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Research on the Concrete Dam Damage and Failure Rule under the Action of Fluid-Solid Coupling

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Abstract

This paper evaluates the stability of concrete dam under the action of fluid-solid coupling in the two working conditions of water level raising and rainfall intensity increasing with the method of strength reduction, and the conclusions are revealed as follows: The unstable failure of dam always starts from the slope base, the crack on the slope top and the creep slip in the slop base developed, which led to the gradual destruction of the dam and formed the slip surfaces through the dam; the safety factor of the concrete dam reduced and the potential slip surfaces moved to the inside of the dam with the water level raising; the more rainfall intensity, the larger plastic yield region and the lower safety factor will be, and the dam slip surfaces transferred from the base of slope to the inside of the slope top gradually.

Keywords: Fluid-Solid Coupling; Damage Failure; Rainfall Intensity; Concrete Dam; Creep Slip; Safety Factor

1. Introduction

At present, landslide phenomenon caused by slope instability has become one of the three severe geological disasters in the world. According to statistics, the loss caused by landslide is as much as hundreds of millions of dollars every year, and harm the people's safety and property seriously. The main problem of landslide is the seepage failure for the embankment, rivers and reservoirs bank slope and the earth-rock dam. The main factor induced to slope instability is the action of water. So, it has important engineering value to analyze the dam slope stability under the interaction of fluid-solid coupling.

2. Concrete Dam Body Seepage Field And Stress Field Coupling Mathematical Model

The dam seepage field and stress field is a mutual influence, interaction of the organic whole, the two are coupling .

2.1 The Dam Body Stress Field Mathematical Model

Take a feature in the infinitesimal body in the dam, if the volume force is only considering the gravity and fluid penetration, z direction and the gravity direction, stress to pressure.

(1) Balance Equation

$$\sigma'_{ij,j} + \nabla p + f_i = 0 \tag{1}$$

Where: p , f and σ'_{ij} are the hydrostatic seepage pressure, seepage force vector and effective stress respectively.

(2) Constitutive Equation

$$\tau_f = c' + (\sigma - p)\tan\varphi' = c' + \sigma'\tan\varphi' \tag{2}$$

Where: c' is soil cohesion, φ' is soil effective angle of internal friction, σ' is effect of shear surface in the effective normal stress.

(3) Geometrical Equations

$$\varepsilon_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j.i}\right) \tag{3}$$

Where: ε_{ij} is the strain[1-3].

(4) Stress Boundary Condition

$$\begin{aligned} \sigma_{ij}L_j &= s_i(x, y, z)\ ,\ (x, y, z) \in S_1 \\ u_i &= g_i(x, y, z, t)\ ,\quad (x, y, z) \in S_2 \end{aligned}, \tag{4}$$

Where, $g_i(x, y, z, t)$ is the surface displacement on the boundary S_2 of known function. $s_i(x, y, z)$ is the surface forces on the boundary S_1 of known function.

2.2 Mathematical model of the dam seepage

In practical engineering, often have to consider water, pumping, rainfall and evaporation conditions. We can add in the basic equations to be considered the source and sink items I can get:

(1) Seepage Continuity Equation

$$\frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} + \frac{\partial(\rho v_z)}{\partial z} + I = -\frac{\partial \rho n}{\partial t} \tag{5}$$

(2) Initial Conditions

Initial conditions in a given time (usually expressed as t = 0) the D value of each point of the head, namely:

$$H(x, y, z, t)\big|_{t=0} = H_0(x, y, z), (x, y, z) \in D \tag{6}$$

Where, H_0 is on D, the known functions.

(3) Boundary Conditions[4-6]

$$H(x, y, z, t)\big|_{S_1} = H^*(x, y, z, t), (x, y, z) \in S_1 \tag{7}$$

Where $H(x, y, z, t)$ indicates S_1 point on the boundary (x, y, z) at time the head, $H^*(x, y, z, t)$ is a known function on S_1 .

$$k_n \left.\frac{\partial H}{\partial n}\right|_{S_2} = q * (x, y, z, t), (x, y, z) \in S_2 \tag{8}$$

Where, k_n is the boundary normal direction of the permeability coefficient, n is the boundary normal direction, $q * (x, y, z, t)$ is on the S_2 known functions.

$$\frac{\partial H}{\partial n} + \alpha H = \beta \tag{9}$$

Where, α β are known functions on the boundary, the second boundary known as the third type of boundary or mixed border.

