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Working Together to Secure the Future — Cannington Ground Support Rehab Project

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Abstract

The Cannington mine embarked on several significant ground support rehabilitation projects during 2006 in response to safety and business risk concerns arising from falls of ground, decreasing reliability of older installed ground support, and potential time delays of main accesses to the production ore blocks from ground instability. This instability was caused by regional structurally controlled ground movements, triggered by excavation of the stopes within the Southern Zone. This combined with the lack of sufficient ground reinforcement capacity (from historically installed ground support), and absences of surface retention and ravelling prevention between the rocks bolts due to the lack of surface support such as mesh or fibre reinforced shotcrete (fibrecrete) that was not installed during the early Cannington project development.

1 Introduction

Cannington has approximately 80 kilometre of active development underground. The principal areas affected by the recent regional ground response was approximately 25 kilometres of excavations that was developed during the original exploration and main access development that was mined during the period between 1993 and 1997 and some development up to 2000. All of the excavations during this period were supported with HGB (hollow groutable bolts) which were expected at the time to be a Life of Mine (LOM) ground support bolt but with only surface support (mesh or metal fibre reinforced shotcrete) in areas of poor to very poor ground (typically the ground support standard in mining during the period). By early 2000, the HGB bolts were phased out due to early corrosion issues and load/shear capacity concerns, and replaced with resin installed jumbolts. Synthetic fibres were also substituted (new technology development) for fibre reinforced fibrecrete due to corrosion issues and long term performance. The sequence in the fibrecrete cycle after this period was also changed which originally consisted of spraying the metal reinforced fibrecrete on top of the installed rock bolts in areas of the main mine infrastructure (crusher, fine ore bins, load out stations, pump stations, conveyor drives, workshops). Once cracked, this metal reinforced fibrecrete would form slabs and blocks that fell from the back and sidewalls freely since it did not have the benefit of rock bolts supporting the slab against the rock face. By the early 2000, the ground support management plan at Cannington changed to reflect the concerns with the early poor performance of the ground support, mainly the mechanical capacity, ability and shorten service life expectation of the HGB. Mandatory use of partial to full surface support using galvanised mesh or synthetic fibre reinforced fibrecrete was also instigated.

This paper outlines the justification, scoping, installation management and problem solving of one of the largest mining rehabilitation project. It involved almost 24 kilometres of ground support rehabilitation, which installed greater than 245000 bolts (9 different bolt types), 44000 sheets of galvanised mesh, 11000 m^3 of fibrecrete utilising both BHP Billiton development crews and four separate mining contractors.

2 Geology of Cannington

The Cannington deposit is a silver-lead-zinc massive sulphide deposit hosted by Proterozoic high-grade metamorphic rocks of the Soldiers Cap Group. It lies in the Eastern Succession of the Mt Isa Block. Proterozoic host rocks are overlain by Cretaceous mudstones with thicknesses varying from 10–60 m increasing in depth to the east and south. The deposit is hosted by a sequence of garnetiferous psammite, migmatitic gneiss and amphibolite.

2.1 Deposit geology

The simplified deposit and structural geology is illustrated in Figure 1 which is a plan and cross sectional view respectively of the Cannington deposit and some of its major structural features. As shown by the displacement of the two mining sections, the Trepell Fault strikes 135° and dips 80° north-east and divides the deposit into the Northern Zone and the Southern Zone areas. The Southern Zone extends from immediately below the cretaceous mudstones to a depth of approximately 650 m below surface, while the shallower Northern Zone extends to only a depth of 350 m below surface.

Prior to 2004, the majority of mining at Cannington had been carried out on mineralisation south of the Trepell Fault. Mineralisation is stratiform along the limbs of a tight (70–90 m wide) isoclinal recumbent synform. The two limbs of the fold dip between 40 and 70° to the east and the fold has an overall southerly plunge. The eastern or hanging wall limb is typically thicker (about 150 m) than the western or footwall limb (about 45 m). The mineralisation appears to terminate to the north at the Cretaceous unconformity (Bodon, 2002).

