Application of plastic concrete cut-off wall in reinforcement of reservoir

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Abstract. Plastic concrete is a kind of suitable material for cut-off wall of earth dam, which has low elastic modulus and permeability, large ultimate deformation, and good workability. In this paper, the mix proportion of plastic concrete with 50% bentonite content, water-binder ratio of 1.00 and sand-aggregate ratio of 55% is proposed, and the plastic concrete cut-off wall has been successfully applied to the reinforcement project of Huizhou Zengbo Lianhe reservoir. All the indexes meet the design requirements. The seepage of the main dam was reduced by 67%, and the piezometric level behind the wall was reduced by 6-9 m.

1. Introduction

More than 85,000 reservoirs have been built in China, of which 37,000 are unsafe. 14,600 dangerous reservoirs had been reinforced by 2012. A total of 3,484 dams were broken in China from 1954 to 2003, seriously affecting the safety of people's lives and property. Seepage is the most common defect of homogeneous earth dam, and the main cause of dam break [1, 2]. And the major technical measure for seepage prevention and reinforcement of earth dam is cut-off wall.

The cut-off wall prepared with ordinary Portland concrete has been widely used in the reinforcement of homogeneous earth dam [3]. However, the ordinary concrete cut-off wall cannot deform synergistically with the surrounding soil, due to its large elastic modulus and small ultimate deformation. Under the huge negative friction of the surrounding soil, cracks are likely to occur, and then the integrity and continuity of the cut-off wall will be destroyed [4, 5]. Therefore, the safety of dam would be threatened because of the reduced anti-seepage effect [6-9]. Moreover, the early strength of ordinary concrete cut-off wall develops rapidly and the operation of slot connection at II stage is difficult, thus the seepage control effectiveness of the cut-off wall would be reduced due to the hidden danger area of seepage [10].

Compared with ordinary concrete, plastic concrete contains bentonite or clay. The elastic modulus of plastic concrete is similar to that of foundation, and its ultimate deformation is large, so it can adapt to foundation deformation better than ordinary concrete. The plastic concrete can be able to work with the foundation, so it has better crack resistance and earthquake resistance. In addition, plastic concrete has better workability, longer final setting time and lower mechanical strength, is beneficial to improve the construction quality of slot connection at II stage. It's worth noting that, incorporation with an
appropriate amount of bentonite or clay in plastic concrete, not only improves the anti-permeability performance, but also reduces the cement consumption, bringing environmental and economic benefits [11-13].

The Huizhou zengbo lianhe reservoir, located in the Dongjiang river, has a catchment area of 110.8 km² and a total storage capacity of $80.94 \times 10^6$ m³ after reinforcement. Safety evaluation was carried out before the dam was reinforced. The permeability coefficient by water injection test of the dam body was only $1.0 \times 10^{-3}$ cm/s in several sections, which was larger than the standard requirements. The permeability coefficient of dam body fluctuates greatly, the compaction degree of overall soil is insufficient, the seepage reinforcement is necessary. The foundation of the main dam is partially in contact with the silty sand soil layer, and the recommended permeability coefficient $k$ is $5 \times 10^{-3}$ cm/s. The silty sand soil layer should be reinforced due to the severe seepage. Moreover, seepage at the slope toe of the main dam occurs frequently. The water level of reservoir was 51.20 m, and the seepage at the dam toe was about 0.0126 m³/s after on-site inspection, which is unfavorable to the stability of dam. In view of the severe seepage of the main dam, the plastic concrete cutoff wall is adopted for the reinforcement of reservoir.

