

## A positive reinforcement method for rock slope

(Extended Abstract)

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### 1. Introduction

From the viewpoint of mechanism, the approaches of slope reinforcement can be classified into two categories, the passive and the positive reinforcement. Essentially, the positive reinforcement is a protection system which relies on the synergistic action of rock mass and engineering structures to fully develop the self-bearing capacity.

Take the slope reinforcement as example, the current concept is to control the behavior of disaster using artificial structure, which can be called passive reinforcement theory. It concentrates more on the negative effect of geological disasters caused by deformation and destruction of slope, but ignored the positive function of the self-bearing capacity of slope rock. Therefore, the passive reinforcement is usually relatively conservative, and thus the cost is larger.

The current procedure of slope reinforcement design is: predict the shape and position of the potential sliding surface through field investigation, and then calculate the sliding force along the assumed surface; decide the controlling points according to the distribution of sliding force along the surface, and then, the support or anchoring system can be designed.

Obviously, such design doesn't fully consider and make use of the self-bearing capacity of slope rock. In order to minimize the risk, as many anchor bolts or piles as possible will be set to control the break of slope.

Generally speaking, positive reinforcement of rock engineering is a subject in exploration. The paper is to initiate the terms of potentiality of slope self-stability and positive reinforcement, propose the method for locating of anchor bolts/cables and determination of force and depth of anchorage. The calculation in the method is done with the software Flac3D by Itasca Co. Ltd and developed modules.

### 2. Potential self-stability of slope and positive reinforcement

#### • Potential slope self-stability

The potential slope self-stability (PSS) means the capacity of a slope to maintain stable under natural states. This potentiality can be fully developed while the slope reaches the critical state of instable and failure.

The PSS in rock slope has the characteristic of self-organization. By modifying the existing circumstances of rock with engineering measures, the potential capability can be activated towards different level favorable to the slope stability.

The PSS depends mainly on the slope geological structure, i.e. the combination of geo-material, dominant low-strength structural surfaces and the free surface of slope, slope stress field and the interaction of these two factors.

Definitely, slope stress field is the driving force of slope deformation and failure. However, on the other hand, the stress influences the strength property of the slope rock mass.

According to Mohr-Coulomb theory, the compressive strength,  $\sigma_1$  of any rock element is positive-linearly correlated with the lateral compression stress,  $\sigma_3$ , i.e.,

$$\sigma_1 = \sigma_3 \tan^2 \theta + \sigma_c, \quad \left( \theta = \frac{\pi}{4} + \frac{\varphi}{2} \right) \quad (1)$$

where  $\varphi$  is the internal friction angle of rock mass.

The formula (1) indicates that the strength of slope rock mass is influenced not only by the internal friction angle  $\varphi$  and uniaxial compression stress  $\sigma_c$  of rock material, but also by the lateral stress  $\sigma_3$ . Since  $\tan^2 \theta \gg 1$ ,

the contribution of  $\sigma_3$  is remarkable.

• Positive reinforcement of slope

In essence, slope protection project depends on the cooperation between slope rock mass and engineering structure. It aims at maximizing the utilization of the strength capacity of rock mass with its self-adjustment. This is called “positive reinforcement (PR)”.

From the contribution to PSS analysed above, we can modify the stress condition and improve PSS of slope by pre-stressed artificial structure. This measure provides assistant condition for the stress self-adjustment in rock mass.

**3. Positive reinforcement method of slope based on self-adjustment of PSS**

• Requirement for reinforcement

We can obtain the cloud charts of  $\sigma_1$  and  $\sigma_3$  through the calculation of slope stress field. Meanwhile, using Morh-Coulumb model, we can also calculate the critical value of lateral stress,  $\sigma_{3c}$ , with which the rock mass could keep from being broken, that is

$$\sigma_{3c} = \frac{\sigma_1 - \sigma_c}{\tan^2 \theta} \quad (2)$$

We define the difference between actually existed  $\sigma_3$  and the critical lateral stress  $\sigma_{3c}$  at the corresponding point in slope rock mass as

$$\Delta \sigma_3 = \sigma_3 - \sigma_{3c} = \sigma_3 - \frac{\sigma_1 - \sigma_c}{\tan^2 \theta} \quad (3)$$

Obviously, the lower the value of  $\Delta \sigma_3$  is, the higher the requirement for reinforcement. The negative value of  $\Delta \sigma_3$  indicates the demanded reinforcement force at the point.

Fig.1 shows the  $\Delta \sigma_3$  value distribution in a typical slope. It is usually affirmative that the position with lowest PSS often appears at the surface, and more specifically, located at lower 1/3 to 2/3 of the slope surface. This means that reinforcement can be normally applied by adding force on slope surface, particularly at the middle and lower part of slope surface. In experience, anchorage is a more efficient choice for the measure.