The core of the synform where the majority of the decline is located, is composed of amphibolite with the silver-lead-zinc sulphide wrapped around it and hosted by quartzite, garnetiferous quartzite or minor mafic bands. Outside of the mineralised horizon, is muscovite-sillimanite schist bound by migmatitic gneiss consisting of narrow bands of biotite-sillimanite-quartz and quartz-feldspar.

The sequence is cut by a series of pegmatite dykes that are unmineralised. The silver-lead-zinc mineralisation has been divided into mineralisation types based on textural, mineralogical and geochemical characteristics. The mineralisation styles are typically divided into footwall (western limb) and hanging wall (eastern limb) lead-rich and zinc-rich lodes with an additional style defined in and around the fold nose (keel). Within each of these areas, the mineralisation is further divided into either a more mafic host or a more siliceous host.

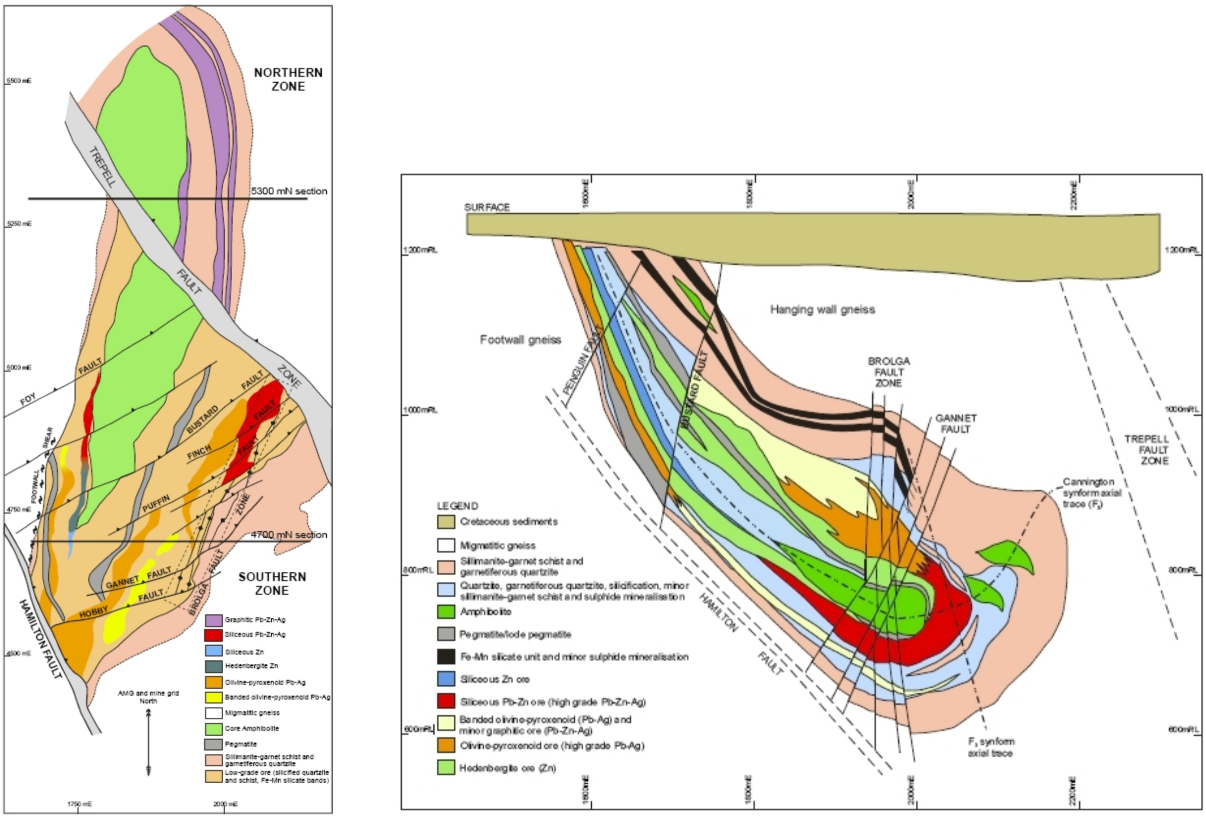

Figure 1 Illustrating the simplified geology in plan and cross section views respectively

