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Numerical Modeling for Cable Bolting System under Axial Loading

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Abstract: The reinforcement of the rock by bolting system is a frequent process to ensure the stability of the underground gate (mines, civil engineering). Although the reinforcement technology is controlled perfectly, but the description of the mechanical behavior of reinforcement and its interaction with the rock mass are not clearly explained. The objective of our research is to understand, using simulation of laboratory test, the various mechanisms of failure of the reinforcement with cable bolting system and to purpose a more effective reinforcing in static or dynamic conditions in underground gate.

Key words: Numerical modelling, geotechnical, reinforcement, cable bolting, pull out test

INTRODUCTION

Reinforcement element in UDEC code: Reinforcement consists of tendons (i.e., cables) or bolts installed in holes drilled in the rock mass. Two types of reinforcement model are provided in UDEC: *Local* and *global* reinforcement. A local reinforcement model "CABLE command" considers only the local effect of reinforcement where it passes through existing discontinuities. A global reinforcement model "Reinforce command" considers the presence of the reinforcement along its entire length throughout the rock mass. In this paper, we are simulated with the "CABLE command". Cable elements in UDEC allow the modelling of a shearing resistance along their length, as provided by the shear resistance (bond) between the grout and either the cable or the host medium. The cable is assumed to be divided into a number of segments of length L, with nodal points located at each segment end. The mass of each segment is lumped at the nodal points, as shown in Fig. 1 (Itasca Consulting Group, 1993).

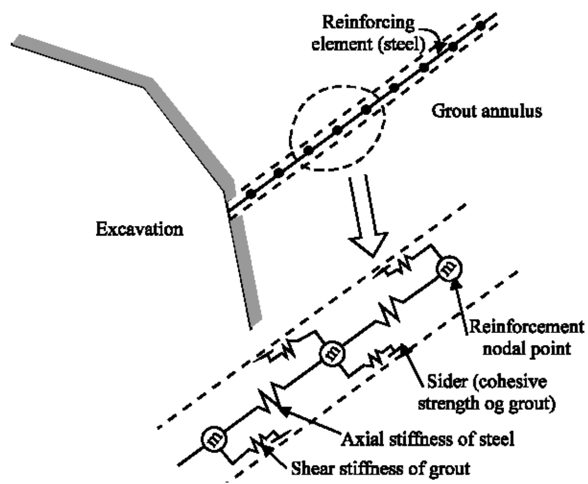

Fig. 1: Conceptual mechanical representation (Itasca Consulting Group, 1993)

Simulation of pull out test with "CABLE" command
Properties of cablebolt "standard Flexibolt":

- Length of cablebolt =900 mm
- Tensile strength = 355 kN
- Shear strength = 345 kN
- Axial deformation at the elastic phase = 12 mm
- Axial deformation at the rupture phase = 20 mm

Properties of the blocks:

- Density = 2.4 t m^{-3}
- Modulus of deformation (G) = 7800 MN m^{-1}
- Modulus of rigidity (K) = 10400 MN m^{-1}

Properties of the joint:

- Normal stiffness = 0.1 MN m^{-1}
- Shear stiffness = 0.1 MN m^{-1}
- Cohesion = 0

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- Angle of friction = 0
- Tensile strength = 0

Properties of grout:

- Cohesion = 3 MN m^{-1}
- Shear stiffness = 140 MN m^{-1}

SIMULATION OF A PULL OUT TEST

In a pull out test, it is the axial behavior of the bolt which is predetermining (Fig. 2). In the "UDEC" code, it is the "Cable" command which takes into account this behavior. For the "Reinforce" command, it highlights more the tangential behavior than axial. For this reason during our interpretation of the results for the pull out test, we interested more in the results of the "Cable" command than the "Reinforce" command.

Geometry of the model: The model consists of two juxtaposed blocks of 2 m on 2 m. The two blocks are recut perpendicular to their face of contact by a bolt (Fig. 3). The joint between the two blocks is supposed to be opened; it thus does not intervene in the simulation of the test.

Boundary conditions: For block 2, we impose a null horizontal and vertical displacement on all the faces (Fig. 4). Also, we impose null vertical displacements on the higher and lower face of block 1.

