AN ASSESSMENT OF ROCKBOLTING
IN GEOLOGICALLY DISTURBED MINE ROADWAYS

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ABSTRACT

The rockbolting method of support is employed widely in several countries in different mines. Hard rock mines use this method extensively. Soft rock mines, such as coal mines, have employed standing supports (steel sets) as the main method, although some countries such as the U.S.A. and Australia have preferred rockbolting. There is increasing interest in extending the rockbolting method in coal mines.

The application of rockbolting techniques in an industry which traditionally has not applied such techniques, has required the development of a systematic design approach. This design approach uses extensive monitoring, to assess the stability of the support system in differing conditions.

Currently at a number of new and existing mine developments in the U.K., rockbolting is being successfully applied. Although inevitably some localised geotechnical problems have been encountered and have needed to be taken into account.

The effect of faulting on roadway conditions is discussed in this paper and a design approach has been applied using a numerical analysis method, namely the Finite Element Method.

The results presented in the paper serve as a useful guide to roadway support design, and in particular the role played by different bolts in a range of conditions.

INTRODUCTION

Rockbolting is aimed at providing early and effective support in mine roadways. This form of support is active in promoting the rocks surrounding the excavation to develop increased natural supporting ability.

The size and quality of underground excavations has increased as a result of improved technical developments. In the recent years these excavations have required efficient and safe support systems at an economic cost especially in coal mines. The high cost of conventional passive support systems has focussed attention on lower cost support systems such as rockbolting.

Rockbolting has been used for more than a hundred years; this technique has only been used as a very comprehensive support system, however, in the second half of the 20th century (Stillborg, 1986). Only the United States mining industry uses more than 100 million bolts a year (Bierenwolk, 1984). Recently, rockbolting has been a major support system in underground mining applications (Peng, 1986).

Surprisingly, universal bolting patterns have not been developed in spite of this extensive usage. Generally, they are based on trial and error or previous local experience which usually cause overdesign or underdesign (Serbousek, 1987).

At the final stage, design engineer has to know the amount of load taken by the bolts to decide on the bolting density and how the rockbolts change the stress distributions in the rock to determine the bolting pattern. In-situ stress measurements on bolts have been carried out by many researchers. These studies are essential to
understand the conditions of the rockbolts in terms of stability. Meanwhile, similar comprehensive studies have been continued in laboratories to simulate the effects of bolting (Farrell et al., 1989; Hellimshend, 1971; Kaill et al., 1966; Whitaker and Frieth, 1990).

In shallow underground excavations, bolt density and their pattern can be decided in a number of different ways: in joined rocks by the geometry and weight of unstable blocks; in continuous rocks by the weight and depth of loosened ground; or in many other cases by empirical designs based on past experience.

However, in highly stressed deep mining applications, rockbolting design methods are less developed than for the shallow excavations which are less stressed (Fellborg, 1986). Therefore, it might be more useful than any other approach to concentrate on the stress distributions not only associated with the rockbolts but also in the rock in which the excavation is opened. In order to do this, the Finite Element Method (F.E.M.) which is one of several available numerical analysis methods has been used.

DATA

The roadway studied relates to a typical new mine development in the U.K. The depth below the surface is 450 m and the roadway in rectangular shape, 6 m in width and 2.6 m in height.

The bolts employed are 2.4 m in length, 2.7 cm in diameter, fully resin bonded and their spacing is ~60 cm. The bearing plates are ~15 cm in diameter (or in width if square). Bonding strength between rock-resin and resin-bolt is assumed equal or higher than the rock (especially in coal mining and for many sedimentary rocks).

In the first and second cases, it has been assumed that the rock has homogeneous lithology without any geological structure. The modulus of elasticity is 2.2\times10^6 N/m² for rock and 200\times10^6 N/m² for the bolts. In the third and fourth cases, a clay filled weakness zone has been considered near the rib side and corner. Poisson's

ratios have been taken as 0.2, 0.3, 0.4 for the rock, the bolt and the filling material respectively.

The modulus of elasticity of the filling zone has been taken as 0.1\times10^6 N/m². The unit weight is 2500 kg/m³ for rock, 2300 kg/m³ for filling material and 7800 kg/m³ for rockbolt.

MESH

In order to simulate the structure in detail and for a realistic stress distribution, a large number of elements have been created (Figure 1). Gravity loading has been applied, which is considered to be realistic form of stress generation in underground conditions.

