USE OF CONE BOLTS IN GROUND PRONE TO ROCKBURST

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ABSTRACT: Big Bell Mine started using the Cone bolt as a yieldable support to combat rockburst in September 1999. Australia has little experience of mining in rockburst conditions which makes the ground support requirements a new experience to all involved. Much work went into the design of the support patterns and the sequence of operations. The workforce required training in installation procedures, the theory behind yielding support and in the importance of good quality installation practices. Testing has been carried out on various grout mixes to determine the best mix for optimum bolt performance. This paper gives an overview of the introduction of Cone bolts at Big Bell.

INTRODUCTION

Big Bell Mine is located 25 km north west of Cue in Western Australia and about 540 km NNE of Perth. The mining method used is longitudinal sub-level caving with current operations working to a depth of approximately 535 metres. A combination of natural stresses and mining induced stresses has resulted in a number of rockburst ground failures at Big Bell. Production in the lower levels of the mine was halted in September 2000 after a number of major rockbursts, one resulting in a fatality. Production prior to closing the lower levels was 1.8 million tonne per year yielding 160,000 ounces of gold.

A major upgrade of the ground support to combat rockbursts in the lower levels was begun in August 2001 after a decision was made to continue mining the lower levels of the orebody. The yielding Cone bolt tendon was chosen as the primary support. The upgrade consisted of rehabilitation of existing drives using 4 metre long Cone bolts. It also involved replacing the tubular groutable rockbolt and the grouted rebar with 3 metre Cone bolts as the main form of reinforcement in the new development drives. 24,000 Cone bolts are expected to be installed before the mine returns to normal production.

Non-seismic support of debonded Gewi-bars is used in drives more than 75 metres from the orebody.

ROCKBURST

Rockbursts are explosive failures of rock when very high stresses occur around mine openings. They result in the ejection of rock ranging from a fraction of a cubic metre to thousands of cubic metres. Fig. 1 shows the damage caused by an outburst. The seismic energy associated with the rock ejection process can reach the equivalent an earthquake of magnitude five on the Richter scale. An event of this magnitude is usually associated with fault slip activity and has only occurred in South Africa. The largest reading at Big Bell has been 2.4, with the biggest rock fall being approximately 1,000 tonnes. Geophones are positioned throughout the mine to determine intensity and location of seismic events.

Ejection velocity can be up to seven metres per second with commonly around one metre thick rock being ejected.

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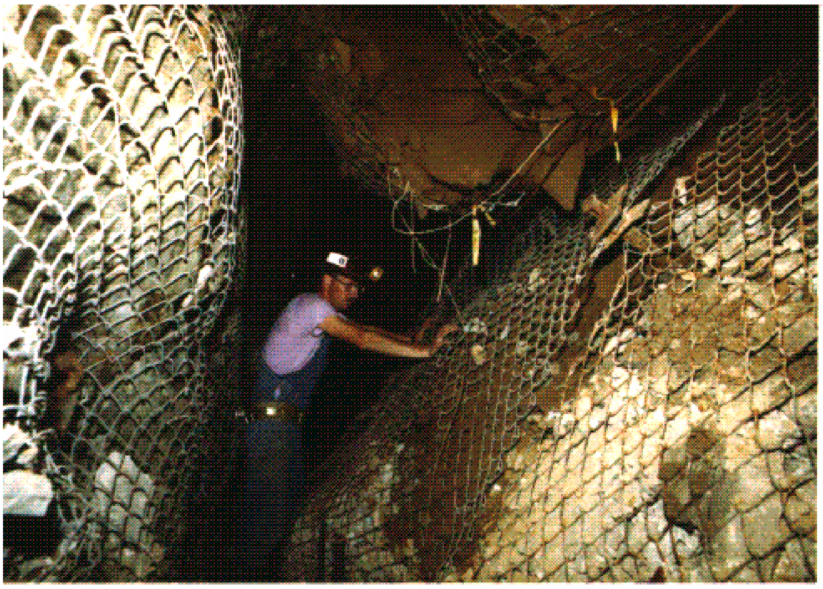


Fig. 1 Damage to a drive from rockburst

REINFORCEMENT REQUIREMENTS

The large displacements and high strain rates resulting from a rockburst cannot be countered by conventional stiff reinforcement systems. For the support to be effective it must be able to absorb the kinetic energy, imparted to the rock mass by the seismic event, without failing. Support tendons spaced at one per square metre must have the capacity to absorb at least 60 kJ of seismic energy. This is equivalent to the kinetic energy in a one metre thick slab in the backs, accelerated to a velocity of 7 metres per second. The energy absorbed by conventional rigid tendons prior to failure is of the order of 4 to 6 kJ.

