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Research the Effect on Bedding Slope Stability of Angle between Weak Intercalation Strata and Slope Surface

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Abstract: Analysis of slope instability is an important research topic in subgrade engineering and it is of great significance to analyze main control factors of slope instability. Weak intercalation is one of the main factors to control the stability of rock, particularly those mudding interlayer, which is a very weak structural surface. In condition of containing mudstone interlayer, this paper mainly consider the effect on gently inclined bedding slope stability of angle between weak intercalation strata and slope surface. By means of three-dimensional numerical analysis, conclusion is obtained: without considering the effect of fissure water, when angle between weak intercalation strata and slope surface is 5° ~20°, the impact of bedding should be fully considered because it has great influence on the slope; when the angle is more than 30 °, the bedding slide of slope can be ignored, and slope treatment can be as general.

Keywords: *weak intercalation; angle between weak intercalation strata and slope surface; bedding slope; strength reduction; finite element; stability*

1. Introduction

Instability analysis of bedding slope has been the technical difficulty of the project construction. Improper handling of bedding slope will increase substantial investment and cause schedule delay. In 1997, Jiang Jueguang conducted a detailed survey about rock slopes of domestic 12 railway lines and found that: most of railway rock slope all be bedding slope. In bedding slope area, regardless of the steepness of slope gradient, as long as the slope is greater than the strata inclination and rock strata inclination is greater than 15°, bedding slumping or sliding phenomena nearly all have occurred. Even some of Red-bed soft rock side slope with bedding in alternating layers of sandstone and mudstone, strata dip bedding-slip phenomenon occurs less than 10°. For example, in the K174 + 800 of Cheng-South Expressway, scattered flat push slip occurred, but inclination of slip surface is just 6° [1].

Weak intercalation refers to hard rock filled with soft rock of low mechanical strength, high content of mud or carbon, extend longer and thin thickness [2]. Internal weak intercalation often becomes the main factor of slope instability. Weak intercalation is discontinuity in the rock surface, and due to its poor physical and mechanical properties, it often brings a series of questions to the project and becomes controlled weak surface in underground caverns, slope stability, dam foundation and dam abutment stability against sliding [3]. It should be noted that weak intercalation is the result of geological evolution. It distributes in rigid-flexible rock combination that relatively hard in the upper and lower and relatively weak in the middle. Tectonic movement caused mutual dislocation between layers and rock crushing, and strength is greatly reduced.

Weak intercalation in layered rock mass has important implications for the overall stability of the rock, even under certain conditions control the stability of rock mass [4]. Song Zengxiang believes that in condition of slope containing weak intercalation rock mass, c-value accessor methods should consider the effect of excavation and blasting, thereby reducing 40%~60%; c-value can be neglected when shallow sliding [5]. Through the three-dimensional elastic-plastic numerical simulation with slope containing weak intercalation, Yuan Wei concludes that compared with the three-dimensional homogeneous slope, safety factor of three-dimensional weak intercalation slope is much lower, damage surface range is wider, concentrated phenomenon in plastic strain area is more obvious, and damage mode is significantly different [6]. For weak structural plane, Feng Zhijun put forward methods and principles that according to the filling thickness or density to determine the shear strength parameters [7]. Theoretical method of bedding rock slope damage is difficult to describe the process, so numerical simulation has become a breakthrough and is gaining more and more attention [8].Relied on typical sections of Fuling-Fengdu-Shizhu highway engineering in Chongqing, this paper selected c , φ value and used strength reduction method to do three-dimensional numerical simulation on sandstone dipping bedding slope contained weak mudstone interlayer. Through displacement of features points, value of critical angle was determined. When exceeding critical angle, bedding slip of slope cannot be considered, which provide the basis for similar engineering problems.

2. Basic Principle of Strength Reduction

Strength reduction was first proposed by Zienkiewicz and is widely used by many scholars latter. They proposed a concept of shear strength reduction factor, which is defined as ratio of the maximum shear strength offered by soil and actual shear stress generated by external loads in the case of external loads remain unchanged. In extreme case, actual shear stress produced by external loads and the minimum shear strength to resist external load which is reduced in accordance with the actual strength index and practice to play is equal. When assumed that all soil shear strength of the slope play the same extent, the shear strength reduction factor is equal to the traditionally monolithic stability safety factor , also known as strength safety margin and is same in the concept with stability safety factor given in limit equilibrium method [9].

Shear strength parameters after reduction can be expressed as

$$c_m = c / F_r \quad (1)$$

$$\varphi_m = \arctan(\tan\varphi / F_r) \quad (2)$$

In above formulas, c and φ is the shear strength of soils could provide; φ_m and c_m is actual shear strength to maintain the balance; F_r is strength reduction factor.