3 Model establishment and analysis of concrete dam

A reservoir staunch that is shown as fig.1 is built of concrete materials. There is no crack instability and signs including no bad geological process.

3.1 Calculation related conditions

We set the horizontal and vertical two constraints in the bottom of the dam foundation. In contact with water on the boundary of the added pore pressure boundary, through to the definition of drainage boundary, it can satisfy the face completely saturated area and unsaturated area in the boundary, the pore pressure is zero [7-9]. The concrete material parameters are shown in table 1.

Table 1 Basic mechanics parameters of the dam

$\rho\,[Kg/m^3]$	$E[GPa]$	μ	k[cm/s]	$\gamma_w\,[kN/m^3]$	e
2500	30	0.35	1E-007	9.8	1

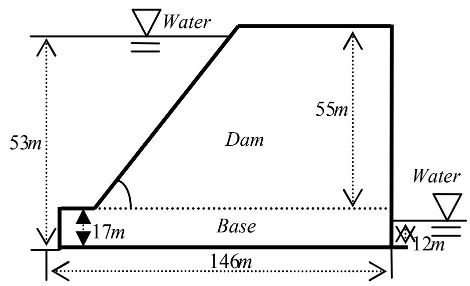

Fig. 1 Slope of the dam

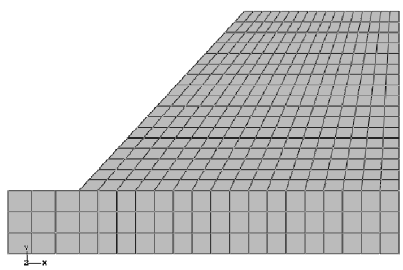

Fig. 2 Computational grid diagram

The cohesion and inner friction angle with the reduction coefficient function is shown below.

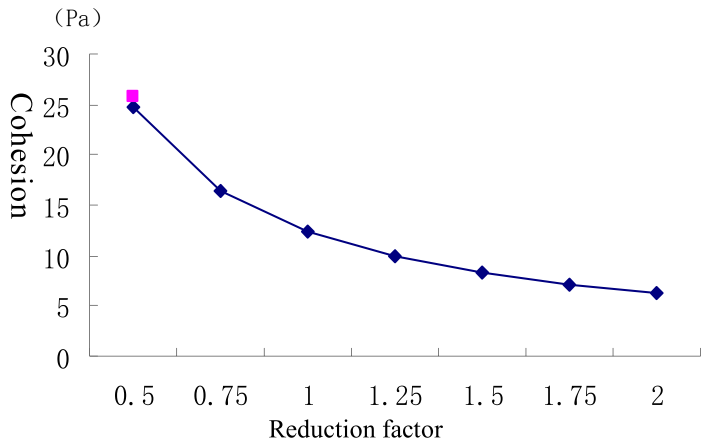

Fig.3 Diagram of cohesive with strength reduction factor

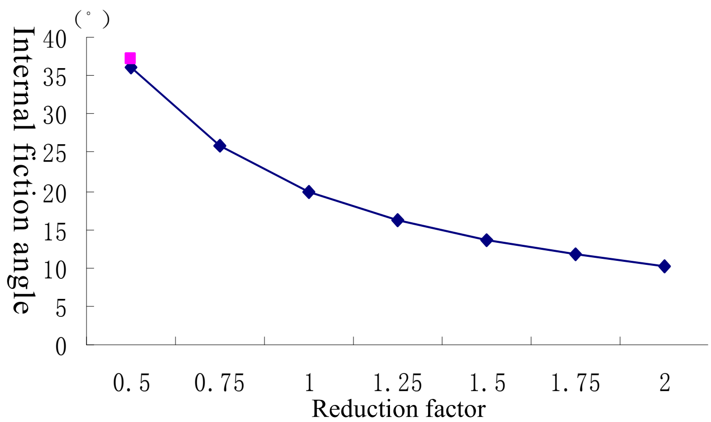

Fig. 4 Diagram of internal friction angle with strength reduction factor

3.2 Calculation results

In this paper, the stability of the slope safety reservoir staunch calculation, three kinds of cases were analyzed. Specific include: a. without considering the effect of the seepage situation, that is, only considering gravitational field of dam slope stability; b. consider seepage field and stress field of the coupled action of the slope stability analysis of the dam, the situation are divided into two kinds, one kind is the general state of the dam water under the slope stability analysis, and the other is the consideration of the rising water; c. consider rainfall on the dam the effect on the stability of the slope, including contrast of natural conditions and after rainfall.

