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Advanced numerical modelling methods of rock bolt performance in underground mines

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ADVANCED NUMERICAL MODELLING METHODS OF ROCK BOLT PERFORMANCE IN UNDERGROUND MINES

Chen Cao[1], Jan Nemcik[1] and Naj Aziz[1]

ABSTRACT: Current developments in numerical modelling techniques are presented to investigate the load transfer between the steel bolt surface and resin encapsulation. Underground measurements of steel bolt performance indicate that amongst many parameters bolt profile configuration plays an important role in load transfer capacity between the bolt and resin that encapsulates the steel bolt. The short encapsulation pullout tests of roof bolt capacity can be successfully modelled and directly compared to the insitu pullout tests. Using the numerical modelling techniques, changes in the bolt profile can be studied in detail to provide a better understanding of the bolt reinforcement mechanism. In particular, emphasis is placed on the bolt profile geometry and its influence on the load transfer characteristics. Even though this work does not discuss any results, it is intended to outline the procedures and methods employed as part of the continuing research at the University of Wollongong.

INTRODUCTION

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 modelling to bolt/resin/rock interaction with the aim of better understanding of the load transfer mechanisms for effective strata reinforcement around underground excavations. Blumel, Schweiger and Golser (1997) 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 behaviour versus the rib geometry and in particular the spacing between the ribs. 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 modelling. Further studies by Aziz and Jalaifar, (2007, a and b) extended the work to include modelling of bolt profile configuration under axial and lateral loading conditions. Aziz and Jalaifar simulated short encapsulation pull and push tests and compared the results with the laboratory and field tests. The work presented here outlines 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.

NUMERICAL MODELS OF MINE EXCAVATIONS

As part of the numerical models that are extensively used to simulate mine excavations (FLAC, UDEC and other available software packages), standard rock bolt reinforcement can be routinely modelled to study the strata performance. Simplified assumptions of bolt reinforcing capabilities are used in these models, requiring bolt properties as the data input. Typical rock bolt elements with axial and bending behaviour are available within the ITASCA software to model steel bolts for ground reinforcement. As described in the FLAC manual, the shear behaviour of the modelled grout annulus is represented as a spring-slider system located at the nodal points along the reinforcing member. The maximum shear force developed in the grout is a function of the cohesive strength of the grout and the confining stress-dependent frictional resistance of the grout (Itasca, 2005). The effective confining stress that develops normal to the rock bolt depends on the bolt profile and other parameters such as the grout annulus size.

The routine bolt functions available in these packages cannot be used to study the effectiveness of the bolt profiles. In order to successfully determine the optimum bolt profile geometry it is essential that only a small part of the bolt-resin-rock is modelled and appropriate sensitivity studies are carried out to evaluate the optimum load transfer between the bolt and the resin/strata interface.

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NUMERICAL MODELLING OF BOLT PROFILES

To maximise the load transfer between the steel bolt and the surrounding rock mass, detailed investigations of interaction between the bolt profile, grout and the rock interface need to be undertaken. The in-situ pullout tests of various bolt profiles indicate that the bolt profile and rib spacing have a significant influence on the bolt to ground load transfer (Blumel, 1997 and Aziz, 2007). Such field results are depicted in Table 1 while a typical bolt rib spacing is shown in Figure 1.

