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Analytical simulation of passive and pre-tensioned grouted rockbolts performances in bedding rock slopes

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ABSTRACT: Rockbolts are one of the best systems to stabilize plane failure of rock slopes. The passive bolts are loaded and activated when rock block slides while pre-tensioned types are initially loaded before any rock sliding. The pre-tensioned rock bolts make the rock layers pressed together and the friction between them is activated before slipping, and probably no displacement between the layers is occurred. If a slippage occurs after the installation of a pre-tensioned rock-bolt, an excessive load is applied. In this paper, the bolt contribution generated by the pre-tensioned and passive rock-bolt in discontinuity is analytically simulated, and the effect of roughness angle, inclination of the bolt to the joint plane, pre-tensioned force, and strength of the rock are evaluated. For modeling, it is assumed the sliding imposes a bending moment to the rockbolt, which leads two plastic hinges to be created. The part of the bolt between two hinges (located on either side of the joint) is considered a beam with two cantilever supports, which is loaded by a uniform distribution generated by surrounding grout/ rock. The results showed that the pre-tensioned rock-bolts are effective when the resistance of the rock or grout around the bolt is high.

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1. INTRODUCTION

Rock-bolts are one of the most popular systems of stabilizing in rock engineering. They are used to restrain sliding of a rock block on a single dipping out of the face or to confine movements of stratified rock masses along joints in rock slope engineering. Grouted bolts have often been found to be more economical and more effective than other types of rock-bolts. The grouting effect makes a rock-bolt to be more rigid through having contact with surrounding rock, thereby efficiently restricting sliding displacements.

Grouted rock-bolts can be installed as passive or pre-tensioned bolts. In passive type, a small sliding of a rock block is necessary to activate bolts and mobilize forces. A shear and a tension force are induced in the bolt due to respectively confinement of movements perpendicular and parallel to the sliding plane [1-7]. However, pre-tensioned bolts are installed under tension prior to any rock block sliding. The purpose of pre-tensioning is to modify the resulting normal stress on the sliding plane, and hence, increase the resistance shear strength against sliding movement. Therefore, for the pre-tensioned grouted rock-bolts, two mechanisms can be expected:

-The pre-tensioned force or the resulted normal stress is so great that it prevents any sliding. In this case, no further forces are developed in rock-bolts, and grouting the reminder of bolt length has no influence on its behavior, but will only protect the bolt from corrosion.

-The pre-tensioned rock-bolts cannot completely prevent sliding of rock block due to, e.g. increase of external load on block, generation of a water pressure, creep, etc. In this case, the rock-bolt is also subjected to a shear and a tension force (originated from rock blocks sliding) like passive bolts. Therefore, the bolt contribution is first initiated by the pre-tensioned force and then by the subsequent axial and shear forces.

In spite of the many achievements that have already been made for the design of passive grouted rock bolts, there are still some inconveniences and insufficiencies that need to be overcome. The effects of pre-tensioning of bolts on bolt contribution and joint roughness has not been adequately studied. As well, the rock strength in the interaction between the joint and bolt has been ignored in the previous studies. Hence, this paper presents an analytical model to bridge these gaps.

2. ANALYTICAL SIMULATION

The installation process of a pre-tensioned grouted rock-bolt consists of placing a grouted anchor, tensioning of the bolt, tying near end of the bolt by nut and plate to the rock block surface, and then injecting the grout into the remaining bolt length. Once a pre-tensioned force is applied to the bolt, the normal force and its corresponding stress on the joint plane increases, and as a result, the shear strength of the joint is much more stimulated. However, if the additional shear strength is not sufficient to prevent rock block sliding, a bolted rock joint will be subjected to a shear displacement,

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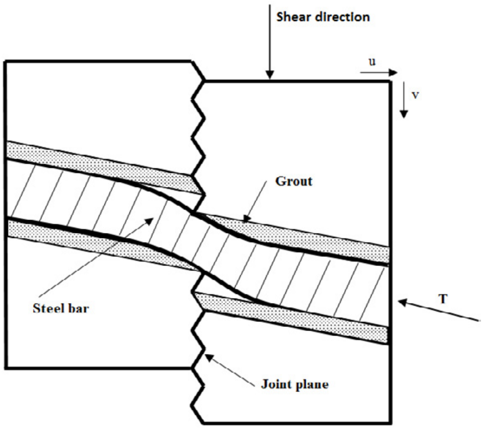

Fig. 1. Antisymmetric deflection of bolt and it separation from the grout when joint subjected to shearing

