COMPARISON ANALYSIS AMONG DIFFERENT CALCULATION METHODS FOR THE STATIC STABILITY EVALUATION OF TAILING DAM

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Abstract. *The static stability evaluation of tailing dam is one of the most important tasks in the mine environmental protection project. The methods for the static stability calculation were discussed in this paper, which were Swedish Circle Method, Janbu Method, Bishop Method, Finite Element Method and Strength Reduction Finite Element Method (SRFEM) with five different failure criterions considered. The analysis results show that the failure surface simulated by SRFEM was closed to the result of classical method, and the safety factor by SRFEM with D-P3 failure criterion was much more closed to the one got from the Fellenius Method. So, it is feasible to evaluate the static stability of tailing dam through SRFEM. Also, it indicates that the finite element method and SRFEM are suitable to simulate practical engineering with the complicated cross section and non-linear materials.*

Keywords: *Tailing dam, SRFEM, Static stability evaluation.*

1. INTRODUCTION

The static stability analysis for tailing dam was started from 1930s using the limit equilibrium method originated from soil mechanics. After the finite element method was put forward in 1966, Clongh and other researchers started the strain and deformation analysis for earth dam. Then the Finite Element Method (FEM) was used for the evaluation of tailing dam. Till now the limit equilibrium method and strain stress analysis method are widely used in the static analysis of tailing dam and those methods were theoretically improved.

There were many factors which influenced the stability of tailing dam, such as material strength, ground water conditions and pore water pressure. However, there is no independent analysis system for tailing dam. All of the methods were from soil mechanics, such as Swedish Circle Method (1936), Janbu Method (1957), Bishop Method (1955), Morgenstern-Price Method (1965), Spencer Method (1967) and Sarma Method (1973). The main differences between those methods were the shape of failure surface and treatment for unknown variables.

Another important method for the static stability analysis is the finite element method. By this method, the stress distribution, the force in weak structure surface and failure could be got. Based on the finite element method, there were two different methods which were elastic-

plastic finite element method and strength reduction finite element method (SRFEM). The latter one is more popular now. Zheng Y. R. and Zhao S. Y. (in China) make great contributions to this method in theoretical research and its engineering applications [1-5].

In this paper, the comparative analysis for the static stability analysis of tailing dam was carried out by the Swedish Circle Method, Janbu Method, Bishop Method, Finite Element Method and SRFEM.

2. METHODS FOR STATIC STABILITY EVALUATION OF TAILING DAM

2.1. Traditional Method

The limit equilibrium method was based on the theory of Mohr-Coulomb. The function was

$$\tau_f = c' + \sigma' tan\phi' = c' + (\sigma - u) \cdot tan\phi' \tag{1}$$

Where τ_f is the shear stress on the slide surface, c' is the effective cohesion, σ is the total stress, σ' is effective normal stress, and ϕ' is the effective internal friction.

The safety factor was defined by the ratio of τ / τ_f which stands for the strength reserve coefficient for materials. Only the static stability conditions and Mohr-Coulomb failure criterion were considered in this method. There were many advantages for this method such as simplified calculation and easily used in practical engineering. But the relationship between stress and strain of soil cannot be got from this method. The three main methods based on the limit equilibrium method were Swedish Circle Method, Janbu Method and Bishop Method.

For the static stability analysis of this project the limit equilibrium methods were used through the Civil FEM module in ANSYS. The safety factors and slide surface can be got easily by this module.

2.2. Finite Element Method

(1) Finite Element Method

The stress and strain distribution of the whole tailing dam can be simulated by FEM. The first step was to get the value of each element. Then the stress distribution in each potential slide surface can be calculated through the transform of stress tensor. According to the concept of limit equilibrium method, the safety factor of each potential slide surface can be got [6-7].

(2) Strength Reduction Finite Element Method

The secondary development language APDL in ANSYS was used for the programming of SRFEM, because there is no existing module for this method. This program contains five main parts. (1) Create the finite element model and input material parameters. (2) Apply the loads and boundary conditions. (3) Set solution settings and input initial condition for rou-

tine. (4) Get the reduction factors and the displacement curve on the top of dam. (5) According to the curve of displacement and reduction factors, obtain the safety factor of tailing dam.

There are two instability criterions for SRFEM. One is when the FEM calculation is non-convergence. The other is when generalized plastic strain or equivalent plastic strain areas were connected from the toe to the top of the slope. According to the reference [8-9], the former one was thought to be much more reasonable for slope stability and it was used in this paper as the tailing dam instability criterion.

There are three parameters for Drucker-Prager (D-P) criterion in ANSYS. They are internal friction angle φ, cohesion c and dilatancy angle ψ. If $\psi = \varphi$, the rule is associated flow rule. If $\psi < \varphi$, the rule is non-associated flow rule.

