Analysis of application of cement paste grouting curtain in coastal environment

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Abstract. Zhejiang Datang Wushashan power plant is composed of farmland and aquaculture ponds in the Xizhou seawall, which are backfilled with artificial riprap. In order to block the seepage path in the rockfill layer, the vertical curtain cement paste grouting anti-seepage reinforcement measures are adopted to block the connection between the underground water and the surrounding surface water in the plant area, so as to achieve the purpose of gas closure. This paper mainly analyzes and evaluates the technical indexes, such as grout diffusion range and impermeability, of the cement paste grouting curtain, via field tests and two dimensional numerical simulation based on the platform of PFC2D or Geostudio.

1. Introduction
The site of Zhejiang Datang Wushashan Power Plant is located in the eastern part of the Xizhou Plain in the northwest of Xiangshan County, on the west side of Wusha Mountain and inside the Xizhou Seawall. It is about 21km away from Xiangshan County and 2.5km away from Xizhou Town. The site is backfilled by farmland and breeding ponds in the West Zhou Seawall. The original natural elevation of the ground is about 0.50~2.0m, and the design floor elevation of the site is 4.05m. It is backfilled with gravel, and the maximum backfill thickness is more than 3.5m. Since the artificial rockfill backfill is a permeable foundation, in order to block the seepage path in the rockfill layer, the vertical curtain cement paste grouting is adopted to prevent seepage and reinforcement measures to isolate the groundwater in the plant area and the surrounding surface water to achieve the purpose of air-sealing.

The control standard of curtain grouting effect is that the permeability coefficient K of foundation after grouting is less than 5.0 × 10^{-5} cm/s, and the minimum effective curtain thickness of curtain grouting is 3.0m. Adding quick setting agent (polymer organic substance) into common paste to form quick-setting paste can control and adjust the gel time of slurry by adding different additives. It has good applicability for seepage control under the condition of certain velocity and dynamic water. The material has been successfully applied to many projects in the water and electricity industry, and remarkable economic benefits have been achieved.

The control standard of curtain grouting effect is that the foundation permeability coefficient K after grouting is less than 5.0 × 10^{-5} cm/s, and the minimum effective curtain thickness of curtain grouting is 3.0m. Adding quick-setting agent (polymer organic matter) to ordinary slurry to form quick-setting slurry. Seawater is moderately corrosive to concrete, long-term water immersion and alternate dry and wet conditions, weakly corrosive and strong corrosive to steel bars in reinforced concrete structures, respectively, and moderately corrosive to steel structures; underground diving is weakly corrosive to concrete, underground confined water is non-corrosive to concrete, and long-term water immersion and alternate dry and wet state, It is non-corrosive and moderately corrosive to steel bars in reinforced
concrete structures, respectively, and moderately corrosive to steel structures [1-4]. This article aims to analyze the application of cement paste curtains in coastal seawater environment.

2. Field Test
In order to study the adaptability of grouting materials, groutability of foundation and the feasibility of forming anti-seepage curtain, the grouting parameters, construction technology, grout diffusion range, allowable permeability gradient of anti-seepage curtain and durability of curtain are analyzed, and the rationality of relevant parameters of anti-seepage curtain design is demonstrated, so as to provide guidance data for large-scale curtain grouting construction Field tests were carried out.

2.1. Test purpose and content
The permeable foundation of this project is mainly formed by artificial rock dump. The main work content of the field grouting test includes: construction preparation, sequential drilling, grouting, waiting for coagulation, transfer, post-grouting inspection, etc.

2.2. Experiment method

2.2.1. Pressure (note) water test before irrigation. In order to understand the current characteristics of the grouting area, evaluate the anti-seepage effect of paste grouting, and compare the changes of permeability before and after grouting, the permeability coefficient of the test area was determined by water injection test before grouting.

2.2.2. Borehole grouting. According to the requirements of grouting in the test area, the drilling is carried out in the order of outer row → inner row → middle row, each row is first drilled with sequence I, and after the first sequence is filled and solidified, the second sequence is drilled.

