Deep Mining 07 — Y. Potvin (ed)
©2007 Australian Centre for Geomechanics, Perth, ISBN 978-0-9804185-2-1
https://papers.acg.uwa.edu.au/p/711_22_Sandy/

Canadian and Australian Ground Support Practices in High Deformation Environments

M.P. Sandy *AMC Consultants Pty Ltd, Australia*

W. Gibson *AMC Consultants Pty Ltd, Australia*

D. Gaudreau *BHP Billiton Nickel West, Australia*

Abstract

Ground support is often a substantial component of mining costs. Many mining operations face significant challenges as they progress to greater depths and the stress environment becomes more aggressive. At some point, the level of stress-related damage becomes such that large deformations occur at the excavation boundaries. Changes to ground support designs are then necessary to ensure development remains serviceable and rehabilitation costs are contained at acceptable levels.

This paper presents case histories from several Australian and Canadian mines that have dealt with this transition and discusses some of the practical and technical issues involved in selecting the most appropriate support and reinforcement systems for particular conditions.

The mechanisms controlling the deformation around the excavations are discussed in terms of their implications for support and reinforcement system design and selection.

Numerical modelling of the stress-induced damage around the excavation has been undertaken and the results are compared with the observed mechanisms. Monitoring options are also discussed.

1 Introduction

Many Australian mining projects involve some exposure to low strength, foliated rocktypes, including ultramafics (especially talc-chlorite schists) and micaeous metasediments or metavolcanics. The pre-mining stresses in Western Australia's Yilgarn Craton are acknowledged to be amongst the most aggressive in the world. Stresses in Eastern Australia are comparable with the Canadian Shield. The combination of high stresses and weak rocks can result in adverse mining conditions.

The consequences of poor sequencing and layout in weaker rock materials can be severe, progressive degradation of development conditions associated with large deformations, which can lead to premature loss of access and reserves. In extreme cases, development closure of 30-50% has been experienced. This high-deformation style of ground behaviour has been observed in a number of Australian and Canadian mines.

Managing high deformation conditions has proved challenging. While there are various options for modifying the properties of support components to allow for large axial displacements, the significant shear displacements that are known to occur in the excavation walls are more difficult to accommodate.

2 Australian experience with high deformation conditions

The lead author's understanding of the mechanisms controlling deformation in foliated ground was initially based on observations at the Big Bell gold mine in the mid-1990's (Sandy and Player, 1999). At that time, the underground mine was being redeveloped, having closed in 1955. By chance, some of the new trackless levels were developed at elevations that allowed the backs of the old rail haulages to be scrutinised (Figure 1). This provided a relatively rare opportunity to examine the fracturing styles and intensity of stress-induced damage.

From these observations, it was clear that intense, stress-induced fracturing had developed above the backs of the haulage drives. Shearing on the stress-induced fractures had been accompanied by significant dilation or 'bulking'. The fractures had developed initially parallel to the drive backs, but then 'rotated' somewhat presumably as the failed ground had shed stresses deeper into the backs. Stress-induced fracturing had 'stabilised' once factures had developed parallel to the local major principal stress (sigma 1).

The overbreak profile at a number of rockfall locations matched these observations, suggesting a similar mechanism of failure. The observations and interpreted mechanisms are summarised in Figure 2.

Figure 1 Stress-induced fracturing above the backs of 1950s haulage drives at Big Bell

Offsets observed in blastholes drilled through the backs confirmed that significant shear was occurring on the stress-induced fractures (Figure 3). Similarly, shearing was observed in sludge sampling holes drilled in the ore drive hangingwalls and footwalls (Figure 4). Observations showed consistent indications of the sense of shear, as shown in Figure 2.