• Stability Factor

We can also define the Stability Factor in the traditional way of limit equilibrium method.

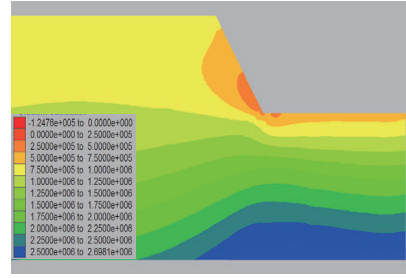


Fig. 1 Cloud chart of  $\Delta \sigma_3$  value

Since the shear stress and shear strength at any point in rock slope are respectively,

$$\tau = \frac{\sigma_1 - \sigma_3}{2} \sin 2\theta ,$$

$$\tau_c = \frac{\sigma_1 - \sigma_{3c}}{2} \sin 2\theta ,$$

then the stability factor,  $K$ , at the point can be written as

$$K = \frac{\tau_c}{\tau} = \frac{\sigma_1 - \sigma_{3c}}{\sigma_1 - \sigma_3} \quad (4)$$

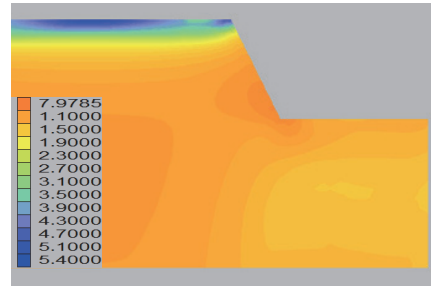


Fig. 2 Distribution of stability factor in slope

Using the equation above, we can estimate the local stability of rock mass and obtain its distribution in the slope.

Figure 2 shows the cloud chart of stability factor in a slope calculated by equation (4). Compared with figure 2, we can see that in both of the two, the stability factor and PSS are well fitted to each other.

• Anchorage force

According to the requirement of the designing safety factor, the pre-stress for anchorage,  $\sigma_{3K}$ , can be calculated based on equation (4), i.e.,

$$\sigma_{3K} = \sigma_1 \left(1 - \frac{1}{K}\right) + \frac{\sigma_{3c}}{K} \quad (5)$$

The lateral compression stress at this time is

$$\Delta\sigma_3 = \sigma_3 - \sigma_{3K} = \sigma_3 - \sigma_1 + \frac{1}{K}(\sigma_1 - \sigma_{3c}). \quad (6)$$

If the area covered by each anchor cable (bolt) is  $A$ , the anchoring force of single anchor should be

$$F = \Delta\sigma_3 A = A[\sigma_3 - \sigma_{3K} = \sigma_3 - \sigma_1 + \frac{1}{K}(\sigma_1 - \sigma_{3c})]. \quad (7)$$

• Anchoring direction and depth

Based on the distribution of stability factor in rock slope, the length of anchor cable (bolt) can be figured out.

For instance, if the safety factor is required to be  $K=1.2$  according to the technical standards, then the anchorage cable can be extended to the area where the stability factor is larger than 1.2 (Fig. 3).

The anchorage direction can be designed referring to the contour trend of stability factor, i.e. approximately perpendicular to the extending direction of the contour of  $K$ .

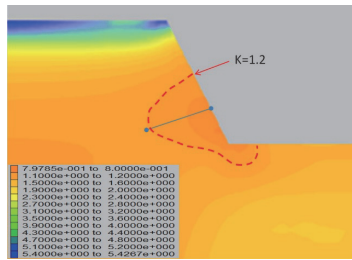


Fig 3 The depth and direction of anchorage cable

4. Conclusion Remarks

Different from passive reinforcement, the positive reinforcement advocate making full use of the bearing capacity of rock mass with appropriate reinforcement approaches in order to guarantee rock mass maintaining in stable. From the opinion of the potentiality of self-stability, the idea of positive reinforcement is proposed which is to maximize the utilization of self-bearing capacity of rock mass, with its self-adjustment and the interaction of rock mass and artificial structures. Based on this idea, the software Flac3D and Mohr-Coulomb model are applied to analyze the stress field and safety factor in rock engineering like slopes and tunnels, then determine the reinforcing area and the reinforcement demand degree  $\Delta\sigma_3$ .

The procedure of the proposed method is designed after analyzing the influence of geological structure slope. For slopes with general shape, the suitable position for reinforcement is located at the 1/3 to 1/2 of height from the slope toe.

References

Zhong Li (2008), Calculation method for active slope reinforcement based on stress control in critical slip surface, Chinese Journal of Rock Mechanics and Engineering. Vol. 27, No.5, pp, 979-989