ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0044

Numerical Simulation of Stress, Displacement and Slope Stability Coefficient of Earth-Rock Dam

Dongcheng Dai

College of Ocean Science and Engineering, Shanghai Maritime University, Shanghai 201306, China

*499043770@qq.com

Abstract

According to the finite element calculation software ABAQUS, the stress, displacement and slope stability of earth-rock dam were calculated under certain conditions. The stress, displacement, the most dangerous sliding surface and the safety factor of the dam body are obtained through the calculation and analysis of the hypothetical engineering example. The numerical simulation results show that the plastic variation process of earth-rock dam is in good agreement with the actual engineering plastic variation process. Therefore, the finite element strength reduction method is practical and reliable to evaluate and analyze the final state stability of slope of earth-rock dam slope and other similar engineering.

Keywords

Finite Element, Strength Reduction, Dam Stress, Safety Factor, Dam Deformation.

1. Introduction

Based on the strength reduction theory, this paper uses ABQUS software to analyze the stress, displacement and slope stability of dam body under the action of designed flood level in the following engineering examples: The dam height of an earth-rock dam is 50m, the width of the dam crest is 8m, the design flood level of the dam body is 46m, the downstream water level is 3.0m, the slope ratio of the upstream and downstream slopes of the dam body is 1:2.5 and 1:2.0 respectively, and the dam foundation is complete rock mass.

The stress, displacement and slope stability analysis of earth-rock dam are important contents in the design of earth-rock dam. It is also an important basis to determine the section size, slope Angle and safety of dam body. The slope stability of earth-rock DAMS is generally evaluated by safety factor method. Its reliability and accuracy have an important impact on the safety of water conservancy facilities.

2. Calculation Principle

This design needs to calculate the stress, displacement and slope stability coefficient of the dam body, using ABAQUS software for numerical simulation. The stress and displacement of dam body can be obtained directly after setting the basic parameters of dam body through software function[1]. The stability coefficient of slope is complicated, so it needs to use the basic principle of finite element strength reduction method to analyze and calculate. For the strength reduction method, the slope soil is set as an ideal elast-plastic material. It is convenient to simplify the calculation of shear strength parameters in finite element. In the calculation, it is reduced gradually until it breaks. In this failure state, nonlinear program is usually used to determine whether the slope is unstable by examining its convergence and displacement change.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0044

According to the calculated results, the failure sliding surface and the corresponding safety factor are obtained. By dividing the values of soil strength index C and φ by the reduction coefficient F, the new sum value can be obtained. As a new material parameter into the trial calculation, iterative calculation. When the slope meets the given critical failure condition, the corresponding F is called slope safety factor [2].Because the ideal elastic-plastic model is used in this paper to solve the slope stability problem with the reduction coefficient method, the Mohr-Coulomb yield criterion is more reliable [2].

3. Criterion of Slope Instability in Finite Element

The slope will have a large displacement when certain damage occurs. At this time, the slope will change from a relatively stable state to an unstable state (i.e., the following state), and the amount of slope displacement deformation and plastic deformation will change from constant to a variable. The computational iteration method of the finite element simulation software is to calculate the mechanical balance of the slope as a whole, and find a suitable value to meet the conditions during the whole calculation process. A key problem of slope stability analysis by finite element strength reduction method is how to determine whether the slope is in the failure state according to the finite element calculation results.

At present, there are mainly two types of instability criterion: the first is that when the finite element numerical simulation software is used to calculate the slope stability, the overall displacement of the slope or the non-convergence state after the reduction of the overall stress parameter is taken as the overall instability indicator of the studied slope; The second type mainly uses macroscopic plastic strain (usually refers to the effect variables and equal effect variables in the simulated post-processing) to form a certain through deformation from the top of the slope to the foot of the slope as another criterion for the instability of the whole slope[3].

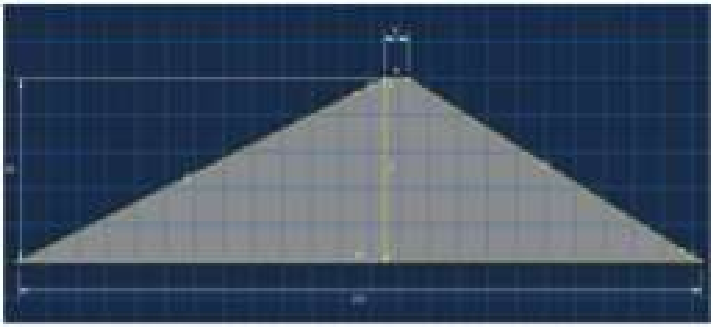

Figure 1. A cross section diagram of an earth-rock dam

In this model, the earth-rock dam adopts homogenous body and mohr-Coulomb elast-plasticity. Using ABAQUS finite element calculation software, the maximum cross section of earth-rock dam was selected as a typical section for two-dimensional nonlinear finite element analysis [4]. Horizontal constraints are applied to the left and right boundaries of the dam foundation model, and horizontal and vertical constraints are applied to the bottom surface. Figure 1 is a cross section schematic diagram of earth-rock dam.