(1) The dam slope stability analysis without the seepage

Only considering gravity, using strength reduction calculus, until the computer calculation iteration so far, obtained the expected results.

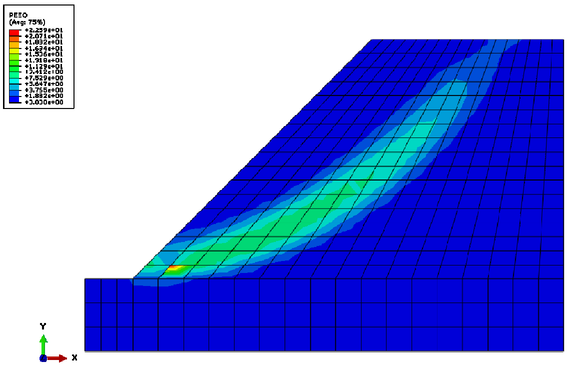

Fig.5 Equivalent plastic strain diagram

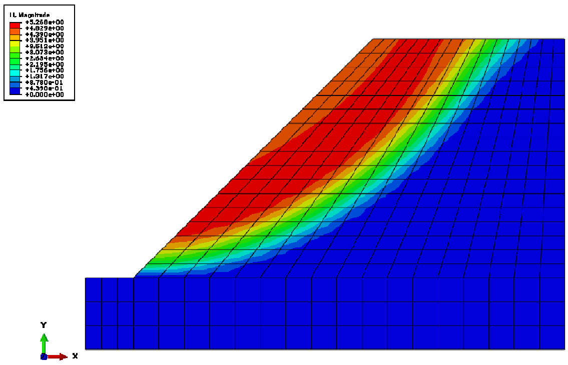

Fig.6 Displacement diagram

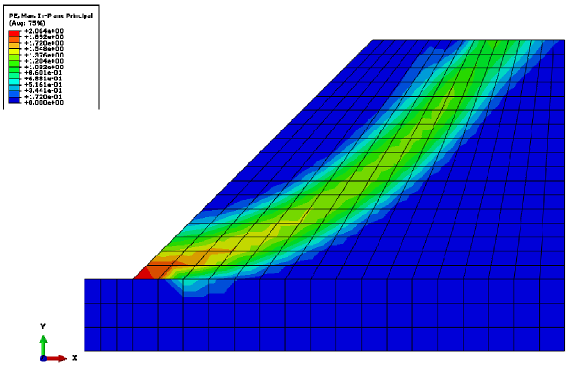

Fig.7 Max principal plastic strain distribution

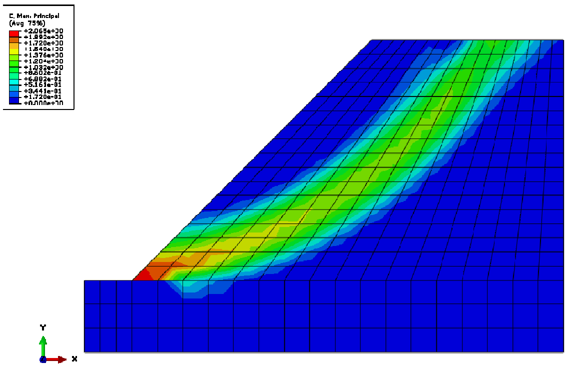

Fig.8 Max principal strain distribution

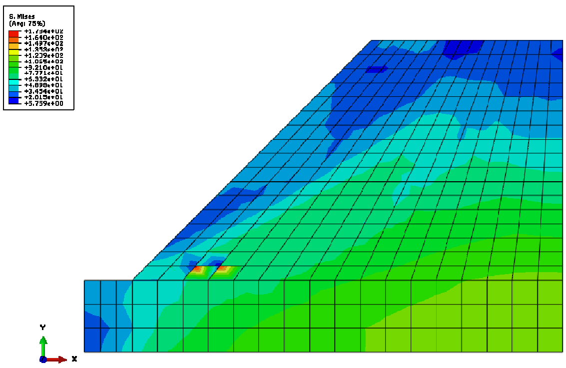

Fig.9 Mises stress distribution

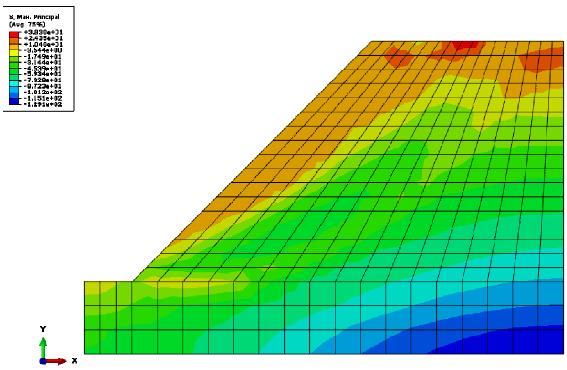

Fig.10 Max principal stress distribution

The dam slope safety factor is 0.985 under gravity action. A long and narrow sliding surface is shown in fig.6. The potential sliding surface formed at feet starts at a point, gradually extending to the top.

(2) The dam slope stability analysis with consideration the coupling of seepage and stress

In order to analyze the change of water level on the stability of the dam's influence, in this case two case studies, shown as the following:

(a) Under natural conditions for the slope stability analysis of the dam

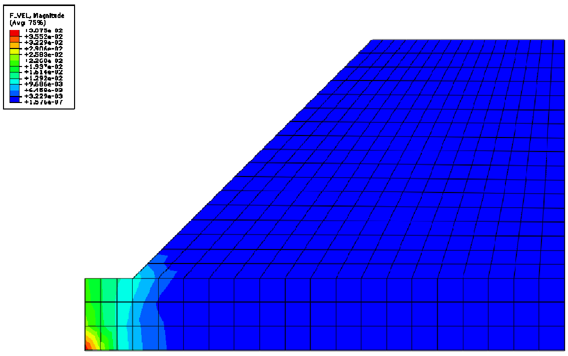

Fig.11 Diagram of penetrating velocity

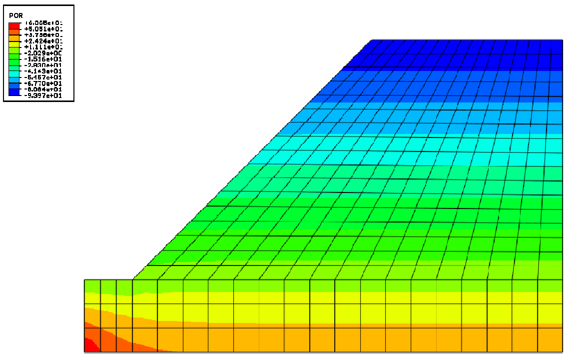

Fig.12 Diagram of pore water pressure distribution

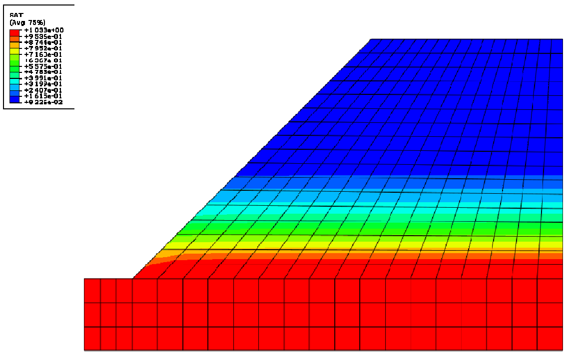

Fig.13 Diagram of saturation

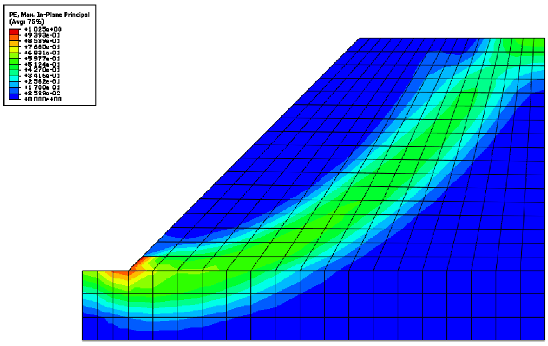

Fig.14 Max principal plastic strain distribution

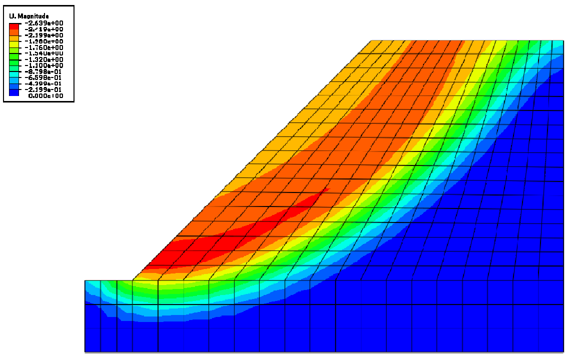

Fig.15 Displacement diagram

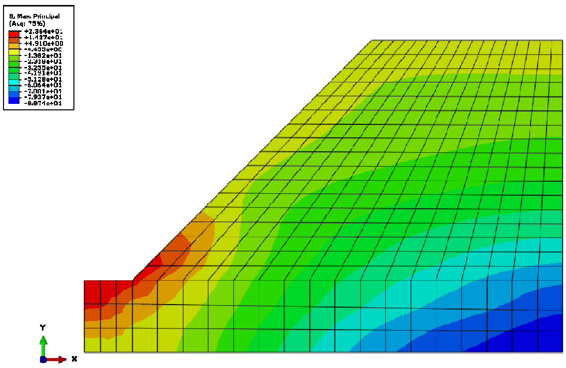

Fig.16 Max principal stress distribution

(b)The dam slope stability analysis after the water level rising

For the more accurate research on the dam seepage role the effect on the stability of dam, now will heighten water level, to simulate the change of the seepage field to the stability of the dam body changes.

Owing to the rise of water level, the seepage velocity of the dam accelerates, which results its stress redistribution. As shown in Fig. 12 and Fig.18, the pore pressure doesn't keep linear relationship with water height. It can be known from Fig. 14 and Fig.20, the rise of water level makes the vertical size of potential slip plane increase and the biggest plastic strain regions move left, it leads to the probability of landslide taking place increasing.