Assume different strength reduction factor F_r to calculate strength parameters. Based on the reduced strength parameters, do finite element analysis to observer whether convergence. Continue to increase F_r to reach critical damage strength, at this time F_r is F_s .

The main evaluation criteria of judging slope reaches critical damage are the following:

(1) Convergence or not is the evaluation criteria, associated with finite element algorithm.
(2) Displacement inflection point of the characteristic parts is the evaluation criteria.
(3) Whether to form a continuous transfixion zone are the evaluation criteria.

3. Model Foundation

3.1. Early Basic Assumptions

This article uses the ABAQUS finite element software to carry on three-dimensional modelling and numerical analysis, the fundamental assumptions of which are as follows: Weak intercalation only shear from the toe of slope; Lithology is sandstone interlayered by weak mudstone; Rock layers mutually parallel; Do not consider the effect of fissure water; Compared with the thickness of the entire rock layer, the thickness of the weak intercalation is very thin. Model uses the following parameters.

Table 1: *Model parameters*

Lithologic	Natural weight (kN/m^3)	Elastic Modulus (MPa)	Poisson ratio	φ (°)	C (kPa)
mudstone inter bed	25.74	2306	0.29	28	100
sandstone	25.18	4609	0.17	35.4	1793

3.2. Model size

The height of the sandstone and mudstone bedding cutting slope is 12m in the thesis, with 1:1 of slope ratio. The specific size of the model and labeling of critical points are as shown in Fig. 1.

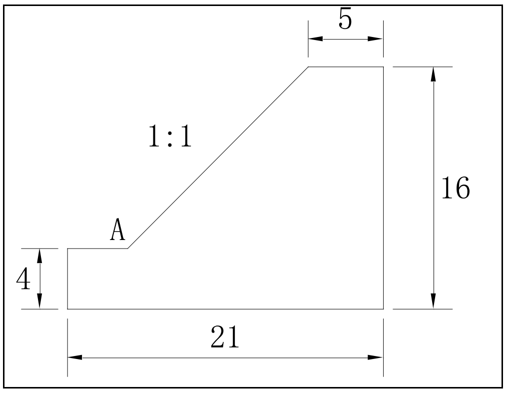


Fig. 1 *Model dimensions*

3.3. Strength reduction method in this case

From the perspective of principle of strength reduction, strength in the slope is reduced by gradually decreasing c, φ values, which leads to a certain unit of the model exceeds the yield strength and excessive stress will be distributed into the surrounding structural units. When appears continuous transfixion zone, slope will be overall instability. Therefore, in ABAQUS the value of c and φ decreasing or increasing gradually can be achieved by defining field variable parameters. And then the reduced material parameters can be used as new ones in the process of finite element tentative calculation. When the result converges, takes reduction factor slightly larger and then recalculates until the finite element diverges. In this case, rock reaches a critical limit state and the slope has the shearing damage and meanwhile, critical displacement and safety factors can be acquired.

Specifically, c and φ values of sandstone is decreased gradually according to formula (1) and (2). Parameters can be selected on the basis of table 2.

Table 2: *Sandstone cohesion and strength reduction of internal friction angle*

Reduction factor	φ (°)	c (kPa)
0.50	54.87	3586.00

0.85	39.90	2109.41
1.25	29.62	1434.40
1.40	26.91	1280.71
1.75	22.10	1024.57
2.00	19.56	896.50
3.10	12.91	578.39

4. Nephogram Characteristic of Horizontal Displacement and PEEQ (Equivalent plastic strain)

In this paper, three-dimensional finite element numerical analysis is adopted to establish model as angle from 0° (weak intercalation parallel to the slope surface) to 40°. Weak intercalation varies with angle, but A(0,0,8) is a slope feet point has been always in the intersection of weak intercalation and slope, so select point A as the feature point and record its horizontal displacement ($F_r = 1$ that not reduction) to reflect slope deformation better. Different reduction coefficients are selected to perform trail, and the computed result is obtained through simulated operation of ABAQUS software. The development of equivalent plastic zone is shown with nephogram. When there is no continuous transfixion zone or partial yield damage occurs, it indicates that the slope at the reduction coefficient is stable; reduction coefficients continuously increase. When plastic strain increases excessively iteration between adjacent or equivalent plastic strain reaches the yield limit in some points, plastic strain results display that plastic zone has been through the slope top, and equivalent plastic strain and displacement has infinite development trend and distinct mutation. At this moment, slope has been already in a critical damage condition, and the strength reduction factor is defined the minimum safety factor of overall stability.

