Key issues on seepage analysis in mountain river embankment

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Abstract: Seepage control is one of the key technical problems faced by mountain river embankment construction. Seepage analysis is an important way to achieve optimal design of dike seepage control. The floods of mountainous rivers are steeply rising and falling, the peaks are concentrated and short. The dikes are relatively difficult to form stable seepage. Taking the river dike in the upper reaches of Xinxi River in Jinyun County as an example, this paper comprehensively analyzes the characteristics of topography, geological structure and anti-seepage scheme, establishes the three-dimensional finite element model of the dike, and uses the parabolic Signorini-type variational inequality method to calculate the unstable seepage of the embankment. The research results have a guiding significance for the optimal design of seepage control measures for mountain river embankments.

1. Introduction

The mountain river embankment project is an important component of China's water conservancy project. It has a non-negligible influence on environmental protection and flood control. Floods in mountain rivers are caused by heavy rains, and they are characterized by steep and steep peaks, concentrated peaks, and short peaks. At the same time, in the geological area, the riverbanks of the mountain rivers are thin, and there are many pebbles in the riverbed, and the seepage prevention materials are scarce. The two sides of the river are more agricultural land, as well as farmers' living areas, and the terrain and geomorphology environment is very complicated. Therefore, the seepage movement of mountain river embankments is essentially unsaturated and unsteady, and often has coupling effects with stress-strain, gas transmission and thermal energy transfer, and has an important impact on the structural stability of dike engineering. Unlike stable seepage, the phreatic surface of unsteady seepage changes with time, and during the process of phreatic surface variation, the embankment geotextile will release or store groundwater accordingly. Therefore, it is necessary to describe the movement process of gravity water in mountain river embankment through unsteady seepage analysis, and the variation range of phreatic surface in embankment geotechnical medium during river water fluctuation.

Xinxi is located in the west of Jinyun County. It is one of the birthplaces of Wuyi River, a tributary of the Qianjiang River. The main landform types are low hills and river valleys. The newly-built dyke-filling materials are basically gravel-containing gravel excavated from the original river channel or excavated on the bank of the embankment. Only a small amount of surface layer is silty sand, and the water permeability is strong and permeable; the fine-grained soil is less. In the flood period, the erosion of high water level and soaking are prone to unfavorable geological phenomena such as erosion, piping and collapse. In order to evaluate the rationality of the seepage control scheme for the new dyke

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construction project in Xinxi, and to demonstrate the possibility of optimization, it is necessary to carry out a fine simulation of the whole process of the unstable seepage of the dike in order to optimize the optimal seepage control scheme.

In this paper, we use the substructure, Signorini type variational inequality and adaptive penalty Heaviside function to combine the unsteady seepage analysis method (referred to as SVA method, the specific implementation of the algorithm can be found in references [1~3]), relying on the newly built upstream dike, through The typical section model of the embankment was established, and the phreatic surface variation process of the unsteady seepage in the dike during the river water fluctuation process was simulated. The seepage control measures of the dike were evaluated to provide reasonable suggestions for the construction.。

2. Unsteady Seepage Mathematical Model

The nonlinearity of the unsteady seepage analysis is mainly due to the determination of the seepage overflow point and the phreatic surface at each time. In order to overcome this nonlinear problem, Y. F. Chen et al. proposed the Signorini parabolic variational inequality method for unsteady seepage analysis. This method transforms the unsteady seepage problem into a new initial boundary value problem across the universe by extending Darcy's law from the wet zone to the whole domain:

$$\boldsymbol{v}(t) = -\boldsymbol{k}\nabla\phi(t) + \boldsymbol{v}_0(t)$$

Where:

$$\phi = z + \frac{p}{\rho_{\mathrm{w}} g}$$

Where: v is the percolation velocity; v_0 is the initial flow velocity; k is the second-order permeation tensor; φ is the total head; z is the vertical coordinate component; p is the pore water pressure; ρ is the density of water; g is the acceleration of gravity; t For time. The initial flow rate v_0 is introduced to eliminate the virtual flow velocity in the dry zone, and its expression is

$$\boldsymbol{v}_0(t) = H(\phi - z)\boldsymbol{k}\nabla\phi(t)$$

Where: $H(\phi - z)$ is the Heaviside function, its value is 0 in the wet zone Ω_{w} and 1 in the dry zone Ω_{d}.