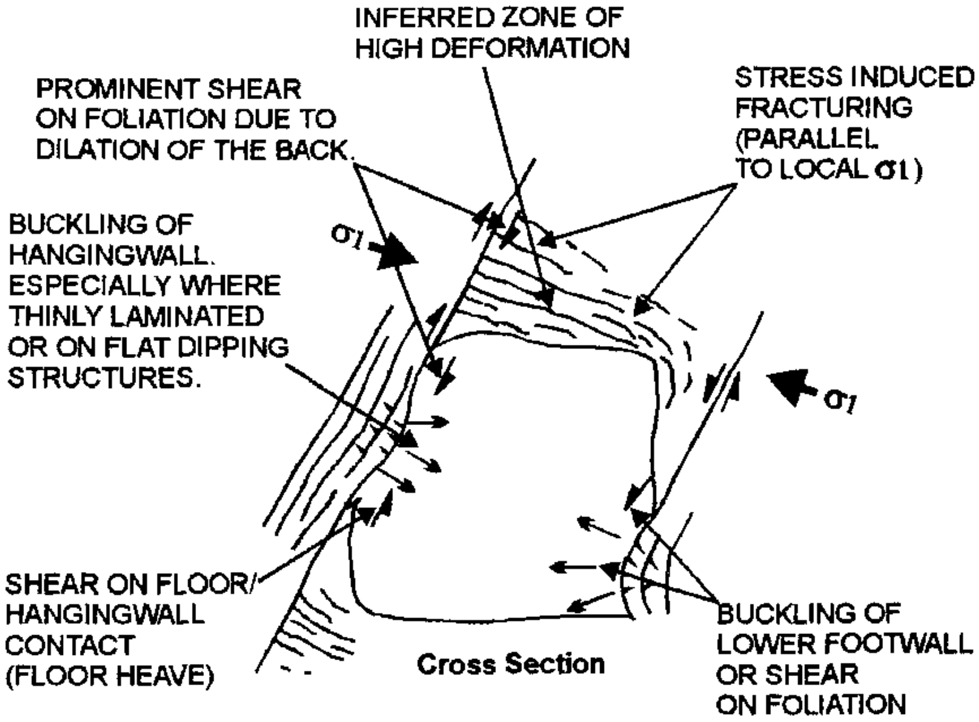

Figure 2 Observed ground behaviour at Big Bell (after Sandy and Player, 1999)

Figure 3 Shearing of 89 mm diameter blastholes in the oredrive backs (Big Bell)

Figure 4 Shearing of 89 mm diameter sludge sampling holes in oredrive hangingwall

Over the next few years, observations at a several underground operations in Western Australia and New South Wales confirmed the initial model for ground behaviour, with some refinements. The common features of these operations were the presence of foliated or thinly laminated rocks of low to moderate strength and the existence of sub horizontal, elevated stresses at a high angle or orthogonal to the drive axis.

Consistent observations included:

- Shearing of foliation in the drive footwall and hangingwall leading to offsets in drillholes (Figure 4) and 'guillotining' or truncation of the support elements (Figures 5 and 6).
- Stress-induced fractures sub-parallel to the drive backs and floors, leading to significant 'bulking' as the fractures shear and dilate (Figure 1). This in turn results in deformation and closure between the floors and backs of the drives, and contributes significantly to the shearing in the walls.
- The initial indication of significant bulking above the backs is usually the development of an open crack where the backs meet the hangingwall (Figure 7). Support elements in this location are often the first to become trapped in shear, indicated by the loss of the faceplate. Where meshing or fibrecreting are employed, the development of this crack may be difficult to observe.
- Buckling of the drive walls may occur if shearing is prevented. As a result of the confinement provided by the drive floor and the beneficial effect of reinforcement in the upper part of the walls, buckling tends to be most commonly developed in the lower part of the footwall (Figure 8).

Shearing in the footwall and hangingwall is promoted by local rotation of the major principal stress as the stresses redistribute around the opening. It should be recognised that the role of stress redistribution and rotation in terms of promoting shear in foliated rocks was identified in the late 1970’s in the Lead Mine at Mount Isa (Lee and Bridges, 1981).

A summary of the key mechanisms that have consistently been observed in mines exhibiting the high deformation, foliated ground behaviour is presented in Figure 9.

Figure 5 Guillotining of friction bolts installed in the footwall. Note the sense of shear indicated by the damage to the bolts

A more recent example of observations of fracture development above the backs of an oredrive is presented in Figure 10. An example of a drive exhibiting an advanced stage of deformation, in which serviceability has been compromised, is shown in Figure 11.

3 Canadian experience with high deformation conditions

Canadian experience is very similar, although high deformation behaviour is generally seen only in very deep mines due to the more moderate stress versus depth gradients that apply relative to the very aggressive conditions present in Western Australia (Lee et al., 2001).

For example, the degree of damage and deformation seen in the lower levels at the LaRonde mine ie at depths of 2400 m below surface are practically identical to those seen in the Yilgarn Star mine at 400 m below surface (Figure 12).

The very weak rocks at Yilgarn Star (typical uniaxial compressive strengths in the ore range from 40-60 MPa) only partly account for this – the pre-mining major principal stress in many Yilgarn Craton mines has been shown to increase at typically at 0.07 to 0.09 MPa per metre depth ie 70-90 MPa at 1000 m depth. This is almost twice the stress that would be expected at comparable depth in Canadian Shield mines.

Figure 6 Necking and guillotining of friction bolts installed in the hangingwall. Note the sense of shear indicated by the damage to the bolts

Figure 7 Initial indication of high deformation – dilation/shear of the hangingwall/back contact