The load in the model includes the dead weight of the dam body and the seepage pressure of the designed flood level of 46 m and the downstream water level of 3 m. Firstly, the stress balance of the whole model is carried out, then the stress and displacement of the dam body are analyzed by applying osmotic pressure, and finally the stability of the dam body under the action of design flood is analyzed.

4. Analysis of Numerical Model and Calculation Results

4.1 The Use of Strength Reduction

First, a field variable is defined as the intensity reduction factor F. Moreover, the material model parameters that vary with field variables are defined. Then, the gravity load is applied to the model by specifying the size of the field variable to establish the equilibrium stress state. At this point, F can be set to a smaller value, and the model is destroyed directly when placed. Finally, the field variable F is linearly added in the subsequent analysis steps until the results are processed at the end of the calculation, and the safety factor is determined according to the instability evaluation criteria. For specific parameter selection and replacement, refer to Table 1 to define the friction Angle and cohesion that change with field variables, and Table 2 to define the friction Angle and dilatancy Angle that change with field variables[5].

Table 1. The frictional angles and cohesive forces that vary with the field variables are defined

Cohesive yield stress	Absolute plastic strain	field
80000.000	0.000	0.500
53333.333	0.000	0.750
40000.000	0.000	1.000
32000.000	0.000	1.250
26666.667	0.000	1.500
22857.143	0.000	1.750
20000.000	0.000	2.000

Table 2. The angles of friction and dilatancy that vary with the field variables are defined

riction Angle	Expansion Angle	field
43.003	0.000	0.500
31.871	0.000	0.750
25.000	0.000	1.000
20.458	0.000	1.250
17.269	0.000	1.500
14.920	0.000	1.750
13.124	0.000	2.000

4.2 Stress Analysis

Since the stress in ABAQUS is positive in tension (contrary to the rules of soil mechanics), the small principal stress in ABAQUS corresponds to the large principal stress in geotechnical engineering. The yield stress and small principal stress contour map of earth-rock dam under design flood action and strength reduction are shown in Figure 2. The yield stress of earth-rock dam under design flood action and strength reduction action and Figure 3. The small principal stress of earth-rock dam under design flood action and strength reduction action. It can be seen from the figure that the yield stress and small principal stress of the dam body have a good distribution law. The yield stress decreases with the increase of the elevation of the dam body, and the stress is more concentrated in the middle region, while the small principal stress increases with the increase of the elevation of the dam body.

 Volume 8 Issue 1, 2022
DOI: 10.6919/ICJE.202201_8(1).0044

The maximum yield stress of the dam body is 319Kpa, and the maximum small principal stress of the dam body is 9.27kpa.

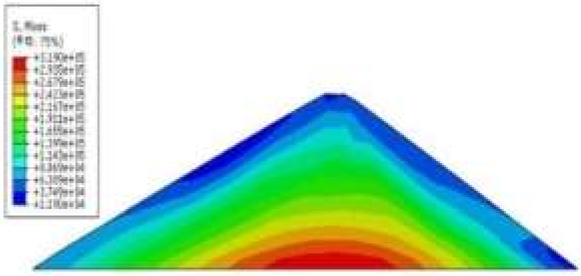

Figure 2. Yield stress of an earth-rock dam under the action of design flood and strength reduction

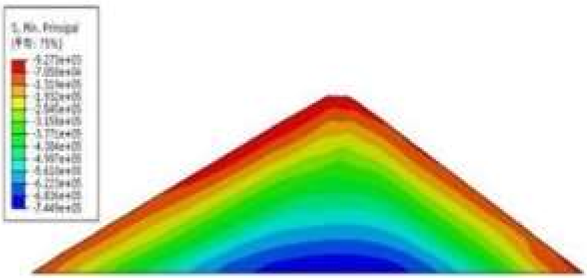

Figure 3. Small principal stress of an earth-rock dam under the action of design flood and strength reduction

4.3 Displacement Analysis

Figure 4, Figure 5, Figure 6, Figure 7 are horizontal displacement cloud and vector diagrams of earth-rock dam under normal and strength reduction under the combined action of dead weight and seepage pressure respectively. The displacement symbol specifies that downward is positive, and the unit is meters.