The equation of continuity of water flow over the whole domain Ω can be expressed as

$$[1 - H(\phi - z)]S_{\mathrm{s}}\frac{\partial\phi}{\partial t} + \nabla\cdot\boldsymbol{v} = 0$$

Where:

$$S_{\mathrm{s}} = \rho_{\mathrm{w}} g(\alpha + n\beta)$$

Where: S_{s} is the unit storage of the medium, α and β are the compressibility coefficient of the geomaterial skeleton particles and water, respectively, and n is the porosity.

Equation above should satisfy the following conditions:

(1) Head boundary (Γ_ϕ) conditions:

$$\phi(t) = \bar{\phi}(t)$$

Where: $\bar{\phi}$ is a known head.

(2) Flow boundary (Γ_q) conditions:

$$q_n(t) \equiv -\boldsymbol{n}\cdot\boldsymbol{v}(t) = \bar{q}(t)$$

Where: $\bar{q}$ is the boundary flow (permeability is positive, overflow is negative), for the water separation boundary, $\bar{q} = 0$, $\boldsymbol{n}$ is the normal vector outside the boundary surface unit.

(3) Significant overflow surface Signorini type complementary boundary (Γ_s) condition:

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$$\left.\begin{aligned}&\phi(t)\leqslant z,\ \ q_n(t)\leqslant 0\\&[\phi(t)-z]q_n(t)=0\end{aligned}\right\}$$

(4) Free face boundary (Γ_f) condition:

$$\left.\begin{aligned}&\phi(t)=z\\&q_n(t)\equiv q_n\big|_{\Omega_w}-q_n\big|_{\Omega_d}=-\boldsymbol{n}\left(\mu\frac{\partial\phi}{\partial t}\boldsymbol{e}_z\right)\end{aligned}\right\}$$

Where: $\boldsymbol{e}_z=\{0,\ 0,\ 1\}^{\mathrm{T}}$; $\boldsymbol{n}$ is the normal vector outside the phreatic surface unit, and the wet area Ω_w points to the dry area Ω_d; μ is the water supply of the medium with the phreatic surface variation range.

(5) Initial conditions (Ω):

$$\phi(x,\ y,\ z,\ t)\big|_{t=t_0}=\phi_0(x,\ y,\ z)$$

Where: t_0 is the initial moment; ϕ_0 is the initial water head field

The above problem is solved by the parabolic variational inequality method, which can theoretically overcome the singularity of the overflow point and greatly reduce the difficulty of the selection of the trial function in the numerical analysis process. The specific finite element implementation of the algorithm can be found in YF Chen et al. [3-4] Research.

3. Calculation Model

3.1. Project Overview

The structure of the new dyke dike is the coarse-grained soil, and the lower is the double-layer structure of the rock; the tidal foundation is filled with plain, silty clay and pebbles, and the underlying bedrock is the Upper Cretaceous of the Cretaceous (k_2t) tuff. Pebble is mainly used as the base bearing layer. According to the pebbly particle grading condition, the main type of pebbing damage is piping, which allows the hydraulic slope ratio to be reduced according to the design specifications and grading conditions of the embankment, and J_{allowed} is 0.10. If the seepage ratio of the escaped section of the foundation surface is calculated to be greater than the allowable ratio drop, protective measures such as the filter layer and the weight shall be provided. The results of drilling water test show that the permeability of rock mass below the embankment is generally medium to strong, and the tuff with vertical depth below 5m is mostly medium to weak. According to the topographic and geological conditions, the typical bank protection structure of the ecological flood control embankment is drawn up. Use dry masonry + green slopes to protect the shore. Below the hydrophilic platform, the dry block stone retaining wall is about 1.1~1.5m, the top of the retaining wall is 0.2m wide, and the top of the wall is 0.5~0.8m above the normal water level, which fully reflects the hydrophilicity. Above the retaining wall is a hydrophilic platform, and the hydrophilic platform is 1.5m wide. The hydrophilic platform is connected to the top of the embankment with a 1:2 slope or gentle slope. The slope protection adopts three-dimensional vegetation net turf slope protection, planting low-lying trees suitable for the local area and preserving the existing trees as much as possible. The roof is set with a 3m wide flood control road. The sectional view is as follows.

