A Study on the Optimum Mix-Proportion in the Jumbo-Jet Special Grouting Method and the Influences of Bentonites

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Abstract

The jumbo-jet special grouting method, introduced from Japan to Taiwan, is often used for the geological improvement of the start and terminus shafts of shield tunnels and the outside of cross passages. The geological conditions of Japan and Taiwan are different, and the mix-proportion of the construction method adopted in Taiwan is based on Japanese specifications, which leads to difficulties in the excavation of shield machines due to the high strength. Through a series of laboratory experiments under simulated site conditions, this study explores the appropriate mix-proportion and the influences of bentonites on strength so as to provide assistance to engineering.

1. Introduction

The waste resulting from the more than 10 million tons of Taiwan's average annual steel output is enormous. Through recycling, during the production of 1 ton of pig iron, 300 kg of blast furnace slag can be produced on average. When the new product is added to concrete, experiments have shown that its strength, flowability, permeability, alkali-resistance, and durability are as good as those of conventional concrete.[1)2)] In recent years, governments around the world have paid a great deal of attention to promoting environmental protection and recycling, and the recycling of such a large amount of waste steel each year not only reduces waste but is also environmentally friendly and economic. In this context, blast furnace cement has been widely used in public works.[1)]

The jumbo-jet special grouting method is mainly adopted for the geological improvement of the start and terminus shafts of shield tunnels and the outside of cross passages.[2)] To avoid its influences on the excavation of shield machines, its strength must conform to the demand of the standard minimum strength limit and not exceed the maximum limit. The geological improvement is only for temporary structures and must be removed within six months, so blast furnace cement is suitable. The jumbo-jet special grouting method has been based on Japanese specifications since it was introduced from Japan to Taiwan. The cement content is 500 kg/m^3, the strength required by the specification is above 2 Mpa, the permeability coefficient is below 10^{-6}cm/s, and the core sampling rate is above 85%.[3)] In addition to strength, workability, geological factor, compactness, and permeability are important factors affecting the quality of geological improvement. Therefore, strength above 5 Mpa is recommended in Taiwan's engineering. At actual sites, cores are often sampled at a strength

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above 15 Mpa, which leads to difficulties in the excavation of shield machines.[4] The reasons for this are the different geological conditions between Taiwan and Japan, the mix-proportion of grouting materials, properties of grouting materials, structure property of shield machines, and operation method of shield machines. [5]

By simulating the site conditions and making a series of cylindrical specimens with different mix-proportions indoors, this study explores the optimum mix-proportion and the influences of bentonites on strength so as to develop a mix-proportion suitable for Taiwan's geological conditions for reference in engineering in order to complete projects in the safest, most economical, and most efficient way.

2. Experimental Method

A trial mix of specimens, compression strength tests, and permeability tests are conducted to determine the optimum mix-proportion of various soils, and the influences of bentonite are explored. The research planning process is shown in Figure 1.

