Study on Anti-seepage Effect of Different Schemes for Upper Reservoir of a Pumped Storage Power Station

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Abstract. With the development of geomenbrane, geomenbrane has been adopted in more and more hydraulic engineering as anti-seepage arrangement. A three-dimensional finite element model was built to analyze two different anti-seepage schemes for upper reservoir of a pumped storage power station. Under the reinforced concrete face slab & geomembrane anti-seepage scheme or geomembrane anti-seepage scheme, the seepage field and the seepage discharge of the reservoir were calculated and analyzed under normal conditions and local damage of geomembrane conditions. It is shown that the seepage characteristic was obviously influenced by the fractured zone around right abutment. Moreover, based on the calculation results, seepage discharge under normal working conditions and local damage of geomembrane was analyzed and it was found out that both schemes were able to satisfied requirements of the reservoir under different conditions. After comprehensive consideration, it is recommended that the reinforced concrete face slab & geomembrane anti-seepage scheme should be adopted as the anti-seepage scheme of the reservoir.

1. Preface
Because of the shortcomings of anti-seepage arrangements, such as concrete face slabs, asphalt concrete slabs and so on, geomenbrane had been adopted as horizontal impervious blanket used in large water conservancy and electricity project since 1998 in China[1]. Nowadays, anti-seepage schemes using geomembrane and schemes combined with geomembrane, concrete face slabs, asphalt concrete slabs and so on have been widely adopted in upper reservoirs of pumped storage power stations. When the ground water level is deep below the upper reservoir, it is important to select a suitable geomembrane scheme by comparing the anti-seepage effect of candidate schemes during the process of reservoir design and construction.

2. The general situation of the reservoir engineering
A pumped storage power station is located in the northeast of Hami, Xinjiang, and the location of its upper reservoir is on the top of the left bank of Sandaogou River. The shallow part of the bedrock in the upper reservoir site area is mainly weak permeable rock mass. The strong weathering and some structural belts are medium permeable rock mass and the deep part is micro-permeable rock mass. The groundwater level around the reservoir area is deep below the bottom of the reservoir.

This upper reservoir engineering is belong to a large water conservancy and electricity project and
the effective storage of the reservoir is $7.24 \times 10^6$ m$^3$.

3. Introduction of the finite element model

3.1. The finite element model

Based on natural topography, some structures such as excavation area, dam body, backfill area at bottom of reservoir, drainage corridors and so on were added in the finite element model (FEM). Main buildings were built in the FEM according to their actual size[2]. There were 52335 finite element mesh nodes and 48611 elements in the FEM. The 3D- FEM of upper reservoir area and anti-seepage measures of reservoir basin were shown in Figure 1 and Figure 2.

![Figure 1. The 3D - FEM of upper reservoir area.](image1)

![Figure 2. The 3D - FEM of anti-seepage measures of reservoir basin.](image2)

3.2. Boundary conditions

In the condition of steady seepage, the boundary types of seepage analysis includes deterministic hydraulic heads boundary, outlet boundary and impervious boundary. The part of bank, bottom of the reservoir and the upstream slope of the dam under the water line were set as deterministic hydraulic heads boundary; the surface of slopes between upstream and downstream water line were set as outlet boundary; the periphery, except for the part under the known groundwater level, and the bottom of the FEM were set as impervious boundary.

3.3. Calculating parameters and conditions

3.3.1. Calculating parameters. Based on geological prospecting data and related experimental data, the permeability coefficient of rock mass layers in dam foundation was shown in the Table 1 and the permeability coefficient of each material area of dam body was shown in the Table 2. Due to the crack fractures at reservoir area mostly were tension cracks and filled with fragment rock or rock powder, the permeability coefficient of fracture, fracture zone and faults were equivalent to $1.0 \times 10^{-4}$ cm/s, $5.0 \times 10^{-3}$ cm/s and $2.0 \times 10^{-2}$ cm/s. Besides, based on the Reference 2, the thickness of geomembrane was equivalent to 0.4 m[3].

| Permeability of bedrock   | Rock classification | Permeability coefficient | Remarks       |
|--------------------------|---------------------|--------------------------|---------------|
| Medium permeability      | 10Lu ~ 100Lu        | 5.0×10^{-3}              | Strong weathered |
| Weak permeability        | 3Lu ~ 10Lu          | 5.0×10^{-4}              | Weak weathered |
| Relative impervious      | 1Lu ~ 3Lu           | 2.0×10^{-5}              |               |

