Precision Analysis of Strength Reduction FEM based on ABAQUS

Jialong Liu[1, 2, a], Qiaojia Yang[1, b], Qiufen Hu[1, c]

[1]College of Civil Engineering & Architecture, China Three Gorges University, Yichang 443002, China

[2]Collaborative Innovation Center for Geo-Hazards and Eco-Environment in Three Gorges Area, Yichang 443002, China

[a]190222591@qq.com, [b]982319036@qq.com, [c]386981752@qq.com

Abstract. Strength reduction FEM has been the concern of the majority of researchers and engineers in recent years, which is one of the strength reduction methods to calculate safety coefficients. The precision of strength reduction FEM is affected by many factors from existing researches, and the finite element mesh has a great influence on the calculated results. By comparing the safety coefficients of four different density mesh models of a 2D example, some conclusions are getting as follows: Safety coefficients are approaching to the exact solution when the mesh is fine enough, and a balance of time and accuracy can be achieved through local mesh refinement.

Keywords: Geotechnical Engineering; ABAQUS; Strength Reduction FEM; Accuracy; Mesh.

1. Introduction

Slope stability analysis has been an important research area of geotechnical engineering since the ordinary method of slices was developed by Wolman Fellini's as a result of slope failures in sensitive clays in 1927 [1]. Duncan presented a detailed review of equilibrium methods of slope stability analysis in 1996 [2]. These methods are the ordinary method of slices, force equilibrium methods, Bishop's modified method, Jamb's generalized procedure of Slices, M-P method and Spencer's method. Those limit equilibrium methods need some assumptions, for example, the side forces and their directions, have to be given out before the calculation in order to build the equilibrium equations. Finite element method does not have those disadvantages. There are no assumptions needs to be made about the side forces and their directions. Soil displacement field, stress field and plastic zone can be obtained by finite element analysis. But we can't get a stability coefficient to evaluate the stability of slope directly. With the development of personal computer, finite element method has been increasingly used in slope stability analysis [3, 4]. FEM strength reduction method is a method that can be used to get the stability coefficient. Although there are some researches have been done about FEM strength reduction method, this method is still relatively a new method for some reasons. Different yield criterion, the boundary conditions, the density of mesh and the methods of choosing rock and soil mechanic parameter have a big influence on calculation accuracy. The influence of the density of mesh on calculation accuracy by FEM strength reduction method has been studied in this paper.

2. Application of strength reduction FEM in ABAQUS

Strength reduction FEM is proposed by Sienkiewicz et al. (1975) [5]. The basic idea is to reduce shear strength parameters until the reduced strength parameters c_m and φ_m bring the slope to the failure state. In this method, the reduced shear strength parameters c_m and φ_m are given by

$$c_m = c / F_r \qquad \varphi_m = \arctan\left(\tan\varphi / F_r \right) \tag{1}$$

Where F_r a strength reduction is factor, c and φ is the original shear strength parameters. The value of F_r is the factor of safety (FOS) when the slope failure occurs and $FOS=F_r$. This definition of FOS is identical to that used in the limit equilibrium methods.

Material parameters change with field variables in ABAQUS, so field variables can be defined as strength reduction factors. The main calculation processes are as follows: first, define the material parameters by gradually increasing the strength reduction factor; second, apply gravity load on the model and balance the stress state; third, to deal with the calculation results and get the factor of safety.