Figure 8 Buckling of the lower footwall

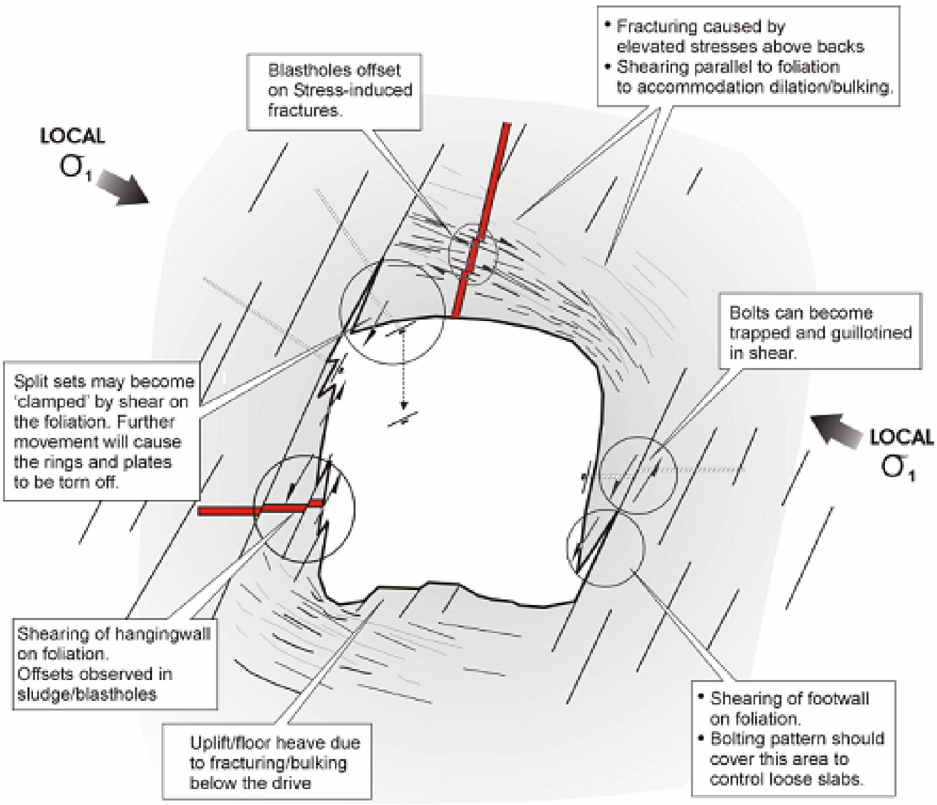

Figure 9 Summary of observed deformation mechanisms (After Beck and Sandy, 2003). Note the sense of shear at various locations around the opening

Figure 10 Stress-induced fracturing above the backs of an oredrive at the Yilgarn Star gold mine

Figure 11 Drive exhibiting advanced stage of wall deformation. Serviceability has been lost

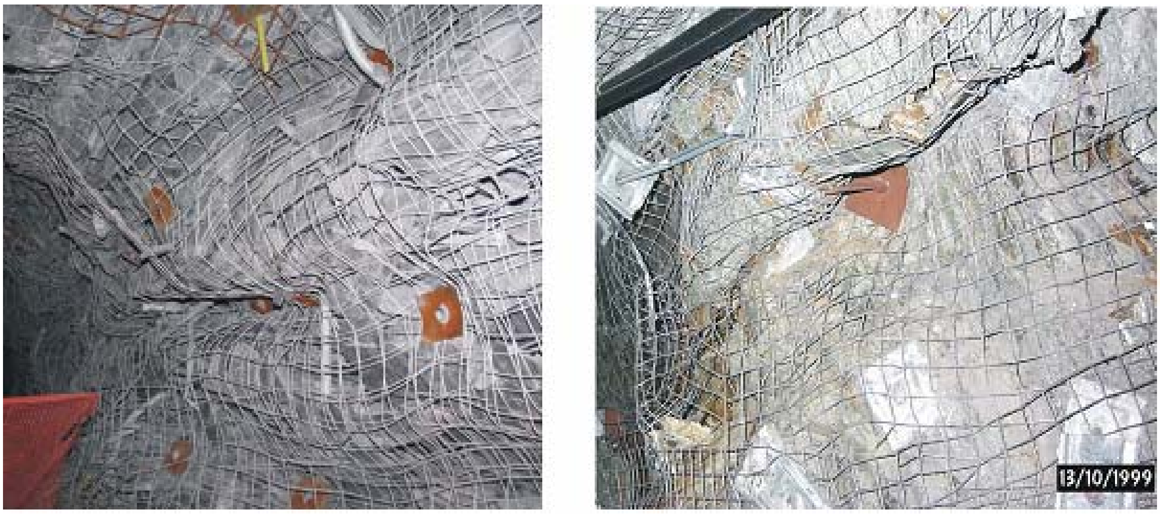

Figure 12 Substantial shearing and bulking of drive hangingwalls at 2400 m depth, LaRonde (left) and comparable behaviour at 400 m depth at Yilgarn Star (right)

Canadian studies of the mechanisms responsible for the deformations come to similar overall conclusions e.g. Simser et al., 2006 (Figure 13). The observations of the shear couples responsible for trapping support elements in the footwall are consistent with Australian experience, although the interpreted underlying mechanism is somewhat different. In the lead author's experience, it is important when interpreting ground behaviour to carefully review the observed shear couples to ensure that they are compatible with the mechanisms being proposed.

