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Proportioning Test of Grouting Material for Seabed Shield Tunnel

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Aiming at the complex and changeful engineering geological conditions of the intake tunnel of Taishan nuclear power station, such as large diameter, large water pressure and long tunnel length, the proportion of slurry material is studied to ensure the grouting effect of shield. The controlling factors of grouting material, such as process performance, water dispersibility, preventing floatation and durability of segments, are analyzed. The performance indexes of high performance synchronous materials are discussed, and reasonable grouting materials and proportioning experimental instruments and equipment are selected and determined. Through the proportioning test of grouting material, the synchronous grouting material formulation, slurry configuration method and suitable grouting process are studied to improve the synchronous grouting effect and achieve the purpose of tunnel reinforcement and water stop. The engineering application shows that through the proportioning test, the mixture ratio of 1 and the mixture ratio of 9 grouting material can meet the needs of on-site construction, and the filling effect is good, so it has wide application value.

1. Introduction

The engineering structures of Taishan water tunnel in nuclear power plant is located between the land area Yaoguju and Dajin Island (crossing the sea tunnel). The tunnel has a full length of 4,330.6 m, and the structure of the water intake tunnel is two holes for water, the diameter of the hole is 7.3m, and the working diameter of the hole is 9.03 m. The shield section of No. 1 and No. 2 tunnel passes through the clay, sandstone and strong weathered granite stratum. The tunnel is shallow buried, the section is large, the engineering geology is complex, and the technical standard is high. The tunnel adopts the shield tunneling construction scheme, which is the first subsea mud water shield tunnel in China.

The main purpose of grouting in shield construction is to control the formation deformation, ensure the stability and even force of the segments, improve the impermeability of the tunnel, and better restrain the segments, so as to prevent the tunnel from floating up to (Oh et al., 2014). The selection of grouting material is one of the key factors affecting the success or failure of grouting, which directly affects a series of problems, such as grouting effect, grouting technology, and so on (Xu et al., 2011). If the slurry type, performance and proportion are not suitable for engineering, it is very likely that the tunnel will float upward. And the tunnel floating may cause the axis of the tunnel deviating from the design axis. If it is serious, it may invade the building gauge and will bring difficulty to the subsequent project (You and Liang, 2012; Ji et al., 2013).

2. Analysis of Control Factors of Grouting Material

High performance synchronous grouting material is a synchronous grouting material (Zhou et al., 2014), which integrates process performance, mechanical properties, water dispersibility, prevent segment floating, durability (Moeinossadat et al., 2016).

2.1 Prevent the floatation of the tube

The factors affecting the consistency are the water consumption of the slurry, the ratio of mortar and the thickening component in the material. The consistency of the slurry is controlled between 9 and 10.5 cm, and the consistency of the slurry is easily improved by selecting the appropriate thickening component by controlling the water gel ratio. The key to controlling the slump of the slurry is to control the cohesiveness of the slurry (Yang et al., 2018). The proper slump can effectively solve the problem that the size of the slurry flow through the size of the slurry to the bottom of the tunnel arch to lift the executive film. In order to prevent the floatation of the tubes, the proper adhesion components should be selected to control the amount of the added adhesive components, and the slump degree should be controlled between 3 and 4 cm. When the consistency is the same, the slump is not the same, and the index of consistency can not be used to evaluate the size of the slurry loss (Han et al., 2007). Through the double index of consistency and slump, the effect of preventing the floating of the pipe sheet can be achieved by controlling the loss range of the slurry.

2.2 Preparation of raw materials and specimens

The water soluble polymer materials used as flocculants, which are mainly polyacrylamide and cellulose ether. These two polymers can be combined with suitable water reducing agents (Gul et al., 2014). By changing the synthetic conditions and producing different molecular weights or different viscosity, the ideal flocculation effect can be achieved as the addition in the case of little amount of admixture (Gou et al., 2013; Cardinale et al., 2017). In this experiment, cellulose soluble polymer hydroxyethyl cellulose and polyacrylamide are selected as the main anti water dispersing agents.

High performance water reducing retarder development, by adding compound plastic components in reducing agent in high performance, inhibiting the initial hydration of cement (Yang et al., 2008; Zhou et al., 2015). High efficiency water reducing agent and plastic composite flocculant interaction, realized the effect of the grouting material, such as decrease water, plastic, adsorption, stability and flocculation (Wei et al., 2010).