Table 1. The permeability coefficient of rock mass layers in dam foundation.
Table 2. The permeability coefficient of each material area of dam body.

| Material area     | Permeability coefficient | Material area     | Permeability coefficient |
|-------------------|--------------------------|-------------------|--------------------------|
| Bedding area      | 2.0×10^{-2}              | No-fines concrete | 1.0×10^{-2}              |
| Special bedding area | 7.0×10^{-3}          | Drainage material | 3.0×10^{-9}             |
| Transition area   | 2.0×10^{-1}              | Downstream rockfill | 4.0×10^{-9}             |
| Main rockfill area | 3.0×10^{-1}              | area              |                          |
| Concrete face     | 1.0×10^{-7}              | Geomembrane       | 4.0×10^{-8}             |

3.3.2. Calculating conditions. In order to study the anti-seepage effect and its sensitivity to the area of local damage of geomembrane, calculating conditions were determined, which were shown in Table 3. The seepage field and the seepage discharge of the reservoir were calculated and analyzed under reinforced concrete face slabs & geomembrane anti-seepage scheme (Scheme A) or geomembrane anti-seepage scheme (Scheme B). The concrete face slabs were arranged in the side of the reservoir basin and geomembrane was arranged in the bottom of the reservoir in Scheme A. The whole reservoir basin was covered with geomembrane in Scheme B.

Normal water level of the reservoir was 2247.00 m, which were used as upstream water level. The natural river bed elevation was used as downstream water level in calculation. In order to simplify the calculation, the groundwater level in the finite element model was fixed at 1985.00 m.

Table 3. Calculating conditions of anti-seepage schemes of the reservoir. Scheme A and Scheme B had been described above.

| Condition code | Condition description                      |
|----------------|------------------------------------------|
| HMSK-1         | Scheme A, water level 2247.00 m           |
| HMSK-2         | Scheme B, water level 2247.00 m           |
| HMSK-4         | Scheme A, one hole in geomembrane per 4000 m² |
| HMSK-5         | Scheme A, one hole in geomembrane per 2000 m² |
| HMSK-6         | Scheme B, one hole in geomembrane per 4000 m² |
| HMSK-7         | Scheme B, one hole in geomembrane per 2000 m² |

4. Analysis of the calculation result

Three sections were selected for analysis and their positions were shown in Figure 3 and Table 4, with description of the reservoir layout. For space limitation, only the seepage equipotential lines of the sections under reinforced concrete face slab & geomembrane anti-seepage scheme, with the water level 2247.00 m (HMSK-2), were shown in Figure 4 to Figure 6.

Figure 3. Positions of selected sections and description of the reservoir arrangements.
Table 4. Positions of each selected section.

| No. | Position | Description          |
|-----|----------|----------------------|
| 1#  | x=100m   | Typical section      |
| 2#  | y=0      | The dam axis         |
| 3#  | y=295m   | Middle of the reservoir |

Figure 4. The potential of seepage in Section 1# under Condition HMSK-2.

Figure 5. The potential of seepage in Section 2# under Condition HMSK-2.

Figure 6. The potential of seepage in Section 2# under Condition HMSK-2.

4.1. Analysis of Seepage field under normal water level

After the groundwater level under different conditions was compared, geomembrane anti-seepage scheme (Scheme B) had the best anti-seepage effect of all, which reduced 99% upstream water level so that the difference between the ground water level under normal water level and that in natural period was the smallest. Under both schemes, concrete face slabs and geomembrane played an important role in reducing water head. Due to the excellent drainage effect of cushion and backfill under the slabs and geomembrane, there was no artesian area under the bottom of anti-seepage measures. The water leaking through concrete face slabs and geomembrane could be drained off by ripped-rock layers and cushion, thus there was no saturation region in dam body and backfill zone. Therefore, the saturated surface only existed in weakly-weathered bed which was deep below the reservoir basin. Because of the influence of the fracture zone around the right dam abutment, the seepage field of the whole reservoir area was slightly asymmetrical: the variation of the groundwater level around right dam abutment was faster than that around left dam abutment, so was the seepage gradient.
4.2. Analysis of seepage discharge

4.2.1. Seepage discharge under normal condition. According to the seepage discharge shown in Table 5, the leakage of the reservoir water through the anti-seepage arrangement was very small and the seepage discharge satisfied anti-seepage requirements of upper reservoir of the pumped storage station.

