Seeping Performance of Reinforced Concrete Slab Dam

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Abstract. Taking the panel dam as the research object, the finite element simulation analysis and the design working condition scheme comparison method are used to study the impermeability of the panel dam. The results show that the anti-seepage system is the key guarantee for the safety of the dam body, and it plays an important role in the anti-seepage safety of the dam system under the limit state. At the same time, the complete and effective upstream and downstream anti-seepage drainage system has obvious effects on the overall safe operation of complex hydraulic large-scale systems such as reinforced concrete face rockfill dams.

1. Introduction

The face dam is a kind of dam body which is used more in the current earth and stone filling dam type and is safer, more reliable and durable than traditional earth-rock dams. However, the dam type structure is more complicated, and the dam body material is more divided. At the same time, the filling material has porous media, loose, discontinuous, large pore ratio, and high permeability coefficient. These all have the potential to cause penetration safety problems in the panel dam system as a whole. At present, the singular and qualitative models and detection methods given by conventional and existing specifications are used for evaluation research, and it is impossible to make scientific judgments on the working behavior of such complex hydraulic structures.

Therefore, this paper takes a panel dam in the southeast as the research object, and uses the finite element analysis method to calculate the overall impermeability of the dam, and compares it with different working conditions. The obtained results have important practical significance for the evaluation of the seepage stability of the dam type and its optimization design.

2. Basic algorithm for finite element simulation of seepage field of panel dam

The FEM equation obtained by numerical discretization of the definite solution problem is

\[
[K]^p[H] = \{F\}
\]

Among them, \([K]^p\) representing the physico-mechanical constitutive relationship of model materials, \(\{F\}\) for dissipative items.

FEM approximation relation function \(N_i (i = 1, 2, \cdots m)\) (m is the number of unit nodes)Computational physics constitutive subarray of various parts of the model \([K_i]^p\) as follows:
\[
[k,'] = \int \int \int [r] [k] [r] dx dy dz \\
\]
\[
[k] = \begin{bmatrix}
k_x & 0 & 0 \\
0 & k_y & 0 \\
0 & 0 & k_z
\end{bmatrix}
\]
\[
[T] = \begin{bmatrix}
\frac{\partial N_1}{\partial x} & \frac{\partial N_2}{\partial x} & \ldots & \frac{\partial N_m}{\partial x} \\
\frac{\partial N_1}{\partial y} & \frac{\partial N_2}{\partial y} & \ldots & \frac{\partial N_m}{\partial y} \\
\frac{\partial N_1}{\partial z} & \frac{\partial N_2}{\partial z} & \ldots & \frac{\partial N_m}{\partial z}
\end{bmatrix}
\]
\[
\alpha, \beta, \gamma = \begin{bmatrix}
\cos \beta_1 \cos(\alpha_2 - \alpha_1) & \cos \beta_1 \sin(\alpha_2 - \alpha_1) \\
\cos \beta_2 \cos(\alpha_3 - \alpha_2) & \cos \beta_2 \sin(\alpha_3 - \alpha_2) \\
\cos \beta_3 \cos(\alpha_1 - \alpha_3) & \cos \beta_3 \sin(\alpha_1 - \alpha_3)
\end{bmatrix}
\]
\[
(x, y, z) = (\xi, \eta, \zeta)[C]^{-1}
\]

In the formula, \([k]\) represents a generalized matrix of physical and mechanical parameters. For the reinforced concrete face rockfill dam in this paper, the complex material zoning determines the full field seepage analysis of the overall model. First, coordinate transformation is required for the material partitions at each spatial location, and can be calculated later. The conversion relationship between the two is as follows:

\[
(x, y, z) = (\xi, \eta, \zeta)[C]
\]

Where \([C]\) is the transformation matrix, and there is the following relationship:

\[
(x, y, z) = (\xi, \eta, \zeta)[C]^{-1}
\]

3. Calculation model

Taking a dam as the research object, the main body of the dam is a reinforced concrete slab dry block rock dam. The total storage capacity is 113,000m$^3$, the maximum dam height is 24.1m, the dam crest elevation is 59.0m, the upstream dam slope is 1:0.5, and the downstream dam slope is 1:1.0 and 1:0.5. It is 88.0m long and is divided into 9 dam sections. The dam crest is 4.0m wide.

3.1. Finite element model and parameters

The finite element method is used to analyze and simulate the stable seepage field of a reinforced concrete face rockfill dam. The finite element numerical model material partition consider the dam foundation rock mass, the dam dry block stone, the reinforced concrete face of the upstream dam surface, the fine stone concrete filling stone layer under the panel, the upstream bottom gravel and the anti-seepage cover, and the dam concrete intercepting wall.