In addition, the support has to allow for at least 500mm of rock displacement without failing. Conventional end-anchored or grouted support tendons can fail when subjected to deformation as low as 60 mm.

CONE BOLTS

The Cone bolt was developed as a result of work done by the Chamber of Mines Research Organisation (COMRO) in South Africa and is manufactured by Steeledale Strata Control Systems.

The toe end of the bolt has a forged conical enlargement. The collar end is threaded like a conventional roof/rock bolt or may have a 'Shepherd's Crook' eye to facilitate cable lacing. The entire length of the bolt is coated with a debonding agent to reduce the resistance caused by the bond between the grout and the bolt. Both types of bolt are used with a bearing plate and in the case of the threaded bolt, a nut and hemispherical washer is also used (Fig. 2).

The bolt chosen for Big Bell had a diameter of 22mm, a cone diameter of 32mm and an M24 thread. The bolt has a yield strength of 22 tonne.

Fig. 2 Threaded Cone Bolt

INSTALLATION

Two different length cone bolts are installed, three metre in new development drives and four metre in the rehabilitation of existing drives. Hole diameters vary for the different lengths. The three metre bolts in the new development are installed in 45mm diameter holes drilled by the face jumbo. The four metre bolts are installed in 51mm diameter holes simply because of the need to do extension drilling for the longer holes.

The hole is pumped full with a thick self-supporting grout and the bolt pushed into the hole through the grout. Minimal thread is left protruding to allow the mesh to be pulled to the backs. The bolt is then tied to the mesh to prevent it sliding out of the hole.

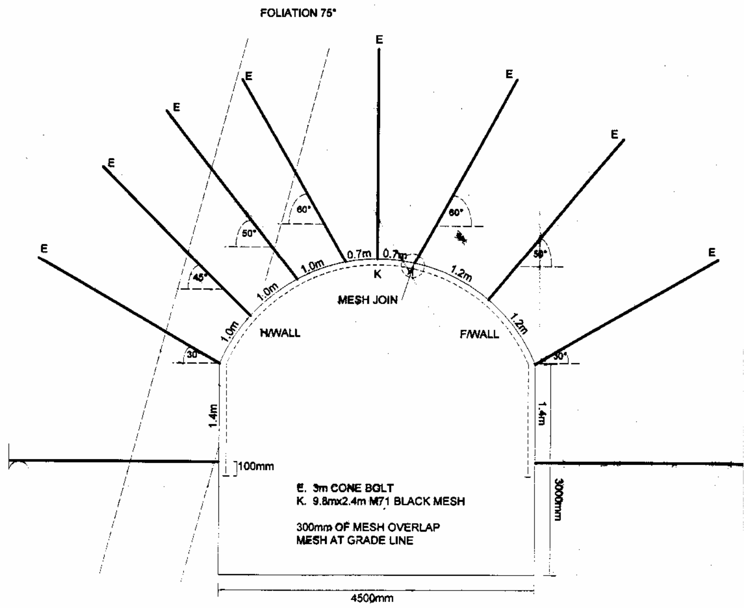
After the grout has cured sufficiently, which takes six hours in the case of new development drives, the bearing plate, ball washer and nut are fitted and the whole system tensioned using an impact wrench.

Bolting patterns vary depending on drive type whether rehabilitation or new drives-drive size, orientation, and location in relation to seismic prone areas. Generally speaking eight to ten Cone bolts are installed in a ring pattern on 1.2 metre spacings. Fig. 3 shows the bolting pattern for 4.5 x 4.5 metre ore drives.

The rate of installation is another issue, especially in the rehabilitation areas. It was originally expected that the contractor would be able to install up to 60 of the 4 metre Cone bolts in pre-drilled holes in a 12 hour shift. This has been met on occasions, but the average is well below this level.

The main reason for the lower than expected installation rate is the high number of redrills required as a result of collapsed holes in the broken ground of the rehab areas. Reliability and performance of the grouting equipment also caused problems.

