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Application of AutoBank Software in Earth-rock Dam Seepage Flow Computation

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Abstract: Earth-rock dam is one of the most widely used dams in the world, and has huge comprehensive benefits in flood controlling, irrigation, power generation, water supply, shipping, tourism and so on. This paper elaborate the theory and method of earth-rock dam seepage analysis, including the basic equation of seepage and boundary condition, and also introduce a hydraulic analysis software, Autobank seepage module, including the analysis steps and boundary conditions. Then two-dimension seepage analysis of earth-rock dam is carried out by using Autobank. The seepage line of the dam under three working conditions is calculated. This result can be used as reference for the design.

1. Introduction

As a kind of dam with long history, low cost, simple structure and convenient construction, the earth-rock dam is still being built on a large scale all over the world [1]. According to statistics, the proportion of earth dam accounts for more than 60% of all dam types, and around 40% of the destruction of the earth das was caused by seepage problems. It has now become the main factor affecting the safety of earth dam. Therefore, it is very significant for correctly analyzing the types of seepage [2-5].

Analysis of earth-rock dam infiltration under various conditions can not only determine the safety of seepage force, the loss of fine particles in the dam and the loss of reservoir water caused by seepage water flow, but also is a prerequisite for the stability calculation of dam slope. According to the results of seepage analysis, corresponding engineering measures can be selected to provide detailed and reliable basis for the design and construction of the project [6]. This is the meaning of seepage calculation.

2. Seepage calculation principle of earth-rock dam

2.1. The basic equation

Assuming that the seepage water flow is laminar at low Reynolds numbers when it flows in the soil framework of the dam, Darcy linear seepage law is assumed:

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$$v = -k\frac{dH}{ds} \tag{1}$$

Where v is (average) seepage velocity (m/s); k is the medium permeability coefficient (m/s); $-\frac{dH}{ds}$ is hydraulic gradient.

In the unsaturated seepage process, the continuity equation is as follows:

$$\frac{\partial}{\partial x}(\rho v_x)+\frac{\partial}{\partial y}(\rho v_y)+\frac{\partial}{\partial z}(\rho v_z)=-\frac{\partial}{\partial t}(\rho n S_w)+S \tag{2}$$

Where v_x, v_y and v_z are the component of velocity in the direction of x, y and z in unsaturated seepage field. s_w is the saturation, which satisfies the condition $0 \le s_w \le 1$.

2.2. Boundary conditions of seepage field

The initial condition is a function of coordinates, which can be written as:

$$h(x,y,z,t_0)=h_0(x,y,z,t_0) \tag{3}$$

Boundary conditions:

$$\begin{cases} h(x,y,z,t)=h_1(x,y,z,t),(x,y,z)\in S_1 \\ -\left[k_{ij}k_r(h)\frac{\partial h}{\partial x_j}+k_{ij}k_r(h)\right]n_i=q_n,(x,y,z)\in S_2 \\ -\left[k_{ij}k_r(h)\frac{\partial h}{\partial x_j}+k_{ij}k_r(h)\right]n_i\ge 0,\ \ h(x,y,z,t)=0,(x,y,z)\in S_3 \end{cases} \tag{4}$$

Where S_1 is boundary with known head distribution; S_2 is boundary with known flow conditions; q_n is normal flow rate; n_i is directional cosine outside the unit; S_3 is boundary of saturated seepage surface.

3. Seepage calculation

Autobank is hydraulic engineering analysis software, which designed to meet the requirements of China's water conservancy industry. It can analyze and calculate the dike, sluice, earth dam, culvert and other hydraulic structures in detail. The software is all graphical interface, easy to operate and improve work efficiency.

3.1. Calculation procedure

Using finite element technology, the seepage calculation module of Autobank software is carried out according to the following procedures: (1) Build a model, which can be established directly in Autobank or imported directly from CAD drawings. (2) Graphics partition. (3) Define the material infiltration characteristics, when the seepage is steady, only the permeability coefficient is given; when the seepage is unstable, the permeability coefficient and the water supply are needed [7]. The material is given to the geometric partition and the material partition is obtained. (4) Divided grid, which can use semi-automatic or fully automatic meshing, finite element calculation model. (5) Impose boundary conditions; there are fixed head boundary, exit boundaries and impervious border. (6) Save the graphics file, generate data files. (7) Calculation. (8)Post-processing, then the contour map of water head and water pressure is obtained, and calculation is formed.

3.2. Example Introduction and Modeling

The Autobank analysis software is used to calculate the seepage stability. The permeability coefficient of sandy earth dam shell is 4.61×10^{-4} cm/s, the permeability coefficient of clay core wall is 1.60×10^{-6} cm/s, and the permeability coefficient of drainage prism is 1×10^{-2} cm/s. This paper intends to calculate the seepage state of the dam body under three conditions: design water level 462.55m, design flood level 463.10m and check flood level 463.55m. Modeling is shown in figure 1.