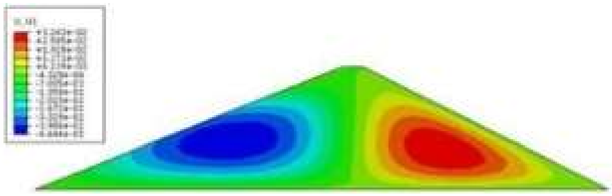

Figure 4. Cloud diagram of horizontal displacement of earth-rock dam under gravity stress and seepage pressure

According to the horizontal displacement cloud diagram of earth-rock dam under dead weight stress and seepage pressure in Figure 4 and horizontal displacement vector diagram of earth-rock dam under dead weight stress and seepage pressure in Figure 5, the horizontal displacement of dam body under dead weight stress and seepage pressure is roughly symmetrical, pointing to the direction outside the slope respectively. The horizontal displacement of flood level slope in the upstream of dam body is obviously greater than that in the downstream of dam body. This is because the water level of the upstream dam body is higher than that of the downstream dam body, and the permeability of the upstream dam body is obviously greater than that of the downstream. Therefore, in the actual project, the water level that the dam body can bear is controlled. Once the high water level occurs,

ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0044

corresponding engineering measures (drainage) should be taken in time to protect the stability of earth-rock dam.

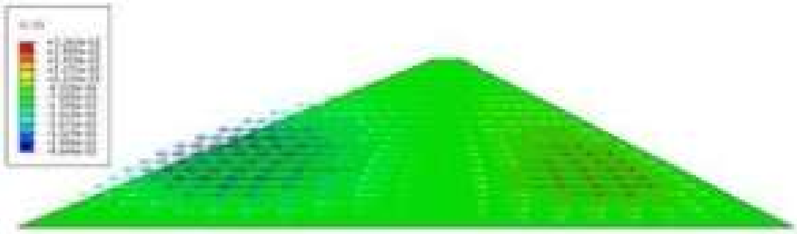

Figure 5. Horizontal displacement vector diagram of earth-rock dam under gravity stress and seepage pressure

From Figure 6 gravity stress and seepage pressure strength degradation of horizontal displacement nephogram, Figure 7 gravity stress and seepage pressure strength degradation of horizontal displacement vector map, the soil strength, small itself upstream high water penetration is big, which can lead to high water level of dam displacement, there will be a great by local area expanded to middle slope toe, resulting in slope instability. Therefore, attenuation of soil slope strength should be avoided in engineering practice. At the same time of attenuation, the displacement of the right low-water slope also tends to decrease.

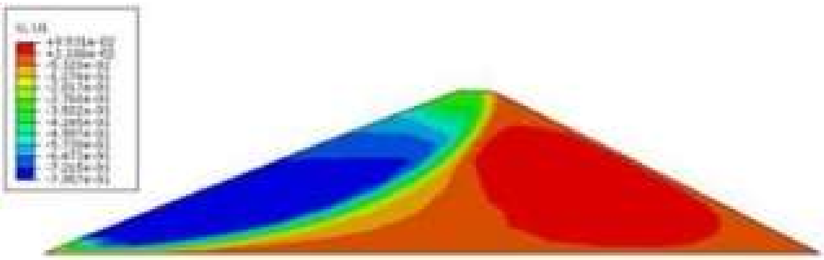

Figure 6. Horizontal displacement cloud diagram of strength reduction under dead weight stress and seepage pressure

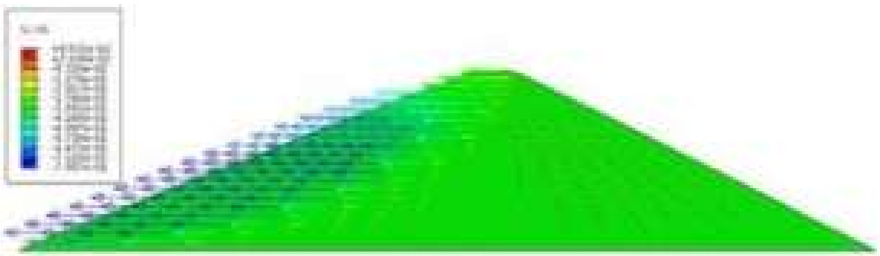

Figure 7. Horizontal displacement vector diagram of strength reduction under dead weight stress and seepage pressure