2.2 Cannington's structural geology

Cannington has a complex structural history with five discrete generations of deformation events. These have developed many large shear and fault zones. There are three main structures that bound the Southern Zone. These are the footwall shear and the Trepell and Hamilton faults. The footwall shear forms the basal contact with the western side of the ore body. It was formed during the folding and thrusting that created the Cannington's Synform and is characterised by intense fracturing and alteration. The Trepell Fault is up to 60 metres wide, is northwest striking and northeast steeply dipping. With its intensive brecciation zones consisting of angular rock fragments and chlorite-clay rich rock flour gouge, the Trepell fault exhibits about 300 m of sinistral displacement as shown by the separation of the Northern and Southern Mining Zones. The Hamilton Fault has a similar orientation, dip and material characteristics to the Trepell Fault, however it is only 20–40 m wide and forms the southern boundary to the main southern orebody and is the hangingwall of the R4 mining zone.

Smaller scale but more important for stope scale stability is the Bird Faults. These northeast trending, steeply dipping structures which occur at 10–50 m intervals with widths of centimetres up to 30 m they are conjugate fault structures between the Trepell and Hamilton Faults. As illustrated in Figure 1, these faults cut across the entire deposit and can interconnect structurally, the Keel, HW and FW mining blocks. The Bird Faults can be very sharp, narrow and distinct in the ore zone, whereas in the host waste rock, they can be metres wide and full of chlorite-rich gouge. As the amount of mining void is increasing underground, the mining induced stress appears to release strain energy by either; shear movement along the bird faults, rotation of principal stresses causing movement, or movement along the bird faults in response to movement along the Hamilton or Trepell faults. In areas of the Southern Zone where σ_1 clamping pressure is reduced due to the partially or completely shielded from the closing of transverse pillars, the Bird Faults have been observed to open several centimetres. All of these structures can allow sliding and block release as more of the principal stresses are shielded and blocked by the mining activities in the HW and FW of the orebodies.

3 Project scope for the rehabilitation projects

3.1 Cannington historical ground support

Cannington's early ground support practice consisted of installing 6–10, 3 metre HGB (Hollow Groutable Bolts) within the 6 x 6.2 m wide decline with only meshing (decline only 9% meshed) occurring in areas of poor to very poor ground as observed at the time of the development with minor amounts of metal reinforced fibrecrete in areas of very poor ground. The HGB was a thin walled (3.2 mm) hollow tubular pipe bolt (25 mm OD) made of mild steel that was not galvanised (Figure 2). It had 150 mm of the bolt threaded on the anchor end and 500 mm threaded on the collar. These became weak spots at the contact with the plate due to atmospheric corrosion and at the anchor end when they were not grouted properly (Todd et al., 2006). It relied on the cement grout to provide long term corrosion protection. Corrosion was measured during a WA School of Mines research project as low as 0.0022–0.04 mm/year atmospheric to high of 0.18–0.28 mm/year under high temperatures and humidity (Hassell, 2004). During the early development, in aerated flowing ground water conditions, the extremely corrosion rates were measured as high as 0.6–0.8 mm/year. Early testing of the HGB indicated that a 1 mm reduction in wall thickness would degrade the load capacity from 12 to 9 t (Pascoe, 1995).

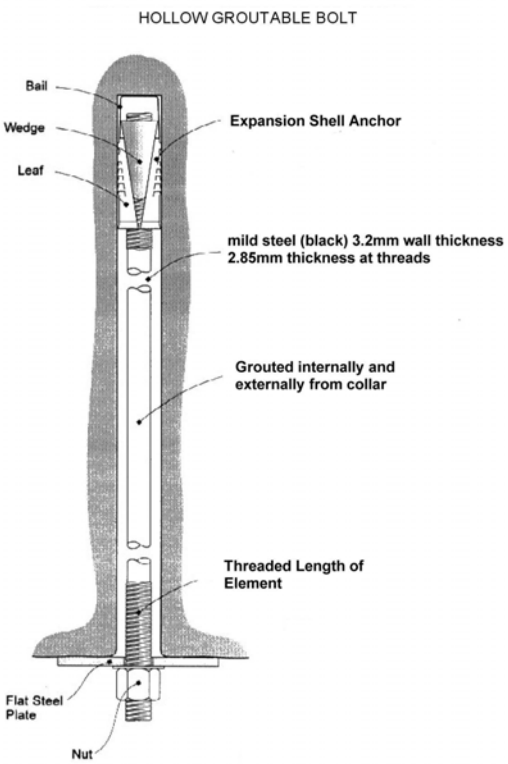

Figure 2 Hollow Groutable Bolt (HGB) – modified after Windsor (2003)

