The Basic Theory of Fluid-Solid Coupling And Dam Slope Stability Analysis.

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Abstract; This paper researches the static and dynamic simulation analysis of the cracks' dynamic development in the slope stability and the process of the dam's unstable failure , combined with the engineering practice and based on the effective stress principle, seepage theory, slope stability theory, damage theory and the strength reduction limited theory with the extended finite element numerical simulation technology and fluid-solid coupling.

Keywords; Seepage theory, effective stress, slope stability; simulation; damage theory; finite element; numerical simulation technology;

1 Introduction

The stability of slopes has been one of the hottest issues in engineering and scientific community. The problem of slope failure has been concerned by many scholars. Many accidents of slope failure indicate that groundwater has a large effect on the slope stability. The seepage of underground water affects the stress field through the change of seepage volume force. And variation of stress field changes the pore characteristics of slope medium. Then it changes the seepage field. The coupling of fluid and solid is the internal cause of slope failure. This paper based on the internal mechanism of slope failure, and established mathematical model of slope failure system under fluid-solid coupling, calculated slope stability coefficient by use of strength reduction FEM, and analyzed the effect of slope stability considering seepage action. A dam slope stability analysis is done as an example in the seepage stability analysis and slope stability is an important part of the engineering safety. According to former engineering practice, it shows that the ignorance of rapid drawdown , rainfall infiltration and some other action of unsteady seepage ,which make the slope failure happen frequently. So the analysis of unsteady seepage and dam stability under the action of unsteady seepage should be paid special attention, and recognize the characteristics of the flow field and its adverse effects to the slope stability The fluid flow phenomenon in porous medium is an extremely complex. Because of the lack of distribution regularity of pore and fracture, it is impossible to study and determine the fluid characteristics of the movement in the individual pores generally, and do like that has little practical value. In the study of seepage problem, we usually don't research the motion law of the individual fluid particle directly, but research the fluid average movement in rock; it is the seepage rule with an average property. The main task of the Seepage analysis is the determination of the basic physical quantities like the given seepage field, water head, the velocity distribution, seepage flow , evaluate the engineering security and the economic benefits to adapt the reasonable seepage control measures by the relevant calculation.

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In terms of the earth-rock dam and embankment, mainly have the three hydraulic elements followings: Seepage head, Seepage gradient, Seepage flow.

2. The seepage theory of the dam—

Darcy law; In the dam two points, a and b, the head of point a is H1, the head of point b is H2, water flows from the high (point a) to point (b), the Length of the sample flow through by the water is L, infiltration velocity is:

$$v = ki = k\frac{\Delta H}{L} \tag{1}$$

Where: v—infiltration velocity, cm/s. it is not the real underground water velocity, but is the water yield cm^3.flow though unit soil section cm^2 per second (s);
k—permeability coefficient,cm/s, a very useful constant reflects the soil permeability.
i—head gradient or hydraulic gradient.

3. The effective stress theories.
In 1925, Terzaghi put forward the concept of effective stress, and proved the effective stress $\sigma^{'}$ is equal to the total stress σ minus the pore water pressure p by the experiments. By its balance condition, we can get:

$$\sigma = \sigma_s + u_a + u_w \tag{2}$$

Where σ the total is stress; σ_s is the normal stress among the soil particles; u_a is the gas pressure; u_w is the water pressure. To the saturated soil;

$$\sigma = \sigma_s + u_w = \sigma^{'} + u \tag{3}$$

Where σ the total is stress; $\sigma^{'}$ is average stress on the contacted surface among the soil particles; u is the pore water pressure. The concept of the expressed by type (3) is the so called effective stress principle.

4. Mohr- Coulomb criterion;

Coulomb put forward the sandy soil shear strength expression according to sandy soil shear test in 1776;

$$\tau_f = \sigma \tan\varphi \tag{4}$$

Type(3) And Type (4) together is called the coulomb's formula. So, for the coulomb's formula, the soil effective stress intensity can be expressed as:

$$\left.\begin{aligned} \tau_f &= (\sigma - p)\tan\varphi' = \sigma'\tan\varphi' \\ \tau_f &= c' + (\sigma - p)\tan\varphi' = c' + \sigma'\tan\varphi' \end{aligned}\right\} \tag{5}$$

Later put forward the cohesive soil shear strength expression according to test results:

$$\tau_f = c + \sigma\tan\varphi \tag{6}$$

Where τ_f — soil shear strength,(kPa); σ —the normal stress on the shear section,(kPa); φ —sandy soil internal friction angle ,C—the soil cohesion ,kPa.

