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Modelling of Rock Reinforcement Systems in Cut and Fill Mining

by

K. E. MATHEWS, B.E., M.E., M.Aus.I.M.M.

Associate Professor of Mineral Engineering, University of British Columbia, Canada

and

J. L. MEEK, B.E., Ph.D., M.I.E.Aust.

Reader in Civil Engineering, University of Queensland

SUMMARY. The procedures currently used for the design of rock reinforcement in fractured strata are reviewed briefly. The trend to install support systems using full column resin or grouted dowels as opposed to point anchored bolts, is discussed and the reasons are given. The application of mathematical modelling techniques to the design of dowel reinforcement systems in fractured rock is discussed and the results of investigations carried out are reviewed in context with design objectives associated with cut and fill mining systems. It is shown that finite element analyses of alternative extraction sequences in adjacent, multiple orebodies can provide valuable information on the superposition and change in strain concentration as mining progresses. Examples are given to illustrate the problems encountered and the procedures developed to resolve them. Future developments leading to improved design of reinforcement systems in fractured strata are postulated and topics worthy of continuing research and development activity are discussed.

1 INTRODUCTION

A review of the literature on deep mining systems in hard rock indicates that cut and fill stoping and long wall caving are proven methods yielding high ore recovery. These methods involve mining close to the advancing face, and use waste materials to take load and reduce stresses in this region. Conventional cut and fill mining of steeply inclined ore bodies is known to be carried out at depths of 2100m and long wall caving of near horizontal ore bodies at depths of 3000m. However, artificial support installed to reduce convergence near the advancing face is massive and costly. Both mining methods have traditionally been labour intensive, requiring well trained and experienced miners for safe operations at depth.

During the last ten years, there has been an increasing trend to mechanize cut and fill mining operations within 610m of the surface and performances of twenty tonnes mined per manshift have been reported. Back (roof) and wall support in these operations has been mainly designed to prevent ravelling of small blocks by using steel mesh pinned with tensioned anchor bolts ranging in length from 1.8m to 3m. Ribs and pillars are left as required to reduce the span of exposed back and in wide ore bodies, their spacing and pattern is regular. These pillars are often stressed close to the upper limits of allowable loading because of the desire to maximize ore recovery in the initial stopes. Pillar mining under these conditions is more costly and usually less efficient. There has been a trend to support the back with regularly spaced, toothpick pillars in some nickel mines located in the Sudbury Basin of Canada. These pillars are designed to progressively yield as mining advances and are regarded as unminable. At the current depth of operations, they comprise about 15 percent of the ore reserve. In the process of yielding, load is progressively transferred to the abutments, but the pillars provide stable support even though they become crushed.

Loading on pillars and abutments adjacent to the advancing face is related to the depth of mining and the shape of the opening. In the case of

multiple ore bodies, their relative spacing and sequence of extraction are additional factors to be considered. As the workings deepen, the effectiveness of the artificial support installed to prevent failure of the back and walls is directly related to the volume of pillar ore required. These arguments highlight the incentive to develop artificial support systems commensurate to a given mining situation. In this regard, an accepted design approach is as follows.

- (a) Model alternative extraction sequences in individual and/or multiple ore bodies with the aim of minimizing buckling stresses in the vicinity of the advancing face.
- (b) Review the application of artificial support systems with the aim of minimizing the volume of pillar ore required to reduce stresses and/or provide support.
- (c) Review the overall mining programme to ensure production flexibility and facilitate the mechanization of the drilling, mucking, ground support and filling activities.

2 SUPPORT SYSTEMS IN CUT AND FILL MINING

Jaeger and Cook (1969) state that support systems can be classed as active, which impose loads on the rock surface, or passive, which generate load as a result of compression by convergence towards the opening. Examples of active support include hydraulic props and tensioned rock bolts anchored into compressed and solid elastic rock beyond the failed boundary of the excavation. Fill materials between walls and packs supporting the back are examples of passive support, as are tensioned rock bolts anchored in failed rock to stiffen the aggregate of separated blocks.