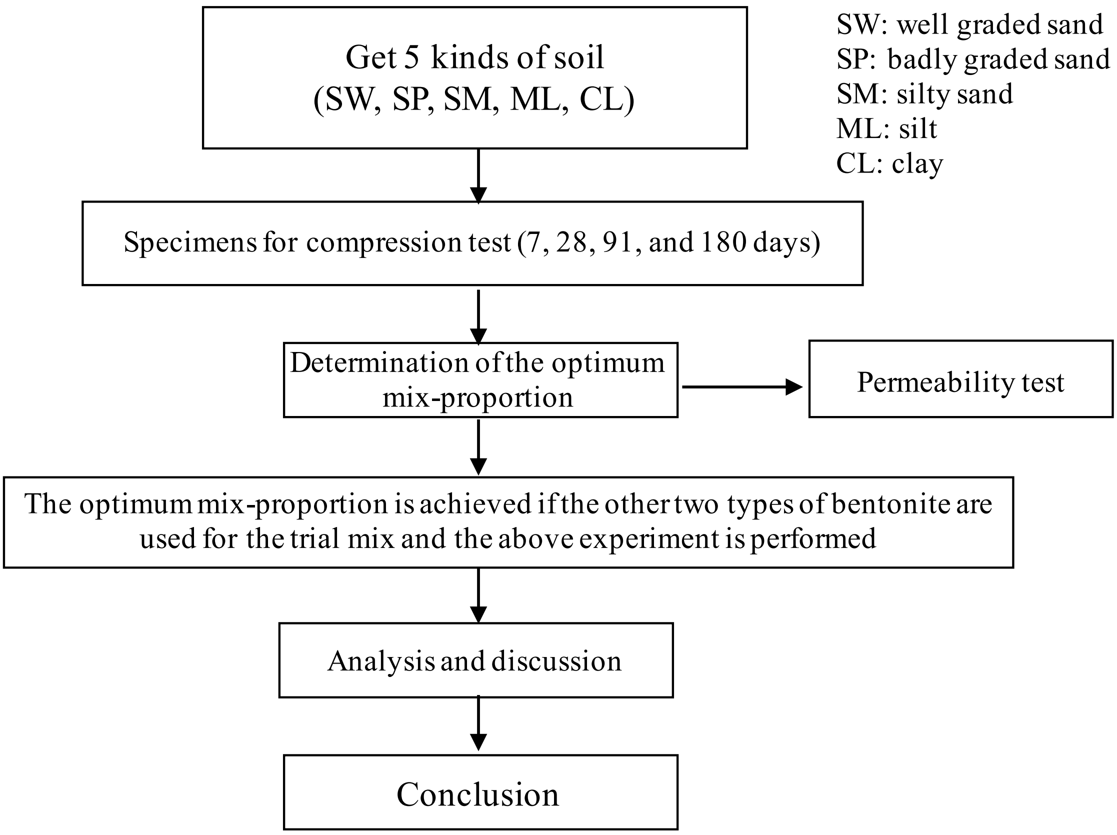

Figure 1. Planning process

2.1 Mix-proportion combination

For three kinds of soil percentages and five kinds of soil, this experiment was carried out in 33 types of mix-proportions, namely, A1~A11, B1~B11, and C1~C11, to obtain the optimum mix-proportion. The mix-proportion of the A, B, and C series is shown in Table 1. The percentage of soil on site ranges from 0 to 20%.

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)
Slag cement	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 16 cylindrical specimens with D = 5 cm and H = 10 cm were made in each mix-proportion, and four specimens were taken on the 7th day, 28th day, 91st day, and 180th day for the compression test; one of the four specimens intended to be used for the compression test at 180 days was taken for the permeability test. There were 33 types of mix-proportions and a total of 528 specimens in this experiment.

2.3 Determination of the optimum mix-proportion

The optimum mix-proportion was determined by the compression test at 28 days qu = 5 to 7.5 Mpa, and the permeability coefficient was $k < 10^{-6}$cm/s.

3. Research Results Analysis

The unconfined compression strength of the A, B, and C series of the mix-proportion at 7, 28, 91, and 180 days is shown in Figures 2 to 4.