Where c' —the soil effective cohesion, φ' —the soil effective internal friction angle, σ' —the effective normal stress on the shear section, kPa , p —pore water pressure, kPa.

5. Morgenstern-Price method

Imagine that the sliding soil of a certain slope slide down along the slide plane y = y (x), see the figure 1 below. At this time, according to the definition of safety factor, the shear strength parameters of the soil mass and the slide plane have been reduced to c_e'、 $\tan\varphi_e'$.

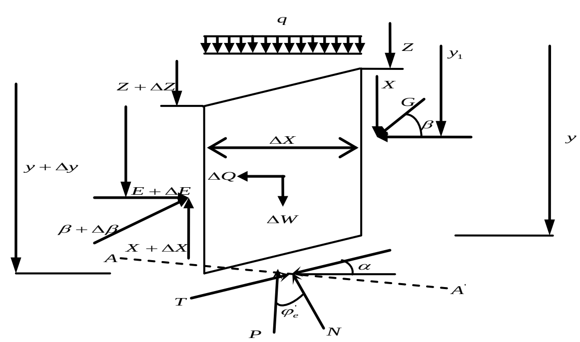

Fig 1 diagram of pressure on soil stripe

On the basis of the linearization, use the integral method on type 7, in the interval from x_i to $x_i + \Delta x_i$, we can obtain

$$E_{i+1} = \frac{1}{L + K\Delta x}\left(E_i L + \frac{N\Delta x^2}{2} + P\Delta x\right) \tag{7}$$

Start from first interface $E_0 = 0$ of the slope top, from top to bottom, solve the normal inter-slice force E_i article by article, and the last soil stripe must satisfy the conditions

$$E_n(F, \lambda) = 0 \tag{8}$$

Integrals the differential equation considering the E (a) = E (b) = 0, we get

$$M_n(F,\lambda) = \int_a^b \left(X - E\frac{dy}{dx}\right)dx - \int_a^b \frac{dQ}{dx}h_e dx = 0 \tag{9}$$

Morgenstem-Price method is a strict slice method.

6. Limit analysis method Lower bound theorem;

According to the related flow laws, the plastic strain rate vector $\dot{\varepsilon}_{ij}^{pc}$ should be perpendicular to the yield surface, and the stress vector σ_{ij}^0 satisfied the static fields are commonly within the yield surface, we can know that from the figure below

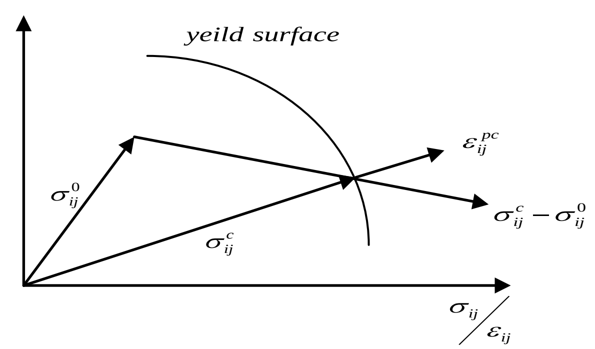

Fig 2.Velocity field

then $(\sigma_{ij}^c - \sigma_{ij}^0)\dot{\varepsilon}_{ij}^{pc} = 0$, (10)

The velocity discontinuity value $[\Delta v_i]$ is unknown in the real displacement field; but during the material shear process, $c - (\tau - \sigma_n \tan\varphi) \geq 0$,

so $[c - (\tau - \sigma_n \tan\varphi)][\Delta v_i] \geq 0$, (11)

then the formula (14) changed into

$$\int_A T_i^c \dot{u}_i^c dA + \int_V F_i^c \dot{u}_i^c dV \geq \int_A T_i \dot{u}_i^c dA + \int_V F_i \dot{u}_i^c dV \tag{12}$$

Type (12) shows that the structure limit load is equal to or greater than the load corresponding to the structure's any static stress field, that is, the loads solved from the structure's any static stress field are all the lower limits corresponding to the structure's limit state .

