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Optimization of the fully grouted rock bolts for load transfer enhancement

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ABSTRACT

The purpose of this study is to investigate the role of bolt profile configuration in load transfer capacity between the bolt and grout. Therefore, five types of rock bolts are used with different profiles. The rock bolts are modeled by ANSYS software. Models show that profile rock bolt T_3 and T_4 with load capacity 180 and 195 kN in the jointed rocks, are the optimum profiles. Finally, the performances of the selected profiles are examined in Tabas Coal Mine by FLAC software. There is good subscription between the results of numerical modeling and instrumentation reading such as tells tale, sonic extensometer and strain gauge rock bolt. According to the finding of this study, the proposed pattern of rock bolts, on 7 + 6 patterns per meter with 2 flexi bolt (4 m) for support gate road.

1. Introduction

Rock bolting has advanced rapidly during the past four decades due to a better understanding of load transfer mechanisms and advances made in the bolt system technology [1]. A rock bolt consists of a bar inserted in a borehole that is drilled into the surrounding soil or rock mass and anchored to it by means of a fixture. A rock bolt reinforcement system has four principal components: the rock or soil, the reinforcing bar, the internal fixture to the borehole wall and external fixture to the excavation surface [2]. Such system is very efficient if used in one or several of following applications: stabilization of blocky rock masses, provided the far end of the bolt is anchored to a stable zone; rock confinement, contributing to the use of the broken rock bolt to confine the stable rock mass; improvement of the mechanical properties of the rock mass [3,4].

In addition, the easy installation and low cost of rock bolts, compared to those of other reinforcement elements, have contributed to their worldwide success [5]. During mining, stresses and displacements of strata are constantly changing. Stress conditions in strata just ahead of the coal face typically exceed the rock strength and initiate fractures that lead to strata displacements and typically need steel bolt reinforcement. Over the past two decades, there has been a growing interest on the application of numerical modeling to bolt/grout/rock interaction with the aim of better understanding of the load transfer mechanisms for effective strata reinforcement around underground excavations [6]. Blumel was the first to report on the influence of profile spacing on load transfer capacity of the bolt [7]. Blumel et al. carried out numerical simulation of the bolt load transfer characteristics with the main aspect of the analysis being to investigate the difference in the bolt behavior versus the rib geometry and in particular the spacing between the ribs, and the numerical simulation was based on using finite element mesh to study the load transfer mechanisms which was aimed to be incorporated in future interface modeling [8]. Stillborg extended the work to include modeling of bolt profile configuration under axial and lateral loading conditions [9]. Aziz and Jalalifar simulated short encapsulation pull and push tests and compared the results with the laboratory and field tests. Their findings outlined the refined techniques available to conduct sensitivity studies on various bolt rib profiles and their spacing to enable selection of the optimum bolt profile geometry [10].

Chen et al. presented advanced numerical modeling methods of rock bolt performance in underground mines. This study showed how the numerical modeling methods could be successfully used to optimize the load transfer between the bolt and the surrounding strata. The study indicated that the standard rock bolt reinforcing elements which are commonly used in the numerical simulation of the supported underground excavations cannot be used to optimize the load transfer capabilities of the bolt. A detailed model of the bolt profile must be constructed, loaded to failure and

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compared with other profiles to find the optimum bolt profile with maximum load transfer capabilities between the bolt and host strata [6]. Further studies by Chen et al. were due to the improvement in profile rock bolt. The study of the bolt profile shape presented how the mathematical equations were derived. These equations are used to calculate the pull-out force needed to fail the grout for different bolt profile configuration. The calculations can be applied to any plane of probable failure within the grout. The important outcome of their study was to show that there was another way to examine grout failure around the bolt for different profile configurations that could be compared with the laboratory tests and numerical modeling. This method could provide better understanding of the bolt-grout interaction with rock reinforcement [11]. Deb and Das presented analytical model for fully grouted rock bolts considering movements of rock joints. The proposed analytical solution has been applied for evaluating the bolt displacements, axial load and shear stress along the bolt length when the bolt intersected a single and multiple joint planes [12]. Aminaipour studied geometric parameters affecting the load transfer mechanism. Their studies showed that the most important parameter is the thickness of the resin [13]. In this study, five types of rock bolts are used with different profiles. The rock bolts are modeled by ANSYS software. Finally, the performances of the selected profiles are examined by FLAC software in Tabas Coal Mine and results compared with instrument readings.