3.2 Project justification and determining the scope of work for the projects

After several groundfalls and increased groundfall frequency involving areas supported by HGB, a decision was made to initiate the planning and scheduling of the rehabilitation of the main decline, level accesses and some of the principal infrastructure chambers. Through Cannington's involvement and sponsorship with the ACG on "Towards the Elimination of Rockfall Fatalities in Australian Mines" (ACG, 2001) the mine has a detailed and comprehensive database of all falls of ground (rock, fibrecrete, ground support, down to as low as 10 kg). This allowed a detailed understanding into the size, location, age, ground support type, failure type and expected rockfall triggers. This back analysis was then combined with the level by level hazard mapping that the geotechnical engineering group had collected that illustrated all of the active development, the type of installed ground support, current rock mass conditions, type of surface support, and level of the priority of rehab. This collection of information was then assessed based on the future mining schedule and business risk associated with the development. This was collated in the drafting package AutoCAD™ which allowed the ground support rehab requirements to be designed and provided the ability to determine the exact linear metres of drive and the varying width and intersection perimeters. This data was summarised in a spreadsheet to allow for detailed scheduling of rehab jumbos, estimating of time for manning levels and bolting by ground conditions and allowed the scheduling and procurement of the various ground support supplies and scheduling of cement grouting resources and service crews. Once completed, the detailed review indicated that approximately 24 kilometres would not meet the future ground support requirements due to corroded HGB bolts, lack of mesh or fibrecrete surface support, or results from the numerical modelling and the current ground response for that area. In summary: 6.1 kms of the main Southern Zone decline including the upper portion that allows access to the Northern Zone below the ARMCO tunnel (Decline Rehab Project – DRP), 16.9 kilometres of the main accesses and production cross cuts including the 255 level cross cut from the North Zone through the Trepell Fault (Southern Zone Rehab Project – SZRP) and 3920 m^2 of mesh surface support and rebolting over the old original metal reinforced fibrecrete in the primary infrastructure areas such as main loadout station, top of jaw crusher station, main workshop, main trunk conveyor station and electrical sub station and pump areas (Boutique Rehab – due to the specialised air leg and staging required for the project).

3.3 Decline Rehabilitation Project (DRP)

The decline was the first rehab project to commence in February 2006. From the surface down to the 450 m level the decline is 6 x 6.2 m with a 1 in 7 gradient and then from the 450 m level down to 605 m and 645 m level (bottom of shaft) it is 5 x 5.2 m in a 1 in 8 gradient. The majority of the decline was located within the core amphibolite (centre of the Cannington Synform) with cross cutting dykes of pegmatite, Bird Faults, and mineralised and unmineralised foliated Quartzite. With up to nine primary joint sets the amphibolite has a blocky behaviour (Figure 3). The majority of the decline can be classified as poor ground (49%) with approximately 36% being classified as very poor ground. The very poor ground areas occur where the decline comes close to the Trepell Fault at 508 m elevation, where the Bird faults cross cut the decline, and in corners of the decline where the orientation roughly parallel some unfavourable joints. Since only 9% of the decline had mesh surface support which was now very corroded, the entire decline needed to be re-supported. It was determined to use fibrecrete as the main surface support with mesh reinforcement in areas of poor ground influenced by structural features that could displace in the future or where the old corroded mesh could not be safety removed to improve the adhesion.

The DRP was contracted to a mining contractor where 2–3 jumbos, additional service crews with Integrated Toolcarriers fitted with a man basket, and the on site fibrecreting fleet were used. The final scope of the DRP was to strip services (air, water, electrical, leader feeder), mechanically scale, and then prepare the surface by hydroscaling, spray 50–75 mm of fibrecrete and rebolt the 6.1 kilometres (5700 m of decline and 700 m of level access from the decline).