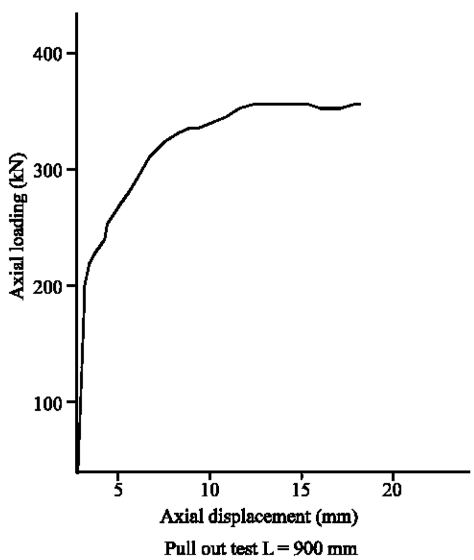

Fig. 2: Test results at the laboratory for cablebolt "Flexibolt" (CESC, 1994)

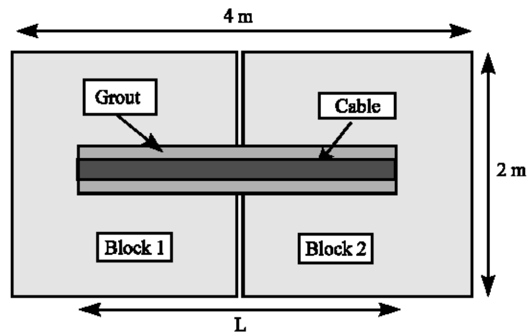

Fig. 3: Geometry of model

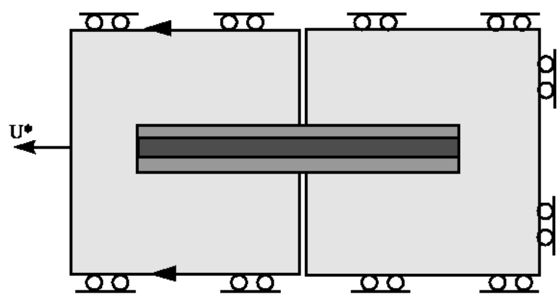

Fig. 4: Boundary conditions imposed

To simulate the wrenching of the bolt, a horizontal velocity (U) is applied. According to the various pull out tests of carried out in laboratories, the rate loading varies 1-10 mm s^{-1}, the author announces that this factor does not have a great influence on the test flow (Moosavi, 1997). For our simulation, we note that a rate of 5 mm s^{-1} remains valid. This rate of displacement is applied to the facet of block 1. This imposed rate of displacement induced wrenching strength in the bolt which increases until the simulated rupture.

For the computer codes of the finite elements type (no explicit resolution of the equations strength/ displacements), we cannot impose a velocity like boundary conditions (Kaiser *et al.*, 1992). In this case, the boundary conditions will be displacements like imposed forces. While proceeding in an incremental way, we build the curves requested.

Interpretations of the results: In various calculations of sensitivity, we notice that the behavior of the bolt passes by three phases (Fig. 5):

Elastic phase (1): This phase is assured as long as the ultimate axial capacity of the bolt is not reached.

Plastic phase (2): As soon as the bolt reaches its ultimate axial capacity, it enter in plasticity behavior.

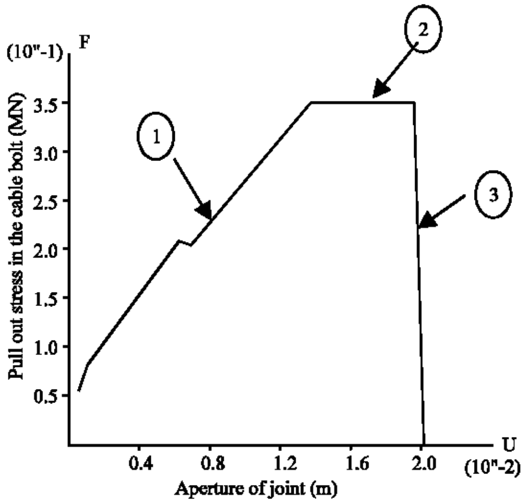

Fig. 5: Behavior of the bolt during the simulation of a pull out test with the UDEC code

Rupture phase (3): This phase will take place when the bolt reached its ultimate axial deformation.

MODES OF RUPTURE OBSERVED WITH "CABLE" COMMAND OF UDEC CODE:

- Grout Rupture (without rupture of steel): Rupture in sliding mode → interface grout/bolt. 2) Rupture the grout then steel → Rupture in extension mode

In the various calculations of sensitivity, we noticed two types of rupture (Fig. 6).

The rupture in extension: This mode of rupture passes by two phases:

Rupture of sealing: This mode of rupture is reached when the tangential constraints in the medium (block) exceed the shear strength ultimate of sealing, this state results in the cancellation of the tangential stress in sealing.

Rupture of steel: After the rupture of sealing, a transfer of load is observed to sealing towards steel. The steel undergoes a significant axial deformation and enter in rupture as soon as its maximum deformation is exceeded.

Rupture in sliding: This mode of rupture is represented by a significant relaxation of the shearing force in sealing without this effort being null, the nonnull value explains nonthe rupture of sealing. The effort of wrenching in the steel is slackened with a more significant value.

