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MODELLING OF REBAR AND CABLE BOLT BEHAVIOUR IN TENSION/SHEAR

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ABSTRACT: Cable bolting and rock/rebar bolting are the two main reinforcement techniques used in underground coal mines to maintain the stability of openings. Due to the structural features of cable strands, cables and solid bolts behave differently in reinforcing rock strata. Since the generation of a cable model is different in a numerical program, and especially impossible in a 2D program, some researchers tend to replace cable bolts with rebar bolts in numerical models, which is still pretty suspicious. To compare their performance differences when subjected in tension and/or in shear, numerical models of cable and rebar bolt were built and analysed using Flac3D program. The generated models of cables and rebar bolts were assigned identical geometrical dimensions and basic mechanical properties to ensure comparability. Attention was mainly given to the strength and stiffness of cables and rebar bolts both in tension and in shear. Conclusions are drawn from these models, which can be a reference for other studies in this area.

INTRODUCTION

Bolting is an important main reinforcement technique used in openings to control and reinforce rock strata. To better use the bolting technique, a good understanding of the interaction and loading transfer mechanism of bolts and the surrounding media is necessary. Compared to experimental methods, numerical simulation is a good way to investigate the evolution and propagation of stress and strain in detail inside the shear system. It is also cheaper and easily repeatable. Many studies have been carried out with numerical simulation. Spang and Egger (1990) carried out numerical 3D simulation using the Finite Element Method to quantitatively investigate the various phenomena occurring during shear tests on bolted rock blocks. Stankus and Guo (1996) conducted numerical tests on bolted rock joints with various lengths of bolts and pretensions and drew some interesting conclusions on the effects of the pretension and cable length. Grasselli (2005) studied and compared the shear performances of both full steel dowels and frictional swellex using a commercial three-dimensional finite element code, ZSOIL_3D. Tests were also done by Turmo et al., (2006) using a Finite Element Method to study the structural behavior of segmental concrete structures with bolt reinforcement. Song et al., (2010) conducted numerical tests on Double Shear Model (DSM) using a 3D program to study the deformability and stress state of bolted jointed rock blocks. Obviously, past studies with simulation mainly focused on the interaction of rebar bolt and rock strata but did not include cable bolts, because of the structural complexity of cable bolts. For modelling of cable bolts, the grid zones used will be dozens times that used for rebar bolts. The contact interface of strands is also a tough problem in simulation. So when attention is shifted to cable bolting in simulation, especially considering the effect of cables’ surface structure, many problems will emerge. An easy means of this could be to replace the cable bolt with a rock bolt in numerical simulation. But the feasibility of this means has not yet been determined, which requires further research prior to its adoption.

In this paper, the preliminary work carried out to study the performance differences of rebar and cable bolts is reported. Attention was mainly given to the strength and stiffness of cable and rebar bolts both in tension and in shear. For the cable bolts, only its main structural feature, the spiral structure, was considered. No consideration was given to the cables’ bird structure or strand indentation.

CONSTITUTIVE MODEL OF BOLT COMPOSITE

Deformability of cable strand

The deformability of cables in tension and in shear plays an essential role in their performance when loaded in shear. Since they are made from steel, their main deformability is determined by the steel material. Steel material normally has four typical stages in its stress strain curve, elastic stage, yield stage, strain hardening stage, and strain softening stage. Several cable strands have been tested in...
tension and two stress strain relationship profile were gained and illustrated in Figure 1 and Figure 2. The cable strand results are consistent with the typical relationship except the strain softening stage since cable strands do not have an obvious strain softening stage. In these figures, the yield stage and the strain hardening stage are combined and represented by another strain hardening stage which simplifies the stress strain relationship as a linear relation and is easy to be used in analysis. In addition, both two stages can be considered as linearly elastic with two different moduli.