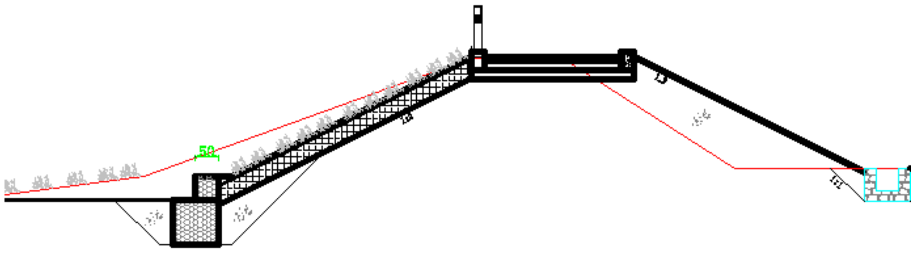

Fig.1 Typical section of the embankment

3.2. Finite Element Model

By analyzing the engineering geological, hydrogeological and dyke layout schemes of the typical section of the embankment, a three-dimensional finite element model of the typical section of the dike is established, and the layer structure of the dike is accurately simulated.

The finite element mesh of the typical section of the embankment is shown in Figure 2. A total of 7584 units and 17734 nodes are divided. The model calculation range is: taking the water-side boundary from the foot of the embankment 20m, and the backwater side boundary from the top of the embankment 20m; taking parallel The direction of the axis of the embankment is 5m; the upper and lower boundaries of the whole calculation model are 60m apart, the left and right boundaries are 5m apart, the maximum elevation of the model is 16m, and the lowest elevation is 0m.

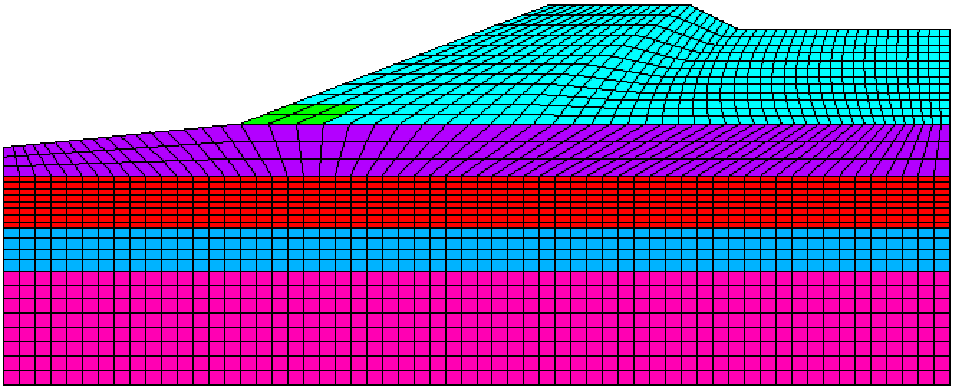

Fig.2 Typical section finite element mesh

3.3. Calculation Parameters and Boundary Conditions

According to the geological survey data, the basic seepage calculation parameters of each cover layer are shown in Table 1.

Table 1 The permeability coefficient of each cover layer

Medium	Prime fill	Silty clay	pebble	Strongly weathered tuff	Stroke tuff
Permeability coefficient (cm/s)	4.84E-04	9.36E-04	7.62E-03	6.92E-04	2.47E-05

The boundary conditions of the numerical simulation are as follows: the water boundary of the bottom of the calculation model is taken; the boundary between the water head and the constant pressure head is determined below the water level on the left and right boundary, and the potential overflow boundary is taken in the unsteady seepage model above the water level and the top boundary. .

According to the long-time observation data of precipitation in Xuefeng and the newly built two rainfall stations, the flood process line in the upper reaches of Xinxi River is derived. The whole flood fluctuation process lasts for 3 days. The current seepage analysis takes the flood standard of 20 years.