For the properties of sealing, we attribute to the value cohesion the value shear strength ultimate to the interface

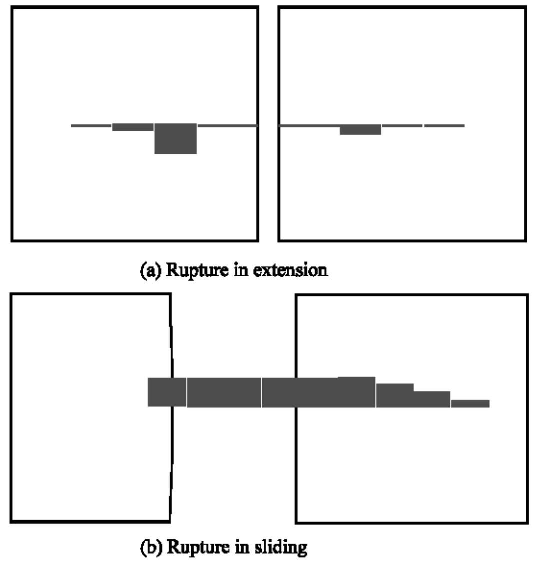

Fig. 6: Modes of rupture in the simulation of a pull out test with UDEC

bolt/sealing, given from the pull out tests. This method thus permits to take account of the surface roughness of the borehole and the resistance of the grout.

The breaking load increases linearly with the anchored length. Beyond a certain length, the breaking load remains constant and equal to the rupture limit load of the stem (bolt). The rupture of the grout generates a transfer of stress towards anchoring as this rupture progresses. This rupture modifies not only stresses shear along the contact stem/grout but also those acting along the contact grout/rock.

Study of sensitivity: For the pull out test, our study concern sensitivity which concerns:

- Influence of the parameters of the bolt (steel);
- Influence of the parameters of sealing (grout);
- Influence length of anchoring.

Parameters of the bolt (steel):

- We noted that when the properties of the bolt (steel) are increased, the mode of rupture passes from a mode of rupture by extension to a mode of rupture by slip owing to the fact that the bolt becomes more resistant than sealing.
- In various calculations of sensitivity, the rupture of sealing always takes place before the rupture of the bolt (steel). Indeed, before the rupture of sealing, a stress concentration appears at the end tended of anchoring, with a progressive reduction towards the

other end of the anchored part. With this phase, the displacement at the tended stem increases linearly with the load. After the initiation of the rupture, the curve of displacement becomes nonlinear and displacement strongly increases with the load as the rupture of the grout progresses towards anchoring.

It is also noticed that when the characteristics of steel (Rc, Rt) are increased, the mode of rupture passes from extension in slip, i.e. the rupture is carried out with the interface sealing/rock, but when one increases the modulus of Elasticity (E) of steel, the mode of rupture remains in extension, which wants to say that steel is less sensitive to its modulus of elasticity than to its tensile strength.

Parameters of sealing: It is noticed that the behaviour of sealing is sensitive to the shear strength more than to its tangential rigidity, i.e. as soon as one decreases the shear strength of sealing, the mode of rupture passes from a rupture in extension to a rupture in slip, which means a low adherence with the interface sealing/rock.

Length of sealing: According to the computation results, the length of anchoring has a significant influence on the behavior of the bolt. With a sufficient length of anchoring (for our example L = 1.5 m) the bolt resists the effort applied until its maximum capacity. As soon as one decreases this length with a certain value (for our case L = 0.5), the bolt does not resist the effort applied any more and the rupture is done by slip of the bolt without this last not reaching its ultimate capacity.

Numerical approach to design the support of galleries: When the geotechnical and geological context is favourable (steep roof), the use of the same gallery to work in two sites can show important economic advantages. The setting of the galleries was deteriorated because of the deepening of sites. It was necessary to modify them to make them function (Kaiser *et al*., 1992).

For this aim, some measures were taken in a coal mine gallery in the Working Unit of Provence of France. A three-Dimensional model (3DEC) which took into account the soil stratification, the cutting progression, the gallery processing, helped in the appearance of most of the phenomena observed in situ (Fig. 7).

Some of the differences which were observed between the measured values and the calculated ones were localized and explained. The very important duration of calculation (at least two months for a simulation) does not allow a quick answer to the workers questions. That is why we decide to simulate in bi-dimensional model.