Adding fiber in the slurry, the slurry layer segregation and bleeding performance are improved. After hardening, the tensile strength and fracture resistance are improved, the number of cracks is reduced, the impermeability is improved, the aggregate connection is more firm, and the water dispersibility of slurry is improved (Ye et al., 2009; Amara et al., 2017). This is the choice of anti-crack and anti-permeable polypropylene fiber.

2.3 Pumping

At design time, you must add components, which can reduce the effect of reducing water and molding in grouting materials (Liu and Li, 2005). The adaptability between flocculant components and superplasticizer is studied, and the best matching relationship between components is sought, so that grouting material can maintain a certain fluidity within a specified time and meet the design requirements of synchronous grouting.

2.4 Corrosion resistance

When there are defects such as honeycombs, pores and pores in the slurry, there will be leakage channels. The seepage water will release the calcium hydroxide from the hydration products of cement by physical and chemical processes, and eventually lead to the decrease or even destruction of slurry strength (Nizamani et al., 2017; Hassan et al., 2017). This is closely related to the density of the slurry. In order to improve the corrosion resistance of the slurry, it is necessary to increase the density of the slurry.

3. Proportioning Experiment of Grouting Material

3.1 Performance index of synchronous grouting material

(1) Setting time: The initial coagulation is between 3 and 5 h, and the final coagulation is between 4 and 10 h. According to the geological conditions and driving speed, the setting time is adjusted by adding the coagulant.
(2) Consolidation strength: The day is not less than 0.2 MPa, and 28 days is not less than 2.5 Mpa.
(3) Consolidation rate: More than 95%, that is, the contraction rate is less than 5%.
(4) Consistency: It is between 8 and 12 cm.
(5) Stability of slurry: There are few static precipitation, no segregation or low precipitation segregation in gelation time, and the dipping rate (the ratio of the floating volume and total volume after settling) is less than 5%.
(6) Dilution resistance: Under the action of groundwater pressure, the slurry has good waterproof dilution performance (There is no dispersion under water, and the pH value of the slurry is less than 9).

3.2 Preparation of synchronous grouting material

(1) Selection of raw material for grouting
According to the relevant work done by the predecessors (Li, 2011; Chen, 2005; Dif et al., 2012), the grouting material is selected as follows. Cement: 425 type ordinary portland cement; fine aggregate: fine sand, fineness modulus is 2.45, the apparent density is 2700 kg/m^3, bulk density is 1510 kg/m^3, mud content is 3%; fly ash (FA): II ash, water 102%, density 2.7 g/cm^3, surface area is 3800 cm^2/g; polyacrylamide (PAM): white odorless powder, soluble in water, molecular weight is 800×104; polypropylene fiber (PF): type WK-1

polypropylene fiber; bentonite: calcium bentonite; admixture: type HT-HTC water reducing agent (WRA).
(2) Main experimental instruments and equipment
Main instruments and equipment: ISO679 cement mortar mixer (Figure 1), cement mortar fluidity tester (Figure 2), mortar consistometer, cement standard curing box, electronic balance, YAW-300 type constant loading cement pressure test machine (Figure 3), KZJ-500 type electric resistance testing machine fold (Figure 4).

Figure 1: ISO679 cement mortar mixer

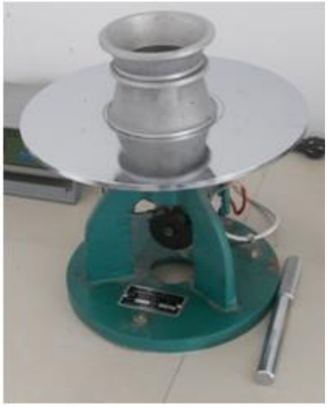

Figure 2: Cement mortar fluidity tester

Figure 3: Constant loading cement pressure testing machine

Figure 4: Electric bending test machine

(3) Datum mix ratio
After a large number of experiments, the optimum mix ratio parameters and basic properties of the synchronous grouting single liquid mortar are obtained, as shown in Tables 1 and 2. The amount of bentonite and WRA is determined according to the test matching, the 1 day strength (1DS) and 28 days strength (28DS) of concrete blocks are tested respectively, and these parameters are used, Water separation rate (WSR), Impermeability grade (IG), and so on.

