Application of Finite Element Seepage Inversion Analysis of a Dam Project

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Abstract. The seepage problem is one of the most important factors leading to the failure of dams, and it is extremely important to carry out inverse studies of seepage phenomena in the safety analysis. The paper uses the finite element inversion analysis method to evaluate the seepage safety of a dam using a water conservancy project in northeastern China as an example. Calculation results show that despite the former engineering quality defects and seepage problems, after the de-risking and strengthening of the reservoir, there is no abnormal seepage nowadays, the seepage pattern is generally normal, and the stability meets the specification requirements.

Keywords: Inversion analysis; seepage; finite elements; reservoirs

1 Introduction

The seepage problem is an unavoidable problem in the construction of reservoir dams. Groundwater not only acts directly on the building in the form of loads, but also has a certain softening effect on the nearby rock soil and affects the stability of the dam slope[1]. On the other hand, since the reservoir level, boundary conditions of the seepage field, and geotechnical properties are not fixed values, they are constantly changing. When the water level of the reservoir rises, the underground seepage intensifies, the infiltration pressure increases and certain parts are prone to infiltration damage such as runoff and pipe surge, jeopardizing the safety of the dam project. Therefore, inversion studies of seepage phenomena are extremely important in reservoir dam safety analysis.

In this paper, a water conservancy project in northeastern China is taken as an example to use the finite element inversion analysis method for dam seepage safety evaluation, which effectively improves the accuracy and reliability of numerical calculations.

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2 Seepage inversion analysis method

As one of the most widely used forms of dams, earth and rock dams are mainly composed of bulk materials filled on different bedrock. Seepage problems arising from upstream and downstream water level differences and fissures are the most important factors leading to the instability of earth-rock dams, and thus seepage inversion analyses of earth-rock dams must be carried out. Currently, the main research methods include flow network method, finite element method, boundary element method, etc.[2]

The accuracy of the results of numerical calculations of seepage depends to a great extent on the reliability of the selected parameters, and in geotechnical engineering, the permeability parameter of the medium is the most basic and important parameter[3]. The most direct method of obtaining permeability parameters is the field test, such as the water injection test, compression test. However, due to the uncertainty of the underground structure, it is often difficult for the test results to reflect the nature of the whole seepage field, and at the same time, it is difficult to be widely promoted in engineering practice due to the high cost. In 1971, Karanagh and Clough proposed the finite element method of inverse analysis, which combines field measurements reflecting the seepage characteristics of pore media with mathematical models in order to calculate seepage parameters that can represent the overall characteristics of the flow field. In the following decades, the finite element inversion analysis method has been continuously developed.

Literature [4] utilizes genetic algorithm for global search, selects the corresponding seepage field at a certain moment of reservoir operation for inversion, then selects the seepage field at different moment points for validation based on the inversion results. Literature [5] established an inverse analysis method of unsteady seepage field based on the combination of orthogonal design, unsteady seepage positive analysis, BP neural network and genetic algorithm, which better solved the problem of uniqueness and reliability of the inverse analysis of the permeability coefficient of the rock mass. Literature [6] proposed a method of permeability coefficient inversion analysis based on the response surface method, which improved the efficiency of permeability inversion analysis. Literature[7], finite element calculations of saturated-unsaturated seepage in a leachate landslide were developed and the calculations were simulated using a BP network and inverted by a genetic algorithm.

3 Practical application of engineering

The total storage capacity of the reservoir is 523 million m^3. According to the "Grading Classification and Flood Standards for Water Conservancy and Hydropower Projects" (SL252-2017), the scale of the reservoir project is Type II (2). The main buildings such as clay core earth-rock dam, spillway, irrigation tunnel and water supply tunnel are also grade 2. The reservoir is designed according to the 100-year flood standard and checked to the 5000-year flood standard. The normal water storage level is 318.00m, the dead water level is 298.00m, the design flood level is 319.69m, and the verified flood level is 323.26m.

The dam was originally an earth-rock dam with a clay core wall, but the construction quality of the original core wall was defective, unable to meet the design and specification requirements, and seepage damage had occurred. Seepage control emergency treatment was carried out to reinforce, firstly, the clay heart wall and the dam body has been infiltration damage parts of the filler reinforcement, and secondly, the new dam body seepage control wall reconstruction of the dam seepage control system. The reconfigured dam containment system is based on a plastic concrete impermeable wall scheme, which is constructed in the clay heart wall of the original dam.