2.2.3. Inspection after grouting. Post-grouting effect inspection is a necessary step to inspect the grouting effect. According to the purpose of the test, the inspection is mainly to check the improvement of the impermeable performance after the irrigation, the shape of the stone body after the irrigation, and the continuity of the stone body. Therefore, the content of the effect inspection includes drilling. Hole water pressure test, excavation inspection and coring inspection.

2.2.4. coring. The purpose of coring is to check the cementation between the slurry and the formation after grouting, which is closely related to the geology: for the stratum with large gap, such as riprap layer, the slurry is easy to form an accumulation channel, so it can be well cemented with the formation; for the stratum with small particles such as silt and small pores, the paste can not enter into its interior, so it can not form cementation Because of the splitting effect of grouting pressure, the local channel may be formed, and thus become the plasma vein. In this test, one core is taken randomly from each test area. The first one is taken after excavation, and the second one is taken from the ground.

2.2.5. Observation after completion. According to the observation data, the water level in holes W1 and W2 did not change significantly with the tide in the observation period of one year in the Western anti-seepage curtain body; the water level in hole W3 changed significantly with the tide in March and April of 2016; after the secondary grouting treatment in April of the same year, the water level in the holes was stable and the anti-seepage effect was good; the five observation holes in the North anti-seepage curtain body were in the In one year observation period, the water level in hole N2 ~ N5 did not change significantly with tide, and the anti-seepage effect was good; in March of 2016, the water level in hole N1 changed obviously with tide; after secondary grouting treatment in this area in April of the same year, the water level in hole E1 was stable and the anti-seepage effect was good; in the two observation holes of the East anti-seepage curtain, the water level in hole E1 did not change significantly with the tide, The results show that the seepage control effect is good; the water level of E2 hole changes
obviously with the tide during March to June of 2016. After the secondary grouting treatment in July of the same year, the water level in the hole is stable and the anti-seepage effect is good; in the five observation holes of the South anti-seepage curtain body, the change of water level with tide is not obvious, and the anti-seepage effect is good.

3. Simulation calculation

According to the observation results of underground water level, the underground water level in the plant area is related to the sea level, and the underground water is salty and corrosive to the concrete structure. Due to the relatively low ground elevation of the plant area, it is urgent to close the air in the plant area to meet the requirements of flood control. In this paper, two-dimensional numerical simulation is carried out for different schemes of gas tight seepage control. The seepage flow and maximum seepage gradient of different schemes are obtained. The results are analyzed and reasonable suggestions are put forward.

3.1. Numerical simulation method

3.1.1. PFC\textsuperscript{2D} numerical simulation

(1) Establishment of model. The model is composed of spheres representing soil particles and walls. The width and height of the model are taken as 10 m respectively. The generated model is shown in Figure 1. The blue particles around the boundary represent the impermeable boundary. The model contains 323 particles and 282 domains. In Figure 2, the green dots represent the domains, the green lines connecting the green dots are the channels of fluid flow, the red spheres represent the geotechnical particles, and the white lines connecting the round particles represent the contact connection between particles.

(2) Selection of micro parameters of particles. The macro parameters can not be directly influenced by the meso parameters of the proposed macroscopical medium. The macro parameters obtained are similar to the results of physical tests. Finally, the most suitable meso parameters are determined, as shown in Table 1.

| Parameter                        | Value   |
|----------------------------------|---------|
| Particle stiffness ratio         | 1       |
| Normal bond strength of particles | $1 \times 10^4$ |
| Tangential bond strength of particles | $1 \times 10^4$ |

The permeability coefficient is usually measured with water as the seepage fluid. Because the viscosity and density of the slurry are different from that of water, the permeability coefficient measured through the permeability experiment is obtained with water as the medium [5]. Therefore, in order to obtain the permeability coefficient of the slurry, the permeability coefficient obtained from the experiment needs to be converted.
(3) Result analysis. The grouting pressure is 0.05, 0.1, 0.2 and 0.3 MPa respectively, and the grouting fluid is the four grade paste used in the field. The permeability coefficients of paste with different proportions in riprap layer are $1 \times 10^{-2}$ cm/s, $5 \times 10^{-2}$ cm/s, $8 \times 10^{-2}$ cm/s and $1 \times 10^{-1}$ cm/s respectively. The grouting time is CYC = 10000, and the diffusion radius of paste with different proportions under different pressures is obtained. The radius of each circle is 0.3, 0.6, 0.9, 1.2, 1.5, 1.8 and 2.1 m respectively.