The calculation period is 3 days, including the three steps of sudden rise in water level, stability of water level and sudden drop. It should be pointed out that the unsteady seepage analysis also involves the selection of time steps. A reasonable time step ensures a better balance between calculation accuracy and calculation. Considering that the flood in the mountain river has a short duration, the calculation time step takes 6 hours. The following is an analysis of the unsteady seepage analysis of the newly-built river channel embankment for the two conditions of sudden rise and sudden drop in water level.

The water level swell condition: the initial condition is that the water level on the side of the dike is 13.2m (model elevation), and the water level on the back water side. From the time of 0h, the water level rises by 0.5m every 6h, to 24h. The water level on the side of the embankment reached a flood level of 15.2m (model elevation) in 20 years.

The water level dip condition: the initial condition is that the embankment side takes the flood level of 15.2m (model elevation) in 20 years, the groundwater level on the backwater side, the starting time is 48h, and the water side is every 6h from 48h. The water level plummeted by 0.5m, and the calculation was completed at 72h, and the water level on the side of the embankment fell to 13.2m (model elevation).

4. Analysis of Calculation Results

4.1. Unsteady Seepage Field Analysis

The SVA method of unsteady seepage analysis [4~6] was used to analyze the seepage field of the upstream levee of Xinxi River during a flood fluctuation process.

(1) Water level swell condition

The equal water head line of the typical section of the embankment in the process of rising water level is shown in Figure 3. Under the action of embankment anti-seepage measures, the seepage phreatic surface is significantly reduced from the water-side direction to the backwater side in the embankment. Most of the interior of the embankment is above the phreatic surface, and the bank foundation pressure is effectively controlled.

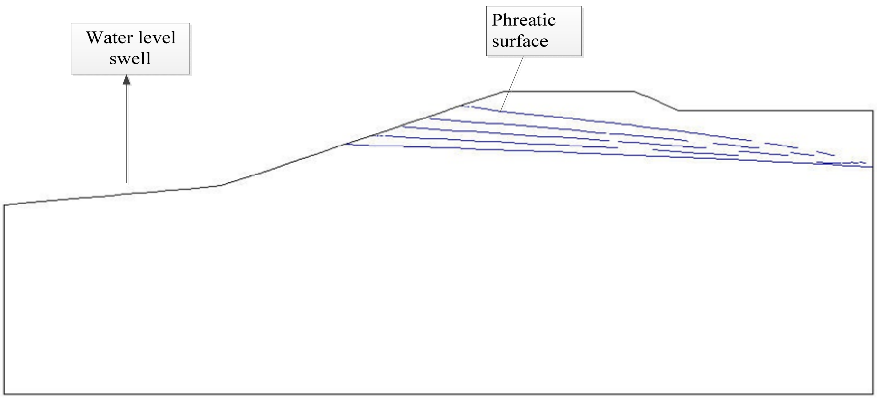

Fig.3 Variations of phreatic surface in water level swell condition

(2) Water level dip conditions

The contour of the typical section of the embankment in the water level dip process is shown in Figure 4. In the mountain river embankment, the high-head water groundwater seeps into the river channel, and the overflow point is located in the waterfront surveying dike. Because there is pore water pressure that has not dissipated inside the embankment near the overflow point, the overflow point has a large slope.

