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Procedia Engineering 15 (2011) 5263 – 5267
Procedia Engineering
www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

The stability analysis of the dike slope in Bdg reservoir under the seepage of flood

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Abstract

The research on the mechanics of flood infiltration induced dike collapse and its evaluating method is a complicated problem which is difficult to be solved and interested by academic field and engineering field. To solve the problem of dike slope stability under flood infiltration, the unstable seepage field of dike slope is simulated under the condition of flood discharge combining with the shear strength reduction finite element method. The paper studies the changes of unstable seepage field when flood .Combined with engineering slope example, numerical simulation is carried out and some significance conclusions are drawn through the calculation result of the example.

Keywords: dike slope,flood infiltration,unstable seepage flow,stability;

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doi:10.1016/j.proeng.2011.08.975

1. Introduce

In china, there are many river way dike projects; the dike lays an important role in protecting people's life and properties in middle and lower reaches of rivers [1].It is a great significance for dike safety to be ensured. Seepage failure and other failures related with seepage are the main forms of failures in the dike engineering during the flood period. Upon the infiltration of flood, the stability problem of the dike engineering is a very complicated process, which involves water movement in saturated-unsaturated states and the decrease in the strength of the unsaturated soil. Study of the dike collapse mechanism under the seepage of flood would be helpful in reinforcing embankment and effective preventing flood damage. The effect of flood level on river dike is a typical unstable seepage process. After soil slaked, in view of the effect of soil slaking deformation; stress and stress level markedly drop. The difference of maximal principal stress on the bottom of waterlogged soil between before or after slaked goes nearly to fifty percent in the case. The difference of stress level in waterlogged soil is also prominent. After soil slaked, displacement field is variety that horizontal displacement and vertical displacement increase. In the case, the max of horizontal displacement and vertical displacement increase twenty percent and ten percent separately [2].

In this paper, the shear strength reduction finite element method is adopted to analyze the 2D unstable seepage of the dike slope and the program about it is built. The finite element analysis of an engineering case is illustrated. Some significance conclusions are drawn through the example. And this research establishes the foundation for more seepage analysis of the dike slope or earth dam.

2. Fundamental Theory

Considering the compressibility of soil and water [3], the 2D unstable seepage field control equation can be expressed as:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial H}{\partial z}\right)=S_s\frac{\partial H}{\partial t} \qquad (1)$$

Where H is the water head function; K_x and K_z respectively is x-direction permeability coefficient and z-direction permeability coefficient, S_s is specific storage, it is the amount of water that a portion of an aquifer releases from storage per unit change in hydraulic head, while remaining fully saturated.

According to relevant papers, the boundary conditions of 2D unsteady seepage field control equation may be written as:

1) the initial hydraulic head condition:

$$H\Big|_{t=0}=H_0(x,z,t) \qquad (2)$$

2) the deterministic hydraulic head boundary:

$$H\Big|_{\Gamma 1}=f_1(x,z,t) \qquad (3)$$

3) the deterministic impulse boundary:

$$q\Big|_{\Gamma 2}=K_n\frac{\partial H}{\partial n}=\Big|_{\Gamma 2}=f_2(x,z,t) \qquad (4)$$

Based on the variational principle, the solution of Eq.(1) may be expressed in the following form:

$$I(H)=\iint_{Q}\left\{\frac{1}{2}K_x\left(\frac{\partial H}{\partial x}\right)^2+\frac{1}{2}K_z\left(\frac{\partial H}{\partial z}\right)^2+S_s\frac{\partial H}{\partial t}H\right\}dxdz \tag{5}$$

Using the initial conditions q=0, Eq. (5) can be expressed in the form

$$I_1^e=\iint_{e}\left[\frac{1}{2}K_x\left(\frac{\partial H}{\partial x}\right)^2+\frac{1}{2}K_z\left(\frac{\partial H}{\partial z}\right)^2\right]dxdz \tag{6}$$

$$I_2^e=\iint_{e}S_sH\frac{\partial H}{\partial t}dxdz \tag{7}$$

Then the deviation of Eq.(6) and Eq.(7) are expressed as follows:

$$\begin{bmatrix}\frac{\partial I_I^e}{\partial H_i}\\ \frac{\partial I_I^e}{\partial H_j}\\ \frac{\partial I_I^e}{\partial H_m}\end{bmatrix}=\left[\frac{K_x}{4\Delta}\begin{bmatrix}b_ib_i & b_ib_j & b_ib_m\\ b_jb_i & b_jb_j & b_jb_m\\ b_mb_i & b_mb_j & b_mb_m\end{bmatrix}+\frac{K_z}{4\Delta}\begin{bmatrix}c_ic_i & c_ic_j & c_ic_m\\ c_jc_i & c_jc_j & c_jc_m\\ c_mc_i & c_mc_j & c_mc_m\end{bmatrix}\right]\begin{Bmatrix}H_i\\ H_j\\ H_m\end{Bmatrix}=[K]^e[H]^e \tag{8}$$

$$\begin{bmatrix}\frac{\partial I_2^e}{\partial H_i}\\ \frac{\partial I_2^e}{\partial H_j}\\ \frac{\partial I_2^e}{\partial H_m}\end{bmatrix}=\frac{S_s\Delta}{12}\begin{bmatrix}2 & 1 & 1\\ 1 & 2 & 1\\ 1 & 1 & 2\end{bmatrix}\begin{bmatrix}\frac{\partial H_i}{\partial t}\\ \frac{\partial H_j}{\partial t}\\ \frac{\partial H_m}{\partial t}\end{bmatrix}=[S]^e\left\{\frac{\partial H}{\partial t}\right\}^e \tag{9}$$

Where Δ is element dimension.

Finally, the finite element equation can be expressed as:

$$[K]\{H\}+[S]\left\{\frac{\partial H}{\partial t}\right\}H=\{F\} \tag{10}$$

Where $[K]$ is the permeability coefficient matrix, $[S]$ is the memory input bus matrix.

Strength reduction technique is that the shear strength parameters (i.e. c and ϕ) of soil are reduced according to a certain percentage [4~5], this method can be written as:

$$c_m=c/F\ ,\ \arctan(\frac{\tan\phi}{F}) \tag{11}$$

Where c_m and ϕ_m are the reduction shear strength parameters, F is reduction coefficient.

3. Example

Bdg reservoir is located in the new coastal region of Tianjin and situated on the left bank of the ZY river . It is an annual regulating plain reservoir, the design flood control storage is 5,00000000m^3.This reservoir has the utility in flood control, irrigation, shipping, urban and industrial water supplying etc. ZY river is a key channel of flood propagation below the reservoir, The design flood discharge flow is 300m^3/s, and the check flood discharge flow is 300m^3/s. It is a very important part of the flood control project system of Haihe river catchment, the cross section of dike slope subjected to water level fluctuation is shown in Figure 1.

Table 1. Parameter values

soil body	internal friction angle (。)	cohesion (kN/m^2)	saturated unit weight (kN/m^3)	bulk density (kN/m^3)	conductivity coefficients (cm/s)
clay	21.3	21.0	18.66	1.338	2.4×10-^{5}

By the above theory of 2D unsteady seepage, a seepage analysis program is developed based on shear strength reduction method. By means of this program, The stability of the dike slope in Bdg reservoir under the seepage of flood is analyzed, as shown in Figure 3.The results are shown in figure 4~6 .