Calculated cross-section selected from the riverbed cross-section 0+300. The permeability coefficient of each material partition of the section is firstly taken according to the value of the ground investigation data. If there is no ground investigation data, according to the design requirements and reference to "water conservancy and hydropower engineering geological investigation specification" (GB50487-2008). After the initial value is taken and then the inverse calculation is carried out based on the observation data to finally determine the value of the permeability coefficient of each material zoning. Preliminary values of material permeability coefficients are shown in Table 1.

Table 1. of values for material permeability coefficients

<table>
<tr><th>0+300</th><th>Materials</th><th>Permeability Coefficient (cm/s)</th><th>Devise(cm/s)</th></tr>
<tr><td rowspan="7">Embankment</td><td>Cofferdam Stone Stacking</td><td>5×10^{-1}</td><td>$2\sim5\times10^{-1}$</td></tr>
<tr><td>Gravel Dam Shells</td><td>5×10^{-2}</td><td>$K>1\times10^{-3}$</td></tr>
<tr><td>Gravel Filter</td><td>1×10^{-2}</td><td>$K\geq1\times10^{-3}$</td></tr>
<tr><td>Clay-core Wall</td><td>1×10^{-5} (Consider filling grouting)</td><td>$K<1\times10^{-5}$</td></tr>
<tr><td>Medium Coarse Sand Flter Layer</td><td>2×10^{-3}</td><td>$K\geq1\times10^{-3}$</td></tr>
<tr><td>Gravel Dam Shells</td><td>5×10^{-2}</td><td>$K>1\times10^{-3}$</td></tr>
<tr><td>Drainage Prism</td><td>5×10^{-1}</td><td>/</td></tr>
<tr><td>Impermeable Wall</td><td>Plastic Concrete Impermeable Walls</td><td>1×10^{-6}</td><td>$K<1\times10^{-6}$</td></tr>
<tr><td>Grouting Curtain</td><td>Grouting Curtain</td><td>1×10^{-5}</td><td>/</td></tr>
<tr><td rowspan="5">Base of Dam</td><td>Gravelly Soil Mix</td><td>5.8×10^{-2}</td><td>5.8×10^{-2}</td></tr>
<tr><td>Mixed Earth Pebbles</td><td>5.8×10^{-2}</td><td>5.8×10^{-2}</td></tr>
<tr><td>Strongly-weathered Granite</td><td>5×10^{-4}</td><td>/</td></tr>
<tr><td>Weakly-weathered Granite</td><td>1×10^{-4}</td><td>/</td></tr>
<tr><td>Slightly-weathered Granite</td><td>5×10^{-5}</td><td>$<$5Lu</td></tr>
</table>

The calculations were performed using the seepage analysis calculation software Autobank. Inverse calculations based on pressure tube measurements under steady seepage at section 0+300. Taking date of 10 November 2018, the reservoir level was 318.15m (the highest level in history) and the measured values of XQ1-5, BTJ4-1, BTJ4-2 and BTJ4-3 were 301.38m, 279.60m, 279.76m and 279.62m respectively. The calculation results are shown in Fig. 1. The head value near the seepage manometer is closer to the value measured by the seepage manometer, and the value of the permeability coefficient is more reasonable, which can simulate the actual seepage situation.

The permeability coefficients for each material partition are taken from Table 1. Calculated working conditions are shown in Table 2.

Calculation results are shown in Figure 2 and Table 3, the slope drop at the downstream escape point and the horizontal slope drop at the base of the dam are small and no infiltration damage will occur.

According to the analysis of seepage observation data and finite element calculation results, the seepage pattern of the dam is generally normal, and the infiltration stability of the dam body and dam foundation meets the specification requirements. After emergency reinforcement, no seepage abnormality was observed in the dam.