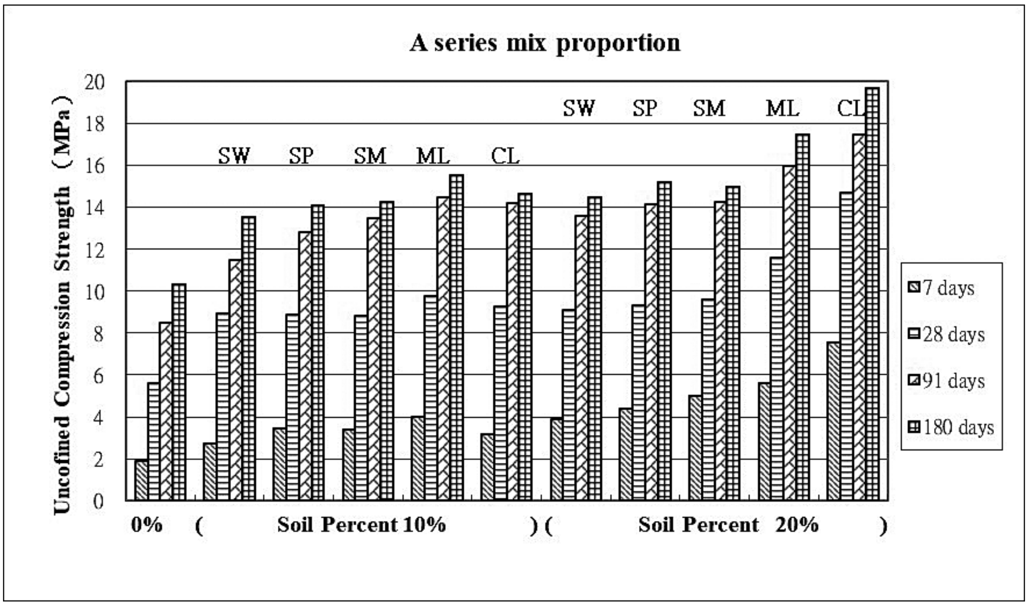

Figure 2. Unconfined compression strength (A series)

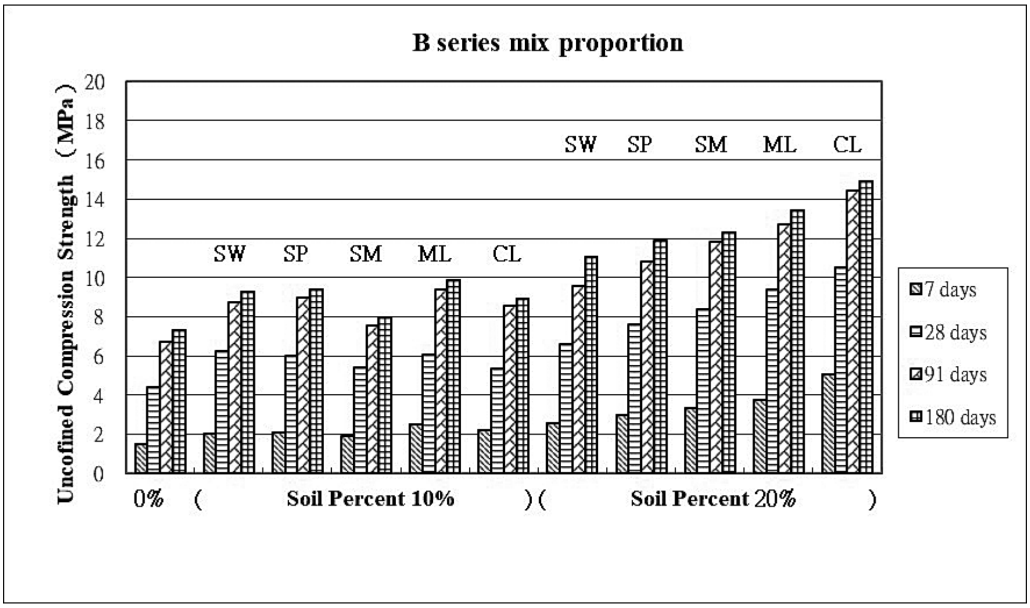

Figure 3. Unconfined compression strength (B series)