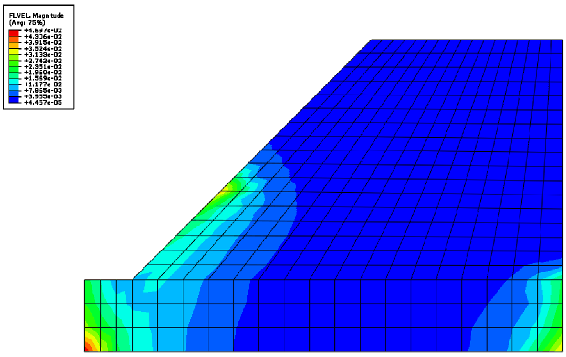

Fig.17 Diagram of penetrating velocity

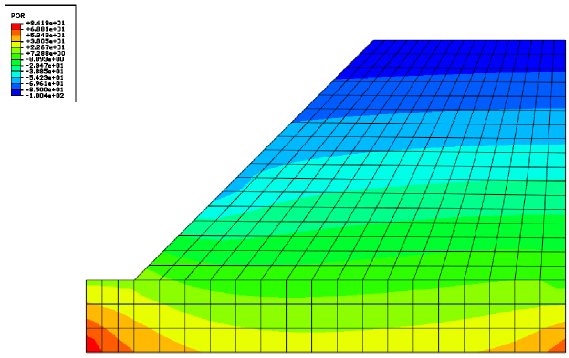

Fig.18 Diagram of Pore water pressure distribution

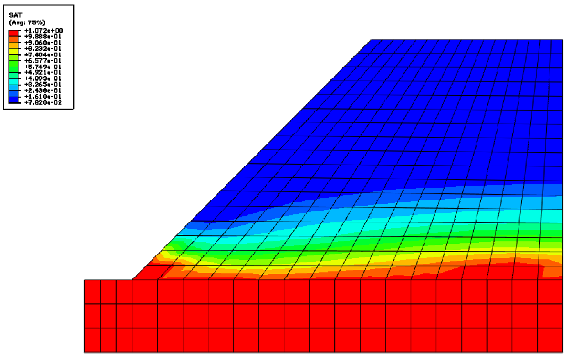

Fig.19 Diagram of saturation

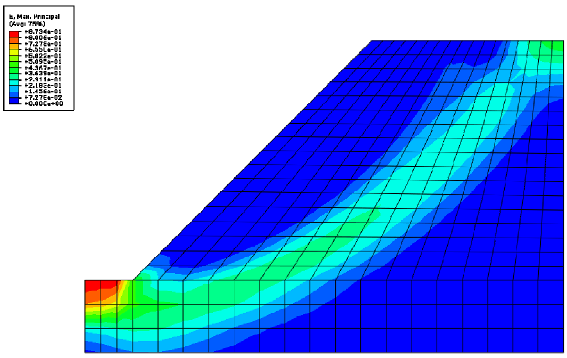

Fig.20 Max principal plastic strain distribution

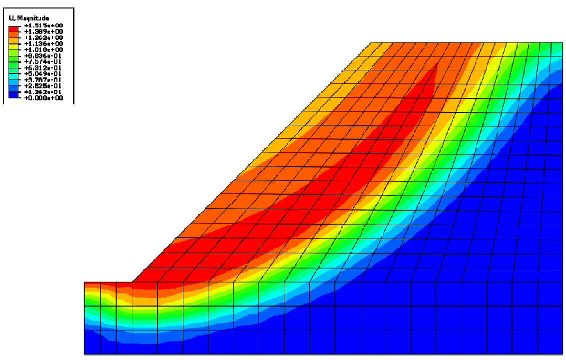

Fig.21 Displacement diagram

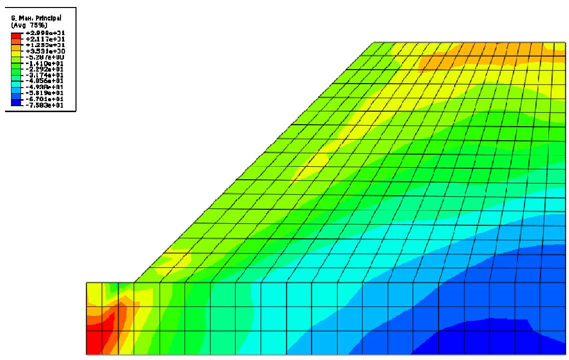

Fig.22 Max principal stress distribution

(3) The dam slope stability analysis under the rainfall influence

The natural conditions of the dam slope stability have a long and huge impact, the rainfall on dam slope stability for a detailed analysis. The rainfall intensity is 0.2mm / h.

