Large scale 3D seepage analysis of whole pumped storage power station project area

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Abstract. The 3D finite element grid for whole pumped storage power station project area is set up. The seepage analysis shows the potential distribution for seepage field is clear and well. The leakage water flow form upper reservoir basin rack mass to underground powerhouse, and then to the lower river. The leakage has little influence on the hydrogeological conditions in the reservoir area. The anti-seepage and drainage measures is technically reasonable for upper reservoir. The permeability stability for upper and lower reservoir is acceptable. And grouting should be strengthened for the mountain in right dam shoulder should, if necessary according to geological conditions.

1. Introduction
Pumped storage power station is mostly built in mountain with complex terrain conditions, complex hydrogeological conditions, and complex engineering geological conditions [1]. There are the upper reservoir, diversion tunnel, underground powerhouse, lower reservoir and dam in the whole pumped storage power station project area. Meanwhile, the project area always includes some faults and drainage holes, which have a great influence on the seepage characteristics of the whole seepage field, and often play a controlling role [2]. Due to geometry size and boundary condition, it is very difficult to accurately simulate the seepage field of whole pumped storage power station project area. Although, the seepage filed of pumped storage power station is simulated based on the combination of large area rough model and local fine model [3], the dynamic unification of the upper basin and the underground powerhouse is separated [4]. The improved cut-off negative pressure method [5], improved drainage substructure method, piping substructure method[6], and preconditioned conjugate gradient method are used to analysis the seepage filed of whole project area, and the methods provide a good foundation for accurate simulation of engineering seepage characteristics.

In this paper, for getting the seepage filed of a pumped storage power station, the 3D finite element grid grid of whole project area is meshed using super element method. The model of saturated-unsaturated seepage, array of wells replaced by a drainage ditch method, and improved drainage substructure method are accepted for simulation. Then, the potential distribution, pressure head of tunnel, and seepage gradient are analyzed.
2. Calculation Model and Parameters

2.1. Calculation Model

2.1.1. Model Calculation Range Selection. The coordinate system follows the right hand rule. Take the vertical direction for \( z \) axis, upward is the positive, calculated by elevation, and the top and bottom elevation is respectively 950.00 m and 1580.00 m. \( x \) direction is parallel to the clockwise 10 degrees of 1\(^{st}\) dam axis, and the range of \( x \) direction is about 3700.00 m. The range of \( y \) direction is about 1845.00 m. The coordinate system and calculation range are shown in Figure 1.

2.1.2. Finite Element Grid. Based on the terrain conditions, stratum and fault in the calculation region, finite element grid is set up with super element method. The total number of grid nodes and total number of grid elements is respectively 82536 and 78776. As shown in Figure 1, the finite element grid includes the upper reservoir, diversion tunnel, underground powerhouse, lower reservoir and dam.

![Figure 1. Coordinate system and finite element grid](image)

Table 1. Permeability coefficient of rock mass and dam material zone

| Location of rock mass | Weathering degree | Permeability coefficient (cm/s) | Dam material zone          | Permeability coefficient (cm/s) |
|-----------------------|-------------------|-------------------------------|-----------------------------|--------------------------------|
| Upper reservoir       | Weakly weathering | \( 2.23 \times 10^{-5} \)     | Upper rock-fill             | \( 1.22 \times 10^{-4} \)     |
|                       | Weakly weathering | \( 1.59 \times 10^{-5} \)     | Downstream rock-fill        | \( 9.06 \times 10^{-4} \)     |
|                       | Lightly weathering| \( 0.88 \times 10^{-5} \)     | Drainage cushion            | \( 1.48 \times 10^{-2} \)     |
|                       | Strong weathering | \( 4.12 \times 10^{-4} \)     | Asphalt concrete face slab  | \( 1.00 \times 10^{-7} \)     |
| Diversion tunnel      | Weakly weathering | \( 3.14 \times 10^{-5} \)     | Concrete structure of water inlet and outlet | \( 3.50 \times 10^{-7} \) |
| Lower reservoir       | Weakly weathering | \( 1.83 \times 10^{-5} \)     | Transition zone             | \( 3.39 \times 10^{-2} \)     |
|                       | Lightly weathering| \( 2.33 \times 10^{-5} \)     | anti-seepage curtain        | \( 1.00 \times 10^{-5} \)     |
2.2. *Calculation Conditions and Parameters*

The types of boundary for steady seepage analysis of whole pumped storage power station project area can be divided into the known head boundary, seepage boundary, and impervious boundary [7]. The known head boundary include the bank and the bottom of the reservoir below the water level, and upstream dam slope. The seepage boundary consists of slope upon the water level, downstream dam slope, and dam crest. The other boundary is impervious boundary, including steel lining for diversion tunnel and pressure piping, and the reinforced concrete lining for tailrace tunnel.