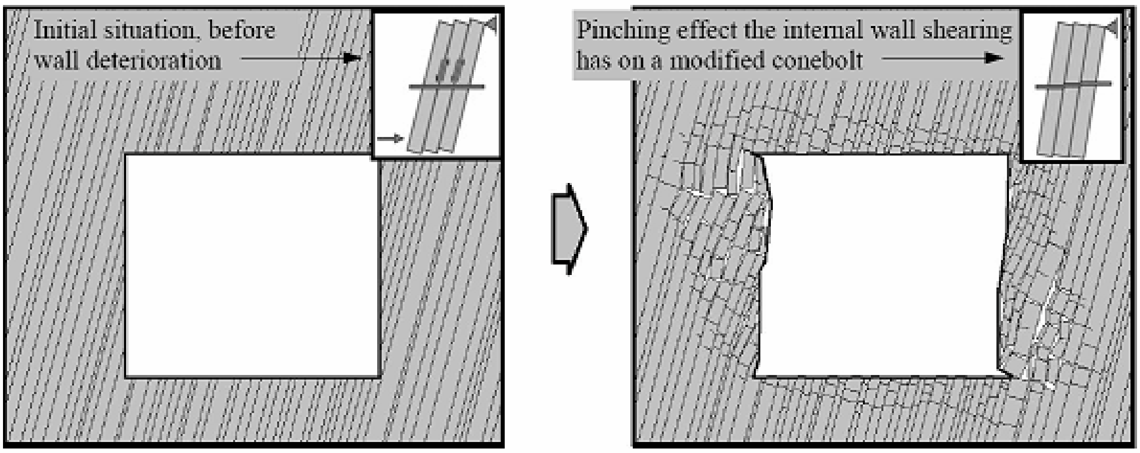

Figure 13 Observed ground behaviour in Canadian mines and interpreted mechanism of support entrapment (after Simser et al., 2006)

The amount of stress induced fracturing is not widely appreciated. Similarly, the timing, location and amount of shearing occurring on both stress induced and natural structures may not be widely recognised. Modern support practices, particularly meshing, make observation more difficult, as broken rock accumulates in the mesh. Shotcrete also tends to obscure ground behaviour from detailed observation. As a result reliable, clear observations are difficult to obtain in many mines.

Field deformation monitoring tends to focus on axial displacements – a better understanding of the shear component would assist in specifying laboratory tests and in support design. This could be obtained by drilling a series of observation holes in the drive backs and walls.

Redrilling holes may be necessary as shear displacements can be larger than typical hole diameters, and displacements may continue for an extended period. The objective of this work would be to better understand the timing and degree of shear displacements.

4 Managing deformation - implications for support

Debonded or yielding ground support is required to maintain serviceability in high deformation conditions, with the additional challenge presented by shearing, which may trap or cut the support elements. Often several phases of support rehabilitation are required in development with an extended service life, and this can involve substantial cost.

Where deformations have been monitored over an extended period, it is clear that there is significant time-dependent behaviour in these weaker rocks once stress conditions have been attained that are sufficient to induce fracturing. In some mines this has been exploited by deferring development in the weaker rock as long as possible without otherwise compromising the mine plan.

In most operations the response to increasing levels of deformation has been to increase the intensity of the support in terms of both bolt density and bolt length. For example at Mount Isa in the deep copper orebodies, initial support based on split sets and mesh is followed by fibrecrete and cables. A typical design is shown in Figure l4. In addition to upper sidewalls and backs support, cablebolts are installed into the lower parts of the sidewalls, angled downwards, to control deformation in this area.

Observations in mines that have only installed support to the shoulder or the gradeline suggest that severe damage is commonly developed where the lower sidewalls are not adequately reinforced. Where fibrecrete has been used for surface support, inadequate control of lower sidewall deformation results in ‘lifting’ of the fibrecrete shell, often accompanied by severe unravelling of broken ground from behind the fibrecrete. Repair costs after this are always substantial and drive closure may lead to loss of serviceability.