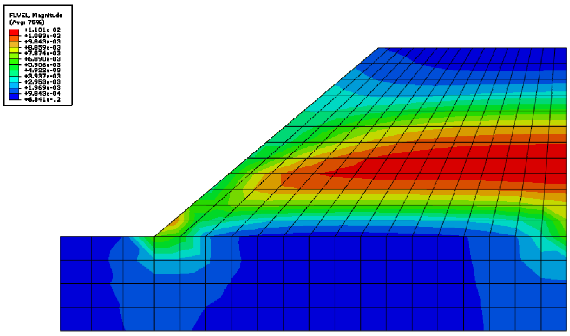

Fig.23 Diagram of penetrating velocity

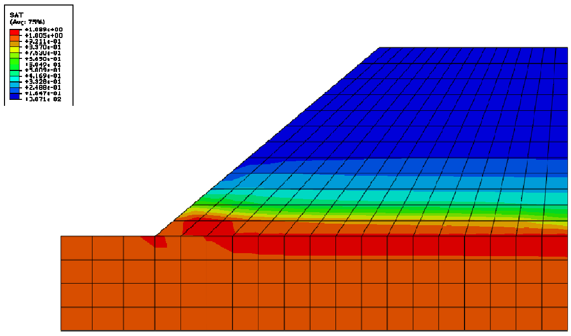

Fig.24 Diagram of Pore water pressure distribution

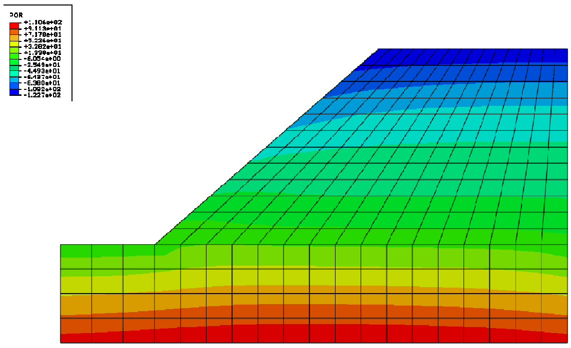

Fig.25 Diagram of Pore water pressure distribution

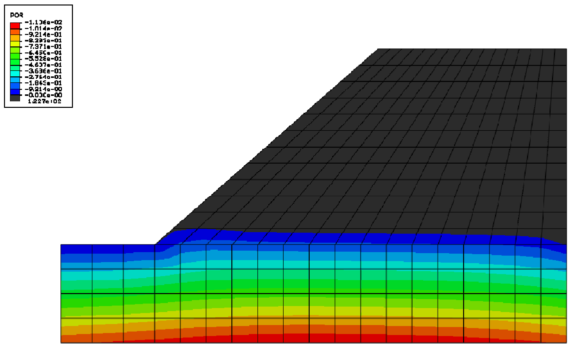

Fig.26 Diagram of saturation line

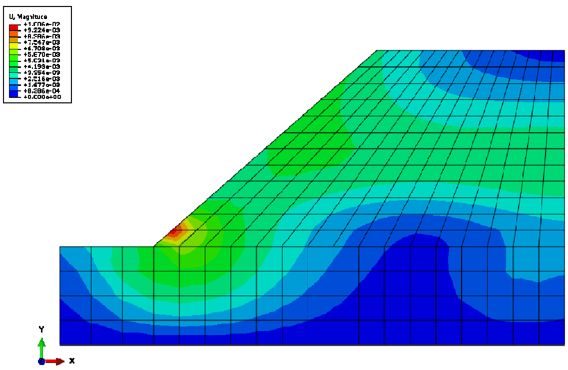

Fig.27 Diagram of displacement

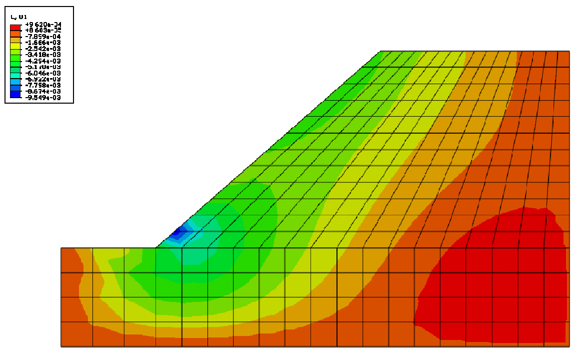

Fig.28 Levels displacement diagram

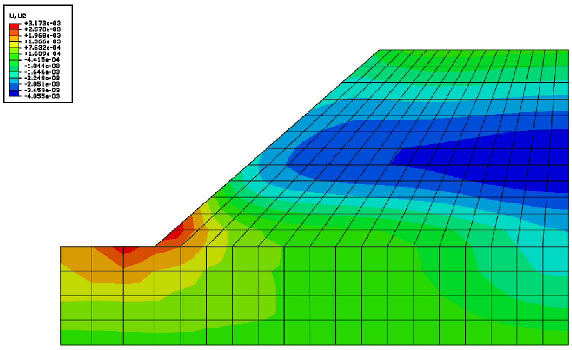

Fig.29 Vertical displacement diagram

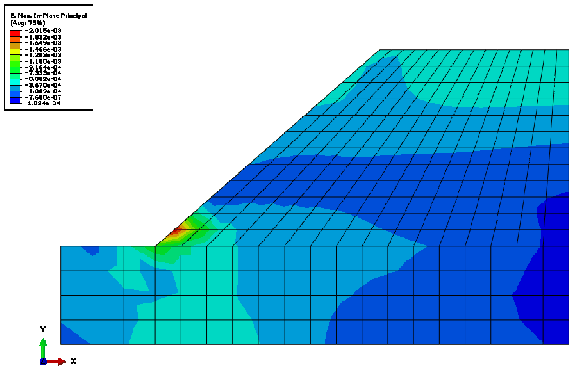

Fig.30 Diagram of plain strain

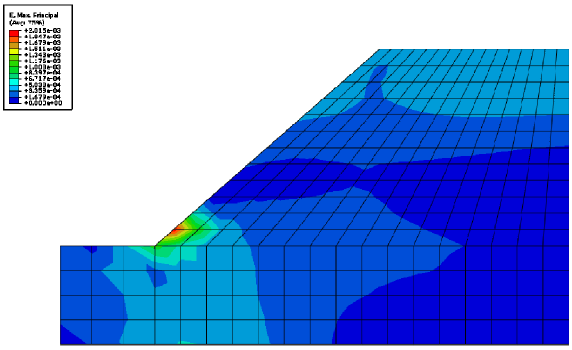

Fig.31 Max principal strain distribution

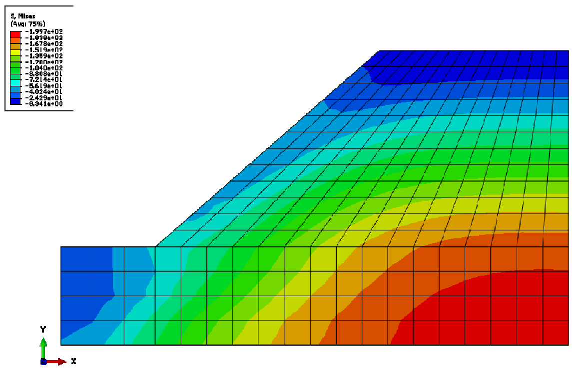

Fig.32 Diagram of mises stress distribution

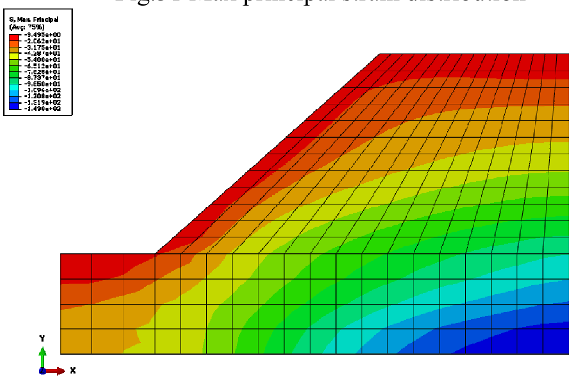

Fig.33 Max principal stress distribution

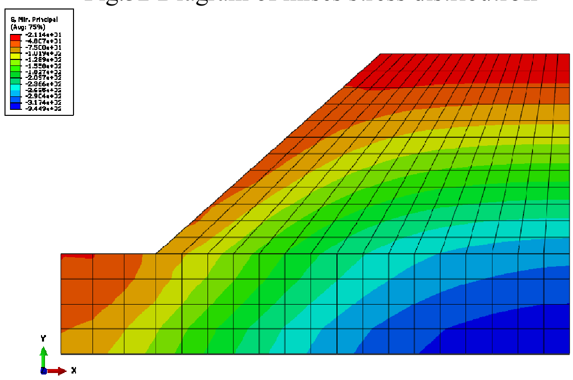

Fig.34 Min principal stress distribution