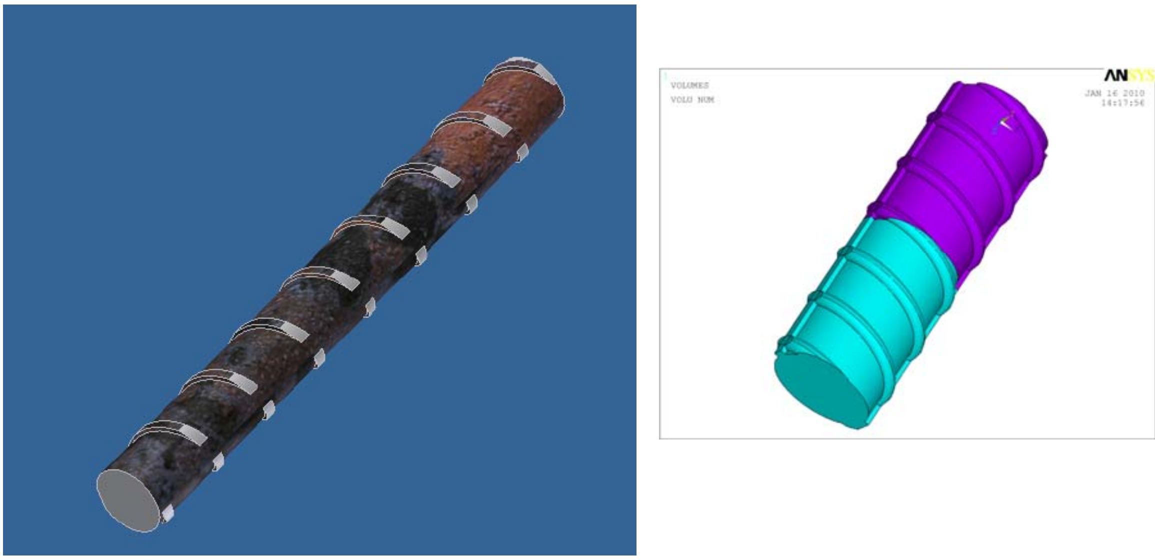

Figure 1 - Model of a steel bolt showing a typical rib profile.

Table 1 - Changes in the load capacity of different profile spaced bolts with respect to Bolt Type T2 in pull testing (encapsulation length 115 mm) (After Aziz, 2007)

Bolt Type	Profile Spacing (mm)	Average Pull load (kN)	Change (increase) in load with respect to Bolt Type T2 (%)
Bolt Type T2	12.5	152.23	-
Bolt Type T3 G1	25	215.23	41
Bolt Type T2-G2	37.5	256.55	69
Bolt Type T2-G3	50.0	244.72	61

In order to optimise the bolt profiles with respect to their load transfer capabilities, sensitivity studies of various profiles and their spacing need to be undertaken. To depict an accurate geometry of the bolt profile embedded in the resin, fine 3-dimensional mesh of suitable elements needs to be constructed. An example of the generated fine mesh for detailed simulation is shown in Figure 2.

Minute changes in the bolt profile geometry can be studied and various parameters such as the location, magnitude and type of the grout failure, displacements and stress distribution recorded. The final outcome of such study is to gain new knowledge how the change in bolt profile geometry and spacing influence the grout failure and what mechanisms contribute to achieving the optimum load transfer between the steel bolt and the surrounding strata. The modelled results can then be compared to the laboratory and field trials.

To study the bolt profile embedded in the resin and its influence on the load transfer between the bolt and the resin, a numerical model with a very fine 3-dimensional mesh was constructed using the 3-dimensional ANSYS finite element method software (ANSYS USA). The model showing the details of the bolt profile, resin annulus and the surrounding rock can be seen in Figure 3.