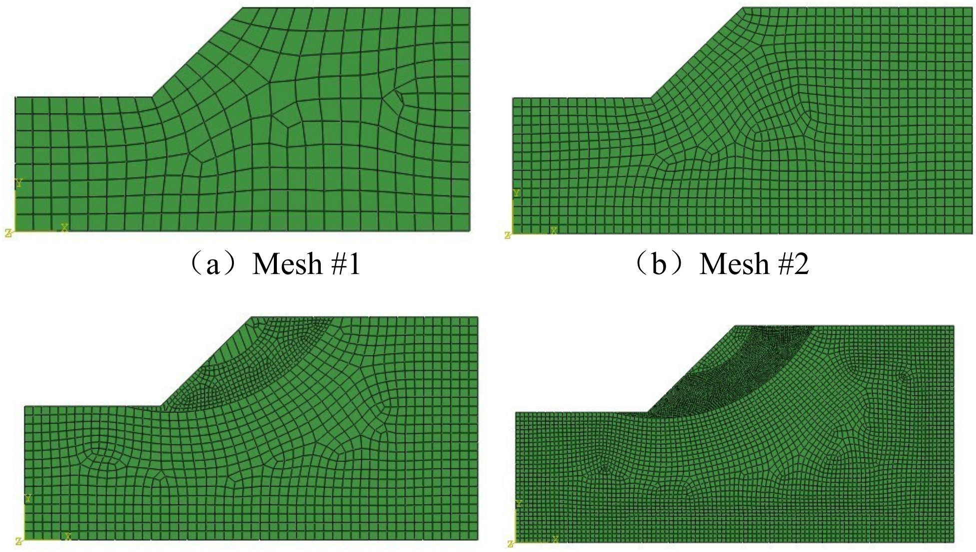
3. The Calculation Model and Parameters

In the finite element calculation, grid generation has a considerable effect on calculation precision. The density of grid should not be too high or too low. In the process of calculations, when we chose the same material model, we found out that the rougher the grid's model, the bigger the factor of safety. In order to analyze the calculation accuracy of Strength Reduction FEM, four different densities of grid are selected. The model of slope is an example used in some references. The slope height is 20m, and the inclination angle of slope is 45°. The Calculation material parameters are shown in table 1.

Table 1 the Calculation Material Parameters

Cohesion c (kPa)	Angle of internal Friction φ (°)	Volume weight γ (kN/m3)	Young's modulus E (kPa)	Poisson's ratio v
42	17	20	1.0*105	0.3

This example of slope was simplified as a two-dimensional plane strain problem. Mohr-Coulomb Failure Criterion provided by ABAQUS was adopted. Finite element model mesh uses the quadrilateral elements. There are four different finite element mesh sizes. The side length is 1/5 of the slope height for mesh number 1. The value of the side length is 4m. The side length is 1/10 of the slope height for mesh number 2. The value of the side length is 2m. Local grid refinement was adopted for mesh number 3 and mesh number 4. The local grid refinement area is the region of the large equivalent plastic strain. Mesh number 3 is the same as mesh number 2 except the local grid refinement area, the value of the side length in the local grid refinement is 0.5m. The side length of mesh number 4 is a half of mesh number 2, the value is 1m. The value of the side length in the local grid refinement is 0.33m. The four calculation models are shown in Figure 1. For mesh number 1, the number of nodes is 278, the number of elements is 240. For mesh number 2, the number of nodes is 1109, the number of elements is 1036. For mesh number 3, the number of nodes is 1471, the number of elements is 1334. For mesh number 4, the number of nodes is 7288, the number of elements is 6954.



(a) Mesh #1 (b) Mesh #2

(c) Mesh #3 (d) Mesh #4

Fig.1 Different densities of grid

4. Comparative analyses of calculation results

There are three kinds of slope failure criteria of strength reduction finite element method to get the factor of safety. They are the abruptness of the displacement, the non-convergence of solution and the connectivity of plastic zone. The three kinds of slope failure criteria are consistent and uniform. There are some disadvantages for the abruptness of the displacement and the connectivity of plastic zone. So the non-convergence of solution criterion is selected in this model. The non-convergence of solution criterion is very convenient and reliable in Abacus. The factors of safety can be obtained through changing the field variables. We assume that there is no absolute error for mesh number 4. And the absolute errors of factor safety for each mesh numbers can be obtained. The results are shown in Table 2. The absolute errors of FOS is 0 for Mesh #4, but the computing time is 20 minutes. Mesh #1 and Mesh #2 have a short computing time, but their absolute errors of FOS are greater than 1%. So Mesh #3 is the best calculation model.

Table 2 the calculation results under different conditions

Mesh Number	1	2	3	4
FOS	1.3888	1.3675	1.3486	1.3480
Absolute errors of FOS	0.0303	0.0145	0.0004	0
Computing time（min）	3	5	12	20

5. Conclusion

Through the analysis of calculation results we draw the following conclusions:

(1) The calculation accuracy of strength reduction FEM is closely related to the mesh model. The rougher the grid's model, the bigger the absolute errors of FOS.

(2) Using the local grid refinement method can get good results and save time.

(3) When the side length is 1/20 of the slope height, we can obtain very good results that balance the computing time and calculation accuracy.

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