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Study on Reinforcement of Tunnel Loose Sand Layer by Grouting

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ABSTRACT

This paper studies the application of grouting reinforcement technology in the reinforcement of sand layer in tunnel and underground engineering. The influence of different factors on the unconfined compressive strength of solid sand was studied by orthogonal horizontal test, combined with physical properties of cement slurry and water content of sand layer. The test results show that the water content of sand, cement water cement ratio and curing time have significant effects on the strength of solid sand, and the curing time has the greatest effect. Finally, the optimal slurry ratio was determined as 8% sand water content, 28 days curing time and 0.8 water-cement ratio. Under this ratio, the strength of the solid sand body was the best, and the gel time and viscosity of the slurry also met the engineering requirements. This study provides an important reference for grouting reinforcement engineering under similar geological conditions.

KEYWORDS

Cement; Medium sand formation; Slip casting

1. INTRODUCTION

Sand layers often encountered in tunnels and underground engineering are characterized by loose structure, low cementation strength and poor self-stabilization ability. These properties make them vulnerable to hazards such as water gusher and sand collapse, resulting in land subsidence [1, 2]. To ensure the safety of the project, it is necessary to strengthen the sand layer. Grouting reinforcement technology has been widely used in solving such conditions due to its advantages such as simple construction, little influence by site conditions, low project cost and large reinforcement effect [3-5].

Grouting technology plays a vital role in underground engineering, its importance is reflected in many aspects, not only related to the safety and stability of the project, but also directly affect the long-term benefit and sustainable development of the project. Grouting technology can effectively enhance the strength and stability of the foundation by injecting the solidifiable slurry into the cracks or pores of the foundation through displacement, filling, extrusion and other ways. This can not only significantly improve the bearing capacity of the foundation, but also reduce the risk of foundation settlement and deformation, providing a solid foundation for underground engineering.

Grouting materials used in grouting technology are mostly environmentally friendly materials, such as cement-based grout, chemical grout and so on. These materials have less impact on the environment during use and meet the current requirements of environmental protection and energy saving. In addition, grouting technology also has the advantages of simple construction and relatively low cost, which helps to reduce the construction cost of underground engineering and improve economic benefits. Cement-based grout has been playing an important role in grouting reinforcement

materials, it has the advantages of high strength, good permeability, suitable for various geological conditions, high cost efficiency and environmental protection.

Based on a subway in Qingdao, through orthogonal horizontal test, combined with the physical properties of cement slurry and the moisture content of sand layer, the optimal water-cement ratio suitable for this project cement is obtained.

2. PROPERTIES OF GROUTING MATERIALS

2.1. Slurry Viscosity

The material used in this test is ordinary Portland cement, and a total of 4 water-cement ratios are set, which are 0.8, 1, 1.2 and 1.4 respectively. The instrument used to measure the viscosity of cement slurry is the Markov funnel viscometer. The measurement results are shown in Table 1:

Table 1. Slurry viscosity

NO.	Water-cement ratio	Funnel viscosity [s]
1	0.8	25.21
2	1	20.14
3	1.2	18.35
4	1.4	17.26

It can be seen from Table 1 that the funnel viscosity decreases with the increase of cement water-cement ratio.

2.2. The Gelation Time of the Slurry

Setting time, including initial setting time and final setting time, is an important index of physical properties of cement slurry. The measurement method of setting time can be seen in GB/T 2419-2005 [6], using Vica instrument test. The measurement results are shown in Table 2:

Table 2. The gelation time of the slurry

NO.	Water-cement ratio	Elling time [min]	Final setting time [min]
1	0.8	442	596
2	1	491	620
3	1.2	561	795
4	1.4	649	883

As can be seen from Table 2, the cementing time of cement increases with the increase of water-cement ratio.

3. SOLID SAND TEST

3.1. Experimental Design

In actual grouting engineering, the unconfined compressive strength of the solid sand body formed after the slurry solidified the sand is an important index to measure the performance of slurry material and the reinforcement effect of grouting [7]. Therefore, the orthogonal test method was adopted in this paper to study the unconfined compressive strength of the solid sand body, and the slurry ratio suitable for medium sand formation was obtained.