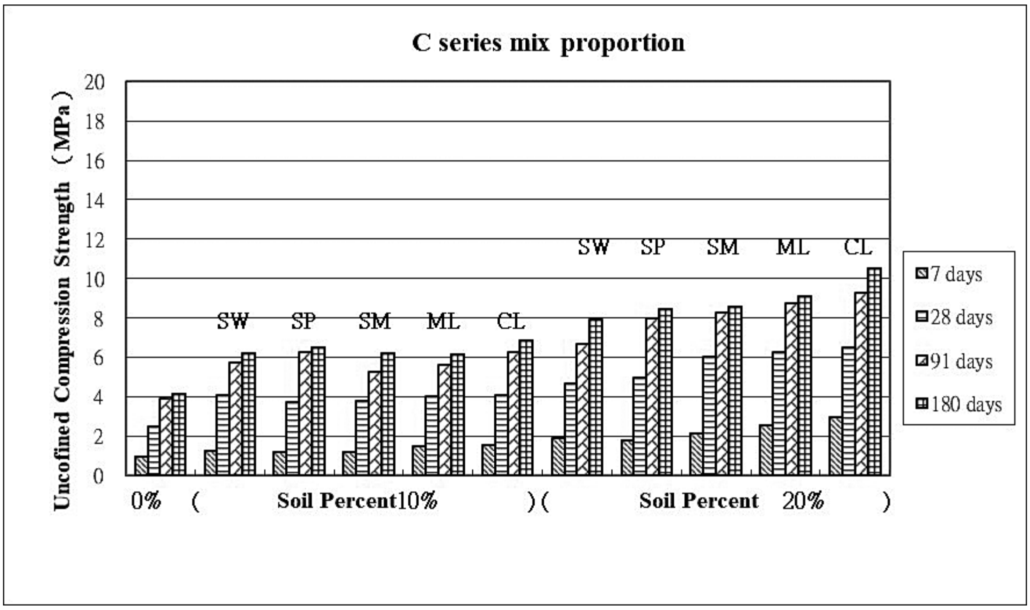

Figure 4. Unconfined compression strength (C series)

(1) The smaller the grain size, the higher the compression strength will be. [6)]

(2) There is no significant difference in the compression strength between SW and SP in different mix-proportions at 28 days, but the strength of SP is significantly higher than that of SW after 91 and 180 days.

(3) The compression strength of all soils at 28 days is slightly different at the soil percentage of 10%, but the compression strength of ML and CL soils is very different and high strength at the soil percentage of 20%.

According to Figures 5 to 7:

(1) In the A series of mix-proportion, the compression strength at 7 days increases by approximately 31% to 58%, the compression strength at 91 days increases by approximately 128% to 173%, and the compression strength at 180 days increases by approximately 151% to 190%. In the B series of mix-proportion, the compression strength at 7 days increases by approximately 28% to 48%, the compression strength at 91 days increases by approximately 127% to 170%, and the compression strength at 180 days increases by approximately 131% to 184%. In the C series of mix-proportion, the compression strength at 7 days increases by approximately 31% to 45%, the compression strength at 91 days increases by approximately 134% to 172%, and the compression strength at 180 days increases by approximately 140% to 184%.

(2) In the A, B, and C series of mix-proportion, the compression strength increases by a slightly different percentage in the early period (7 days), and by a very different percentage in the later period (91 and 180 days) due to different soil mix-proportions and soil types. At the soil percentage of 20%, the compression strength of SW continues to increase in the later period, and the strength is 135→183%, 145→167%, and 135→169% in the A, B, and C series of mix-proportion at 91 and 180 days, respectively, whereas the compression strength declines in other mix-proportions after 91 days. Therefore, during the excavation by shield machines, the compression strength of SW soil is higher in the later period, which should be carefully evaluated.[7]

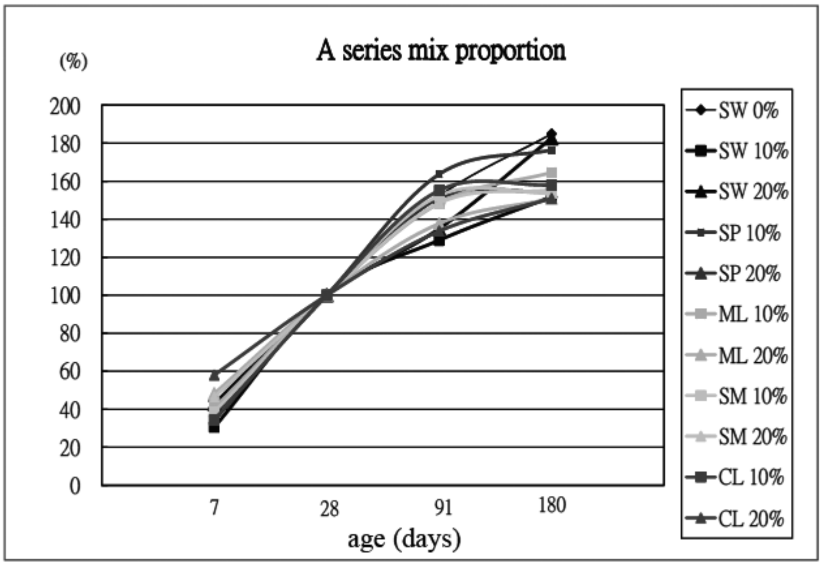

Figure 5. Unconfined compression strength of develop direction (A series)