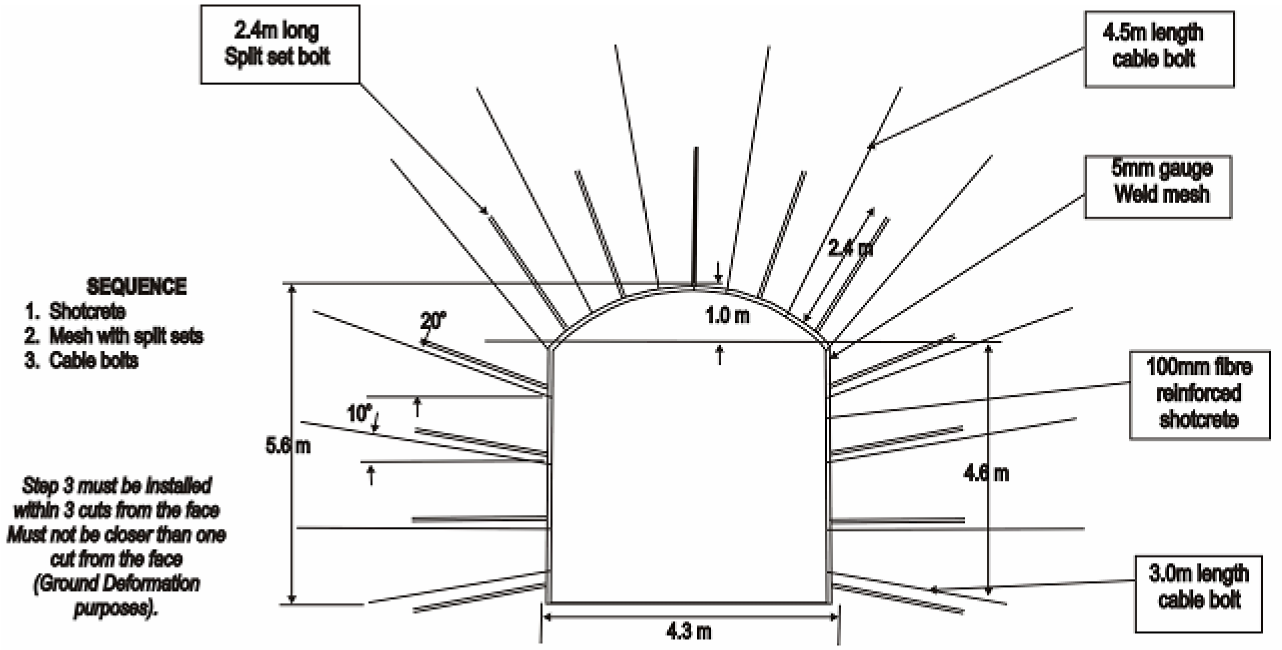

Figure 14 Support standard for high deformation conditions at Mount Isa (Guilfoyle et al., 2006)

The same approach is seen in Canadian mines, with intensive reinforcement directed at the lower sidewalls. As would be expected, the potential benefits of using yielding support in these situations have been recognised by several authors, both for accommodating ongoing deformation and in seismically active mines as a means of controlling material subject to seismic accelerations. However, the entrapment of support elements by shearing on structures and stress-induced fractures has now been recognised as severely limiting or preventing yielding bolts from operating as designed (Simser et al., 2006).

This is not surprising given that the observed deformations often involve localised shear in excess of typical support hole diameters. Trapping and ‘guillotining’ (truncation) of the bolts is inevitable. As observed in many Australian mines, once entrapment has occurred, the bolts are effectively locked-up, and ongoing deformation between the trapped section and the collar leads rapidly to excessive loading and failure, usually of some locally weaker part of the system at the collar.

Recent developments at LaRonde (Mercier-Langevin and Turcotte, 2007) are stated to have endured high deformation conditions better than the previous systems, which were based around Modified Cone Bolts. A ‘hybrid’ bolt comprising a resin encapsulated rebar installed inside a 46 mm friction bolt was installed in some of LaRonde’s “most difficult ground conditions”. The bolts were apparently still functional eight months after installation, a significantly better performance than the other systems that have been tried, including yielding bolts.

Caution is required when interpreting a lack of external damage, as deformation and truncation of support elements may still occur undetected within the rock mass. Particularly with grouted systems, there may be no unusual transfer of excessive deformation and loading of the surface fixtures. This has been observed in several mines where post grouting of friction bolts has reduced the occurrence of collar failures, but had very little effect on the amount of shearing in the rock mass and associated bolt damage or truncation.

In addition to ongoing efforts to develop bolts that can endure the large deformations and shearing within the rock mass, another significant challenge is presented by the surface fixtures that provide the connection between the bolts and surface support. In many mines, the weakest aspect of the system may be the collar fixtures and often their failure can lead to loss of connection between adjoining mesh sheets. Broken rock may spill out presenting a serious hazard (Figure 15).

Figure 15 Failure of collar fixtures can lead to loss of connection between mesh sheets

Some Canadian mines install ‘zero gauge’ weld mesh straps along the overlaps between mesh sheets with additional bolts to improve the durability of the connections. Similar practices have been adopted in Australian mines although the most commonly used straps are made from galvanised steel plate. These are less flexible in terms of collaring locations and have been seen to tear under ongoing deformation.

More recently, a South African development known as an OSRO strap has been applied in a seismically active Western Australian mine to improve the durability of the surface support at the mesh overlaps

(Figure 16). With this mesh strap, the cross-wires are attached to the longitudinal strands by means of a tightly wound 'pig tail'. This allows the strand to slip under load, and to distribute loads across several bolts. It may provide superior performance under ongoing deformation than either the zero gauge weldmesh or steel plate straps.