In the ANSYS, the criterion is D-P1 criterion [10-11]. It means that the safety factors got from ANSYS was under D-P1 criterion. However, there are totally five different D-P criterions which can be converted using equation (2). By input different α and k, the equivalent c, φ can be got and used for the simulation without extra secondary development for new material model.

$$\begin{cases} \varphi_1 = \arcsin \dfrac{3\sqrt{3}\alpha_i}{2 + \sqrt{3}\alpha_i} \\ c_1 = \dfrac{\sqrt{3}k_i}{2\sqrt{(1 + 2\sqrt{3}\alpha_i)(1 - \sqrt{3}\alpha_i)}} \end{cases} \quad (i = 1,2,3,4,5) \quad (2)$$

Where α and k are separately related with internal friction angle and cohesion. For different D-P criterions, α and k represented different circle in π plane [11].

3 BACKGROUND OF PRACTICAL ENGINEERING

The height, width and length of tailing dam were separately 19m, 14m and 113m. The initial dam was constructed by sand stone mixtures. The sub dam was constructed by tailings and soil. The soil thickness covered in the dam surface was from 300mm to 500mm. There were 11 sub dams with 2m height each. The dam scene photo and section selected for calculations of this dam were shown in Fig. 1.

According to the mechanical model shown in Fig. 1, the finite element model was created and meshed shown in Fig. 2. The boundary conditions were added including horizontal constraints in both two sides, and full constraints in the bottom of the model. The load applied in this model was only gravity. The material parameters for calculation were listed in table 1.
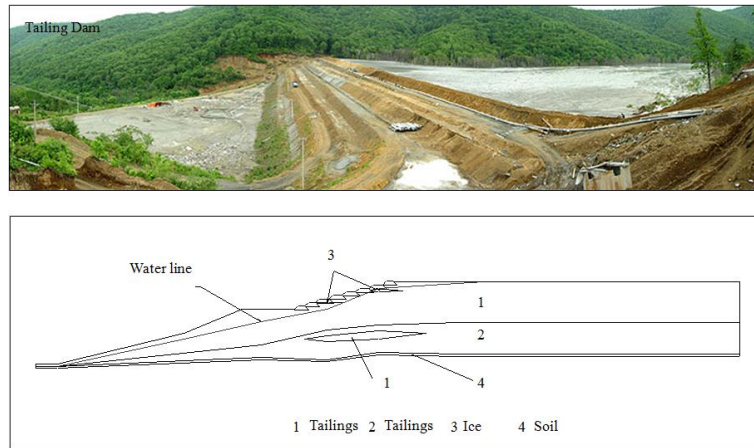
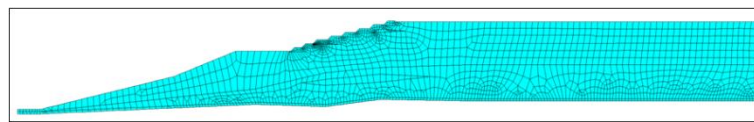Fig. 1 The scene photo and section for calculations

Fig.2 Finite element model of tailing dam

Table 1 Mechanical properties of material

Material Number	Material name	Gravity density （kN/m）	Compression modulus （MPa）	Poisson ratio	Cohesion （kPa）	Internal friction angle （°）
1	Silt sand of tailing	18.4	10.9	0.3	4.2	24
2	Silt soil of tailing	19.5	10.4	0.35	23.8	20
3	Ice layer	16.2	4.5	0.4	0	5.6
4	Natural soil	20.0	7.2	0.35	40	23

4 RESULTS FROM DIFFERENT METHODS

The static stability factors were directly calculated by limit equilibrium method and finite element method using Civil FEM module in ANSYS software. The strength reduction finite element method was realized through the secondary development language APDL of ANSYS.