Rock surfaces should be supported as soon after they have been exposed as possible, however in practice about sixty percent or more of the elastic deformation occurs before support can be installed, considering the systems referred to above (Fairhurst and Singh, 1974). For this reason active support systems have been preferred in the

past and, in fact, most of the documented experience to date deals with the use of tensioned rock bolts. A typical example is the experience of the Snowy Mountains Hydroelectric Authority, Australia, dealing with support of underground power stations and as summarized in Fig. 1 (Alexander and Hosking, 1971). However, the design philosophy associated with artificial support for permanent civil works is rarely applicable to excavations in cut and fill mining because of the temporary nature of requirements arising from cyclic operations. Excavations for permanent works can be shaped to optimize the design situation, whereas this is rarely the case in stoping operations. Also, the expenditure of capital to ensure the objective of permanency can be justified, e.g. tensioned and grouted bolts installed under expert supervision.

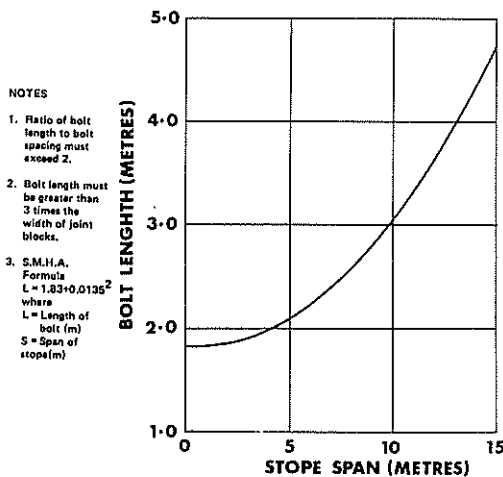


Fig. 1 Graph showing the Relationship of Bolt Length to Excavation Span for Tensioned Bolts used in Civil Works.

There is a trend in mechanized cut and fill mining operations to support all exposed backs in order to reduce the hazard of falling rock (Fig. 2). However, there are few instances where operations have been planned to facilitate the mechanization of these activities, even though they represent 10-15 percent of the total mining costs. Current practice is to drill and install tensioned rock bolts and steel mesh while working off the pile of broken ore, using hand held equipment. Bolt length is generally limited to about 2.1m because of space considerations. Spring steel plates are often installed to give a visual indication of bolt loading and regular check inspections are necessary to ensure performance during operations.

The effectiveness of point anchored bolts is dependent on the maintenance of tension within the rod to compress fractured rock and improve its performance as a beam. The dead weight of the fractured rock can also be suspended if the anchor is installed in sound rock. When transverse stresses are significant, compression across separated weakness planes increases their shear resistance to buckling. However, tensioned bolts have a low effective stiffness to transverse shear because they are not in intimate contact with the sides of the hole. As a result, they perform poorly once differential slip has progressed along a weakness plane beyond the point of peak strength. Therefore, the main criticism directed against the use of point anchored bolts is the decreased performance resulting from anchorage slip or deterioration of rock near the mouth of the hole under conditions of high stressing in deeper workings (Fig. 3). In addition, the bolt becomes useless when stressed to failure.



Fig. 2 Tensioned Rock Bolts and Steel Mesh installed in a Mechanized Cut and Fill Mining Operation. (Courtesy of Mount Isa Mines Limited, Australia)

Carr, et al (1974), referring to roadway design in coal mines, noted an increasing trend to use full column grouted dowels or rods in France and Britain. Dowels have advantages over point anchored bolts in that they give anchorage over the full length of the rod by continuous bonding through the grout to the rock. They are not pretensioned, since the anchorage resistance is throughout the hole and not located at the extreme points, as is the case with the point anchorage type. Carr, et al (1974) concluded that (a) tensioned bolts should be restricted in use to the support of strata in shallow workings, and that (b) dowelling is superior to bolting when several weak strata must be reinforced to form a strong, composite beam in order to resist the substantial buckling forces usually associated with deeper mining. A theory further detailing the role of dowelling in ground support is given by Fairhurst and Singh (1974).

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The results of strata reinforcement trials, using the technique of long hole resin dowelling, are given by Parker et al (1973). These trials in a British coal mine parallel those in progress in cut and fill mining operations at two Australian mines. With this technique, dowels are installed ahead of the advancing face in ground largely unaffected by convergence or relaxation towards the opening. Two methods are being tested in Australia, with faces advancing up-dip as follows.

- (i) Installation of resin dowels (wooden) in extended blast holes.
- (ii) Installation of flexible, high-tensile steel rods up to 18m long, using cement grout.

