Experimental study on impermeability of concrete lining joint

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Abstract. In tunnel and shaft construction, the impermeability of concrete lining joint is involved with the safety of the lining structure. The chloride ion diffusion test is used to test the impermeability of concrete sample. The orthogonal test is designed with three factors, including water-cement ratio, waterproof interface form and prestress load. Each factor establishes three levels. The test results show that the interface form has the greatest influence on impermeability, followed by the prestress load, which can be used to optimize the design of concrete lining joints.

1. Introduction
Water penetration in concrete will indirectly reduce the strength of concrete, especially at the lining joint. The water resistance and porosity of concrete will be affected by the change of concrete ingredients[1]. There are two main ways to prevent moisture from contributing to concrete damage. One is to improve the impermeability of concrete, and the other is to take waterproofing measures in concrete cracks. The influence of several concrete additives on impermeability was studied[2, 3]. The best impermeability of self-compacting concrete were investigated with the a combination of 60% granulated blast furnace slag with 40% Portland cement[4]. Sodium silicate-based concrete sealers react with portlandite in the cement matrix to form inorganic calcium-silicate hydrates to solve waterproof problems[5]. The waterproofing efficacy of an inorganic sodium silicate-based concrete sealer are studied after introducing its composition and preparation process[6]. In-situ synthetizing super-absorbent resin (SAR) can be used to repair concrete cracks to prevent seepage[7]. The studies on various agents and tests about concrete waterproofing efficiency were reviewed[8]. To have impermeability effect, concrete joints of trapezoid and arc were made by the method in which one half was cast firstly, and the other half was cast a month later[9]. However, there are few studies on waterproofing measures for lining joints. In this paper, the effect of three factors on the impermeability of concrete lining joints was studied through orthogonal test, which could give suggestions for lining construction.

2. Orthogonal test design
The design grade of concrete samples in this study is C40. Three factors are considered to influence the impermeability of the joints, including water-cement ratio, waterproof interface form and prestress load. As shown in Table 1, each factor is set at three levels. The orthogonal test scheme is shown in Table 2.

| Level | Factor |
|-------|--------|
|       | A: water-cement ratio | B: waterproof interface form (thickness) | C: prestress load |

Table 1. Factors and levels.
| Number | Group  | Number | Group  | Number | Group  |
|--------|--------|--------|--------|--------|--------|
| 1      | A1 B1 C1 | 4      | A2 B1 C2 | 7      | A3 B1 C3 |
| 2      | A1 B2 C2 | 5      | A2 B2 C3 | 8      | A3 B2 C1 |
| 3      | A1 B3 C3 | 6      | A2 B3 C1 | 9      | A3 B3 C2 |

Table 2. Orthogonal test scheme.

3. Materials and method of impermeability test

3.1 Preparation of concrete samples
The sample model and composition are shown in Figure 1. The main steps of sample preparation in Figure 2 are (b) bottom concrete filling, (c) interface form treatment, (d) upper concrete filling and prestressed curing. There are 9 test groups, each of which has 3 concrete samples.

Figure 1. This is the figure of the sample model. The model is a cylinder with a height of 50 mm and a radius of 50 mm. The sample is divided into three layers, including 24 mm thick bottom concrete, 2 mm thick waterproof interface and 24 mm thick upper concrete.
Figure 2. The preparation of concrete samples.

3.2 Calculation processing

After samples preparation, vacuum saturated water treatment was carried out for 21 hours, and then the test of electric flux and chloride ion was performed immediately. Calculation about the electric flux and chloride diffusion coefficient is shown as Equation (1) ~ (2).

\[
Q = 900(I_0 + 2I_{30} + 2I_{60} + \ldots + 2I_t + \ldots + 2I_{300} + 2I_{330} \ldots I_{60})
\]  \hspace{1cm} (1)

Where \( Q \) is the total electric flux; \( I_0 \) is the initial current value (A); \( I_t \) is the current value at \( t \) (min).

\[
D = \frac{0.0239 \cdot (273 + T)L}{(U - 2)t} \left( X_d - 0.0158 \sqrt{\frac{(273 + T)LX_d}{U - 2}} \right)
\]  \hspace{1cm} (2)

Where \( D \) is the unsteady ion migration velocity in concrete \((10^{-12} \text{ m}^2/\text{s})\); \( T \) is average values of initial and end temperatures (°C); \( U \) is the absolute value of voltage (V); \( L \) is the thickness of concrete sample (mm); \( X_d \) is average chloride ion penetration (mm); \( t \) is power-on time (h).

4. Results and analysis

After 28 days of curing, the samples were tested and the data were recorded and calculated. The test results and average values of 9 test groups are shown in Table 3. According to the principle of statistics, the data were processed and the related indexes were calculated as shown in Table 4.

Table 3. Calculation results of the electric flux and chloride diffusion coefficient.

| Test number | Electric flux | Chloride diffusion coefficient |
|-------------|---------------|-------------------------------|
|             | 1  | 2  | 3  | Average | 1  | 2  | 3  | Average |
| 1           | 6769.61 | 6252.23 | 6591.26 | 6537.70 | 32.31 | 31.44 | 31.91 | 31.89 |
| 2           | 5289.85 | 5178.44 | 5337.29 | 5268.53 | 28.05 | 27.46 | 28.19 | 27.90 |
| 3           | 4487.20 | 4367.52 | 4589.86 | 4481.53 | 26.27 | 25.98 | 26.59 | 26.28 |
| 4           | 6164.43 | 5825.42 | 6093.16 | 6027.67 | 30.47 | 29.68 | 30.08 | 30.08 |
The optimal level of each factor can be selected according to the size of $k_i$, where $I$ is the . The influence of each factor on the test index can be judged by the size of $R$. The optimal level group is $A_2B_3C_3$, where water-cement ratio is 0.42 with interface form as cement mortar (1mm) + polyurea waterproof coating (1mm) and 10kg prestress. The interface waterproofing treatment has the greatest influence on the impermeability of lining concrete joint. The change trend of electric flux with water-cement ratio and prestress load is shown in the Figure 3.

![Figure 3](image)

Figure 3. There are two trendlines of influence on electric flux. The electric flux with the water-cement ratio change is basically stable and decreases as the pre-stress load increases.

5. Conclusion
In this paper, the orthogonal test is designed to estimate the influence on the impermeability of lining joint, including water-cement ratio, waterproof interface form and prestress load. The optimal level group in impermeability test is water-cement ratio 0.42 with interface form as cement mortar (1mm) + polyurea waterproof coating (1mm) and 10kg prestress. The interface waterproofing treatment has the greatest influence on the impermeability of lining concrete joint among three factors. The electric flux of the water-cement ratio change is basically stable and decreases as the pre-stress load increases.

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