The slide surfaces got from tradition limit equilibrium method and failure areas calculated by SRFEM were separately shown in Fig. 3 and Fig. 4. The safety factors were listed in table 2 and table 3.
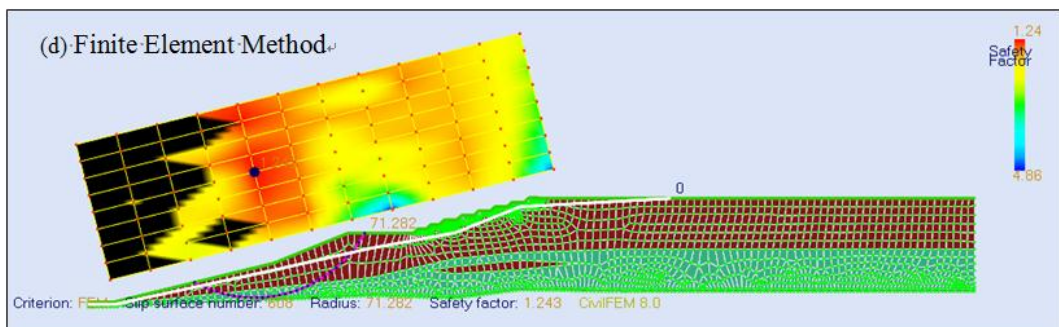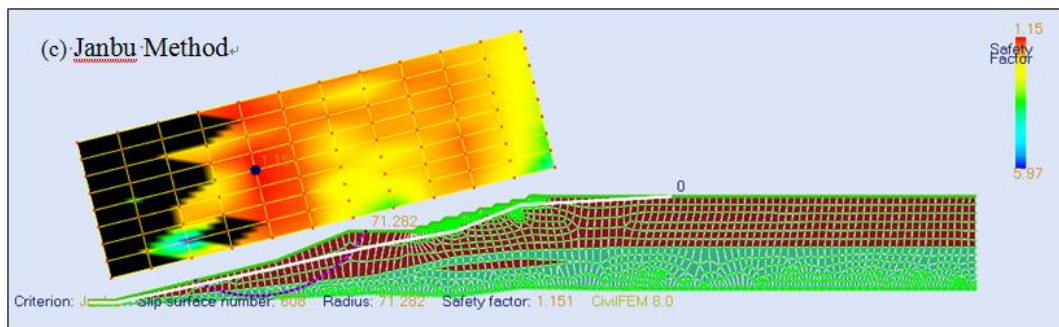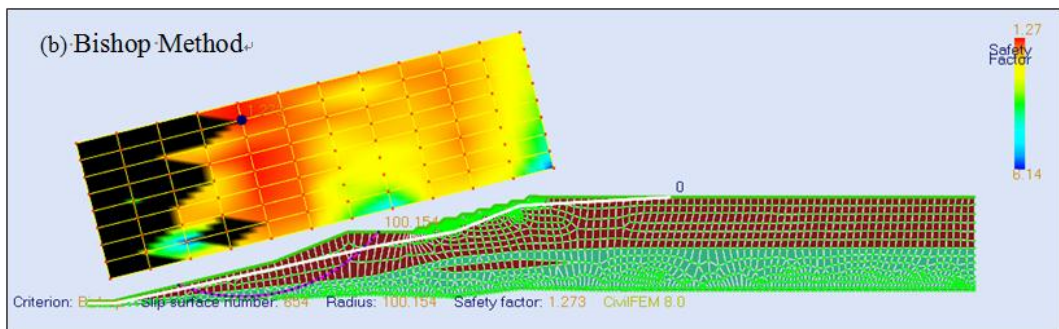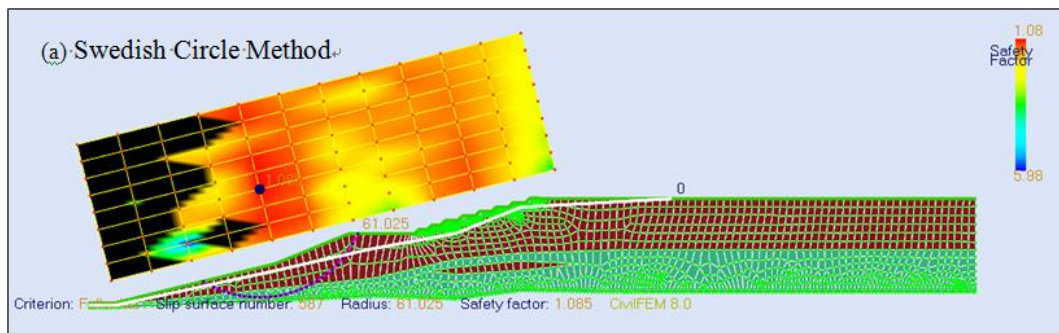
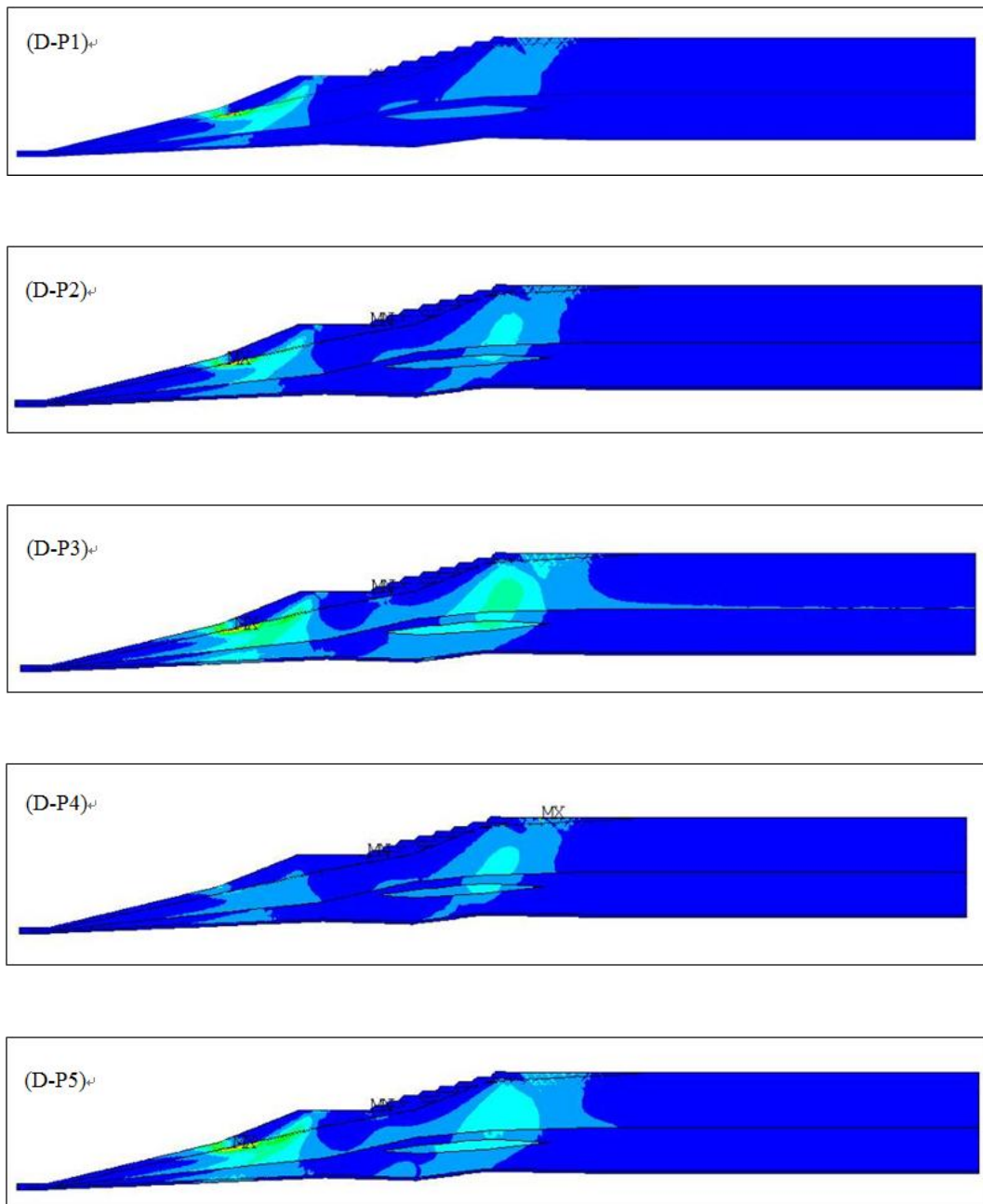Fig. 3 Typical slide surface from traditional method