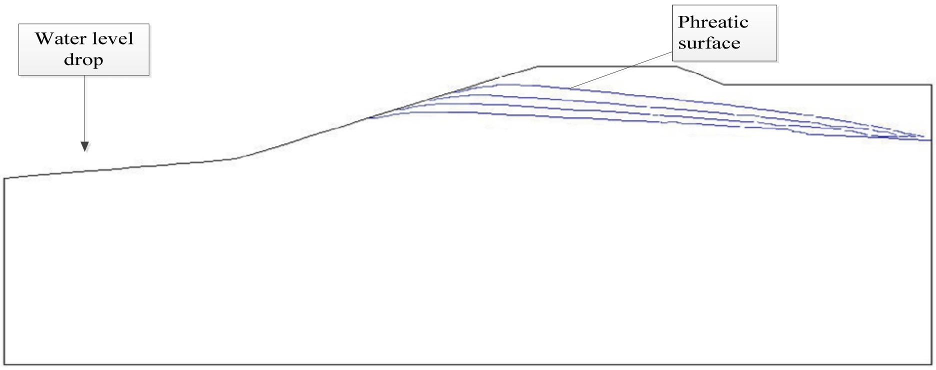

Fig.4 Variations of phreatic surface in water level dip condition

4.2. Sensitivity Analysis of Drainage Facilities

During the sudden drop of water level, the seepage water pressure of the embankment side slope cannot be dissipated in time due to the high water level, which leads to the greatly reduced suction of the slope matrix, and increases the bulk density of the slope soil and reduces the stability of the embankment slope. It is prone to slope instability such as landslides. Therefore, it is necessary to set the riprap foot on the water side to speed up the elimination of water in the slope and reduce the pressure of the osmotic water. In order to study the influence of the stability of the waterfront side slope of the mountain river embankment during the sudden drop of water level, the normal operation of the foot drainage and the failure of the foot drainage are analyzed respectively. The free surface of the seepage in the embankment slope is shown in Fig. 5. It can be seen from the figure that during the water level dip, when the foot drainage is running normally, the permeate water pressure in the embankment slope will quickly dissipate as the water level decreases, the seepage free surface will be significantly reduced, and the seepage control effect will be obvious; At the time of the lack of drainage facilities on the waterside side, the seepage free surface in the embankment slope is higher, and the permeate water pressure is larger, which has a greater impact on the seepage stability of the waterside side slope.

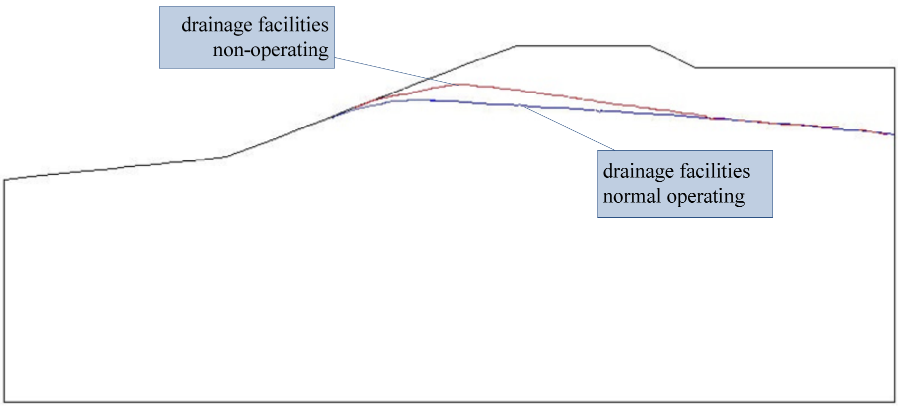

Fig.5 Comparison of seepage phreatic surface under drainage facilities normal or non-operating conditions

5. Conclusions

In this paper, we use the unsteady seepage analysis method (SVA method), which combines substructure, variational inequality and adaptive penalty function. By taking the new levee upstream as an example, several key points for the analysis of seepage in mountain rivers are established by establishing a three-dimensional model of typical sections. The problem was studied and the following conclusions were reached:

(1) Due to the steep rise and fall, the peak concentration and the rising peak of the mountain river,

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the seepage of the embankment is mainly unsteady seepage under the sudden rise and sudden drop of water level. The unsteady seepage analysis method should be used to simulate the mountainous area. Characteristics of river dike seepage. During the sudden drop of water level, the seepage water pressure of the embankment side slope can not be dissipated in time due to the high water level, which leads to the greatly reduced suction of the slope matrix, and increases the bulk density of the slope soil. The slope of the overflow point is larger which reducing the stability of the embankment slope.

(2) The drainage effect of the waterside side protection of the mountain river embankment plays an important role in the stability of the waterside side slope. When the water level is suddenly drained during the sudden drop of the water level, it is beneficial to the drainage of the water side slope and the seepage phreatic surface. Significantly decreased, the slope pressure is significantly reduced, and the stability of the embankment slope is improved.

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