Table 1: Base mix ratio parameter of grouting materia

Cement (kg/m^3)	FA (kg/m^3)	Sand (kg/m^3)	Bentonite (kg/m^3)	Water (kg/m^3)	WRA (kg/m^3)
198	351	829	50	320	3.86

Table 2: Performance of base mix mortar of grouting material

Fluidity (cm)	Slump (cm)	WSR (%)	Consistency cm	1DS (Mpa)	28DS (Mpa)	IG
22	4.1	1.9	11.2	0.65	7.13	S4

(4) Optimization of composition of polypropylene fiber

In the experiment, the composition of polypropylene fiber is optimized on the basis of the reference mix ratio, and the method of controlling the single variable is adopted. The performance of polypropylene fiber is studied. The parameters of the mortar mix ratio and its basic properties are shown in Tables 3 and 4.

Table 3: Optimum mix ratio of polypropylene fiber component of grouting material

Number	Cement (kg/m^3)	FA (kg/m^3)	Sand (kg/m^3)	Bentonite (kg/m^3)	Water (kg/m^3)	WRA (kg/m^3)	PF (kg/m^3)
1	198	351	829	50	320	3.86	0.3
2	198	351	829	50	320	3.86	0.5
3	198	351	829	50	320	3.86	0.9
4	198	351	829	50	320	3.86	1.2

Table 4. Optimum mix ratio mortar performance of polypropylene fiber component of grouting material

Number	Fluidity (cm)	Slump (cm)	WSR (%)	Consistency (cm)	1DS (Mpa)		28DS (Mpa)		IG
					Flexura	Compression	Flexura	Compression	
1	27.5	4.5	1.9	11.5	0.32	1.09	3.78	28.5	S5
2	24.3	4.1	1.54	11.9	0.45	1.22	3.98	30.7	S6
3	22.7	3.7	1.01	12.1	0.55	1.32	4.45	32.2	S6
4	18.8	3.1	0.98	12.6	0.65	1.35	4.63	33.5	S7

It can be seen from Tables 3 and 4 that the slump and fluidity of mortar decrease with the increase of fiber quantity, that is, the consistency of mortar increases with the increase of fiber quantity, which shows that the mortar with polypropylene fiber after mixing, inhibit mortar segregation and bleeding. At the same time, with the increase of fiber content, the density of the mortar matrix increases, and the external moisture intrusion ability is enhanced, that is, the anti permeability grade of concrete mortar is improved.

According to the site construction requirements, the flexural and compressive strength tests of 1 day and 28 days are carried out respectively. The experimental results show that fiber content significantly improves the flexural strength of concrete, which increases with the increase of fiber content, and the amplitude of increase also increases with the increase of volume. The compressive strength of concrete increases with the increase of content, but when the content is more than 0.9 kg/m^3, the change of content has little effect on the compressive strength of concrete.

(5) Optimization of components of water Resistant dispersant

Based on the above results, a comprehensive analysis of mortar performance is carried out. Polypropylene fiber is selected based on the best proportion of polypropylene fiber component 4 in the experiment. The performance of water resistant dispersant polyacrylamide is studied by controlling single variable method. Its mortar mix proportion parameters and their basic properties are shown in Tables 5 and 6.

Table 5: Optimum mix ratio of water dispersant components of grouting material

Number	Cement (kg/m^3)	FA (kg/m^3)	Sand (kg/m^3)	Bentonite (kg/m^3)	Water (kg/m^3)	WRA (kg/m^3)	PF (kg/m^3)	PAM (kg/m3)
5	198	351	829	50	320	3.86	0.9	5.51
6	198	351	829	50	320	3.86	0.9	2.2
7	198	351	829	50	320	3.86	0.9	1.1
8	198	351	829	50	320	3.86	0.9	0.55

Table 6: Optimum mixture ratio mortar performance of water dispersant components of grouting material