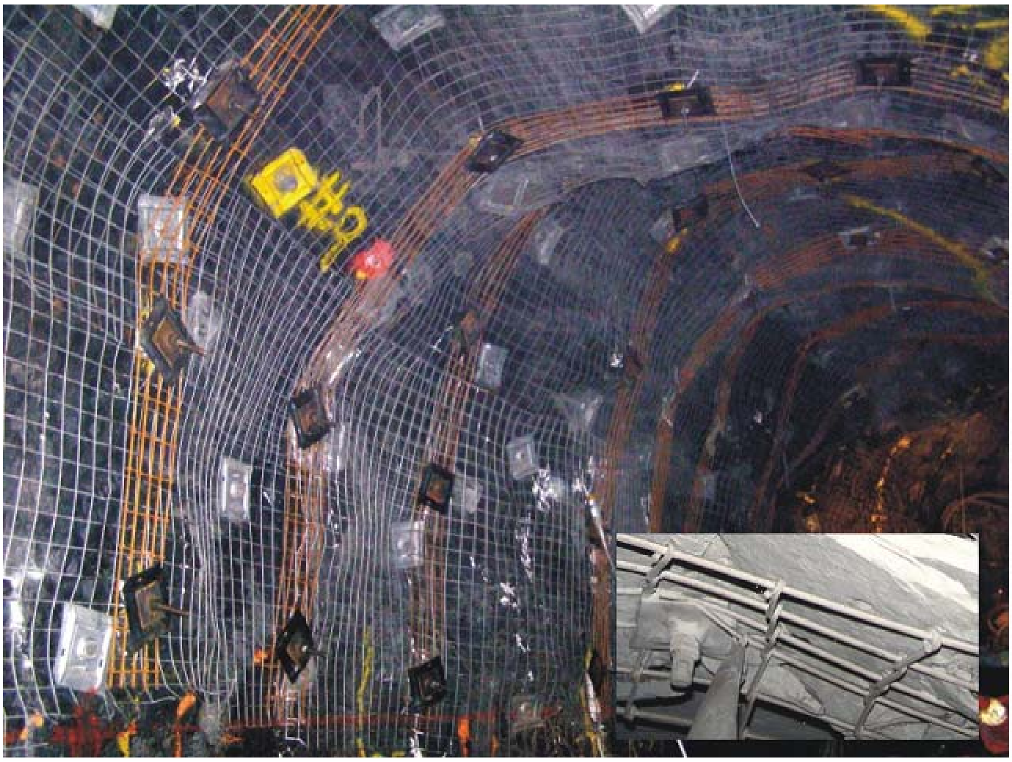

Figure 16 OSRO straps used to increase the durability of the mesh overlaps in a seismically-active mine. The connections between the wires (see inset) allow slip under load

In mines experiencing extreme deformation, drive serviceability can be lost. One option at this stage is to strip out some of the damaged material to regain serviceable drive dimensions. The resultant large excavations are often then very difficult and expensive to re-support.

In areas where the backs have been damaged and tendon support is considered unlikely to be effective, an alternative approach is used at the Leinster Nickel Operation (Gaudreau, 2006). In areas requiring rehabilitation, limited stripping of damaged material is undertaken on one side of the drive only. After re supporting the walls with bolts, mesh and fibrecrete, shotcrete arches are installed at typically 3 m spacing. These appear to be more effective than grouted, tendon based systems in areas that have experienced deep-seated damage.

5 Strategic options

In some mines e.g. LaRonde the layouts and timing of footwall development has been modified to exploit 'stress shadowing' from primary stopes. Development to access the secondary stopes is deferred until the primary stopes have been extracted. The development can be located in the stress shadow of the primary stopes. In other situations, some of the development is deferred until there has been some yielding of the 'pillars' between primary stopes: footwall development is then exposed to a less severe stress path.

Some Australian mines have relocated development either further from the orebody (increased stand-off distances) or into stronger rocks to reduce the level of deformation experienced and lower the costs of rehabilitation. With significant ongoing or 'time dependent' deformation apparent in operations such as Yilgarn Star, as indicated by extensometer monitoring results (Figure 17), scheduling development as late as possible in the mining cycle can also reduce rehabilitation requirements (Valent and Haywood, 2002).