Dam permeability coefficient: 1×10$^{-6}$cm/s; panel permeability coefficient: 1×10$^{-10}$cm/s. Finite element method mesh model is shown in Figure 1. The model adopts the maximum dam height of 23.9m, and the unit design considers the degree of freedom of seepage water pressure. The hexahedron element is used for 3D simulation calculation. The total number of model units is 80020 and the total number of nodes is 88074.
3.2. Boundary conditions
The combined simulation calculation is carried out using the following head boundary and hydrostatic pressure and gravity:

| Characteristic water level | water level (m) | Typical elevation (m) |
|---------------------------|-----------------|-----------------------|
| Full library water level  | 58.80           | /                     | /                     |
| Check flood level         | 56.85           | Dam top elevation     | 58.80                 |
| Design flood level        | 56.75           | Dome elevation        | 56.50                 |
| Normal water level        | 56.50           | Downstream ground elevation | 37.5              |

3.3. Simulation conditions
In order to fully test the reliability and effect of the standard anti-seepage system, first consider the water storage under the full reservoir water level, and the downstream dry water, at this time the dam body and bedrock bear the head difference and the absolute osmotic pressure is the largest.

At the same time, the working condition is set 1: the upstream anti-seepage facility is reliable + the dam foundation has no leakage channel + the dam body packing is intact + the downstream non-seepage ditch.

3.4. Analysis of results parameters
According to the simulation calculation results, the burial area of the dam body is generally dry, which is beneficial to the overall stability of the dam body. However, the maximum hydraulic gradient in the panel reaches 48.2 and the maximum osmotic water pressure is 110 kPa. At this time, the impermeability of the dam filling zone and the panel contact zone is greatly tested. At the same time, the hydraulic gradient in the bedrock area has the potential to exceed 45. This order of magnitude has certain threats to the mountain reservoir and needs attention.

On this basis, further consider the operating conditions of the anti-seepage system unchanged, but the water level drops to the check flood level, and carry out simulation calculation. The corresponding gradient distribution is shown in Figure 3:

![Fig.3 Hydraulic gradient distribution under extraordinary level + impervious system integration](image)

It can be seen from the figure that the reliable anti-seepage system plays an important role in the overall permeability stability of the reinforced concrete face rockfill dam. The overall protection effect on the dam body system under high water level is obvious, and the gradient reduction is far greater than the water level drop.

4. Conclusion
The anti-seepage system is the key guarantee for the safety of the dam body, and it plays an important role in the anti-seepage safety of the dam system under the limit state. Under extreme conditions (i.e., under full storage and check flood conditions), the hydraulic gradient of the dam and bedrock can be reduced by 50%. In terms of anti-seepage function and optimization, the upstream reinforced concrete slab and dam foundation play an important role in controlling the dry and wet areas in the field, while the seepage wall and the guiding gully have an important influence on the osmotic pressure control in the field. The filling of the stone layer under the panel is an important transition buffer layer, which plays an important role in reducing the water pressure in the panel and controlling the dry and wet area of the dam body filling area. At the same time, the complete and effective upstream and downstream anti-seepage drainage system has a significant effect on the overall safe operation of complex hydraulic large-scale systems such as reinforced concrete face rockfill dams.

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References
[1] Yang, Q.G., Tan, J.X., ZHOU, X.M. (2016)Discussion on several problems of concrete face rockfill dam. J.People's Yangtze River., 47(14): 56-59.
[2] Yang, Z.Y., ZHOU, J.P., JIANG, G.C., SHUN, Y.J. (2011) Development of China Concrete Face Rockfill Dam. J. Hydroelectric Power., 37(2):18-23.
[3] GAO, P.Z., GUO, J. (2013) Some questions about setting the venting hole in the face dam. J. Journal of Hydroelectric Engineering., 32(5):179-183
[4] WANG, Y.J., ZHANG, W.H. (2007) Study on Three-Dimensional Random Seepage Field of Yangtze River Embankment. J. Journal of Rock Mechanics and Engineering., 32(5):1824-1831.
[5] TAO, Y.Z., XI, D.Y. (2006) Rule of Transient Phreatic Flow Subjected to Vertical and Horizontal Seepage. J. Applied Mathematics and Mechanics., 27(1):221-223.
[6] CHENG, S., LI, S.Y. (2017) Influence analysis of finite element calculation error of dam foundation stress state. J. South-to-North Water Transfer and Water Conservancy Technology., 15(1):179-185.
[7] SUN, J., SUN, J.S. (2016) Deep-Stability Stability Analysis of Gravity Dam with Residual Thrust Method with Finite Element Stress Integrale. J. Hydroelectric Power., 42(7): 45-48.
[8] WANG, J., QIN, K.F., WANG, M. (2016) Application of discontinuous deformation method in deep anti-sliding stability analysis of gravity dam. J. Sichuan Water Conservancy., 1:40-44.
[9] MAO, C.X. (2003) Seepage calculation analysis and control (Second Edition). China Water Conservancy and Hydropower Press, Beijing.
[10] JIN, W., JIANG, Y.Y., SHENG, Z.Z. (2009) Seepage characteristics and control scheme of Lianghekou core wall rockfill dam. J. Hydropower Energy Science., 27(3): 45-48.
[11] CAI, Y.Q., ZHU, Y.W., TANG, J. (2005) Anti-seepage study of rockfill dam on deep overburden dam foundation. J. Journal of Wuhan University (Engineering Edition)., 38(1):18-22
[12] SU, P.F., WANG, W.M., HE, J. (2009) Comprehensive Simulation Analysis and Safety Assessment of RCC Gravity Dam. J. Rock and Soil Mechanics., 30 (6) :1769-1774.
[13] SL 228-2013. Design code for concrete face rockfill dam (with attached text). S.