Under normal circumstances, with the graphical visualization technology, non-convergence in computing, slope displacement map and plastic displacement map is overall considered for purpose of judging the damages of slopes. This model is divided into a total of 3,664 grids. The grid model in calculating, nephogram of horizontal displacement and PEEQ are shown as follows.

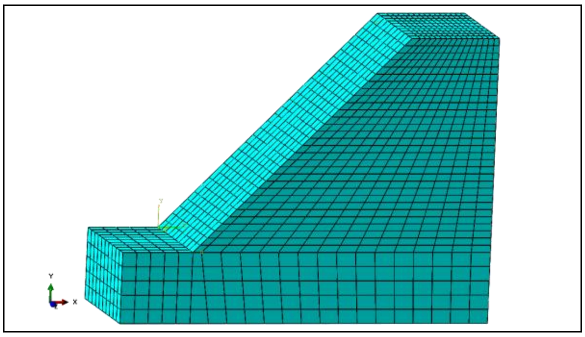


***Fig.2** Model meshing*

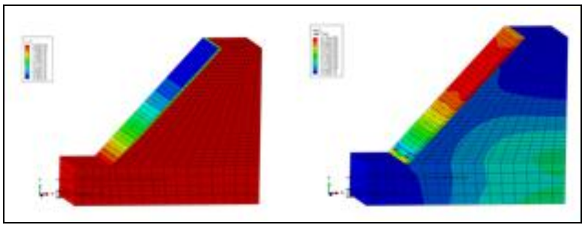


***Fig.3** Nephogram of horizontal displacement and PEEQ at 0°*

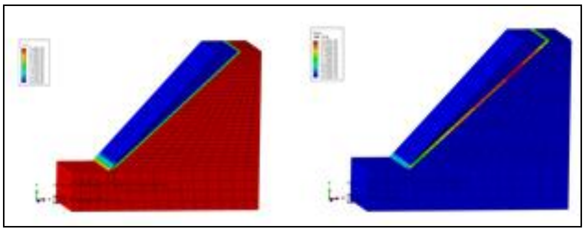


***Fig.4** Nephogram of horizontal displacement and PEEQ at 5°*

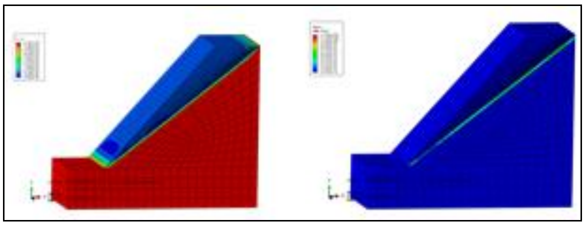


***Fig.5** Nephogram of horizontal displacement and PEEQ at 10°*

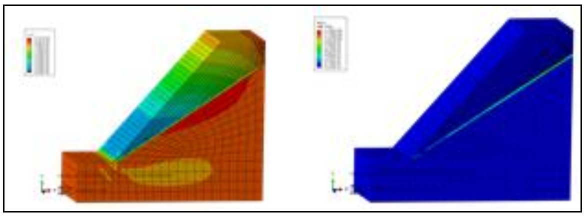


***Fig.6** Nephogram of horizontal displacement and PEEQ at 15°*

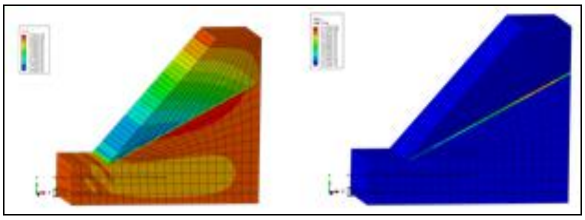


***Fig.7** Nephogram of horizontal displacement and PEEQ at 20°*

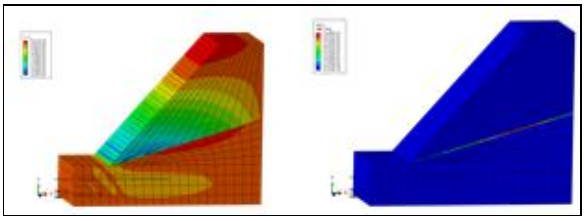


***Fig.8** Nephogram of horizontal displacement and PEEQ at 30°*

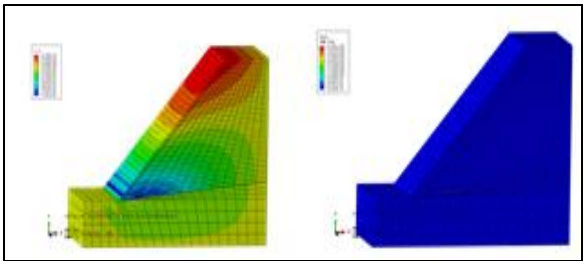
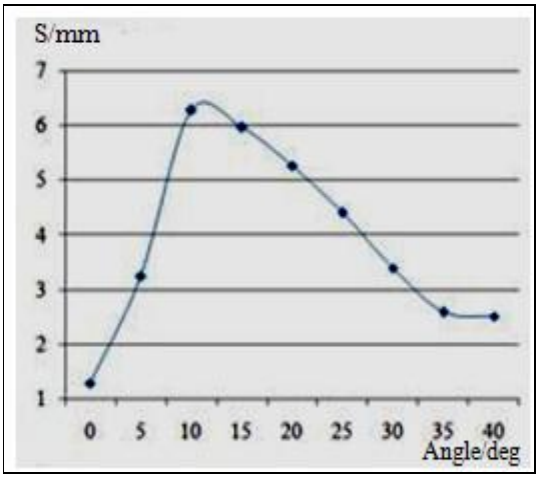


Fig.9 *Nephogram of horizontal displacement and PEEQ at 40°*

In Figure 3 to 9, slope cut at the foot. When the angle is 0°, because there is no shear opening, slope is relative stable; once there is angle, displacement of slope and plastic deformation quickly increases. Nephogram of PEEQ is plastic strain state of slope in limit equilibrium. At this time, from the foot of the slope to the top has completely through and the strength reduction factor is the safety factor.

Horizontal displacement of key point A（0，0，8）is shown in Figure 10.

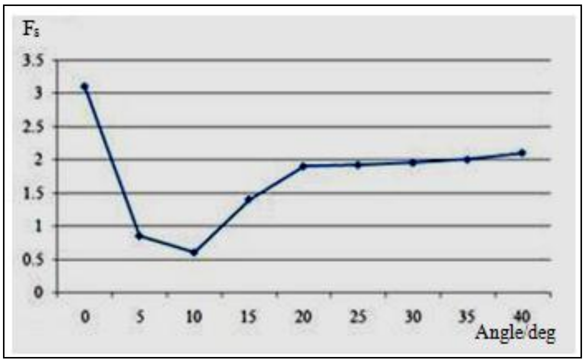


S-Horizontal displacement
Angle- the angle between weak intercalation strata and slope surface

Fig.10 *Changing characteristics of key point horizontal displacement with the angle*

Figure 10 shows that: When weak intercalation parallel to the slope surface, because there is no shear opening, slope is relatively stable and horizontal displacement is small; As the angle increases, horizontal displacement increases rapidly and reaches the maximum at 10°, then decreases; When the angle is greater than 30°, horizontal displacement is flattening.