Table 5. Seepage discharge from each zone of the reservoir (L/s).

| Condition code | Dam body | Bottom of the reservoir | Side of the reservoir | Total |
|----------------|----------|-------------------------|----------------------|-------|
| HMSK-1         | 0.48     | 0.90                    | 0.67                 | 2.05  |
| HMSK-2         | 0.42     | 0.87                    | 0.66                 | 1.95  |

4.2.2. Seepage discharge under local damage of geomembrane conditions. Based on the method used in Reference 3[4], the seepage discharge under conditions of different amount of holes in certain area of geomembrane was analyzed. Combined with the actual engineering conditions, the empirical formulas derived by Giroud[5] and Liu Fengru[6], suitable for general situation of calculating the leakage of defective composite anti-seepage layer, were selected. The results of calculation was listed in Table 6.

It is important to note that because of the randomness of the size, amount, position and other factors of local damage of geomembrane area, average water head was used for calculation in this section. The average water head on geomembrane in Scheme A was 27.00 m and that on geomembrane in Scheme B was 17.37 m. In both schemes, the aperture of local damage of holes in geomembrane was set as 2 mm.

Table 6. Seepage discharge through local damage of geomembrane and whole reservoir area (L/s).

| Formula       | Condition code | Leakage through local damage of geomembrane | Total leakage | Formula       | Leakage through local damage of geomembrane | Total leakage |
|---------------|----------------|---------------------------------------------|---------------|---------------|---------------------------------------------|---------------|
| Giroud        | HMSK-4         | 8.25                                        | 10.30         | Liu Fengru    | 8.06                                        | 10.11         |
|               | HMSK-5         | 14.52                                       | 16.57         |               | 14.43                                       | 16.48         |
|               | HMSK-7         | 9.53                                        | 11.48         |               | 8.42                                        | 10.37         |
|               | HMSK-8         | 15.25                                       | 17.20         |               | 15.07                                       | 17.02         |

It was shown in the Table 6 that the seepage discharge calculated by Giroud Formula was a little larger than that calculated by Liu Fengru Formula. When choosing Giroud Formula, the leakage through local damage of geomembrane was large. After the leakage volume under the normal water level of reservoir (2.05 L/s) was added, the total leakage was 17.20 L/s. Thus the daily leakage was about 0.2% of the total storage capacity. When choosing Liu Fengru Formula, the largest total leakage of the reservoir was 17.02 L/s and the daily leakage was almost 0.2% of the total storage capacity. According to the results calculated by two formulas, the total daily leakage of the reservoir caused by the local damage of geomembrane was relatively small to the total storage capacity of the reservoir and satisfied the requirements of normal operation of the reservoir.

5. Conclusions and suggestions

The effect of two different anti-seepage schemes was calculated and analyzed by the finite element method. Besides, the sensitivity analysis of influence of local damage of geomembrane was also carried out. The detail conclusions and suggestions are as follow:

(1) Two different schemes were both verified that they had excellent anti-seepage effect and were able to meet the anti-seepage requirements of the reservoir. However, attention should be paid to the influence of the fractured zone near the right abutment on seepage.

(2) In both schemes, the leakage was effectively drained by ripped-rock layers and the cushion so that there was no local saturated region under concrete face slabs and geomembrane. Thus, both schemes were able to meet the safety requirements of the reservoir.

(3) The leakage under local damage of geomembrane condition was significantly larger than that under normal conditions, but the total leakage still satisfied the requirements of the reservoir. After sensitivity analysis was carried out, the reinforced concrete face slab & geomembrane anti-seepage
scheme (Scheme A) had smaller leakage than geomembrane anti-seepage scheme (Scheme B). Moreover, because there was less geomembrane in Scheme A, the maintenance of Scheme A was more convenient and cost-effective. After comprehensive consideration, it is recommended to adopt the reinforced concrete face slab & geomembrane anti-seepage scheme.

Acknowledgments
Authors wish to thank The Project of National Natural Science Foundation of China / Yalong River Joint Fund (Grant No: U1765205), the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) and the Fundamental Research Funds for the Central Universities (Grant No: 2018B55614).

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