The orthogonal test includes three factors: sand water content, cement water cement ratio and sample curing time. According to the on-site geological investigation report, the maximum water content of the sand layer through which the subway tunnel passes is 20.1%, so the water content of the sand in the test is 4%, 8%, 12%, 16% and 20%. In addition, the cement's water-cement ratio levels are 0.8, 1, 1.2 and 1.4, and the cure time levels are 1d, 3d, 7d, 14d and 28d. In the orthogonal test, the water content and curing time of sand have five levels, while the cement water cement ratio has only four levels, so the pseudo-horizontal method is used to revise the orthogonal test. The specific design of orthogonal test is shown in Table 3.

Table 3. Factors and levels of orthogonal test

Levels	Factors		
	A: Moisture content [%]	B: Water-cement ratio	C: Curing time [d]
1	4	0.8	1
2	8	1	3
3	12	1.2	7
4	16	1.4	14
5	20	—	28

Table 4. Experiment results of orthogonal test

NO.	A:Moisture content [%]	B: Water-cement ratio	C: Curing time [d]	Compressive strength (MPa)
1	4	0.8	1	1.64
2	4	1	14	2.63
3	4	1.2	7	1.54
4	4	1.4	28	2.71
5	4	0.8	3	1.75
6	8	0.8	14	3.85
7	8	1	7	3.47
8	8	1.2	28	3.52
9	8	1.4	3	1.31
10	8	1	1	1.19
11	12	0.8	7	2.96
12	12	1	28	4.40
13	12	1.2	3	0.94
14	12	1.4	1	0.58
15	12	1.2	14	3.80
16	16	0.8	28	3.50
17	16	1	3	0.96
18	16	1.2	1	0.46
19	16	1.4	14	2.91
20	16	1.4	7	0.70
21	20	0.8	3	1.01
22	20	1	1	0.52
23	20	1.2	14	1.84
24	20	1.4	7	0.73
25	20	1.2	28	2.54

3.2. Test Result

Based on the orthogonal test method, the unconfined compressive strength of the solid sand body is studied, and three factors including water content of sand, cement water cement ratio and curing time are considered in the analysis process. The test results obtained by orthogonal test are shown in Table 4.

According to the results of orthogonal test, the influence degree of each factor on the unconfined compressive strength of the solid sand body was evaluated by range analysis, and the optimal grout mix was obtained. The calculations and results of the range analysis are shown in Table 5.

Table 5. Range analysis results

	Factors		
	A:Moisture content [%]	B: Water-cement ratio	C: Curing time [d]
K_1	10.27	14.71	4.39
K_2	13.34	13.17	5.97
K_3	12.68	14.64	9.4
K_4	8.53	8.94	15.03
K_5	6.64	—	16.67
k_1	2.054	2.45	0.878
k_2	2.668	2.20	1.194
k_3	2.536	2.09	1.88
k_4	1.706	1.49	3.006
k_5	1.328	—	3.334
R	1.34	0.96	2.456
Factor order	C > A > B		
Excellent combination	$A_2B_1C_5$		

It can be seen from Table 5 that the influence degree of each factor on the compressive strength of the solid sand body is in the order of C (curing time)>A (water content of sand)>B (water-cement ratio). Among them, curing time (factor C) has the greatest influence on the unconfined compressive strength of the solid sand body, followed by the water content of the sand (factor A), and the water-cement ratio of cement (factor B) has the least influence on the unconfined compressive strength of the solid sand body. Based on the range analysis of orthogonal test results, the best combination of these four factors is A2B1C5. That is, the water content of the sand is 8%, the curing time of the sample is 28d, and the water-cement ratio of the slurry is 0.8.

Combined with the study of gelation time and viscosity of the slurry, the slurry with gelation time of 596min, funnel viscosity of 25.21s and water-cement ratio of 0.8 was finally selected.

4. SUMMARY

In this paper, the effects of water content of sand, cement water cement ratio and curing time on unconfined compressive strength of solid sand are systematically analyzed through the experimental study of grouting reinforcement of a subway tunnel in Xi 'an. The results show that the curing time is the most important factor affecting the strength of the solid sand, followed by the water content of the sand, and the effect of cement water cement ratio is relatively small. Based on the range analysis of orthogonal test, the optimal slurry ratio was determined as 8% sand water content, 28 days curing time and 0.8 water-cement ratio. In addition, the gel time and viscosity of the slurry under this ratio

are also excellent, which meets the practical needs of engineering. This study not only provides scientific guidance for concrete projects, but also provides theoretical basis and practical reference for the optimization and development of grouting reinforcement technology in the future.

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