Fig. 4 The failure surface calculated by SRFEM with different D-P criterions

Table 2 Safety factors calculated by tradition limit equilibrium of tailings dam

Method	Swedish Circle Method	Bishop Method	Janbu Method	Finite element method
Safety factors	1.085	1.273	1.151	1.243

Table 3 Safety factors calculated by SRFEM with different D-P criterions

D-P criterions	D-P1	D-P2	D-P3	D-P4	D-P5
Safety factors	1.56	1.26	1.17	1.12	1.24

5 RESULTS COMPARISONS

The potential slide surfaces calculated by the traditional method were almost the same which were all in the initial dam. The smallest safety factor was the one got from Swedish Circle Method.

From the study of strength reduction finite element method, the ideal elastic-plastic model was selected for the static stability calculation of tailing dam. The results show that it was feasible and superior to calculate safety factor by SRFEM.

With the different D-P criterions, the slide surfaces were basically identical and they were closed to the traditional method. The factor simulated by D-P1 criterion was the biggest. The other four factors were much closed to those by traditional method and finite element method.

The plastic strain areas calculated with D-P3 and D-P5 criterion were connected from the toe to the top of the initial dam. The potential slide surface calculated with D-P3 criterion was much more closed to the one by limit equilibrium method, shown in the Fig.3. So the safety factor with D-P3 criterion was recommended for the static stability evaluation of tailing dam.

6 CONCLUSIONS

The traditional limit equilibrium method, finite element method and strength reduction finite element method were introduced in this paper. From the results comparison analysis among different methods, the following conclusions can be got.

(1) The SRFEM was feasible for the static stability evaluation for tailing dam.

(2) From the safety factors and slide surface comparison among different calculations methods, the D-P3 criterion was more priority if the SRFEM was used for the static stability evaluation of tailing dam.

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