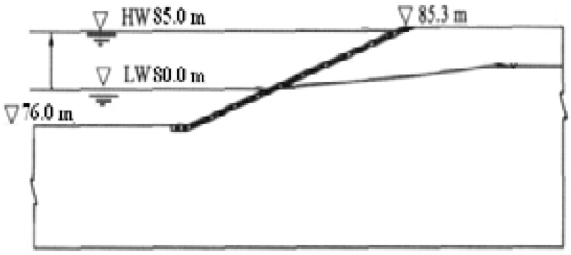

Fig.1 Cross section of dike slope subjected to water level fluctuation

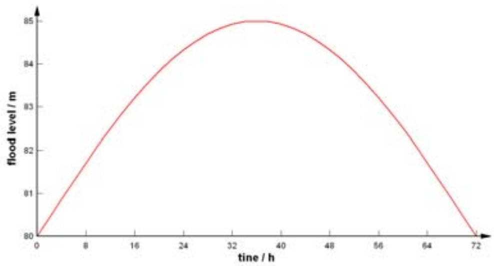

Fig.2 Fluctuation of flood level

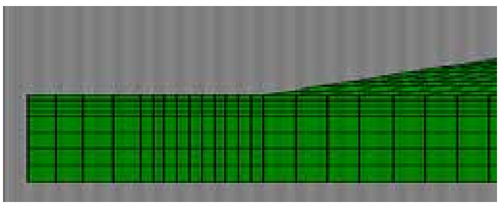

Fig.3 Computational meshes of dike slope

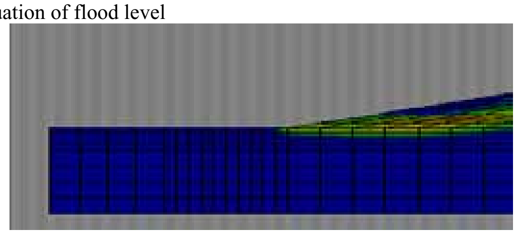

Fig.4 Plastic strain at the slope failure

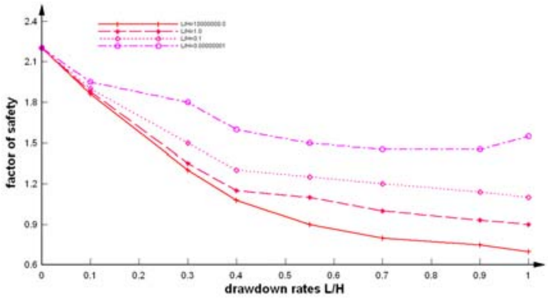

Fig. 5 Variation of FOS with drawdown ratio for hydraulic conductivity coefficients k=2.4×10^{-5}

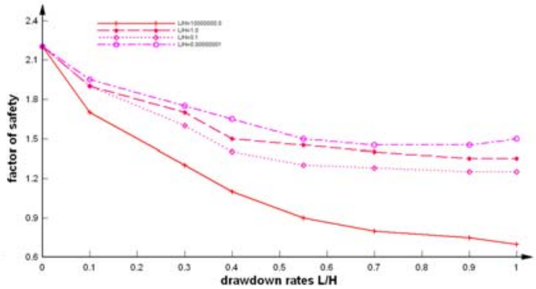

Fig. 6 Variation of FOS with drawdown ratio for hydraulic conductivity coefficients k=2.4×10^{-4}

From Fig. 5 and Fig. 6, the following conclusions could be reached:

（1）It should be noted that the curve with drawdown ratio L/H=1.0 is obviously lower than the curve with drawdown ratio L/H=0.1, that is to say, the larger the flood drawdown rate, the smaller factor of safety.

（2）The larger the hydraulic conductivity coefficient, the better the permeability of dike, so the change of flood level has an inconspicuous effect on the safety factor of the dike slope when the hydraulic conductivity coefficient is relatively great.

Conclusion

On the foundation of the finite element method and shear strength reduction technique, two-dimension finite element calculation program on unstable seepage problem has been worked out. The program is utilized to calculate the stability of the dike slope. The changing rule of the permeate coefficient and different rising or falling speed of the water level is explored. The results show that the drawdown rate has a remarkable effect on the safety factor of the dike slope.Some conclusions have the applicable value, and also present useful reference to the slope stability analysis, slope disaster prediction and slope control under unstable seepage.

Acknowledgements

The authors gratefully acknowledge the financial support of Open Research Foundation Program of Research Centre on Levee Safety & Disaster Prevention Ministry of Water Resources (No. Q410001). This work also is supported by a major program from the National Science and Technique Foundation of China during the 11th Five-Year Plan Period (No. 2009BAK56B04).This work also is supported by Non-profit Industry Financial Program of MWR (No. S411001).

References

[1] CHENG Xin-shu, YANG Xiao-zhe Stability analysis of dam slope based on finite element method of non-stationary seepag,*Journal of Fuzhou University* 2002;**30**:362-366.

[2] NIAN Ting-kail,WAN Shao-shil,JIANG Jing-cai,LUAN Mao-tian.Finite element analysis of slope stability under drawdown conditions by strength reduction technique, *Rock and Soil Mechanics* 2010;**16**:2264-2269.

[3] SONG Er-xiang． Finite element analysis of safety factor for soil structures,*Chinese Journal of Geotechnical Engtneering* 1997; **19**: l-7．

[4] ZHU Wei,Yamamura Kazuya. Stability of river embankment under the seepage of rain or flood,*Chinese Journal of Geotechnical Engtneering* 1999; **21**: 4l4-419．

[5] LIAN Zhen-ying,HAN Guo-cheng,KONG Xian-jing． Stability analysis of excavation by strength reduction FEM,*Chinese Journal of Geotechnical Engineering* 2001;**23**:407—411.