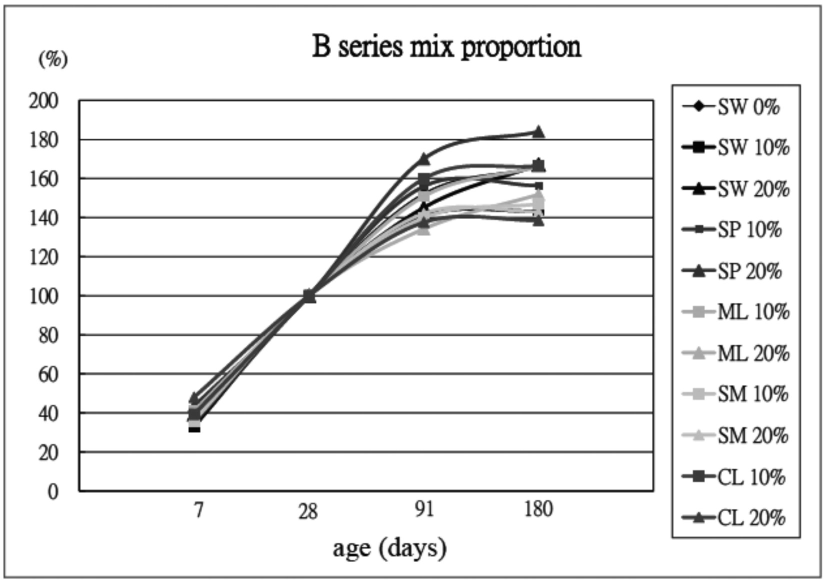

Figure 6. Unconfined compression strength of develop direction (B series)

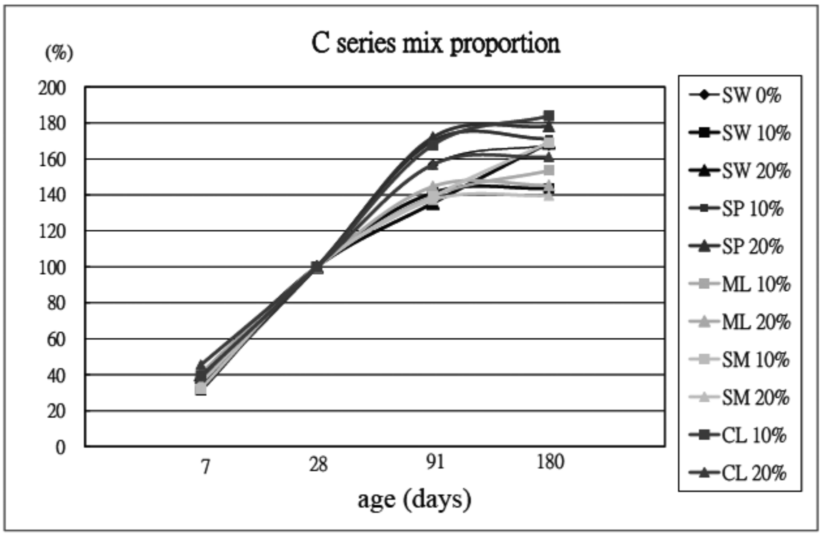

Figure 7. Unconfined compression strength of develop direction (C series)

The optimum mix-proportion is determined according to Figures 2 to 4:

(1) When the soil accounts for 0% in cement mortar, in the A, B, and C series of mix-proportion, the compression strength at 28 days in the A series of mix-proportion is within the initially set range (5-7.5 Mpa). Therefore, at the soil percentage of 0%, the A series of mix-proportion is adopted.