2. Numerical modeling of bolt profiles

A three dimensional finite element model of the reinforced structure subjected to the tension loading was used to examine the behavior of bolted rock joints and validate instrumentation results. Three governing materials (steel, grout and rock) with three interfaces (bolt-grout, grout-rock and joint-joint) were considered for the 3D numerical simulation. A general purpose finite element program (ANSYS, Version 12), specifically for advanced structural analysis, was used for 3D simulation of elasto-plastic materials and contact interfaces behavior. Due to the symmetry of the problem, only one fourth of the system was considered here [14,15]. Fig. 1 shows the three dimensional model.

The interface behavior of grout-concreted as a perfect contact was determined from the test results. However, the low value of cohesion (150 kPa) was adopted for grout-steel contact. 3D solid elements (solid 65 and solid 95) that have 8 nodes and 20 nodes were used for concrete, grout and steel respectively, with each node having there translation degrees of freedom. That tolerates shapes without significant loss in accuracy. 3D surface to surface contact elements (contact 174) were used to represent the contact between 3D target surface (steel-grout and rock-grout). This element is applicable to 3D structural contact analysis and is located on the surface of 3D solid elements with midsize nodes. The numerical modeling was carried out at several sub steps and the middle block of the model was gradually loaded in the direction of shear [16,17].

3. Effect of bolt profile on load transfer mechanism

To select the optimum bolt profile and its effect on load transfer mechanism, it is necessary to examine the different profiles and check parameters, such as (1) bolt, grout and joint rocks displacement; (2) bolt, grout and joint rocks shear stress; and (3) bolt, grout and joint rocks shear strain.

The rock bolt characteristics and material properties are shown in Tables 1 and 2 respectively.

The maximum tensile load of the elements as load capacity is considered. Table 3 shows the results of different profiles. Rock bolts T_3 and T_4 with a capacity of 180 and 195 kN in this study were selected as candidate profiles, and their performance is analyzed in Tabas Coal Mine. Figs. 2–7 show the displacement, shear stress and shear strain contours for rock bolts T_3 and T_4.

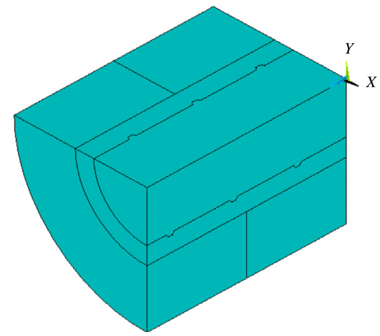

Fig. 1. Three dimensional image numerical model (bolt T_3).

Table 1
Bolts characteristic [15].

Parameter	Bolt type				
	T_1	T_2	T_3	T_4	T_5
Bond length (mm)	75.0	75.0	75.0	75.0	75.0
Rock bolt diameter (mm)	22.0	22.0	22.0	22.0	22.0
Grout diameter (mm)	27.0	27.0	27.0	32.0	27.0
Rib height (mm)	1.00	1.75	1.00	1.00	1.00
Rib spacing (mm)	12.0	12.00	24.0	12.0	12.0
Profile top width (mm)	1.50	1.50	1.50	1.50	2.00
Profile down width (mm)	3.00	3.00	3.00	3.00	3.00
Max. tensile load (MPa)	330	330	330	330	330

Table 2
Material properties [14].

Material	Concrete (20 MPa)	Grout	Steel
E (GPa)	20.0	12	200
Poisson's ratio	0.25	0.20	0.30

4. A case study: Tabas Coal Mine

4.1. Site description

Tabas Coal Mine is located some 85 km south of Tabas town, Birjand province, Iran. A 4.13 m long roof core was taken in East 2 tail gate at MM of 180.7 revealed sequential layers of siltstone, sandy siltstone and silty sandstone immediately above the roof in the tailgate. The core data is summarized in Table 4 together with other observed parameters to calculate RMR values [18].

The long wall panel had a face width of 180 m and panel length of 1200 m. The geometry of the area modeled was 40 m by 40 m with a roadway width of 4.5 m and height of 3.5 m. The coal seam was modeled as 2 m thick and dipping at 20°. The East 2 tail gate immediate roof stratification sequence consisted of siltstone and sandstone above the roof. The vertical stress of 4 MPa and the ratio of horizontal to vertical stress $k = 0.4$ were determined for the site, according to the tectonic history of the region. To provide input parameters for the models, the RocLab software was used to estimate the parameters of rock mass surrounding the roadway and to provide input parameters for the models. The results are listed in Table 5 and the geometry of the model defined is shown in