Initial results, using steel rods, are encouraging but problems have been encountered with wooden dowels due to damage of the ends from blasting. However, various devices aimed at decoupling the blast are being tested.

Loading of long dowels due to relaxation as the face is advanced was investigated using finite element analysis techniques, assuming elastic behaviour of the rock. The model comprised an excavation 61m high in a bedded deposit dipping at 65°. The excavation was formed by mining a series of 6.1m wide by 3.0m high cuts in the up-dip direction from a datum 730m below the surface. Long dowels, each comprising three rods of 7mm diameter,

that a realistic approach to the support of bedded and fractured strata is to accept that they must accommodate the displacement forced on them by the movement of the rock as a continuous, elastic whole, but that any displacements in excess of these result in separation and the formation of voids which are undesirable. Separation can be prevented if support can be designed to prevent tension occurring across weakness planes, and dowels installed before elastic relaxation occurs can meet this criterion. However, it has been shown that it may not be practicable or economic to install sufficient dowels to accommodate the loads due to high lateral buckling stresses in the immediate vicinity of the opening, and when they occur, compromises are necessary.

Investigations were carried out to determine the increase in stress levels arising from advancing excavations in multiple orebodies from a datum 730m below the surface towards worked out and filled stopes above. Two sequences were considered, the first with all excavations advancing to maintain all backs in a horizontal line, and the second to maintain a leading stope in the hanging wall, with the remainder advancing in en-echelon sequence (Fig. 6). The fill, having a modulus of one-hundredth that of the rock, was introduced after each successive stage of excavation. Virgin stress tensors were as indicated in Figure 4. A summary of results is presented in Tables 1 and 2 and Fig. 7.

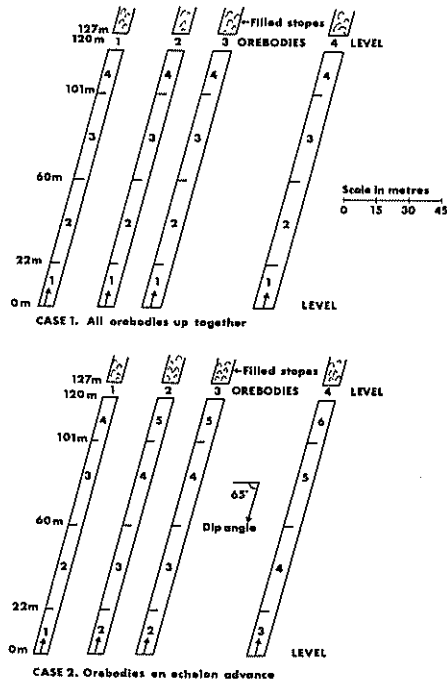


Fig. 6 Alternative Extraction Sequences in Multiple Orebodies

Experience in mining the worked out stopes above, was used to interpret the effect of calculated absolute stresses on mining conditions in the new area below. In this regard, stress levels due to the increase in depth would be about 15 percent higher for the same mining sequence. Also, the volume of unmineable pillar ore could be expected to increase by the same amount and this figure sets the incentive for improved support techniques.

The following maximum absolute stress levels in the back were assumed for the purpose of comparing alternative extraction sequences, (a) Greater than 103 MPa - stop mining and leave a pillar. (b) 83 MPa to 103 MPa and "worked" ground (see

later) - use long dowels and steel mesh. (c) 69 MPa to 83 MPa - use short dowells and steel mesh* (d) Less than 69 MPa - use conventional tensioned bolts and steel mesh*.

The results show that relative spacing of the excavations has a major effect on mining conditions for both extraction sequences. Sequencing has an effect on the occurrence of highly stressed areas but does not greatly change the total up-dip footage of these zones. Large differential stresses exist above stopping areas and in both sequences, mining is advanced through "worked" ground. "Worked" ground is defined as a zone where large differential stresses have most likely caused bed or joint separation, forming blocks that work or adjust to redistribute the stresses involved. This redistribution results in lower stresses than indicated in the elastic analysis carried out. "Worked" ground is encountered in practice, and the importance of being able to predict likely areas of failure cannot be overemphasized considering the trend to mechanization of operations.