Figure 3 Typical decline photo of the blocky amphibolite with no surface support

3.3.1 Surface support – Fibrecrete

The decline was closed off to vehicle traffic in sections, and the existing services were bypassed and isolated and the area is check scaled by the crew. This prepares the area to be hydroscaled. Cannington previously had issues with long term adhesion of fibrecrete. Accumulated dust and soot had attached to the rock surface which in the amphibolite is very planar, chlorite coated joint surfaces and had sections of unbolted, steel fibre-reinforced fibrecrete. Trials of using the hydroscaler at the start of the project had shown good results based on removing the 1–3 cm of grim on the rock surface and removing small rocks that will provide a potential failure surface.

The fibrecrete specifications at Cannington were a 50 MPa mix design to yield 40 MPa insitu 28 day strengths. Historically previous fibrecrete strengths showed a large variation in both mix and insitu strength and thickness assessment and control. To improve and reduce the variability, several projects were completed and trialled during the DRP. A new batching computer was installed to help control the batching and addition of chemical admixtures. Modifications to the contractor's spraymec allowed for better control of the accelerator through a dosage meter and a controller. Higher frequency of testing (every 50 m^3 – once per day) during the project provided the data necessary to assess the quality of the fibrecrete (Figure 4). To improve the thickness assurance and control, plastic depth indicators were used in conjunction with the depth of the old HGB nuts as guides for the operator. Early in the project, a Riegl LMS-Z420i a 5 mm Terrestrial Laser Scanner was used to scan the before and after the fibrecreting to ensure the design thickness was obtained and to provide feedback to the operator and to ensure non-conformance areas were fixed (Figure 5). The majority of the decline was scanned which gave a very high confidence on the thickness of the fibrecrete sprayed on the decline. Probe drilling was also used but it was shortly discontinued after the laser was commissioned, since the probe holes can act as initiation points for early cracking of fibrecrete based on previous decline experience (Todd et al., 2006)

Figure 4 Decline photo after application of Fibrecrete surface support and Posi4bolting

3.3.2 Ground support bolts

The upper 450 m vertical (6.0 m wide section) of the decline was bolted using 3 m–20 mm galvanised Posi4bolts (17 T Yield and 13T Shear capacity in 3 m lengths in the wider 6.0 m sections) with a combination of medium set resin at the toe and slow set resin at the collar to allow for tensioning of the bolt and plate, and 2.4 m–20 mm galvanised Posi4bolts in the narrower 5 m wide drives on the decline from the 450 m level and lower and within the first 10–50 m of the fifteen main accesses. Typically the bolts were installed on a 1.5 metre ring spacing with the good to fair rock mass conditions with approximately 13 bolts per ring, and the poor to very poor rock mass condition with approximately 14 bolts per ring. Daily quality observations of installation quality was completed by the company geotechnical engineers and pull testing of 5 percent of the installed bolts up to 70% of the bolt yield capacity.