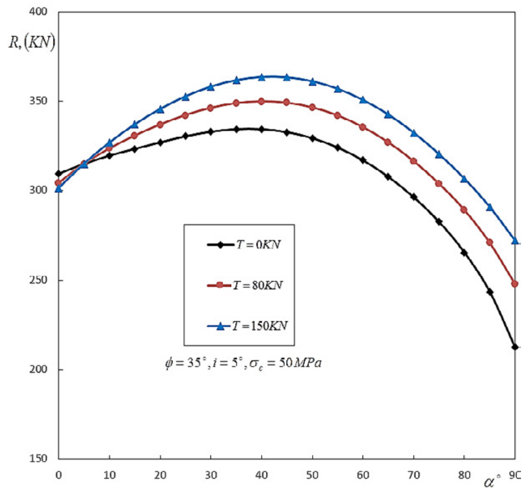

Fig. 3. Influence of pre-tensioned load on the contribution of pre-tensioned bolts

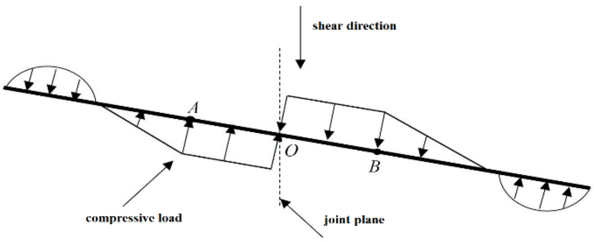

Fig. 2. Plastic joints formation at points A and B due to a shear displacement, and load distribution on bolt from surrounding medium reaction

and additional forces will be imposed to the bolt. That is, a shear and an axial force are developed in the bolt due to respectively sliding and opening of joint. At the same time, the bolt applies resistant forces to the joint and increase the shear strength. Fig. 1 depicts a bolted rock joint subjected to shearing. The bolt deflects anti-symmetrically concerning the joint plane and is separated from the grout in the vicinity of the joint.

According to Fig. 2, after yielding, two plastic hinges are created in bolt (A and B) [2-7].

The contribution of pre-tensioned bolt to support a joint against sliding are:

$$R_Q = Q_O \sin\alpha - Q_O \cos\alpha \tan(\phi_r + i)$$

$$R_{(N+T)} = (N_O + T)\cos\alpha + (N_O + T)\sin\alpha \tan(\phi_r + i) \quad (1)$$

3. SENSITIVE ANALYSES

In continue, sensitive analyses are performed to find out the weight of some effective parameters. The resistance force provided by the bolt to prevent sliding of joint is effected by the angle between the bolt axis and joint plane (α); the roughness and friction angles of rock joint (i and ϕ);the uniaxial compressive strength of the rock/grout (σ_c); the mechanical properties of bolt; and the pre-tensioned force (T).

4. RESULTS AND DISCUSSION

According to the Tresca strength criterion, the axial capacity of a steel bolt for loading is greater than the shear one. Therefore, if the axial capacity of bolt is more stimulated, the contribution of bolt will be more highlighted. Thus, for greater roughness angles, it seems that the total resistance is more likely to be great enough to prevent sliding when the bolt is perpendicular to the joint plane. However, the inclination value in which a bolt gives the greatest contribution is not unique but mostly depends upon roughness angle i.e. in this case, it almost equals to sum of friction and roughness angles. However, the bolt contribution quickly falls with a unique rate (for all cases) from its maximum to the minimum values once the inclination angle becomes greater. Therefore, considering the same bolt inclination, the cases with lower pre-tensioned force or roughness experience more dropping of bolt contribution. Also, a greater rock strength leads the distance between the plastic hinges to be smaller and so forth, the resistance forces developed by the bolt deformation to be less. Therefore, the pre-tensioning bolt for the high-strength rocks is more effective than the low strength rocks.

5. CONCLUSIONS

The results showed that the maximum bolt contribution occurs when the combination of the axial force and the shear force creates in the bolt and the minimum bolt contribution is created when the bolt is completely perpendicular to the joint plane. To prevent the creation of shear force in the bolt, we can put the bolt under the initial tensioning force to use the axial capacity of bolt. So, the pre-tensioned force is a high effect on the bolt contribution especially for the high strengths of rock. In general, under the following conditions, the active rock-bolts are suitable rather than the passive ones:

1- when the rock-bolt is steeply inclined to the rock joint.

2- when the roughness angle of rock joint is low.
3- when the strengths of rock is high.

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