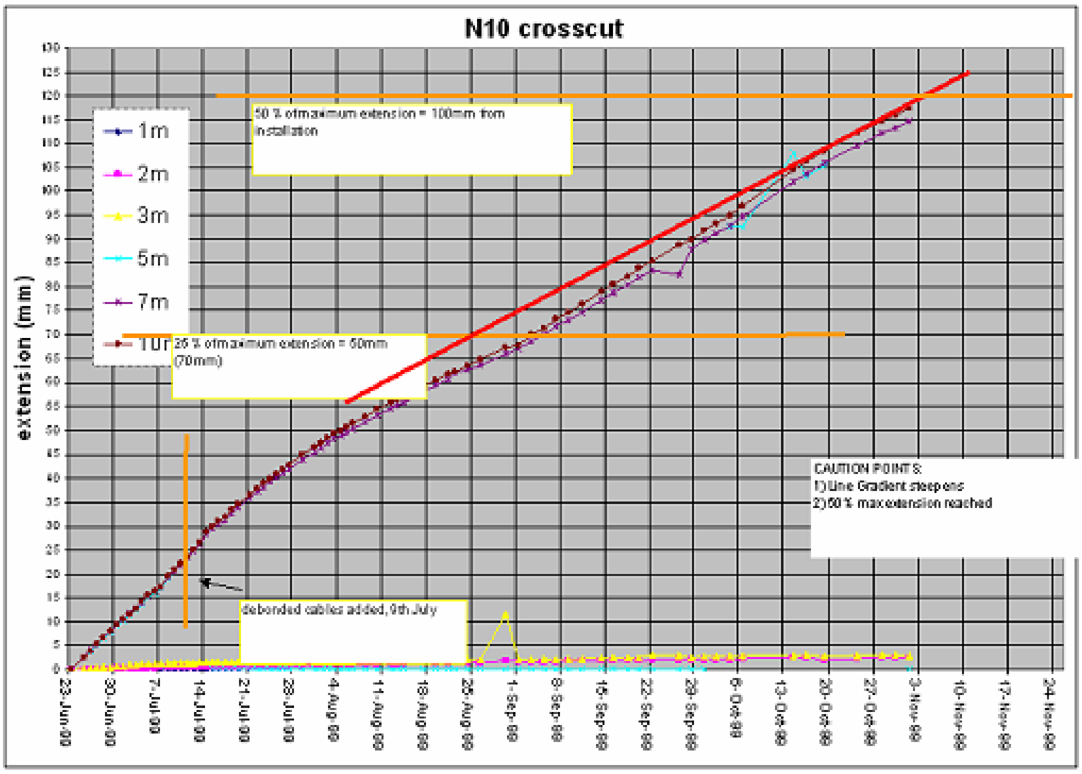

Figure 17 Extensometer results from Yilgarn Star show deformation continuing over many months

6 Modelling studies

Simple elastic models e.g. PHASE2 are unable to predict the location and extent of zones where stress induced fracturing is observed to occur. The fracturing mechanism above the backs is more complex, and is influenced by shearing on foliation. The locations where slip on foliation is likely to occur in the sidewalls can nevertheless be predicted using simple elastic models (Figure 18). Stress-induced damage and associated yielding need to be properly represented if the subsequent stages of damage are to be properly predicted.

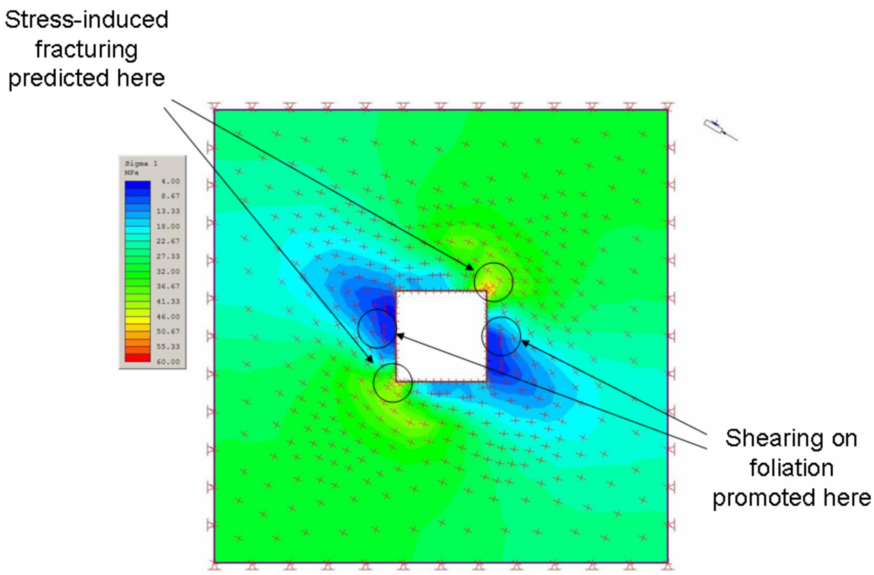

Figure 18 Modelling of stress redistribution around a drive using PHASE2

A FLAC3D model was built to assess the ability of the code to simulate the observed ground behaviour. The intention was to represent various modes of failure such as dilation and shearing of joints in the wall, and progressive failure in the backs due to stress-induced fracturing. The model included an explicit representation of foliation dipping at 60º.