2. Mix proportion and construction technology

2.1. Mix proportion
The plastic concrete was prepared with 42.5R ordinary Portland cement, granite gravel of 16-31.5 mm, medium river sand and mud-type calcium bentonite. The mix proportion is shown in Table 1.

| Parameters          | Water-binder ratio | Content of bentonite/% | Sand-aggregate ratio/% | Cement / (kg/m³) | Bentonite / (kg/m³) | Gravel / (kg/m³) | Sand / (kg/m³) | Water / (kg/m³) |
|---------------------|--------------------|------------------------|------------------------|------------------|---------------------|------------------|---------------|----------------|
|                     | 1.00               | 50                     | 55                     | 168              | 168                 | 688              | 841           | 335            |

2.2. Construction technology
The cut-off wall is arranged at the axis of the dam crest, with a thickness of 600 mm. The bottom of cut-off wall should pass through the silty sand soil layer and intensely weathered granite, and enter the relatively impermeable layer up to 1 m. The axis length of the cut-off wall is 315.5 m, and the designed maximum wall depth is 50.40 m. The construction work quantity is about 9000 m², and the profile of plastic concrete cut-off wall of main dam is shown in figure 1.

![Figure 1. The profile of plastic concrete cut-off wall.](image)

Figure 2 is the flow chart of construction technology of plastic concrete cut-off wall, mainly consist of construction of concrete guide slot and platform, mud preparation and transportation, drilling hole, hole cleaning and mud displacement, and casting plastic concrete. It should be noted that, the bentonite mud was used in this project, and the mud should be recycled and reused.
Figure 2. The construction technology of plastic concrete cut-off wall.

3. Properties of plastic concrete

3.1. Design requirements
The water-binder ratio of plastic concrete mixture is 0.85-1.20, and the slump is 180-220 mm, extended degree is 340-400 mm. The design compressive strength of plastic concrete is 1.0-5.0 MPa, elastic modulus is ≤2000 MPa, permeability coefficient is ≤1×10⁻⁶ cm/s, seepage failure gradient J ≥300, elastic modulus-compressive strength ratio is 200-500.

3.2. Results of laboratory test
The properties of plastic concrete tested in laboratory are shown in Table 2. The experimental results meet the design requirements.

| Slump (mm) | Extended degree (mm) | Compressive strength (MPa) | Splitting tensile strength (MPa) | Permeability coefficient (×10⁻⁷ cm/s) | Elastic modulus (MPa) | Modulus-strength ratio | Seepage gradient |
|------------|----------------------|----------------------------|---------------------------------|--------------------------------------|----------------------|------------------------|------------------|
| 7d         | 28 d                 | 28 d                       | 28 d                            | 28 d                                 | 28 d                 | 28 d                   | 28 d             |
| 200        | 365                  | 3.4                        | 0.35                            | 1.05                                 | 1450                 | 426                    | ≥400             |

3.3. Results of field test
The specimens in the field were selected randomly to test. The compressive strength was 3.2-4.6 MPa, elastic modulus was 1382-1688 MPa, permeability coefficient was 2.4-4.7×10⁻⁷ cm/s, and the seepage gradient was not less than 400. All the results meet the design requirements.

4. Seepage control effect of cut-off wall

4.1. Seepage of main dam
The relationship between seepage and reservoir water level of main dam is shown in figure 3. ‘2017’ represents the annual data of 2017 before the reinforcement of the cut-off wall, and ‘+2019’ represents the data from October 2018 to October 2019 after the reinforcement. When the reservoir water level is between 46.11 and 52.61 m, the seepage of main dam is 1.34×10⁻² m³/s before the reinforcement, and 0.62×10⁻² m³/s after the reinforcement, with a reduction of 53.7%. It should be noted that, the reinforcement measures are not adopted for the dam foundation in this project. It is assumed that the seepage amount of the dam foundation is 20% of the total seepage amount before the reinforcement, and the seepage of dam foundation remains unchanged. The reduction reaches 67% after deducting the seepage influence of the dam foundation, hence the seepage control effect of the plastic concrete cut-off wall is remarkable. In addition, the anti-permeability of plastic concrete increases with the age, and the bentonite can absorb water and expand. Therefore, the seepage control effect of plastic concrete cut-off wall would be further enhanced with time.
Figure 3. The relationship between seepage and reservoir water level.

