles became finer. That is, the addition of bentonite led to a small decrease in strength.

Using the SC as the cementitious material with A, B, and C series of mix-proportions at the ages of 7, 28, 91, and 180 days and taking the ratio of bentonite-free strength/bentonite-added strength as the Y-coordinate, the results of the specimens are shown in Figures 10 to 12.

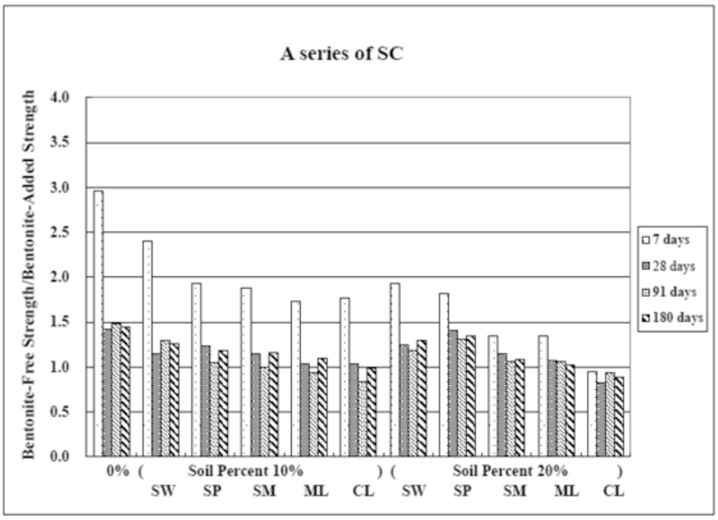

Figure 10 Bentonite-free strength / Bentonite-added strength (A series of SC)

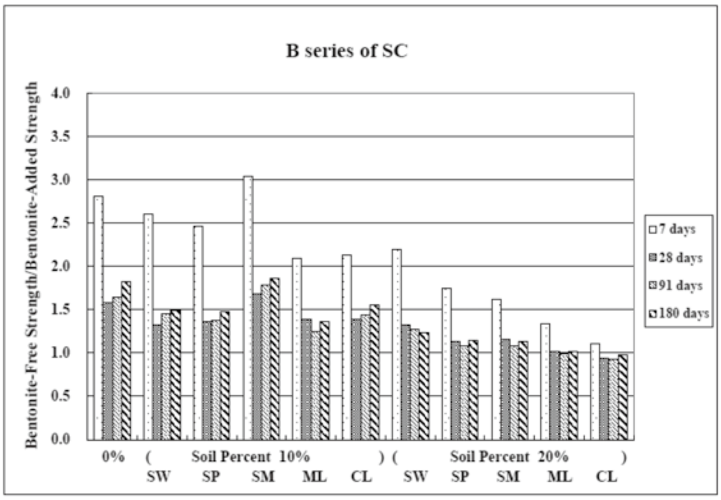

Figure 11 Bentonite-free strength / Bentonite-added strength (B series of SC)

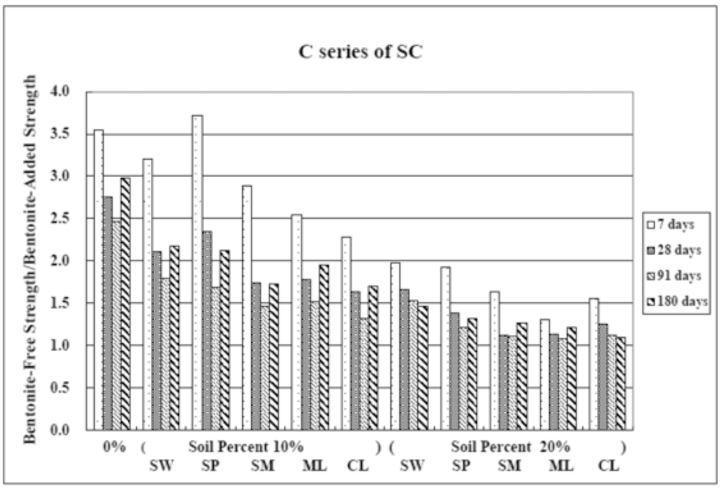

Figure 12 Bentonite-free strength / Bentonite-added strength (C series of SC)

(1) The ratio of those aged 7 days was larger than those of other ages. That is, the early strength of those bentonite-added specimens witnessed a large drop. For the specimens aged more than 28 days, the influence significantly decreased.
(2) Its ratio decreased as the soil particles became finer. Overall, the influence of the bentonite on the unconfined compression strength of the SC cementitious material at any mix-proportion was generally lower than that of OPC. Those in the C series of mix-proportion using the least of cementitious materials were the most noticeable.

4. Conclusion

(1) The unconfined compression strength of SC was higher than that of OPC. The strength developed more rapidly in the later period (91 and 180 days). For the unconfined compression strength of those with a soil percentage of 20%, the finer the particles, the higher the strength. Therefore, the soil properties of the ground and the types of cementitious materials to be adopted should be taken into consideration when designing the mix-proportion.
(2) The addition of bentonite to the mix-proportion of the ground improvement reduced the unconfined compression strength of the specimens. OPC witnessed a larger decrease, while SC had a smaller decrease. The unconfined compression strength of SC aged 7 days exhibited the largest decrease, and those aged more than 28 days had a small decrease.
(3) For the mix-proportion of the ground improvement that added bentonite, to meet the demand of having the same unconfined compression strength, SC can be used to replace OPC in order to reduce the amount of cementitious materials.
(4) Regardless of the cementitious materials, as the soil particles became finer, the addition of bentonite leads to a small drop in strength. The influence of bentonite on the unconfined compression strength of SC at any mix-proportion was generally lower than that of OPC. Those in the C series of mix-proportion using the least cementitious materials were the most obvious.
(5) In the next phase of research, these results will be compared with the compression strength of *in situ* coring samples.

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