Based on various angles, assume different strength reduction factors to calculate. When FEM just does not converge, reduction factor is the minimum safety factor of the slope. Changing characteristics of safety factor following different angle between weak intercalation strata and slope surface is shown in Figure 11.



F_S- safety factor of the slope
Angle- the angle between weak intercalation strata and slope surface

Fig.11 *Changing characteristics of slope safety factor with the angle*

As shown in Figure 11, changing characteristics of safety factor and horizontal displacement following different angle between weak intercalation strata and slope surface is identical. When weak intercalation parallel to the slope surface, slope is relatively stable and safety factor is relatively high; As the angle increases, horizontal displacement increases rapidly while safety factor quickly reduces and reaches the minimum at 10°, then increases; When the angle is greater than 30°, horizontal displacement and safety factor is flattening.

5. Conclusion

By numerical simulation and horizontal displacement of key points with angle, we can see: When weak intercalation exists in bedding slope and it only cut from slope foot, stability is better if weak intercalation is parallel to the bedding slope. When angle between weak intercalation strata and slope surface is 10°, there is a significant inflection point in horizontal displacement and safety factor while influence of weak intercalation on slope is the most. When angle is greater than 30°, impact on the stability of slope is less to consider. So conclusion is draw as follows:

(1) For the sand-mudstone bedding slope with weak intercalation, if the effect of fissure water is not considered, when angle between weak intercalation strata and slope surface is 5° ~20°, influence of bedding is great on the slope, and the maximum occurs in 10°. So effect of bedding should be taken full account to set targeted protection measures.

(2) When angle between weak intercalation strata and slope surface is more than 30°, influence on the slope is less. So the bedding slide of slope can be ignored and slope treatment can be as general.

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