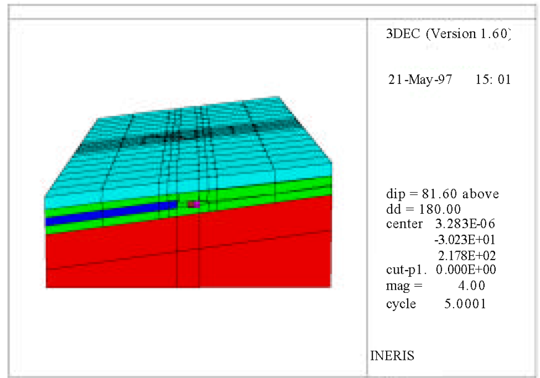

Fig. 7: 3DEC code simulation for the gate way of coal mine of Province Unit (Mimoun *et al*., 1997)

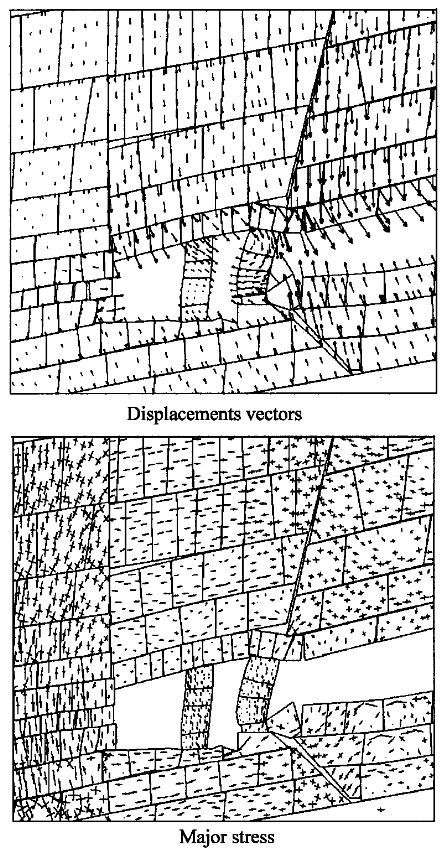

Fig. 8: Mechanism simulated by the model

The combination of experimentation and modelling helped to determine the main mechanisms of deformation which are a loading of the extremities of the gallery and a swinging of the roof.

The results of these modelling helped the worker to think of using such processing in next fields.

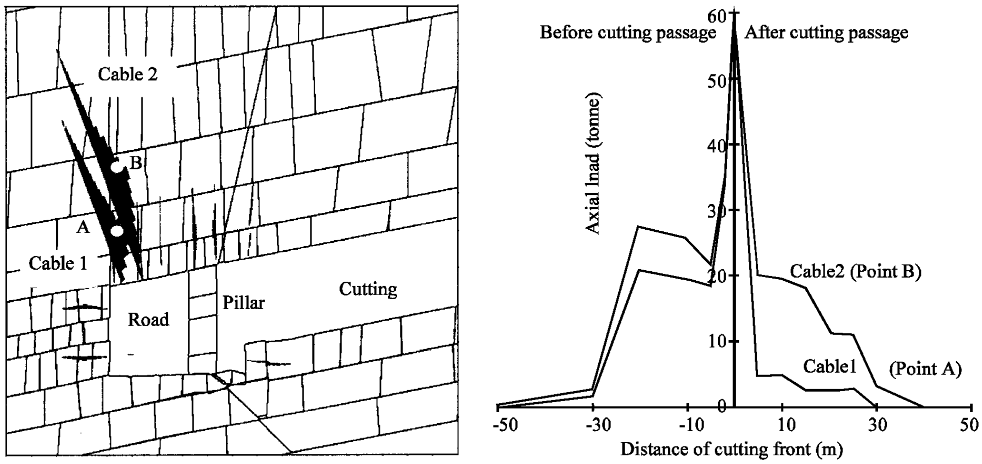

Fig. 9: Evolution of cable axial force

The setting of an additional cable bolting downstream side of the gallery (Fig. 8 and 9).

CONCLUSION

In this study, one could highlight through the numerical simulation of the pull out test of wrenching with the computer code UDEC. Two types of rupture in the system of bolting (standards or with by cable) at knowing: the rupture in extension of the bolt (rupture of steel) or the slip of this last through the ring of sealing. This simulation helped us to determine well the important parameters of the bolting and their influence on the behavior of the system. Three parameters are studied. For the steel of the bolt (stem or cable), one could noticed that the system is more sensitive to its Young modulus, who gives him more rigidity and consequently more resistance compared to the other parameters such as his tensile strength or his compressive strength. For sealing, one notices that it is more sensitive to its shear strength in the interface sealing/rock. The performance of a sealed bolt is proportional with its length of sealing. This proportionality is limited with a certain length from which the bolt is considered without anchoring and the rupture occurs in slip.

This study showed us limits of code UDEC for the reproduction of the curves of test through these simulations. The code could not simulate them to know the rupture in torsion (rotation of the bolt) because it is a 2D numerical code.

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