Horizontal and vertical stresses were derived by the following formulas (Jumikis, 1983):

\[ \sigma_x - \sigma_y = \gamma h \]
\[ \sigma_x = \frac{h}{1 - \mu} \]

where:

\( \sigma_x, \sigma_y \) = vertical normal stress component (MPa).
\( \sigma_x, \sigma_y \) = horizontal, normal stress component (MPa).
\( h \) = vertical depth below ground surface (m).
\( \gamma \) = unit weight of rock (kg/m³)
\( \mu \) = Poisson's ratio

The borders of the structure have been restrained and are shown as rollers, the excavation surfaces and the top of the structure (viz. the earth surface) however, were left free. For clarity the results are presented for the analysis only in the immediate area of the excavation unshaded in Figure 1.
Distribution of Minimum Principal Stresses (mostly tensile)

The evaluation of areas in tension are shown in Figure 2. A fault near the corner of the rib side expands the tension zone (Figure 2-c) in the roof area despite the rockbolting and it is worse than the first case (Figure 2-a). However, it can be seen that rockbolting in an underground roadway slightly improves the tension zone in these stress conditions (Figure 2-b). Meanwhile, a fault near the centre of the roadway causes a reasonably small area of tensioned zone in the same roadway. As is seen in Figure 2-d, in this case there are two separate tensioned areas near the rib side corner and in the centre and it may be said that the area between two tensioned zones is unstable which will allow potential progressive failure.

Distribution of Maximum Principal Stresses (mostly compressive)

Figure 3 shows how compressive stress areas change in the cases examined. It can be seen that without any rockbolting, almost all of the roadway's roof is subjected to tension stresses (Figure 3-a). However, rockbolting improves the tensioned zone on the rib side and in the roof centre (Figure 3-b). Meanwhile, the fault near the corner deteriorates the rockbolting improvement and expands the tensioned zone not only on the corner but also in the roadway roof centre (Figure 3-c). In another case, a fault near the centre does not change the situation compared with the earlier case which is benefited without any fault, but affects the situation negatively on the central roof area (Figure 3-d). That effect, however, is less than with the corner fault.

STRESS DISTRIBUTIONS ON THE ROCKBOLTS

The stress distributions in the roadway without any special geological structure and support system have been shown in Figure 4-a. Naturally, high compressive stresses...
Figure 2. Minimum principal stress (mostly tensile) changes in the roof.

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Figure 3  Maximum principal stress (mostly compressive) changes in the roof.
develop in the corners and will reduce towards the roadway roof centre. In contrast, high tension stresses will occur in the central roadway roof area and will reduce towards the corners and into the surfaces.

Figure 4-b shows how the rockbolts take stresses according to their locations in the roadway without any geological disturbances. Naturally, there is a large stress concentration in the corner region. The bolt in the corner has therefore experienced very high stresses (Figure 4-b). The bolts in the centre are fairly highly stressed too, because of appreciable movements in this area of roadway roof. However, the second and third bolts from the left side have not stressed to any significant extent and practically it may be assumed that they are relatively stress free bolts.

In the third case of the fault in the corner, this has caused very high stresses both on the bolts and in the rock. The corner bolt has been appreciably stressed (Figure 4-c). This fault has caused much more vertical movements in the roadway roof centre and as a result of this the bolts in the centre have been significantly stressed.

In the last case the fault near the centre has caused less change than the previous case (Figure 4-d). However, the second nearest bolt to the centre is more highly stressed than any of the others. The same fairly stress free fault zone has occurred again. The middle bolt has been subjected to more stress because of the additional movement caused by the close proximity of the fault.

CONCLUSIONS

If the maximum principal stresses (mostly compressive) are considered, the rockbolts dramatically reduce the tensile stressed area and do improve the conditions of the roof rock. Even with a fault in corner or centre, the rockbolts still reduce the tensioned area in the roadway roof.

In the case of high vertical and low horizontal stress conditions, it is difficult to identify that the rockbolts improve the rock conditions when the minimum principal stresses (mostly tensile) were considered. In other words, the rockbolts only slightly reduce the tensioned area in the roadway roof rock.

Some significant results have been established from the rockbolting point of view. Firstly, there is no advantage in employing equally spaced rockbolts. As has been demonstrated, the rockbolts in the corner and in the centre experience the bulk of the stresses. Therefore, increased concentration of bolts in the corner and if necessary in the centre is recommended andcalculations to determine the number of rockbolts should be based on stress levels in the rock and the ultimate strength of the rockbolts. Additionally, it can be said that the second and third bolts play a lesser role in the roof in these conditions. In faulted cases, it appears necessary to place more rockbolts either side of the fault with the number depending on the nature of the fault.

The study has demonstrated the value of a design approach to rockbolts and the support of mine roadways. It should be appreciated, however, that geological disturbances introduce uncertainties and that the support design needs to take this into account. Monitoring of performance of mine roadways where rockbolts are employed is a positive and practical support assessment and is strongly recommended. The results presented in this paper serve as a guide to the designers of roadway support systems, and the value of numerical modelling especially where rockbolting is employed. The detailed appreciation of the interaction of geological factors and stress field conditions still remains a predominant consideration involving judgement of the site and operating conditions. The time factor is also important, since where faulted zones occur there is always a measure of stress relaxation when they are disturbed by mining operations. Consequently, the rate of deterioration of the physical conditions can accelerate. The results presented in this paper indicate which rockbolts would be affected first and also which play the more important role.
Figure 4 Minimum principal stresses (mostly tensile) on the rockbolts and rock as vectors

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