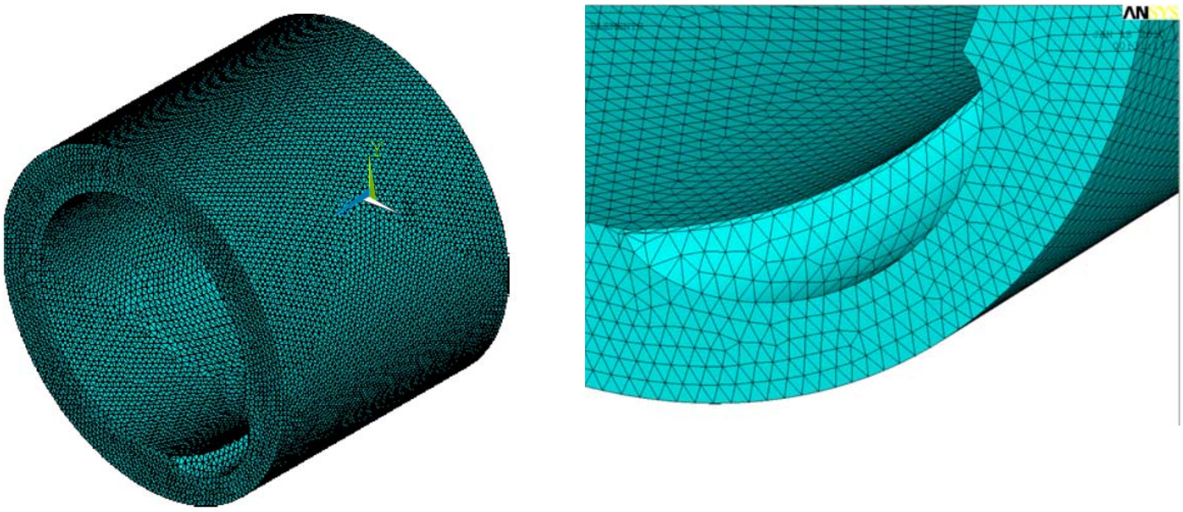

Figure 2 - Generation of the fine mesh for detailed simulation of rib profiles

It is envisaged that several different software packages such as 3-dimensional FLAC, UDEC, PFC, ABAQUS and other finite element models may be trialled for comparison and to ensure accurate assessment of the bolt-grout system behaviour. The sophisticated laboratory tests must be conducted to understand the grout post failure behaviour in detail. To simulate the exact behaviour of small granular particles within the failed grout zone is challenging and may require skilful programming.

To optimise the bolt profile spacing with respect to the maximum achievable load transfer and to understand the reason how the bolt profile spacing influences the load transfer, it is necessary to look at the details of resin failure as it occurs during the simulated pullout test. To replicate the insitu grout behaviour in the numerical model, the sophisticated laboratory tests must be conducted to understand the grout post failure behaviour in detail. The triaxial tests are needed to measure the intact and post failure properties of resin under various loading conditions including Young's Modulus and Poisson's Ratio, compressive and tensile strength, cohesion, angle of internal friction, grout bulking at various points of loading and failure stage and a record of detailed stress strain relationship.

The load transfer is proportional to the compressive stress that develops normal to the failed surface located either at the bolt-resin boundary or within the resin itself. An increase in normal stress perpendicular to the sliding surfaces caused by the bolt profile displacement, bulking of the failed resin and location of the failure zones holds the key to the load transfer.

The drilled hole profile in rock strata is usually rifled with spiral grooves between the resin and surrounding rock. This profile is desirable and it becomes particularly important when considering load transfer in weak strata. Poor cohesion that may develop between the resin and the host strata is aided by the wedging mechanism of an uneven hole diameter and surface roughness. In a similar manner, the numerical modelling is useful to predict what hole profiles are desirable in weak strata to minimise poor load transfer between the strata and the resin surface.

Future work may include the detailed model of the bolt system that can also be used to maximise the quality of the resin mix and encapsulation. The model can simulate the dynamic motion of the rotating bolt and the installation process within the hole. The bolt profile, speed of the bolt rotation, hole size and resin viscosity can be optimised to maximise resin mixing capabilities and viscosity requirements during bolt installation.

CONCLUSION

This study shows how the numerical modelling methods can be successfully used to optimise the load transfer between the bolt and the surrounding strata. The study indicates that the standard rock bolt reinforcing elements commonly used in the numerical simulation of the supported underground