As can be seen from the displacement vector diagram of bank slope instability in Figure 8, under flood level, the strength of earth-rock dam attenuates, and the degree of instability failure is quite severe. The width of dam crest directly sinks, and the left dam body forms a penetrating surface, which directly leads to the dam body being destroyed.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202201_8(1).0044

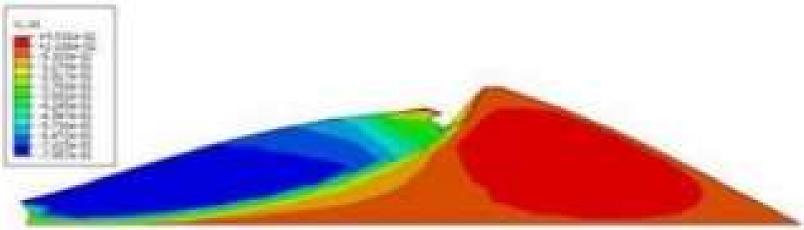

Figure 8. The displacement vector diagram of the instability of most bank slope is released

4.4 Stability Analysis

In order to facilitate the analysis and calculation, the second criterion is adopted in this paper, that is, connecting the plastic zone of potential slip surface as the safety and stability factor of earth-rock dam under design flood action.

Figure 9. t =0.942 (PEMAGE) plastic zone

By using the strength reduction method of ABAQUS software, PEMAGE (equivalent plastic strain at integral point) and PRRQ (cumulative plastic strain) of t=0.924 in the strength reduction analysis step are drawn and shown in Figure.9 and Figure 10 respectively. The plastic strain at a certain point in the deformation process described by PEMAGE in ABAQUS is independent of the loading history; PEEQ is the cumulative result of plastic strain during the whole deformation process. It is clear from Fiugre 10 that ground penetration of plastic zone occurs when t=0.924, and the ground safety factor is Fs=1.886.

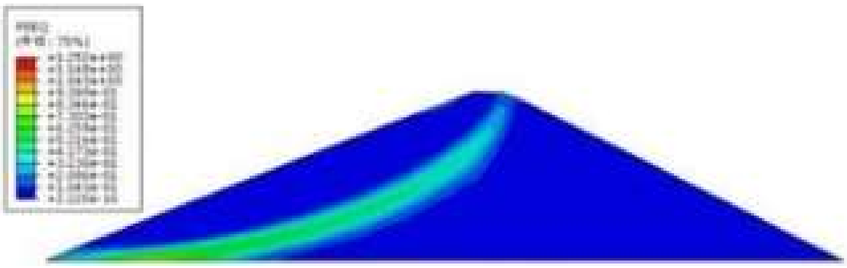

Figure 10. -t=0.924(PRRQ)plastic zone

5. Conclusion

In order to facilitate the analysis and calculation, the second criterion is adopted in this paper, that is, connecting the plastic zone of potential slip surface as the safety and stability factor of earth-rock dam under design flood action.

By using the strength reduction method of ABAQUS software, PEMAGE (equivalent plastic strain at integral point) and PRRQ (cumulative plastic strain) of t=0.924 in the strength reduction analysis step are drawn and shown in FIG.9 and 10 respectively. The plastic strain at a certain point in the deformation process described by PEMAG in ABAQUS is independent of the loading history; PEEQ is the cumulative result of plastic strain during the whole deformation process. It is clearly shown in

ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0044

FIG. 10 that ground penetration of plastic zone occurs when t=0.9242, and the safety factor is Fs=1.886.

References

[1] H.T.Mao. Seepage Calculation and Analysis of Earth-rock Dam on Infinite Deep pervious Foundation. Wuhan University Press, 2014.

[2] G.X.Li. Advanced Soil Mechanics. Beijing: Tsinghua University Press, 2014.

[3] Z.G.Gao, S.H.Liu, X.Huang. Journal of Underground Space and Engineering, 2013 (9) : 1531-1535.

[4] Y.R.Zheng, S.Y.Zhan. Chinese Journal of Rock Mechanics and Engineering, 2004(19): 3,381-3,388.

[5] Y.Q.Ye, Y.C.Zhang, G.H.Yang, et al. Application of variable modulus elastic-plastic strength Reduction method in stability analysis of soil slope. Guangdong Water Resources and Hydropower, 2013(7):4-10.