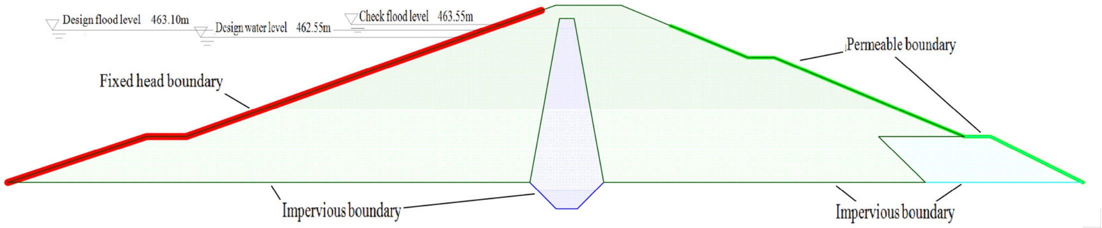

Figure 1 Computational model

The software is calculated by finite element method. When the mesh is divided, the clay core wall and drainage prism should be focused on. Therefore, the mesh should be encrypted (set the size factor to 0.3). As shown in figure 2, the number of model elements is 1487 and the number of nodes is 1532.

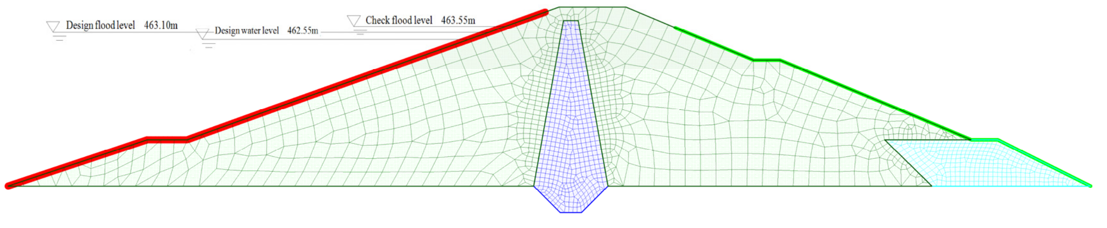

Figure 2 Compute grid diagram of dam body

3.3. Calculation results and analysis

The dam infiltration line (figure 3) conforms to the general rule of the dam wall infiltration line, and the drainage prism also reduces the infiltration line, which is beneficial to seepage. The dams exit in the drainage prism and seepage status is better [8]. Three saturating lines in the figure can be used as stable water level lines.

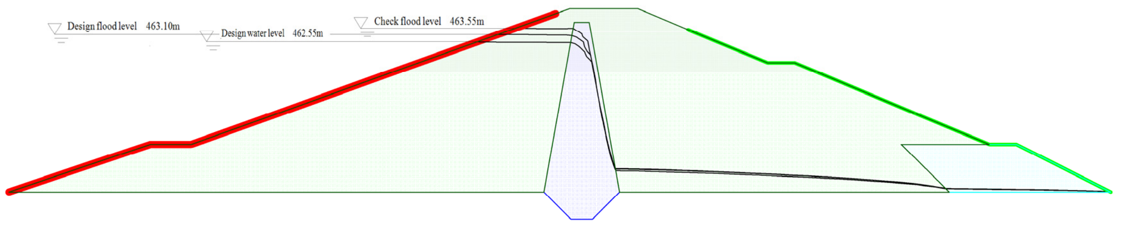

Figure 3 The infiltrating chart

The seepage flow rate under three kinds of water conditions is shown in table 1 . From the perspective of the trend of infiltration, the higher the water level difference, the worse the seepage.

Table 1 Seepage flow

Working conditions	Seepage flow	
Design water level	1.95195e-07(m^3/s)	0.0168648(m^3/d)
Design flood level	2.35746e-07(m^3/s)	0.0203684(m^3/d)
Check flood level	2.56030e-07(m^3/s)	0.0221209(m^3/d)

The contour of water head, hydraulic pressure, hydraulic slope drop, velocity, and the vector diagram of flow velocity and osmotic force under three conditions can be obtained in post-processing. The calculation results accord with the general rule of the wall dam, and the drainage edge is also beneficial to the seepage flow.

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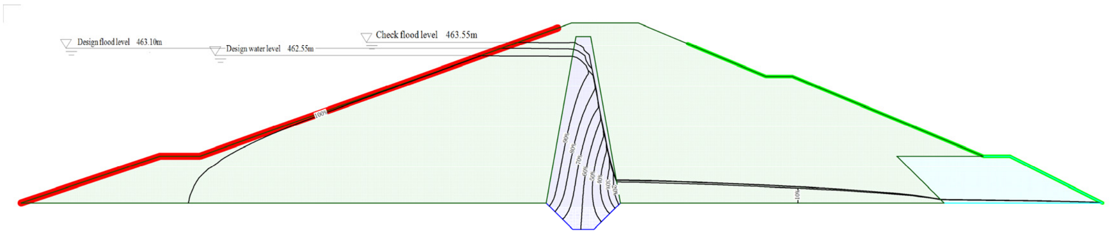