SEISMIC DEVELOPMENT
ORE REINFORCEMENT ONE (OR1)
(4.5mW x 4.5mH)
FINAL DESIGN



E. 3m CONE BOLT
K. 9.8mx2.4m M71 BLACK MESH

300mm OF MESH OVERLAP
MESH AT GRADE LINE

6m AND 4m MESH JOIN MUST BE ON THE FOOTWALL SIDE
COLLARS SPACED AS SHOWN (VIEW FOR DRIVES HEADING SOUTH)
BOLT ANGLES TO PROVIDE ANCHORAGE OF ROCKS TO HANGING WALLS
NOMINAL BOLT ANGLES SHOWN
HAVE DUMP 10-15° INTO THE CAVE ADVANCE ONLY

Fig. 3 Cone bolting pattern for ore drives

PRINCIPLE OF OPERATION

The forces generated in a rockburst are transferred to the bolt via the bearing plate. Depending on the grout strength and quality of installation, the cone is drawn through the surrounding grout. The resistance to displacement is a combination of the friction between the grout and the cone and the force required to compress or crush the grout. In so doing, work is done and energy absorbed from the surrounding rock.

Once all of the energy has been absorbed, a state of equilibrium is achieved and the bolt stops yielding and contains the surrounding rock. Any subsequent build up of force in the bolt will result in the yielding process being re-initiated.

The broken rock between the bolts is supported by mesh and/or lacing.

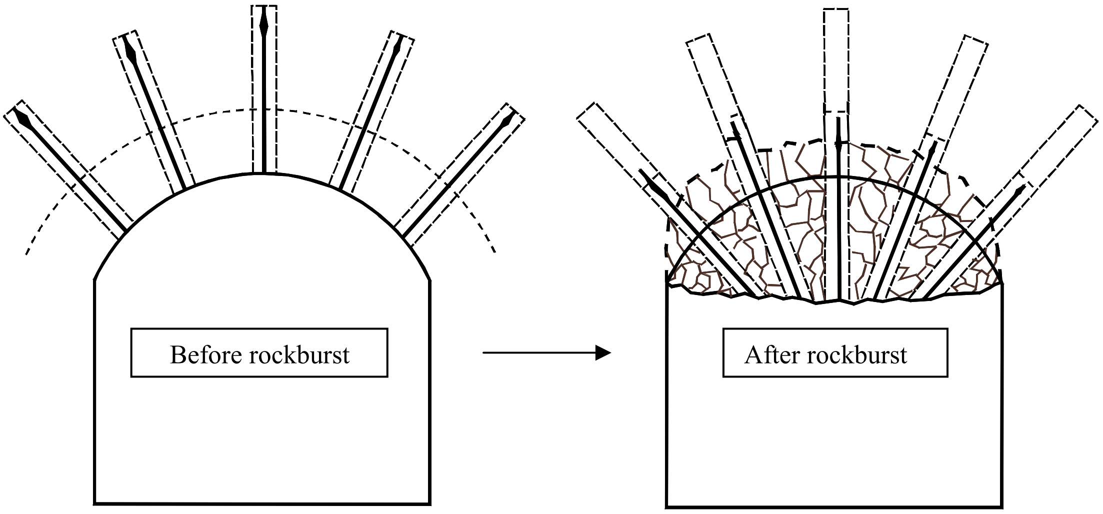


Fig. 4 Depiction of how the Cone bolt contains broken ground after a rockburst. (not to scale)

PERFORMANCE

The major factors affecting the performance of the Cone bolt at Big Bell are the properties of the grout and the quality of installation. There have not been any rockbursts since the introduction of the full ground support Cone bolt pattern shown in Figure 3. Performance of the bolt will not be known until normal production resumes. However previous seismic events, in which cone bolts were used in localised areas, have shown that the damage from a rockburst can be contained by Cone bolts and mesh installed in a suitable pattern.

The initial grout mix used consisted of general purpose (GP) cement with a 0.33 water cement ratio, using mine water, and 2.5% w/w Sikament HE200NN. This additive is a combination of superplastiser and accelerant. The superplastiser improves pumpability and reduces the water demand of the cement. The accelerant is added to provide high early strength to enable the bolt to be tensioned six hours after installation in the new development drives.

A retardant is added to the grout in the rehab areas to give the crews more working time because of delays encountered with blocked holes in the broken ground.

Fig. 5 shows the results of pull tests on a three metre Cone bolt for static testing and quasi-dynamic testing. The static test was the standard pull test where the rate of loading of the bolt is low (less than one tonne per minute) and displacement readings are taken only after stabilisation. The quasi-dynamic test involved loading the bolt at the maximum rate of the testing equipment, 3.5 mm/sec, and recording the maximum load reached during each extension of the ram.

The results from the latter test showed that the bolt was reaching loads approaching the yield strength of the bolt. Numerous UCS tests on the grout mixes gave varying results but tended to be on the high side, that is, greater than 50MPa. However from a number of seismic events that have loaded Cone bolts at Big Bell there is only one documented case where a Cone bolt had failed. The grout mix was changed to reduce the strength. The superplastisiser was cut from the mix to increase the water demand, and hence reduce the strength of the grout, while at the same time the low slump properties were retained.