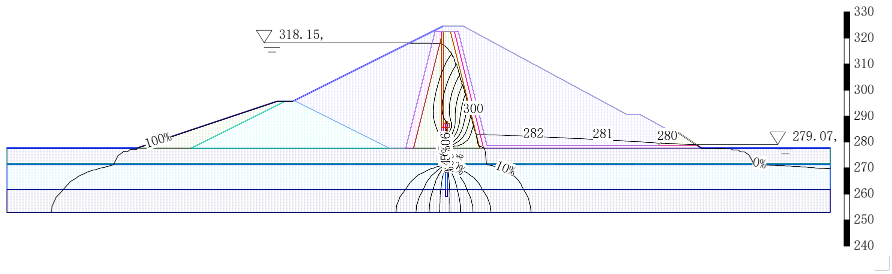
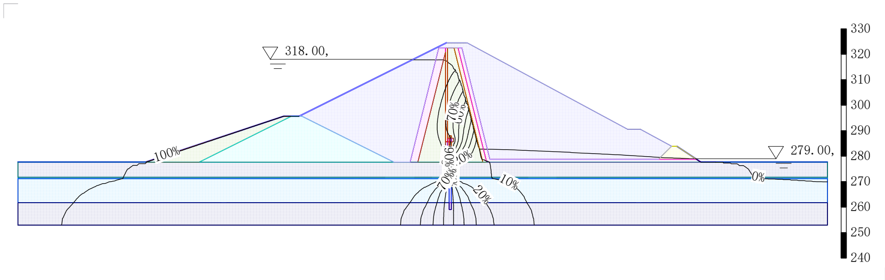


Fig. 1. Head value near the seepage manometer at section 0+300

Table 2. of seepage calculations for a reservoir dam

No.	Calculated section	Calculated working conditions	Upstream Level(m)	Downstream Level (m)
1	0+300	Normal Storage Level	318.00	279.00
2		Design Flood Level	319.69	282.05
3		Calibrated Food Level	323.26	282.90



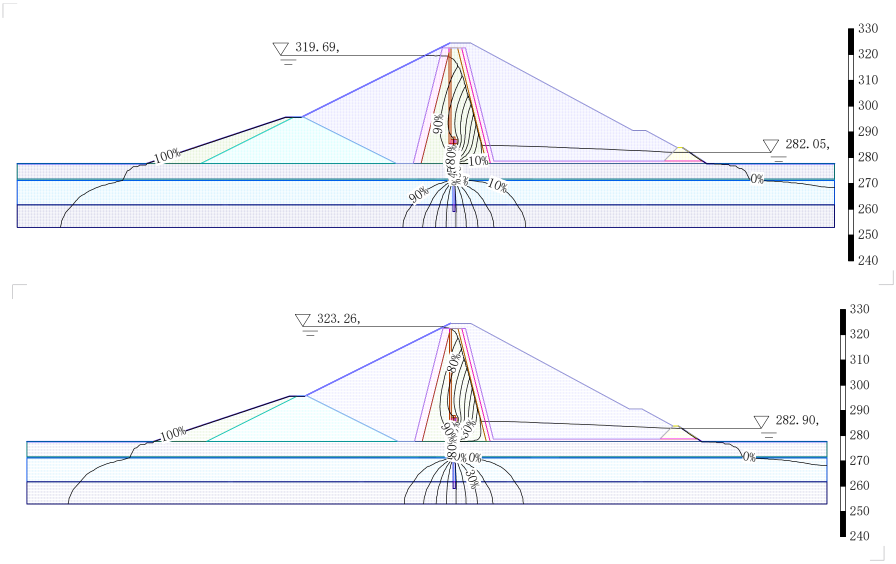


Fig. 2. Contour plot of steady seepage head under various working conditions at section 0+300

Table 3. Statistical table of seepage elements at section 0+300

Working Condition	Slope drop at downstream spillway	Specific drop at dam base	Quantity of seepage(m^3/d/m)
Normal Storage Level	0.03	0.03	18.12
Design Flood Level	0.03	0.03	18.60
Calibrated Food Level	0.03	0.04	19.46

4 Conclusion

Seepage inversion analysis has the characteristics of low economic cost and the results largely meet the engineering requirements. It is an important means of calculating seepage field, and a hot spot for researching underground seepage problems and even geotechnical engineering problems. In this paper, based on the original design data, the permeability parameters of different media in each part of the dam were determined again, and the seepage inversion analysis was applied to a reservoir dam project in Northeast China. Calculation results show that although there were construction quality defects and infiltration damage in the heart wall of this reservoir, the seepage behavior of the dam is generally normal after de-risking and strengthening, the stability meets the specification requirements without abnormal seepage phenomenon. It lays a good foundation for the accuracy and reliability of the subsequent safety evaluation of dams, and helps in the decision-making of dam safety management.

Acknowledgment

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