4.2. Piezometric level of dam

Nine piezometric tubes of three stakes were selected. The inlet section of piezometric tubes were arranged in the dam body, about 6 m away from the dam foundation, in order to avoid the influence of seepage of dam foundation. Table 3 is the arrangement of piezometric tubes.

| Serial number | B1 | C1 | D1 | B2 | C2 | D2 | B3 | C3 | D3 |
|---------------|----|----|----|----|----|----|----|----|----|
| Stake number  | 0+090 | 0+150 | 0+210 | 0+090 | 0+150 | 0+210 | 0+090 | 0+150 | 0+210 |
| Axle distance/m | -4.25 | -4.25 | -4.25 | 3.75 | 3.75 | 3.75 | 23.35 | 23.35 | 23.35 |
| Inlet elevation/m | 22.30 | 23.40 | 28.00 | 20.70 | 22.50 | 28.00 | 20.80 | 20.50 | 27.50 |

A Axle distance is the distance between piezometric tubes and cut-off wall, upstream is ‘−’ and downstream is ‘+’.

The piezometric level before and behind the plastic concrete cut-off wall is shown in figure. 4. It is obvious that the piezometric level increases with the rise of the reservoir water level. Take the B1 and B2 as an example to illustrate the change of piezometric level. B1 and B2 are respectively arranged on the upstream and downstream of the cut-off wall, with a water level difference of 8.28-11.31 m. While the water level difference between two piezometric tubes in the adjacent position is about 1.8-2.5 m, before the construction of the cut-off wall.

As the reservoir water level rises, the water level of B1 and B2 both rises, but the former rises faster. Therefore, the water level difference between B1 and B2 increases, which is consistent with study of Tian [14]. This is because the permeability coefficient of the cut-off wall is smaller than that of dam filling. As the reservoir water level rises, the area of the cut-off wall that plays the role of seepage control increases, then the overall seepage control effect improves. It takes a long time for the seepage to reach the piezometric tubes behind the wall, which has a certain hysteresis effect.
5. Conclusions

Plastic concrete, with low elastic modulus and permeability, large ultimate deformation, and good workability, is a kind of suitable material for cut-off wall. The mix proportion of concrete with 50% bentonite content, water-binder ratio of 1.00 and sand-aggregate ratio of 55% meet the design requirements of plastic concrete cut-off wall. The seepage control effect is remarkable. The seepage of the main dam was reduced by 67%, and the piezometric level behind the wall was reduced by 6-9 m.

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References

[1] Li X, Yang J and Zhang Z 2017 *J. Anhui Agri. Sci.* 45 162-6
[2] Wang X and Bao X 2019 *J. Hydroelectric Engineering* 38 37-43
[3] Gao D, Song S and Yang L 2014 *J. Hydraulic Engineering* 45 360-7
[4] Song L, Liu L and Gao Y 2016 *J. Yangtze River Sci. Research Institute* 33 147-50
[5] Gao Y, He Z and Song L 2019 *Yellow River* 41 148-51
[6] Xiao F 2017 *H Sci. and Tech. of Water Conservancy* 45 63-6
[7] Zou J 2019 *Water Resources South to North Water Diversion* 48 56-8
[8] He J 2017 *Water Resources South to North Water Diversion* 46 39-40
[9] Yue G and Xu F 1994 *Water Power* 3 21-3
[10] Wang S, Li X and Li Y 2014 *J. Chinese Ceramic Society* 42 33-7
[11] Zhang Y 2019 *J. Yellow River Conservancy Tech. Institute* 31 17-20
[12] Tan J, Li R and Chen L 2004 *Water Resources Hydropower of Northeast China* 22 1-2
[13] Fang J, He P and Liang H 2004 *Zhejiang Hydrotechnics* 3 52-4
[14] Tian Y and He Z 2019 *Shanxi Hydrotechnics* 5 4-8