(2) When the soil accounts for 10% in cement mortar, in the A, B and C series of mix-proportion, the compression strength at 28 days in the B series of mix-proportion is within the initially set range (5-7.5 Mpa). Therefore, at the soil percentage of 10%, the B series of mix-proportion is adopted.

(3) When the soil accounts for 20% in cement mortar, in the A, B, and C series of mix-proportion, the compression strength of soils other than SW, SP at 28 days in the C series of mix-proportion is within the initially set range (5-7.5 Mpa). The strength of SW, SP soil at 28

days fails to reach the set range (5–7.5 Mpa), so the B series of mix-proportion is adopted and the C series of mix-proportion is adopted for other soils. Table 2 shows the optimum mix-proportion (including the results of compression strength and permeability coefficient).[7]

(4) There is a small difference in compressive strength between 91 days and 180 days. Compared with the original specifications, up to 150 kg/m^3 of cement consumption can be reduced.

Table 2. All data of the optimum mix-proportion

Soil type	Soil percent (%)	Slag cement (kg)	Bentonite (kg)	Water (l)	28 days strength (Mpa)	91 days strength (Mpa)	180 days strength (Mpa)	Permeability $\times 10^{-7}$ (cm/s)
SW	0	500	25	831				
SP	0	500	25	831				
SM	0	500	25	831	5.59	8.51	10.35	2.5
ML	0	500	25	831				
CL	0	500	25	831				
SW	10	400	27	762	6.22	8.75	8.93	2.06
SP	10	400	27	762	5.99	9.35	9.37	1.45
SM	10	400	27	762	5.41	7.58	7.96	3.60
ML	10	400	27	762	6.05	9.12	10.04	1.40
CL	10	400	27	762	5.36	8.57	8.93	1.99
SW	20	400	27	762	6.60	9.57	11.03	2.61
SP	20	400	27	762	6.31	9.36	9.69	5.30
SM	20	350	28	678	6.03	8.27	8.42	3.00
ML	20	350	28	678	6.28	9.08	9.12	2.60
CL	20	350	28	678	6.51	10.21	10.49	3.00

According to this study, in order to achieve the optimum mix-proportion, in addition to Ca series of bentonites <origin: Australia> (the first type of bentonites), two different brands of Na series of bentonites <origin: the United States (the second type of bentonites) and China (the third type of bentonites) > were used. A trial mix was conducted again in the optimum mix-proportion for analysis and comparison. The results are shown in Figures 8 to 10.

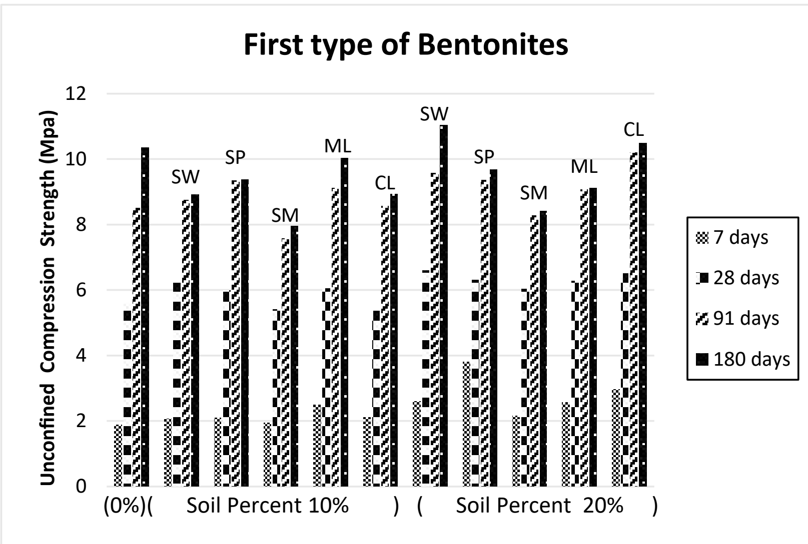

Figure 8. Unconfined compression strength (first type of bentonites)