7. The strength reduction factor and the basic theory

(1) The strength reduction factor According to the Mohr-Coulomb criterion, the anti-shear strength of this point is:

$$\tau_f = c + (\sigma - p)\tan\varphi \tag{13}$$

When that point does not reached strength limit, the geotechnical soil shear strength does not fully play, then if the actual shear stress is τ for that point is:

$$\tau = c' + (\sigma - p)\tan\varphi' \tag{14}$$

The safety factor defined by Bishop Method is:

$$F_s = \frac{\tau_f}{\tau} = \frac{c + (\sigma - p)\tan\varphi}{\tau} \tag{15}$$

The safety factor defined by Duncan method is:

$$F_s = \frac{c}{c'} = \frac{\tan\varphi}{\tan\varphi'} \tag{16}$$

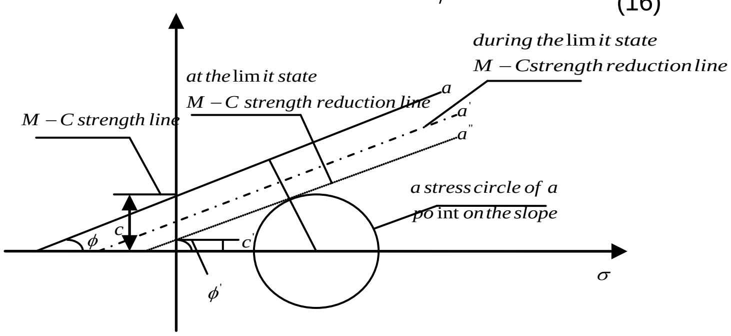

Fig.3

8. Simulation results;

(a) Under the condition of normal water level of the dam slope stability analysis From the maximum principal stress distribution figure 4 can be seen, due to stress concentration, landslides. Then compare the equivalent stress Figure 4 and figure 5, found the water makes the dam slope stress field produced very big change, seepage field on dam slope stability influence.

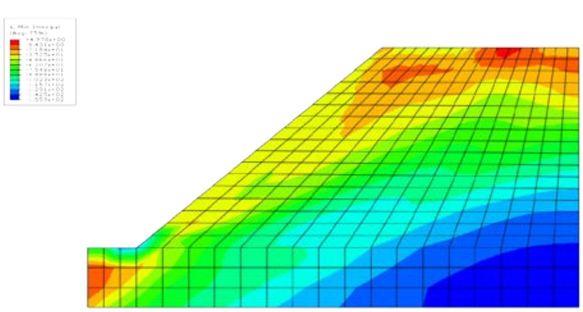

Fig 4 Max principal stress distribution

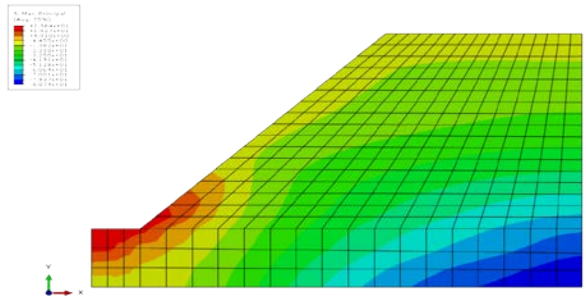

Fig. 5 Min principal stress distribution

(b)The analysis of the stability of dam slope after water level rose in the dam; For the more accurate research on the dam seepage role the effect on the stability of dam, now, water level will be heighten, to simulate the change of the seepage field to the stability of the dam body changes.