Under the effect of rainfall, the slope safety coefficient of the dam is 1. 268. From Fig.23 to Fig.34, due to the increased load, the internal stress field of dam body changes. Rainfall makes the flow velocity of the water inside the dam has increased dramatically, the current water distribution area greatly increase; Internal degree of saturation distribution of the dam is quite changed; The pore pressure distribution has been changed obviously; Of course, infiltrating the position of the line also have outstanding change. This shows that rainfall makes dam of internal seepage field generate a large changes. So the conclusion is: the internal stress field of dam body changes on the seepage field has very big effect.

4. Summary

By analyzing the static simulation of the dam , we get the rules shown as follows:

a) The most dangerous part of the dam is the base of slope. General speaking, dam's slope instability starts with the base of the slope. With the development of the slope top's tension crack and the base of slope's creep slip, the destruction is produced in the dam gradually. The landslide will happen when the potential sliding surface is run through. And the more the external loads are, the easier the dam will be instability and failure, and the larger the failure surface will be;

b) The water level has a great influence on the slope stability of the dam. The higher the water level is, the more strong the seepage effect in the dam, the larger the deformation of the dam skeleton, the stress and the strain in the dam is. The dam body is easier to be instable. The most dangerous point of the base of slope moves towards the left with the rising of the water level;

c) The rainfall has a great influence on the slope stability of the dam. The rainfall impact will cause the great change of the seepage field and the stress field, influences the stress and strain distribution of the dam, and changes the situation of the dam skeleton's deformation, causes the instable failure of the dam finally.

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