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The failure mechanism of gentle incline rock slope during the process of rock cell retreating

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Abstract: The main inducement for collapse disaster of gentle incline rock slope is differential weathering, and for rock breakage of it is rock cell. On the study of gentle incline rock slope in this paper, we established the mechanics mode of arbitrary rock in gentle incline rock slope, analyzed the failure mechanism of gentle incline rock slope during the process of rock cell retreat, and established the distinguish method of its stability based on fracture mechanics. Then, taking the rock mass slope of JIMINGSHAN in CHENGKOU as an example, analyzed the stability change law of each rock block during the process of rock cell retreated. The study result of this essay can provide certain theoretical foundation for the prevention of disaster of gentle incline rock slope.

1. INTRODUCTION

The differential weathering is the inducement of the collapse of the gentle incline rock slope. Generally speaking, the upper part of the gentle incline rock slope is rock mass, which weathered slowly and easily in the form of cliff. The lower part is soft rock, weathering faster and often forming a rock cavity. The more the differential weathering, the deeper the rock cell, and the worse the stability of the upper rock mass. When the depth of the rock cavity exceeds the critical depth, the upper rock mass will collapse. So, the rock cell is the pacemaker to gentle incline rock slope collapse disaster.

The destruction of rock slope has the characteristics of sudden and strong destructiveness, so many scholars have carried out relevant researches at home and abroad. S. G. Lee and his team took typical layered rock slope in South Korea's to study the stability of the slope by analyzing the strength of the structural plane in rock mass slope and its combination mechanism, which has been verified by UDEC software[1]. Ke Zhang and his team analyzed the evolution process of unstability of rock slope which includes joint by fracture mechanics and strength reduction method[2]. N. W. Xu and his team analyzed rock slope's stability which based on finite element software and damage mechanics[3-6]. S. K. Shukla analyzed the stability when earthquake, fissure water and overload at the top of slope act together to the rock slope[7]. Lin-feng Wang and his team studied the failure mechanism when rock slope is cutted by a set of structural plane which based on fracture mechanics[8]. In summary, for their lack of the study of gentle incline rock slope failure mechanism caused by rock cell expanding, this paper will analyze the avalanche mechanism in different parts of a cliff.

2. Stability analysis of complex gentle incline rock slope

Complex gentle incline rock slope means stratum with gentle dip and two or more structural planes inside the slope(Fig.1). As showed in Fig.1, besides the horizontal strata, there are two sets of structural planes: parallel to the slope and perpendicular to the slope. The rock slope is divided into many parts



because of the interaction of these three structural planes, so its distructiness is different from that with one single structural plane and it may be a whole rock slope or a few pieces of rock mass. Therefore, ordinary analysis method of slope stability is not available. In order to analyze conveniently, the rocks are numbered layer from bottom to top, surface to inside. The typical failure mode of gentle incline rock slope is soft and hard interlayer rock slope. Because the weathering speed of soft rock is faster than hard rock, it will generate cavity at the intersection of soft rock and hard rock which make the hard rock suspend in air. Once the depth of the cavity exceeds its limit, the hard rock will began to damage. In such kind of rock slope, the number of vertical suspended rock column will be the crucial factor of slope instability. Professor Hong-kai Chen, who proposed the Chain Law, defined each of the vertical suspended rock column as a macro chain.



Fig.1 Complex rock mass slope with gentle dip

Only when one macro chain rock block is suspend in the air, it as the figure 2 shows the mechanical mode of any suspended rock(called i# block). The height of i# block is H_i, the thickness is B_i, the length of structural plane is a_i , and e_{li} is the water-filling depth of structural plane. The load on the rock block consists of self-weight W_i, vertical earthquake force P_{vi}, horizontal earthquake force P_{Li}, fissure water pressure P_{wi}, thermal stress σ_{Ti} , interlayer pressure q'_{i+1} and q'_i, interlayer shear stress τ'_{i+1} and τ'_i .

When the moment, tensile force and shear force work together on the i# rock block, the stress intensity factor of master control plane as follow:

$$K_{IIi} = 1.12\tau_i \sqrt{\pi a_i} \tag{1}$$

$$K_{12i} = F(a_i)\sigma_{i\max}\sqrt{\pi a_i}$$
⁽²⁾

$$K_{I3i} = 1.12\sigma_i \sqrt{\pi a_i} \tag{3}$$

$$\overline{u}_i = \frac{1}{2} p_{\rm wi} \tag{4}$$

$$\tau_i = \frac{T_i}{H_i} \tag{5}$$

$$F(a_i) = 1.122 - 1.40R_i + 7.33R_i^2 - 13.08R_i^3 + 14.00R_i^4$$
(6)

$$\sigma_{\rm imax} = \frac{6M_i}{H_i^2} \tag{7}$$

$$R_i = \frac{a_i}{H_i} \tag{8}$$

$$\sigma_i = \frac{N_i}{H_i} \tag{9}$$



Fig.2 Mechanical diagram of NO. i# block

Under the action of temperature stress, the stress intensity factor is

$$K_{I4i} = 1.12\sigma_{Ti}\sqrt{\pi a_i} \tag{10}$$

So, the I mode stress intensity factor of master control plane is

K

$$_{Ii} = K_{I1i} + K_{I2i} + K_{I3i} + K_{I4i}$$
(11)