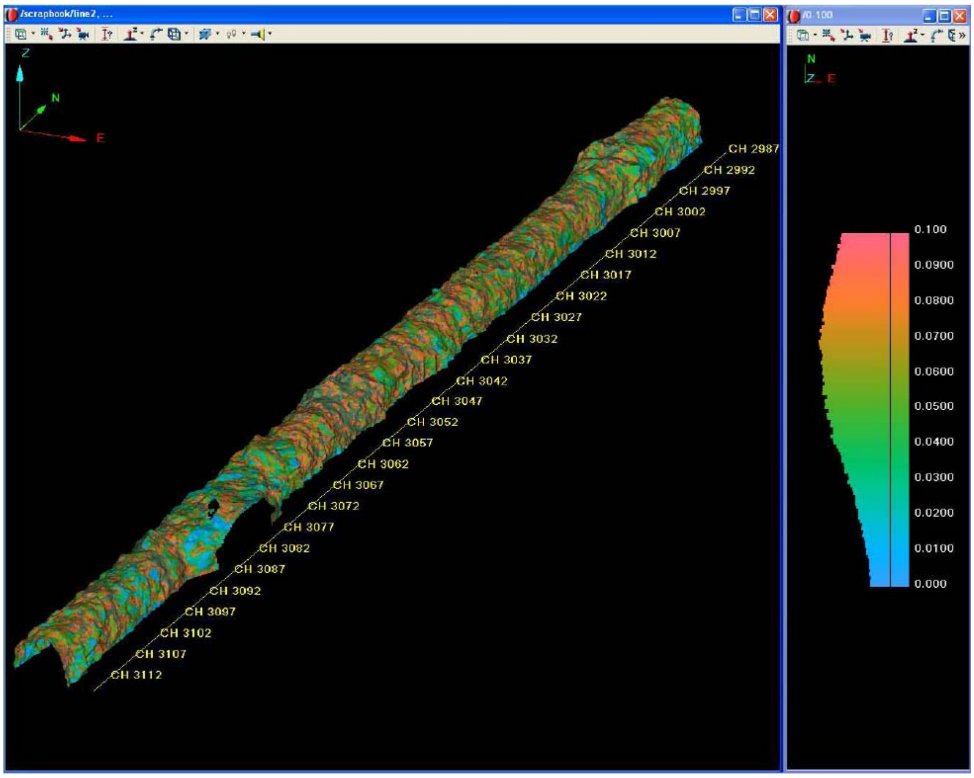

Figure 5 Laser scan showing thickness of fibrecrete by 0.010 m (10 mm) increments

3.4 Southern Zone level Rehabilitation Project (SZRP)

The Southern Zone level rehabilitation project had the largest scope of the projects with over 16.9 kilometres of typically 5 x 5.2 m development. This project was started in May 2006 and was ramped up in July 2006 and was completed by the middle of December 2006. Three separate mining contractors and BHPB crews were utilised during the project.

Early in the program a decision was made to select Hybrid type bolts such as Strata Controls CT Bolt and DSI – DCP (Double Corrosion Protected) bolt which are mechanical anchored, cementitous post-groutable bolts because of the superiority of cement for grouting in poor to very poor ground and the high 22–24 t yield and 22 t shear strength capacity and solid nature for corrosion protection. This was required for the higher density of ore in the mining blocks and the higher structural displacements expected. These bolts had the advantage of a mechanical anchor which provided temporary support before it is grouted and ensured that bolts would not fall out of the back while the grout is curing. Both had a polyethylene sleeve that helps protect it from spot corrosion due to water flowing along discontinuities and cracks in the cement. The bolts specified were 24 mm with a load capacity greater than 22 t and they were galvanised to further protect them from corrosion. They also allowed the use of galvanised hanger nuts that could be spun on to hold up heavy services such as air, water and paste lines that run along the main accesses into the stoping blocks. Early experience gained during the DRP showed that the CT or DCP bolt had rock mass quality limits to what they could be feasibly installed into boreholes, especially horizontally into the walls. Additional bolts were ordered to allow for wide range of ground conditions and operational constraints encountered. In total the campaign used:

- 2.4 m and 3 m galvanised Posi4bolts and 2.4 m Secura-bolt installed with resin shooter installed medium and slow speed 24 x 650 mm resin (35 mm hole).
- 2.4 m DCP/CT Bolts (45 mm hole) – 24 mm, galvanised Hybrid bolts with modification during the program.
- 0.9 m, 2.4 m and 3 m galvanised SS47 friction bolts (Split Sets) (45 mm hole).

- 2.4 m cement grouted 24 mm galvanised CS bolt (rebar with 100 mm M24 threaded end) with wire hanger springs (to hold in place while grout is curing) (45–50 mm hole).
- 2.4 m galvanised Tigerbolts (45 mm hole) – tensionable – 38 mm diameter body with 20 mm rebar end.
- 3 m hollow self-drilling galvanised cement grouted bolts – New trials only (45 mm hole).
- Double stranded garfold bulbed cablebolts (normally 6 or 9 m cables) installed by cabolter (89 mm hole).
- 2.4 m–20 mm galvanised 10 pitch rebar that is cut to size, installed with resin (30 mm med-slow resin) using Quick Chem system for air leg work in tight infrastructure areas (35 mm hole).
- Plates for all of the above, including special purpose plates such as DSI – Dragonfly and Strata-Combi plates for the DCP and CT Bolts which combine a butterfly plate and a rock bolt plate welded together.
- Break out nuts for bolts for the Tigerbolts to suit torque of drill equipment used during the campaign.
- Surface support – Mesh: 2.4 x 3.5 m – 100 x 100 mm, 5.6 mm galvanised mine mesh and 2 x 2 m, 100 x 100 mm, galvanised mine mesh made for tight spaces for Boutique rehab work. Fibrecrete: 40 MPa, synthetic fibre reinforced fibrecrete – combined in combinations of mesh when required.
- In very poor ground areas with potential caving, fibrecrete filled 12 mm rebar form arches were installed to maintain the integrity of the fibrecrete shell (Figure 6).