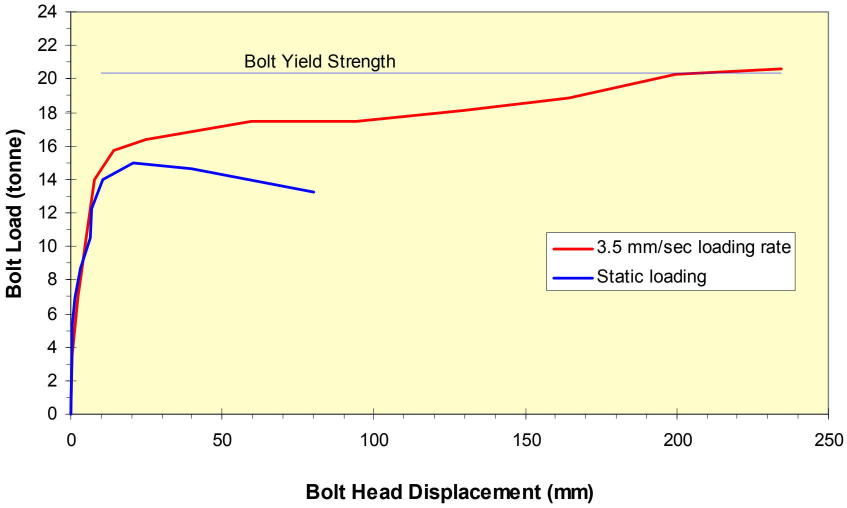


Fig. 5 Load-displacement curves for Cone bolts using original grout mix

Grout strength results varied widely making it difficult to standardise the mix. However increasing the water cement ratio had the effect of reducing the strength to around 35 to 40 MPa. Pull tests have yet to be performed for these grout mixes. If the results are still too high then air entraining admixtures will be looked at for reducing the grout strength. It is not possible to keep adding water to reduce the strength. The grout becomes too thin and simply runs out the hole.

The other major issue affecting bolt performance is quality of installation. It is important that the grout column in the hole is continuous and that no air pockets are present.

When the bearing plate, ball washer and nut are fitted during the tensioning procedure it is important to ensure that the plate pulls the mesh into cavities so that the mesh contours the rock surface.

Tensioning was done using a pneumatic impact wrench set to stall at approximately six tonne. This was sufficient to bed the plate and mesh to the backs and to tighten any "pregnant" mesh in the rehab areas.

TRAINING

Considerable work was done by the geotechnical engineer and consultants at Big Bell to produce a ground support management plan to combat rockburst. Integral to the success of the plan is the performance of the ground support crews. It is important they maintain the correct grout specifications, installation quality and installation rate. To achieve this, training programs were designed that involved classroom sessions as well as time underground with each crew during each stage of the installation. The crews learned not only how to do the job properly but gained an understanding as to why they were doing it.

Big Bell, like a lot of mines in Australia, is a fly-in, fly-out operation, which often leads to a high turnover of the workforce. This places added importance on the training system to ensure that every worker is competent in all aspects of Cone bolt installation. Retaining experienced workers is also important.

CONCLUSIONS

The future of mining operations at Big Bell depends, to a large extent, on the success of the Cone bolt installation in both the rehabilitation drives and the new development drives. The performance of the bolt is heavily dependent on the specifications of the grout, the quality of installation and correct pattern drilling. A lot of grout testing has been done to assess strength and curing times. The workforce has a clear understanding of the importance of installing the bolt correctly.

An audit of installation procedures was performed three months after the start of the rehabilitation work and a recommendation made to modify grouting equipment and procedures, primarily to improve installation rates.

Constant training, assessment, auditing and testing are required to ensure success of the project.

BIBLOGRAPHY

Sandy, M.P., and Player, J.R. 1999. Reinforcement design investigations at Big Bell. Proc. Int. Symp. On Ground Support. Kalgoorlie, Australia. 301-315.

Jager, A.J. 1992. Two new support units for the control of rockburst damage. Proc. Int. Symp. On Rock Support. Sudbury, Canada. 621-631.

Ortlepp, W.D. 1992. The design of support for the containment of rockburst damage in tunnels – An engineering approach. Proc. Int. Symp. On Rock Support. Sudbury, Canada. 593-609.

Player, J.R., 2001. Geotechnical Engineer, Big Bell Mine. Personal communication.

Steeledale SCS. 2001. Web page. www.steeledale.co.za/steeledalescs/scs4.htm. Acc. 20 Dec.2001