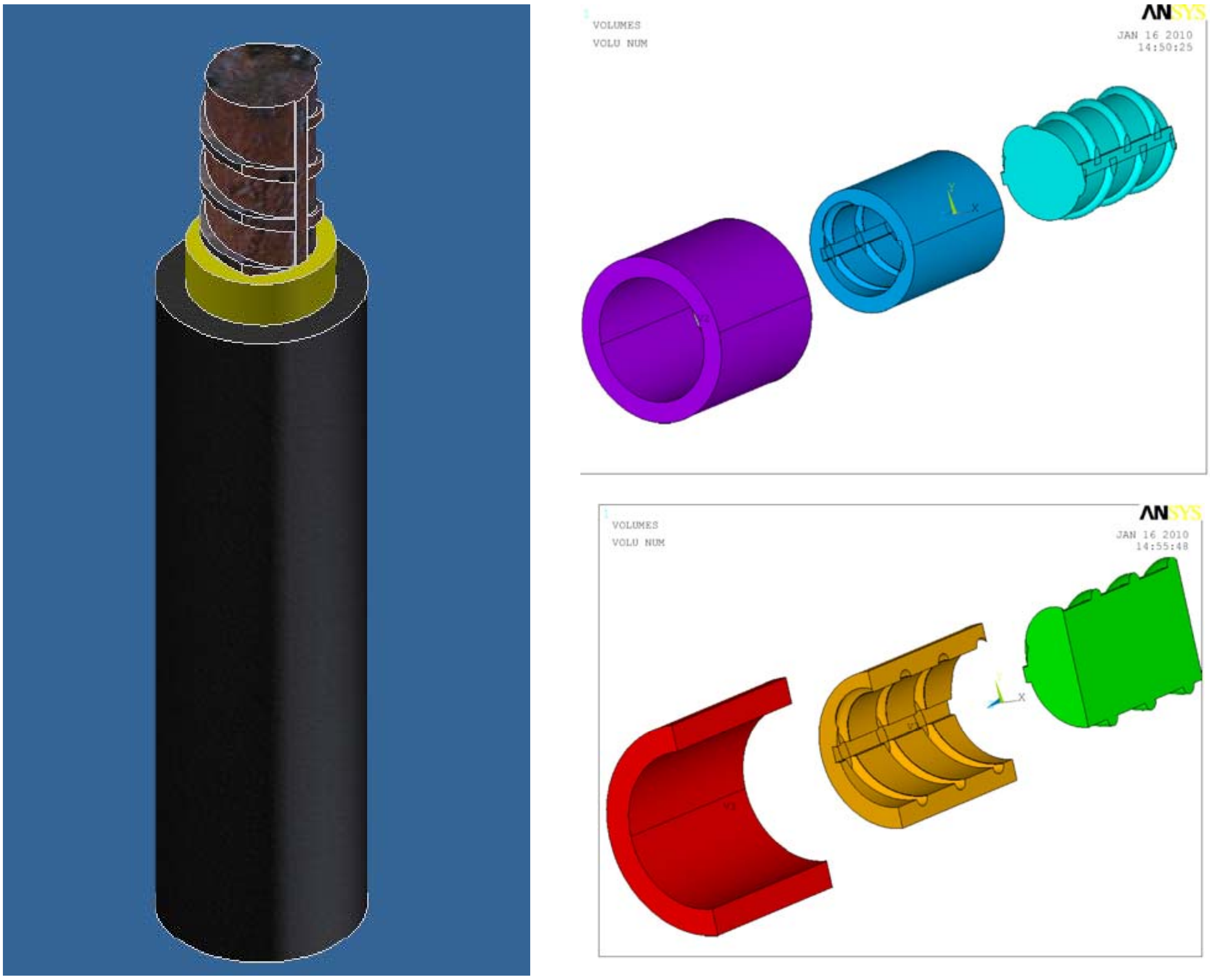

Figure 3 - Model of a steel bolt showing the details of the bolt profile, resin annulus and the surrounding rock

excavations cannot be used to optimise the load transfer capabilities of the bolt. A detailed model of the bolt profile must be constructed, loaded to failure and compared with other profiles to find the optimum bolt profile with maximum load transfer capabilities between the bolt and host strata.

Numerical modelling is an extremely versatile, useful, cheap, fast and accurate tool to enable decision making regarding to the choice of the best reinforcement for a particular application. This method is becoming more accepted in the mining industry and further studies are desirable to provide the industry with cheap and reliable tools that can be used in future on the routine basis.

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