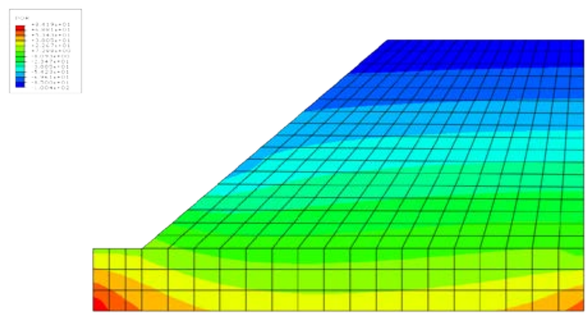

Fig.6 Diagram of penetrating velocity

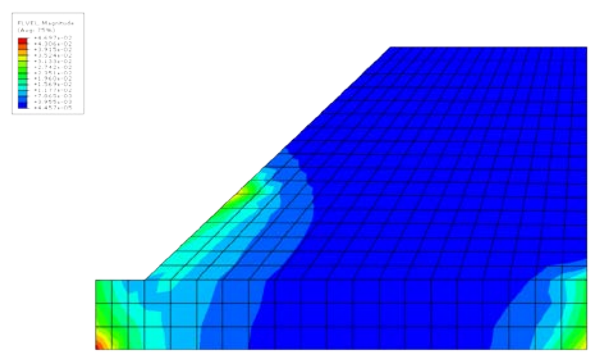

Fig. 7 Diagram of Pore water pressure distribution

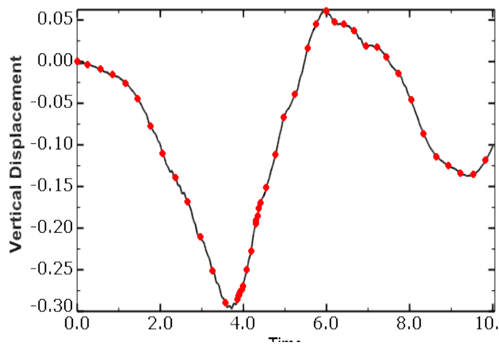

Fig.8 Dam inflection point displacement curves

9. CONCLUSION;

This paper researches the static and dynamic simulation analysis of the cracks' dynamic development in the slope stability and the process of the dam's unstable failure combined with the engineering practice and based on the effective stress principle, seepage theory, slope stability theory, damage theory and the strength reduction limited theory with the extended the finite element numerical simulation technology, and get the following main conclusion; Establish the damage instability mathematical model under the coupling of seepage field and stress field of the concrete dam The instability and the collapse of the dam is induced by both the action of earthquake and reservoir. The damage unstable failure analysis of the dam under the action of fluid-solid coupling is more closed to the actual situation, and it has important guiding value for the dam's construction.

10].References;

1) Spencer ,A Method of Analysis of Embankments Assuming Parallel Inter-slice Forces Geotechnique,1967
2) Runge-Kutta algorithm
3) Eulerian-Lagrangian fluid- shell coupling,
4) Soil structure characteristics and new approach in research on its quantitative parameters 26(6):1290~1296;
5) Geological Hazard andControl.2001, 12(1):18~21;[7].LIU ,Jinlong, etc.
6) Study on Stability of slope and Mechanisms of Deformation and Failure of Embankment
7) Institute of Rock & Soil Mechanics Chinese Academy of Sciences, 2006; Clough, R.W.
8) "Nonlinear Mechanisms in the Seismic Response of Arch Dams." Proc.Int. On Earthquake Engrg., 1980, Skopje, Yugoslavia.
9) Nuss, L.K. "Static and Dynamic Structural Linear Elastic Structural Analysis (EACD3D96) Morrow Point Dam."
10) Technical Memorandum No. MP-D8110-IE-2002-2, Technical Service Center, U.S.
11) Department of the Interior, Bureau of Reclamation, Denver, CO, September 2002.
12) Whirley, R.G. "DYNA3D: A Nonlinear, Explicit, Three-Dimensional Finite Element Code for Soil and Structural Mechanics."
13) Lawrence Livermore National Laboratory Report UCRL-MA-107254-REV-1.
14) Maker, B.N., Ferencz, R.M., and Hallquist, J.O.
15) "NIKE3D: A Nonlinear, Implicit, Three-Dimensional Finite Element Code for Solid and Structural Mechanics."
16) Lawrence Livermore National Laboratory