According to equation (1) and (11), the combined stress intensity factor and fracture angle is

$$K_{ei} = \cos\frac{\theta_{0i}}{2} \left(K_{Ii} \cos^2\frac{\theta_{0i}}{2} - \frac{3}{2} K_{IIi} \sin\theta_{0i} \right)$$
(12)

$$\theta_{0i} = \pm \arccos \frac{3K_{IIi}^2 + \sqrt{K_{Ii}^4 + 8K_{Ii}^2 K_{IIi}^2}}{K_{Ii}^2 + 9K_{IIi}^2}$$
(13)

Then the stability coefficient of i # rock is

$$F_{si} = \frac{K_{IC}}{K_{ei}} \tag{14}$$

Finally, according to the stability coefficient of each rock, it will determine whether collapsing or not and then obtain the failure mode of slope.

3. THE FAILURE MECHANISM OF COMPLEX SLOPE DURING ROCK CAVITY EXPANDING

3.1 Stability analysis of rock in different rock cell depth

This paper will takes rock slope of *JIMINGSHAN in CHENGKOU* as an example (Fig.3). The height of the slope from cavity bottom to the top is 25m. The lithology of this slope mainly consists of sandstone and mudstone, the upper part of the rock cell is made of three layer sandstones and the rock cell depth is 4m,the parameters of each rock are shown in table 1.

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Fig. 3 JIMINGSHAN rock mass slope rock mass slope(m)

Finite element method is used to analyze rock slope stability change law in different rock cell depths and the dimension of the model is shown in Fig.4, meshing model is shown in Fig.5. The stress intensity factor of each rock block shows in table 2, according to stress intensity factor K_I and K_{II} in table 2 can obtain stability coefficient(table2). Due to K_I is bigger than K_{II} , the plane back of the rock block failure mainly result from tensile stress. With the rock cell depth increasing, the gap between K_I and K_{II} is more obvious. Taking advantage of the results in table 2 to make the stability coefficient curve of different rock cavity depth which is shown in Fig.6.With the rock cell depth increasing, the coefficient of stability decrease is shown in Fig.6, and at the beginning of the rock cell's depth increasing, rock's stability coefficient decrease quicklier than later. Meanwhile, the decreasing speed of stability of 3# rock is the fastest, the second is 2# rock, 1# is the lowest, and with the increasing of rock cell's depth, the speed of stability coefficient decrease more and more slowly. When the rock cell's depth reaches 4m, all rocks are instability. The stability coefficient of rock 2# is the minimum 1.08, the second is rock 3# 1.13, the biggest is rock 1# 1.28. Therefore, the structural plane at the back of 2# and 3# rock will joint first, then together with rock 1#, which means when the slope failure, rock 1#, 2# and 3# will collapse together.

Table1 Blocks' parameters											
Rock's number	Height/ m	Thickne ss/m	Structural plane's depth/m	Unit weight/kN/ m ³	Elasticity modulus/MPa	Poisson's ratio					
1#	9	4	3.00	25	40000	0.25					
2#	6	4	2.00	25	40000	0.25					
3#	8	4	2.67	25	40000	0.25					



Fig. 4 Dimension for numerical model of JIMINGSHAN rock mass slope (m)

Fig.5 Mesh figure for numerical model of JIMINGSHAN rock mass slope

Rock cell depth	Rock's number	K _I	K _I K _{II}	K _E	Fracture toughness	Fs
m		$kPa \cdot m^{1/2}$	$kPa \cdot m^{1/2}$	$kPa \cdot m^{1/2}$	$kPa \cdot m^{1/2}$	
	1#	195.79	39.16	206.82	2096.00	10.13
1	2#	60.83	36.12	83.39	2096.00	25.14
	3#	63.60	14.30	68.07	2096.00	30.79
	1#	415.09	107.03	452.56	2096.00	4.63
2	2#	110.49	85.12	170.94	2096.00	12.26
	3#	137.34	37.35	151.00	2096.00	13.88
	1#	890.96	193.79	949.69	2096.00	2.21
3	2#	327.31	132.75	392.89	2096.00	5.33
	3#	403.79	85.01	428.83	2096.00	4.89
	1#	1632.20	54.66	1634.94	2096.00	1.28
4	2#	1916.10	205.02	1948.37	2096.00	1.08
	3#	1823.60	210.13	1859.11	2096.00	1.13

Table2 The result of blocks' stability coefficient with different rock cell depth



Fig.6 The result of blocks' stability coefficient with different rock cell depth

4. CONCLUSION

(1)This paper takes the gentle incline rock slope as the research object, analyzing the failure mechanism of gentle incline rock slope during rock cell expanding.

(2)This paper established a rock mechanical mode of gentle cline rock slope and provided a distinguish approach of stability which based on fracture mechanics.

(3) Taking rock slope of *JIMINGSHAN in CHENGKOU* as an example to analyze a rock's stability change law during rock cell expanding.

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