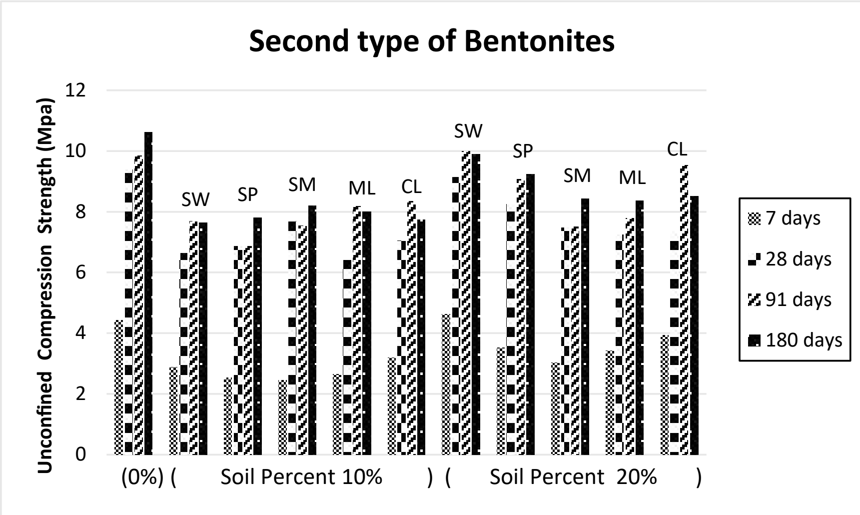

Figure 9. Unconfined compression strength (second type of bentonites)

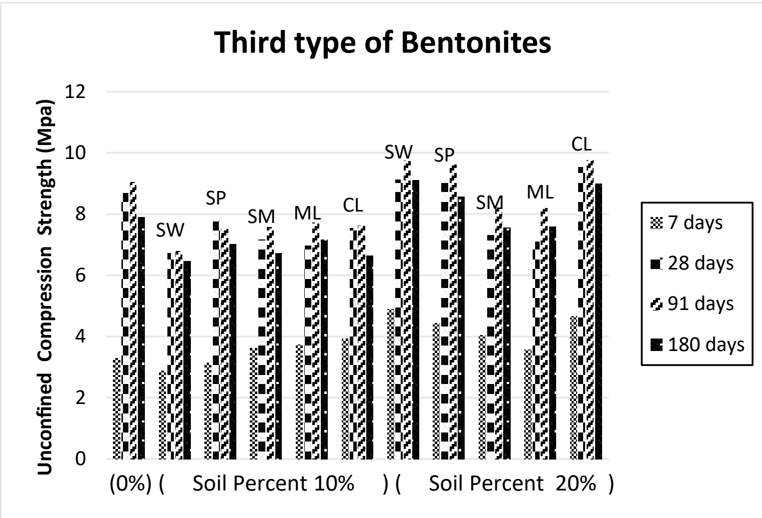

Figure 10. Unconfined compression strength (third type of bentonites)

(1) For any soil at any percent, the compression strength of the first type of bentonites (Ca series) at 7 and 28 days is smaller than that of other bentonites (Na series).
(2) For any soil at any percent, the compression strength of the first type of bentonites increases with age, indicating large growth room whereas the growth room of the third type of bentonites is the smallest.

4. Conclusion

(1) This study explores the optimum mix-proportion for the geological improvement of the start and terminus shafts of shield tunnels and the outside of cross passages. The result varies with soils, can reduce up to 150 kg/m^3 of the cement content, and leads to smooth excavation of shield machines.
(2) For any soil at any percent, the compression strength of the first type of bentonites (Ca series) at 7 and 28 days is smaller than that of other bentonites (Na series), but increases

with age, indicating large growth.

(3) Shield machines usually excavate for geological improvement after mirror surfaces of shafts are broken, which is carried out at approximately 2 to 4 months of age. According to the experimental analysis, the maximum growth rate is 1.8 times after 28 days of compressive strength. If the third type of bentonites (Na series) is used, the strength increases by a small percentage in the later period, which can reduce the difficulties in the excavation of shield machines.

(4) At the soil percentage of 20%, the compression strength of well-graded sand (SW) continues to increase in the later period. Therefore, during the excavation by shield machines, the compression strength of SW soil is high in the later period, which should be carefully evaluated.

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