3.1.2 Finite element numerical simulation
The upstream boundary water level is the most unfavorable water level in the construction process, the elevation is 6.28 m (0.1% high tide level), and the downstream boundary water level is stable groundwater level, 4.6 m below the natural surface. According to the typical section diagram, the two-dimensional finite element model is established by GeoStudio, as shown in Figure 3.

![Figure 3](image)

Figure 3. The finite element model of typical section

In the figure, the blue area represents the riprap layer, the green area represents the silt layer, the yellow area represents the muddy clay layer, and the red area represents the grouting curtain. The upstream boundary water level is defined as 14.6 m constant head by the red dot marked line, and the downstream boundary water level is 7.8 m by the blue marked line.

3.2. Analysis of two dimensional seepage calculation results

3.2.1. Seepage analysis. A typical section of the typical section is selected to calculate the seepage flow, and the seepage flow of this typical section with different schemes is compared and analyzed. It can be seen from Table 2 that the seepage flow of grouting curtain is obviously reduced compared with that before grouting. Before grouting, the main permeable layer is riprap layer with permeability coefficient of $3 \times 10^{-2}$ cm/s, and the total seepage flow of the whole plant can reach $29300$ m$^3$/d. After grouting, the permeability coefficients of grouting curtain are $1 \times 10^{-4}$ cm/s, $5 \times 10^{-5}$ cm/s, $1 \times 10^{-5}$ cm/s and $5 \times 10^{-6}$ cm/s respectively. When the grouting curtain is 2.6 m, the seepage flow through typical section is $8.53 \times 10^2$ m$^3$/D, $4.60 \times 10^2$ m$^3$/D, $1.61 \times 10^2$ m$^3$/D, and $66.7$ m$^3$/D, respectively. With the decrease of permeability coefficient of grouting curtain, the seepage control effect is better.

By comparing and analyzing the wettability of typical sections before and after grouting, it can be found that the wettability after grouting is significantly reduced, which also proves that the anti-seepage curtain has obvious anti-seepage effect. The thickness of grouting curtain changes from 2.6 m (two rows of grouting holes) to 3.0 m (three rows of grouting holes). Although the seepage volume will also decrease, the variation range is limited, which is mainly due to the small change of permeability coefficient. It can be concluded that from the analysis of reducing seepage flow, if two or three rows of grouting holes are made in the project, the seepage flow changes little.

| Scheme name | Seepage flow/m$^3$/s | Total seepage flow of the plant/m$^3$/d |
|-------------|----------------------|---------------------------------------|
| No grouting | $2.26 \times 10^{-4}$ | $2.93 \times 10^4$                     |
| The thickness of the curtain is 2.5 m, the permeability coefficient is $5 \times 10^2$ cm/s | $5.15 \times 10^{-7}$ | $6.67 \times 10^1$ |
The thickness of the curtain is 2.5 m, the permeability coefficient is 5×10⁻⁶ cm/s

The thickness of the curtain is 2.5 m, the permeability coefficient is 5×10⁻⁵ cm/s

The thickness of the curtain is 2.5 m, the permeability coefficient is 1×10⁻⁴ cm/s

The thickness of the curtain is 3.0 m, the permeability coefficient is 5×10⁻⁶ cm/s

The thickness of the curtain is 3.0 m, the permeability coefficient is 5×10⁻⁵ cm/s

The thickness of the curtain is 3.0 m, the permeability coefficient is 1×10⁻⁴ cm/s

It can be seen from the table that with the change of permeability coefficient of grouting curtain, the seepage flow will also have obvious changes. With the decrease of permeability coefficient, the seepage flow will decrease correspondingly. The maximum total seepage flow obtained by numerical simulation is 853 m³/D, which can meet the requirements of the project.