The permeability coefficients of rock mass in project area are given according to the geological survey data and parameter inversion analysis before construction (see Table 1).

3. *Seepage Analysis*

3.1. *Conditions of Analysis*

According to the design specification and inversion analysis before construction for whole project area, the water level in upper reservoir is 1595.00m, and the water level in mountain of reservoir basin foundation is considered as minimum groundwater level. The water level in intercept boundary is 1515.00 m. The water level in lower valley and the lower reservoir is respectively 1110.00 m and 1101.00 m.

3.2. *Potential Distribution*

In order to facilitate analysis, the section A, section B, and section C are defined in Figure 1. The potential distribution for seepage field in whole pumped storage power station project area is shown in Figure 2, Figure 3, and Figure 4, and it is clear and well.

As shown in Figure 2 and Figure 3, groundwater level in reservoir area, the left bank, the right bank and the two dam shoulder is lower than normal water level for upper reservoir. And the seepage face gradually decreases from the reservoir basin to the mountain. Therefore, reservoir leakage happens and reservoir water flow into groundwater. The water in upper reservoir infiltrate from rack mass at bottom of reservoir basin to underground powerhouse, and then eventually flow to the lower river.

As shown in Figure 4, the water leakage in lower reservoir happens from dam body, dam foundation, and dam shoulder to the lower river. Due to the anti-seepage effect of seepage control system in the dam, seepage face suddenly drops in the asphalt concrete core wall.

Considering the seepage control, since the leakage volume is small, it has little influence on the hydrogeological conditions in the reservoir area. Therefore, the dam stability, the stress and strain of dam foundation will not change significantly.

![Figure 2. Potential distribution of Section A (m)](image-url)
Figure 3. Potential distribution of Section B (m)

Figure 4. Potential distribution of Section C (m)

Figure 5. Pressure head of tunnel (m)
3.3. Pressure head of tunnel
The pressure head of tunnel is shown in Figure 5. The maximum value of pressure head of tunnel is located at initial section of intermediate horizontal pipeline, and it is 92.8m. The pressure head of initial section of intermediate horizontal pipeline, initial section of lower horizontal pipeline, and tailrace tunnel more than 85m.

3.4. Seepage Gradient
The maximum water head on the asphalt concrete face slab is 40m, and it is relatively small, so the seepage gradient also relatively small. And the seepage gradient is less than the permissive permeability gradient of concrete face slab. Meanwhile, maximum seepage gradient of rack mass in upper reservoir is 0.26, and it is less than the permissive permeability gradient. There is no saturated zone in cushion around the upper reservoir basin, so the seepage stability meets the requirements.

Due to drainage gallery, the seepage gradient of pressure pipeline and underground powerhouse are relatively big, but both of them are less than the permissive permeability gradient. The seepage gradient between diversion tunnel and tailrace tunnel is very small, it has very small influence on the around rock mass.

As for the dam, maximum seepage gradient of dam core wall is biggest than other dam zone, and maximum seepage gradient of curtain is over 5. The fault f1 and f2 are located in right dam shoulder, and their seepage gradient is respectively 0.24 and 0.26.

Table 2. Seepage gradient of project area

| Location                            | Seepage gradient | Location                | Seepage gradient |
|-------------------------------------|------------------|-------------------------|------------------|
| face slab of upper reservoir        | 123.75           | Upper rock-fill         | 0.01             |
| Rock mass                           | 0.26             | Downstream rock-fill    | 0.01             |
| Diversion tunnel                    | 0.22             | Curtain of left bank    | 5.55             |
| Pressure pipeline                   | 0.56             | Curtain of right bank   | 5.55             |
| Underground powerhouse              | 0.41             | Curtain of dam foundation| 5.53             |
| Tailrace tunnel                     | 0.54             | Fault f1                | 0.24             |
| concrete core                       | 26.67            | Fault f2                | 0.26             |

4. Conclusion
The 3D FEM grid for seepage analysis of whole pumped storage power station project area is set up using super element method, and the FEM grid not only covers fault, but also includes the upper reservoir, diversion tunnel, underground powerhouse, lower reservoir and dam. The potential distribution for seepage field is clear and well. The water in upper reservoir infiltrate from rack mass at bottom of reservoir basin to underground powerhouse, and then eventually flow to the lower river. The leakage has little influence on the hydrogeological conditions in the reservoir area. The pressure head of initial section of intermediate horizontal pipeline is 92.8m. The maximum seepage gradient in tunnel and pipe system is 0.56. And the fault f1 and f2 located in right dam shoulder is respectively 0.24 and 0.26.

As for analysis conditions in this paper, the asphalt concrete face slab for upper reservoir meets anti-seepage requirements, and the anti-seepage and drainage measures is technically reasonable. The permeability stability for upper and lower reservoir is acceptable. Due to ensure seepage control effect, grouting should be strengthened for the mountain in right dam shoulder should, if necessary according to geological conditions.

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