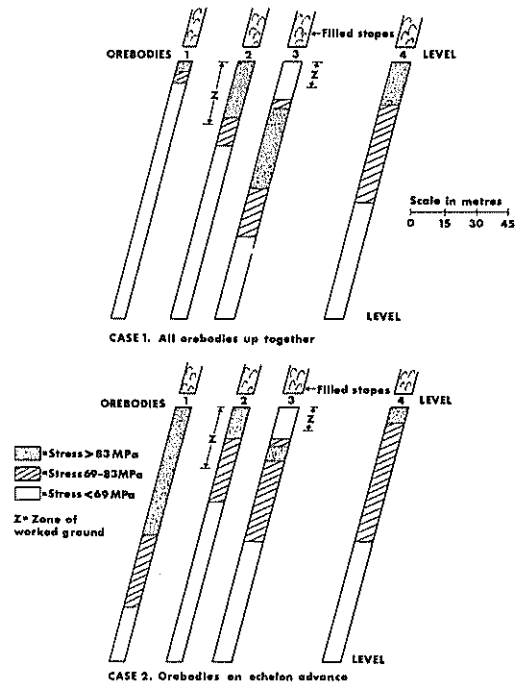


Fig. 7 Diagram showing Stress Levels for Alternative Extraction Sequences

4 FUTURE DEVELOPMENTS

Two rock breaking techniques amenable to the trend to full mechanization of cut and fill mining are up-hole drill and blast, and horizontal drill and blast (flat backing). Cut and fill mining is a cyclic operation, comprising rock breaking, mucking, ground support and filling. The first three of these activities must be carried out sequentially in flat backing, whereas they can be done in parallel with up-hole drilling. Parallel activities permit specialization and more efficient mechanization and scheduling, hence, this rock breaking approach is preferred.

Flat backing is used when ground cannot be safely or economically supported unless wall height is minimized and ready access is provided to the back. It is also applicable to mining narrow orebodies (less than, say 4.6m wide), where the oper-

* Long dowels recommended throughout if economic.

TABLE I
STRESS LEVELS MINING FOUR OREBODIES UP TOGETHER

Location of Stress Reading (m)	Principal E-W Stress (MPa) in Orebodies											
	1			2			3			4		
	A	B	C	A	B	C	A	B	C	A	B	C
0	23			25			23			22		
22.1	55	35	26	45	34	29	63	42	28	52	35	26
60.4	45	30	22	41	37	33	97	59	34	81	52	32
100.6	39	38	37	103	70*	50*	83	63	52	92	57	35
120.7	118			245			-30			117*		

TABLE II
STRESS LEVELS MINING FOUR OREBODIES IN EN ECHELON ADVANCE

Location of Stress Reading (m)	Principal E-W Stress (MPa) in Orebodies											
	1			2			3			4		
	A	B	C	A	B	C	A	B	C	A	B	C
0	23			23			23			23		
22.1	63	41	32	29	28	28	56	34	19	56	37	26
60.4	84	48	36	16	24	28	81	43	29	81	48	29
100.6	91	55	43	75	54*	43*	94	50	28	75	46	28
120.7	172			248			-29*			115*		

Legend: A = Stress at immediate back B = Stress 6.1m above back C = Stress 9.1m above back
 - sign indicates tension * sign indicates tension in up-dip direction.

ation is analogous to advancing a tunnel and production potential is limited with small-scale equipment. In the long term, it is anticipated that narrow orebodies (in particular) will be more efficiently mined through the development and application of hard rock cutting machines and conveying systems.

Short dowels are the logical choice in mechanized flat back operations and are certainly applicable in narrow orebodies where the volume of rock to be reinforced is small (Fig. 1). Long dowels are applicable to medium width orebodies, having widths ranging from about 3.7m to 9.1m. A combination of post-pillars and long dowels should be considered for widths greater than 9.1m. Possible support patterns are illustrated in Figs. 8 and 9.

The basis for mechanization of ground support has been given, but the type of equipment developed will depend on the materials used for support. Combinations of materials currently in use or under development for dowelling include:

- (a) Resin formulations combined with wood, steel, or fibreglass rods.
- (b) Cement grout combined with stiff or flexible steel rods.