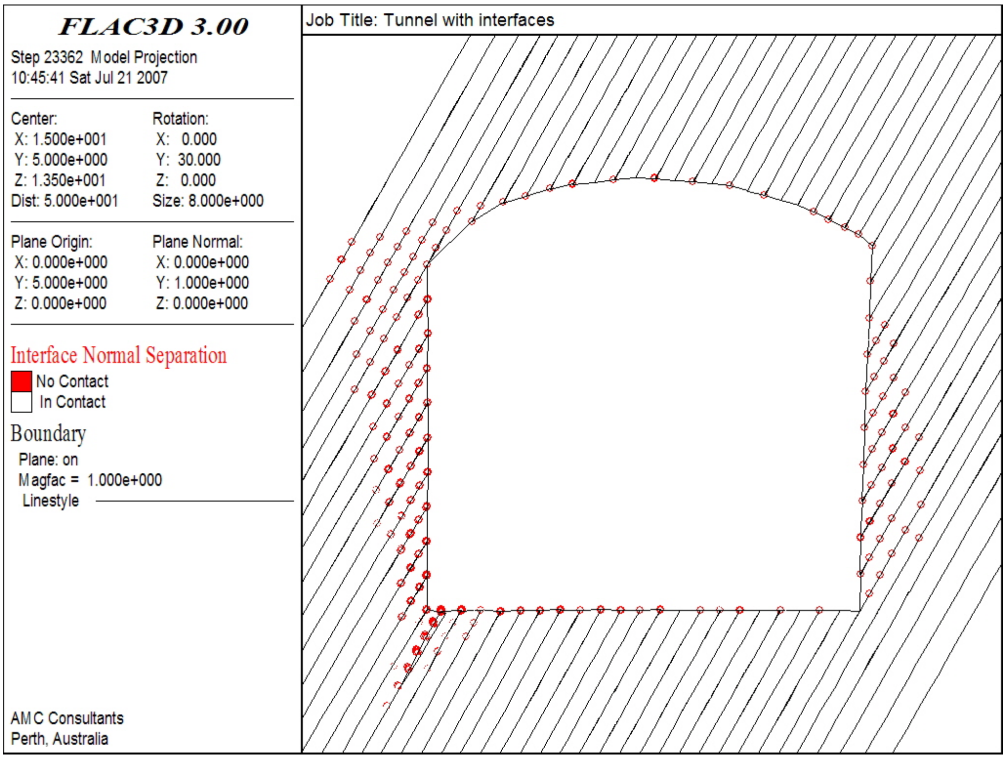

Figure 19 FLAC model showing the predicted shear failure zones

The model predicted failure on the foliation, as indicated by separation of the joints. This is shown in the model with circles indicating 'no contact' on the interfaces used to model the joints (Figure 19). The locations of the zones predicted to shear were generally consistent with the field observations. However, the model did not correctly predict the location and degree of stress-induced fracturing.

Explicit representation of the stress induced fractures would be required in order to model the shearing observed to occur in the backs and floors. A code that is able to represent the fracturing process such as PFC or ELFEN might provide some insight into this aspect of the observed behaviour.

7 Conclusions

In high deformation environments, there is widespread acceptance that the ability to yield whilst retaining capacity is an important characteristic of support systems. A better understanding of failures in shear and interaction between support and the rock mass would be beneficial to design

Field deformation monitoring focusing on shear rather than axial displacements would provide a better understanding of the impact of shear on bolt performance. This could be obtained by drilling a series of observation holes in the drive backs and walls. Redrilling holes may be necessary as shear displacements can be larger than typical hole diameters, and displacements may continue for an extended period. This information would assist in specifying laboratory tests and aid in the design of shear resistant support systems.

Managing high deformation requires a combination of appropriate support systems, and the use of sequencing where possible. Rehabilitation costs and impacts on the schedule can be significant in operations experiencing high levels of deformation.

Results from limited modelling studies to date have been able to correctly reproduce the locations in which shearing has been observed on the foliation. However, other major mechanisms evident from the observations include stress induced fracturing and subsequent shearing on these fractures. These are not readily represented in the same models.

Acknowledgements

The authors would like to acknowledge the assistance of their colleagues at AMC Consultants and BHP-Billiton Nickel West for their support in preparing this paper, particularly Frans Basson and John Albrecht. Discussions with Brad Simser (Xstrata) and Frederic Mercier-Langevin (Agnico-Eagle) were very helpful in gaining some insight into Canadian experience.

References

Beck, D.A. and Sandy, M.P. (2003) Mine sequencing for high recovery in Western Australian mines. AusIMM Bulletin No.3, May/June, pp. 38-46.

Gaudreau, D. (2006) Current support practices at Perseverance mine. Proceedings 3rd Intl. Sem. on Deep and High Stress Mining, 2-4 October 2006, Quebec City, Canada.

Guilfoyle, K., Slade, N. and Kenworthy, S. (2006) The N3500 project – deep, high stress and talc. Proceedings 3rd Intl. Sem. on Deep and High Stress Mining, 2-4 October 2006, Quebec City, Canada.

Lee, M.F. and Bridges, M.C. (1981) Rock mechanics of crown pillars between cut-and-fill stopes at Mount Isa Mine. Applications of Rock Mechanics to Cut and Fill Mining , Stephanson and Jones (eds), Instn Min. Metall., London, pp. 316-329.

Lee, M.F., Mikula, P. and Pascoe, M.J. (2001) Virgin rock stresses vs rock mass strength in Western Australia's Yilgarn greenstones. Ground Control in Mines Workshop, The Chamber of Minerals and Energy, Perth, June 2001.

Mercier-Langevin, F. and Turcotte, P. (2007) Evolution of support practices at Agnico-Eagle's LaRonde Division – innovative solutions to high stress yielding ground. Proc. 1st Canada-US Rock Mech. Symp., Vancouver, Canada, pp. 1497-1504.

Sandy, M.P. and Player, J.R. (1999) Reinforcement design investigations at Big Bell. Rock Support and Reinforcement Practice in Mining. Villaescusa, Windsor and Thompson (eds), Balkema, Rotterdam, pp. 301-315.

Simser, B., Andrieux, P., Mercier-Langevin, F., Parrott, T. and Turcotte, P. (2006) Field behaviour and failure modes of modified conebolts at the Craig, LaRonde and Brunswick mines in Canada. Proc. 3rd Intl. Sem. on Deep and High Stress Mining, 2-4 October 2006, Quebec City, Canada.

Valent, M.C. and Haywood, G. (2002) Yilgarn Star just in time methodology – planning and scheduling implications. AusIMM Underground Operators' Conference, Townsville, pp. 39-46.