3.2.2. Analysis of maximum permeability gradient. The maximum permeability gradient of different formations in each scheme is shown in Table 3. It can be seen from table 5 that the allowable seepage gradient in the design code for earth rock dams is 0.5. In the scheme without grouting, the maximum seepage gradient of riprap layer is 0.68, which exceeds the allowable gradient, and the seepage gradient at the escape point is also 0.68, which exceeds the allowable gradient. Therefore, it is necessary and necessary to adopt curtain for seepage control in consideration of seepage stability. After adopting the grouting curtain scheme, the permeability gradient of riprap layer and escape point is significantly reduced, which is less than the allowable gradient required in the project; the maximum permeability gradient of three rows of grouting curtain is 2.87, less than the design allowable gradient of 3, meeting the requirements, while the maximum permeability gradient of the second row grouting curtain is 3.115, slightly larger than the design allowable gradient.

Table 3. Calculation results of maximum permeability gradient of different strata in each scheme

| Scheme name                  | silt | muddy clay | Riprap layer | heavy curtain | Escape point |
|-----------------------------|------|------------|--------------|---------------|--------------|
| No grouting                 | 0.3  | 0.24       | 0.68         | None          | 0.68         |
| The thickness of the curtain is 2.5 m, the permeability coefficient is 5×10⁻⁶ cm/s | 0.22 | 0.17 | 0.4 | 3.115 | 0.001 |
| The thickness of the curtain is 2.5 m, the permeability coefficient is 5×10⁻⁵ cm/s | 0.23 | 0.18 | 0.42 | 2.818 | 0.002 |
| The thickness of the curtain is 2.5 m, the permeability coefficient is 1×10⁻⁴ cm/s | 0.25 | 0.2 | 0.45 | 1.96 | 0.005 |
| The thickness of the curtain is 3.0 m, the permeability coefficient is 5×10⁻⁶ cm/s | 0.26 | 0.17 | 0.4 | 2.317 | 0.001 |
The thickness of the curtain is 3.0 m, the permeability coefficient is $5 \times 10^{-5}$ cm/s

|        |        |        |        |        |
|--------|--------|--------|--------|--------|
|        | 0.28   | 0.18   | 0.42   | 1.772  | 0.0045 |

The thickness of the curtain is 3.0 m, the permeability coefficient is $1 \times 10^{-4}$ cm/s

|        |        |        |        |        |
|--------|--------|--------|--------|--------|
|        | 0.29   | 0.19   | 0.43   | 1.673  | 0.005  |

4. Conclusion

The gypsum grouting process is adopted in the gas shut-off reconstruction project of Zhejiang Datang Wushashan Power Generation Co., Ltd., and the detection methods of core drilling, water injection test and long-term observation of water level change in the curtain body are adopted. Through the above detection methods, it is verified that: the curtain depth and permeability coefficient meet the design requirements; the water level in the curtain body of the observation section changes stably and is not affected by the tidal water level difference outside the plant area. The curtain has good air sealing performance, and the cement paste can be used in coastal environment. In addition, the two-dimensional numerical simulation is used to simulate the slurry diffusion process and seepage process of the grouting curtain body, which verifies the anti-seepage performance of the grouting curtain scheme.

References

[1] CAI Jian, LI Mingkai, CHEN Qingjun, et al. Chloride ingestion in reinforced concrete beams subjected to flexural loading under cyclic drying-wetting condition[J]. Journal of Central South University (Science and Technology), 2019, 50(11): 2840-2840.

[2] CAI Jian, WEI Mu-yang, LUO Chi-yu, et al. Durability of prestressed concrete beams under simultaneous flexural load and chloride erosion[J]. Engineering Mechanics, 2018, 35(7): 208−218.

[3] SHEN Jun, YUAN Meng, YAN Min, et al. Research Status, Exist Problems and Development Trend on the Effect of the Dry-wet Cycles on the Properties of the Structure Concrete in the Marine Environment[J]. Bulletin of the Chinese ceramic society, 2017, 36(6): 1929-1938.

[4] JIN Weiliang, JIN Libing, YAN Yongdong, et al. Field inspection on chloride ion-intrusion effect of seawater in dry-wet cycling zone of concrete structures[J]. Journal of Hydraulic Engineering, 2009, 40(3): 364-371.

[5] ZHOU Jian, ZHANG Gang, KONG Ge. Meso-mechanics simulation of seepage with particle flow code[J]. Journal of Hydraulic Engineering, 2006, 37(1): 28-32.