Figure 4 Headwater contour

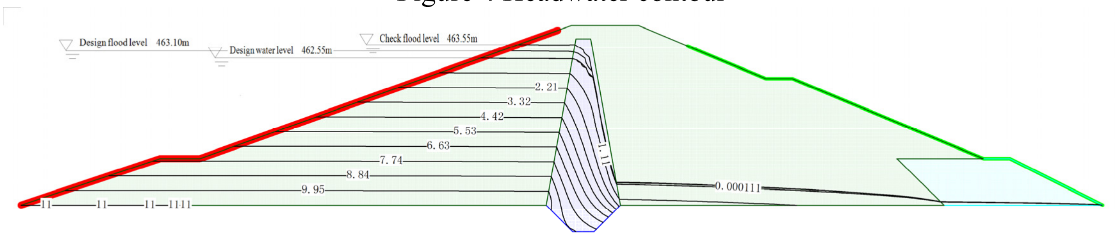

Figure 5 Hydrostatic contour (K Pa)

Figure 6 Hydraulic gradient contour

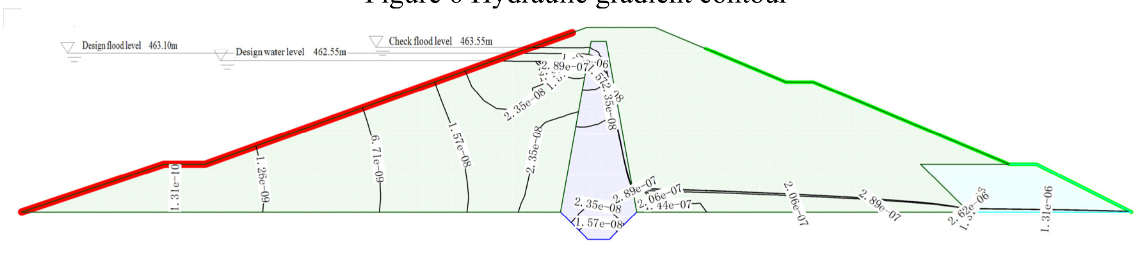

Figure 7 Velocity contour (m/s)

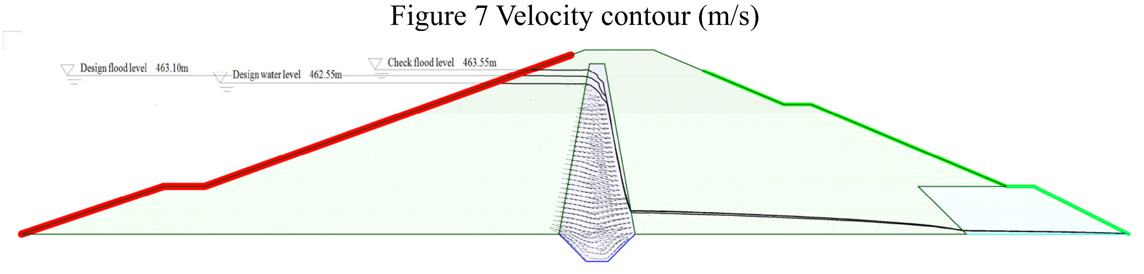

Figure 8 Velocity vector

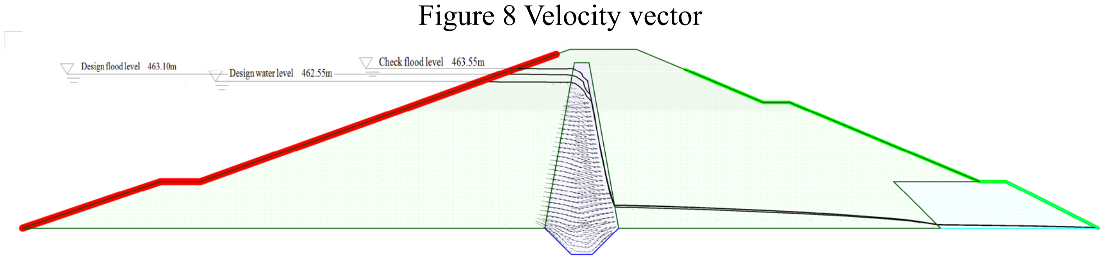

Figure 9 Osmotic vector

4. Conclusions

The seepage problem has now become the main factor affecting the safety of earth-rock dams. It is of great significance to carry out the seepage analysis of earth-rock dams. This paper introduces the theoretical methods of seepage calculation, including the basic equations and boundary conditions of the seepage field, and also introduces the seepage calculation module of Autobank software which used in water conservancy design. This paper analyzes example of earth-rock dam, and calculates the three working conditions: design water level, design flood level and check flood water level. The results are reasonable and consistent with the seepage law of the normal wall dam.

The results show that the drainage prism has a beneficial effect on reducing the infiltration line. The infiltration line obviously drops near the drainage prism, and the result can be used as the water level line for subsequent stability calculation. At the same time can also be hydraulic pressure, head, hydraulic slope equivalent contour map, the calculation results are plentiful.

Acknowledgement

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