![Figure 1: Stress strain relationship of a plain cable strand (source Orica)](image)

![Figure 2: Stress strain relationship of an indented cable strand (source Orica)](image)

**Constitutive model of cable composite**

Considering the tensile tests conducted on the cable strand, two linearly elastic stages were assumed for both in tension and in compression as its constitutive model, as shown in Figure 3. In numerical simulation elastic model with varied moduli was applied to the cable according to its stress state. The tensile moduli used in simulation were 200GPa and 4GPa for the elastic stage and plastic stage, respectively.
Verification of the constitutive model

A single cable strand was generated and assigned the above constitutive model and mechanical properties to verify the effectiveness of this model. The modelled cable strand is 200 mm long by 7 mm in diameter as shown in Figure 4. The steel strand was fixed at one end and tensioned to failure at the other end. The recorded tension load at the fixed end is shown in Figure 5, which is rigidly consistent to the assumed constitutive model in Figure 3, and thus this model can be used in the following study.

Figure 3: Constitutive model used in Flac3D model for both cable and rebar bolts

Figure 4: Model of a single cable strand
COMPARISON OF CABLE AND REBAR BOLT IN TENSION

The uniaxial tensile tests on a section of cable bolts and rebar bolts were conducted in FLAC3D to compare the reaction of cable and rebar bolt. The cable model was created based on an extensively used hollow cable bolt and its counterpart rebar bolt was generated with the identical dimensions. The dimension details of the cable and rebar bolt are given in Figure 6. Figure 7 shows the generated models of cable and rebar bolt.
Figure 8: Stress vs. strain relationships of tendons in tension

The cable bolt, rebar bolt and steel strand all behaved with nearly identical stiffness in tension for both elastic and plastic stages. The main difference is located at the failure point. The cable bolt failed at a smaller strain of about 4.6%, the average tension stress peaking at just under 1800 MPa (1770 MPa to be exact), while breaks of the rebar bolt and steel strand occurred at a similar strain which is bigger than that of the cable bolt due to its early failure. The reason of this could be that stress propagation along the cable bolt was less uniform than the rebar bolt and the steel strand, which led to stress concentration in some cable strands and stress decentralization in others and because of this the cable strands ruptured separately rather than simultaneously. The post-peak stages also support this viewpoint since the average stress of cable bolt decreased much slower than the other two.

Comparison of cable and rebar bolt in shear

Numerical double shear tests were carried out on solid cable bolt and rebar bolt to study their performance and to compare with the experimental result. Regarding these two simulations, all used properties and parameters were in reference to the experimental test. What is worth mentioning is the normal stiffness of contact interfaces was assigned a nearly infinite value to prevent interpenetration of the bolt, concrete and grout. Figure 9 shows the assembly of the shear apparatus with cable and rebar bolt, and the shear force variation is given in Figure 10.
It is seen that for solid reinforcement elements the rebar and cable bolt behaved in different stiffness for both pre- and post-plastic hinge. The shear stiffness of the entire system with rebar bolt is roughly two times that with cable bolt. Failures of rebar bolt and cable bolt happened at similar strength as the experimental result, at a displacement of less than 20 mm for rebar bolt and about 60 mm for cable bolt. The consistency of the cable model and the experimental test is good in general.

Figure 11 shows the numerical and experimental results of shear systems with hollow cable and rebar bolt. Similar to the solid ones discussed above, the hollow cable bolt had good agreement with the experimental result but was less stiff than the hollow rebar bolt in the shear resistance.

So cable and rebar bolt acted differently in reinforcing jointed rock strata, and the former cannot be replaced directly with the latter. The main difference rests on the stiffness, so an assumption can be made that the cable bolt can be matched with the rebar bolt by lowering the stiffness of the latter. Thus, another test was conducted on rebar bolted concrete with one twentieth of the original rebar stiffness, the result of which is also shown in Figure 11. Unfortunately, it seems this method does not help a lot since the shear force – shear displacement curve still deviates from the cable model.
CONCLUSIONS

Numerical tests were conducted on jointed concretes reinforced with cable and rebar bolt, respectively, to study their performance difference. Both tensile and shear tests were done and compared with the experimental test result.

Numerical results show that the rebar bolt with identical geometrical dimensions and mechanical properties displayed similar shear strength to the cable bolt subjected in shear. Thus it is reasonable to use a rebar bolt model for a cable in studying the reinforcement effect. However, the rebar bolt behaved in different stiffness compared to the cable bolt, and the former was twice the latter. So it is reasonable to qualitatively investigate the deformability of the reinforced joint with rebar for cable bolt, but unreasonable to quantitatively do this.

REFERENCE


Orica. 2014, Mechanical property test report, Orica.