Polyester resin formulations are an expensive component of the resin bolting system. Bennet, et al (1974) reporting on research efforts to reduce costs at the White Pine Copper Mine, stated that the key factor in the use of steel dowels was the development of techniques to drill

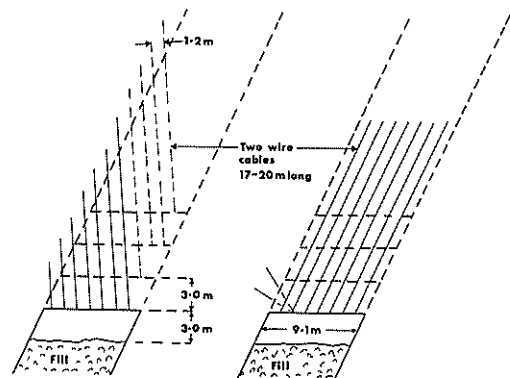


Fig. 8 Cross Sections of 9.1m wide, dipping orebodies showing alternative installation procedures for long cable dowels in uphole drill and blast cut and fill stopping.

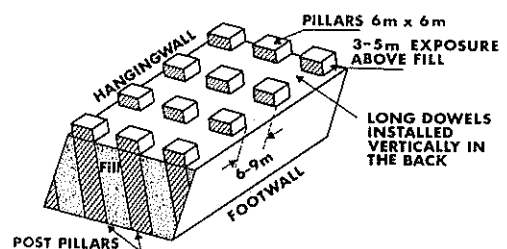


Fig. 9 Diagram illustrating support by post pillars and long cable dowels

holes as small as 25 mm diameter in order to minimize the volume of resin contained in the annulus between the hole and the rod. Wooden dowels (36mm diameter) installed in 43 mm diameter holes are used in some British coal mines to reinforce roadway floors and weak sections of the coal face. Parker, et al (1973) reported a successful strata reinforcement trial at the Daw Hill Coal Mine involving the placement of 15m long timber dowels connected by plastic sleeves and the injection of resin using a hand operated pump. A further development reported by Habberstad, et al (1974) relates to the development of a fully pumpable fibre glass reinforced dowel support system. In this system, 35 mm diameter fibreglass roving is pulled into the dowel hole by a P.V.C. tube and a polymer formulation is pumped in at the same time. The composite then hardens into a unit having a tensile strength of up to 18,000 kg. Costs are estimated to be competitive with other systems and trials have been scheduled in two operating coal mines using a prototype machine and equipment developed by the U.S. Bureau of Mines.

Tensioned steel bolts are currently about 25 percent cheaper to instal compared with resin dowels. However, resin formulations generally available have been developed for point anchored systems and have bond strengths about twenty times that of cement grout which appears to be adequate for full column grouting of steel dowels. It is apparent that the bonding agent should be matched to the rod material used and the design duty of the dowel support system. The challenge, therefore, is to develop cheaper chemical bonding agents to compete with cement grout while retaining the present advantages of a quick setting resin capsule system.

Considering long dowels, bonding agents must be pumped, but high early strengths are not normally required in this situation. Portland cement based grouts combined with steel rods may be considered when explosives are used for rock breaking as in cut and fill stoping. However, cheap, slow setting resins or water based glues appear to have application when wooden rods are required. Flexible steel rods, 7mm diameter, with breaking loads of 6350 kg, are particularly suitable for long hole dowelling. 18m long assemblies of coiled rods (1 to 7 rods) are available, equipped with cone and shell anchors to hold them in position in a 47 mm diameter hole while grouting. Spacers at 1.2m centres are bored to ensure different rod spacings on alternate spacers. Installation is simple as pretensioning is not required. Plastic breather tubes extend the full length of the cable and 0.6m beyond the collar of the hole.

5 CONCLUSIONS

Long dowels can be applied to cut and fill mining operations to improve ground support and permit mechanization of the overall operations at increasing depths.

Finite element analysis techniques can provide useful information on the loading of long dowels due to relaxation as the face is advanced and on anticipated ground conditions when considering alternative extraction sequences. However, presently developed theoretical and empirical procedures must be used to determine dowel spacing and strength characteristics concerning the support of fractured rock.

Resin formulations combined with wood, steel or fibreglass rods have application in short dowelling support systems, but cement grout combined with flexible steel rods appear to be the best combination for long dowelling support systems when blasting in hard rock.

Bonding agents and fillers should be matched to the design duty of the support system and research on their role is warranted.

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