Number	Fluidity (cm)	Slump (cm)	WSR (%)	Consistency (cm)	Water / land compression strength (Mpa)		Water / land strength ratio		IG
					1 day	28 days	1 day	28 days	
5	27.5	4.5	1.9	11.5	0.32	1.09	3.78	28.5	S5
6	24.3	4.1	1.54	11.9	0.45	1.22	3.98	30.7	S6
7	22.7	3.7	1.01	12.1	0.55	1.32	4.45	32.2	S6
8	18.8	3.1	0.98	12.6	0.65	1.35	4.63	33.5	S7

When polyacrylamide is dissolved in water, the anionic polymer is dissociated into an anion with a large amount of large molecular weight in the alkaline cement slurry. And then the same charge strong repulsion to coil like macromolecules into a curve shape, increasing solution viscosity, can play a thickening effect. As shown in Tables 5 and 6, the consistency of mortar decreases with the decrease of polyacrylamide. Polyacrylamide polymer and water form latex liquid, forming many tiny lubrication films, reducing the friction between sand, playing the role of surface dispersion, and improving the mobility of mortar obviously. After the dosage of polyacrylamide reaches 0.1% of the cementitious material, the moisture absorption of polyacrylamide will exceed the "lubrication" effect, and the fluidity of the mortar is greatly reduced. The strength of concrete mortar decreases with the increase of polyacrylamide content, and its water dispersing effect is better. The actual construction against water dispersive polyacrylamide requirement is that the strength of concrete mortar stones is not less than 0.2 MPa a day, and the 28 days is not less than 2.5 MPa. On the basis of test block mechanical test, because of the influence of cement and fly ash proportion and fiber, the compressive strength of 1 day mortar and 28 days mortar can meet the construction requirements. Therefore, the amount of water dispersant polyacrylamide is mainly determined by its physical properties.

4. Engineering Application

Due to the impact performance of shield tunnel synchronous grouting materials by rock condition, the shield construction form, construction conditions and other factors, in the pre construction in Taishan nuclear power plant water tunnel shield segment to the seabed 200 ring formation analysis in the construction area, are selected with the ratio of 1 and 9 in field contrast test. The field construction results show that the mix ratio I can be applied to the hard and weak and uneven rock strata with a certain degree of self stability. At the same time, the fluidity can be increased by the water reducing agent and the amount of water adjusted, and the more uniform filling effect can be obtained. In view of a deep, soft clay layer with high water pressure the rapid tunneling of the shield, because the mixture ratio 9 slurry has better resistance to water dispersion and pumping, it can prevent water from being diluted, and can quickly reach the strength requirement after grouting, which can effectively control the float of the segment, satisfy the grouting needs and achieve good filling effect.

The high performance synchronous grouting material is applied to the actual construction, and the slurry is injected uniformly from the symmetrical position of the segment, so the segment does not appear to be in the wrong place, damaged or floated.There is no obvious seepage or water leakage at the joint of the tube during the grouting. Through the examination of the opening hole of the grouting hole after grouting, it is found that although not completely solidified, there is no leakage phenomenon, which shows that the waterproof performance is better. When the serosity is used in the whole tunnel, the floatation of the tube is obviously controlled.

5. Conclusions

Polypropylene fiber inhibited mortar segregation and bleeding, with the fiber content increasing, the density of the concrete mortar increases, which improves the anti permeability grade of concrete mortar and increases the ability to prevent the invasion of water from outside water. The flexural strength of concrete is obviously improved, and the flexural strength of concrete increases with the increase of fiber content. However, when the dosage is greater than 0.9 kg/m^3, the change of concrete content has little influence on the compressive strength of concrete. polyacrylamide has the effect of thickening and obviously improving the fluidity of mortar. After the dosage of polyacrylamide reaches 0.1% of the cementitious material, the moisture absorption of polyacrylamide will exceed the "lubrication" effect, and the fluidity of the mortar is greatly reduced. The strength of concrete mortar decreases with the increase of polyacrylamide content, and its water dispersing effect is better. In this project, the optimized proportioning test can satisfy the technological requirements of the synchronous grouting under the rapid construction of shield. The mortar made of using this method had good pumping, water dispersibility and seepage resistance, and it can avoid the phenomenon of grouting and pipe plugging. There is no seepage phenomenon in the shield tail and pipe ring after grouting, and the floatation of the pipe has been effectively controlled. It has achieved good grouting effect and has good economic and social benefits.

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