Figure 6 Fibrecrete arches on 475 m level

3.5 Boutique rehabilitation project

Boutique rehab areas such as the transfer station and the load out station at the shaft had very little work space remaining since each chamber was custom excavated for the appropriate size of the mechanical infrastructure. This would make it impossible to rehab with jumbos or man-baskets. Staging specialist was used with a specialised air leg contractor to allow for meshing and bolting of the cracked fibrecrete in these areas. In the Boutique area, 30 mm resin was used to maximise the resin available for CS and rebar bolting since the ground in these areas were poor and typically broke out during the drilling process (Figure 7).

Figure 7 Staging used at the loadout station for the boutique rehab project

4 Quality assurance and quality control during the project

For a project of this size it was import to ensure a very high quality of ground support installation. The quality assurance and quality control was based on a multi-tiered approach. The initial hazard mapping of the decline and main accesses into the Southern Zone was completed by the group focussing on the required amount and type of ground support required based on rock mass quality and the expected rock mass response. The competence of the rock mass dictated the types of ground support that could be specified due to expected installation performance (grouted bolts versus resin or pre-grouted boreholes with CS bolts instead of CT or DCP Bolts). All of the ground support supplies (mesh, rock bolts, cement and control of the batch plant for fibrecrete) were procured and managed by the group to ensure proper specifications were maintained. The group worked closely with the mine operations and contracts team to build the scope of work for the mining contractors and their KPI's (Key Performance Indicators) in regards to quality of installation. During the mobilisation of the contractors and integration of the company crews several familiarisation meetings and presentations were held to review the project scope and to run through the various ground support types and the expect ground conditions. Once the project started, the most important quality control aspect of the project was the geotech engineer's daily visits to the majority of the work sites to problem solve, answer concerns of the operators and to look ahead of the work areas to make the operators aware of potential problems and to make field changes as required. To ensure a quality installation of mesh, fibrecrete and ground support bolts the BHP Billiton's FPe (First Priority Enterprise) system was used to track, and to initiate corrective actions by conducting JSO (Job Safety Observations) for Posi4bolt, DCP/CT bolt installation, fibrecreting and grouting. These detailed checklists are filled out at job sites to ensure a quality installation to ensure issues are not missed. For grouting, three grout samples were taken for every 1000 bolts (or approximately every second day to check for 28 day strengths). The frequency of the 28 day tests was high to check for any emerging issues before a large amount of bolts were grouted with inferior grout and to check the performance of the blended cements. Pull testing of the rockbolts was based on 5% of the DRP and 2% of the SZRP. An initial inspection of the rehab areas outlined the required number of replacement bolts that may need to be installed due to grouting failures (bolts that were damaged during installation that were obvious, were automatically replaced by the operator). These were based on the grouting performance of the bolts surrounding (typically the hybrid bolts would take 3 litres of cement grout each (if less, then a blockage due to a damage bolt was suspected), the rock mass conditions and the quality and present of the previous ground support. These were noted on the QA/QC AutoCAD maps for the level to a detail that every damaged or failed bolt on each level is noted on the maps. Proper position and bolting of the overlaps of mesh are important. After all non-conformances were fixed, a final inspections and sign off are completed by the representative geotechnical engineer and the rehab superintendent. For operations, a manager was appointed to handle the rehab project with a rehab superintendent and supervisory staff seconded from the mining operation department to manage the company and contractor rehab crews. The geotechnical engineering team worked closely with the company rehab team to manage and design the ground support required for the 24 kilometres of rehabilitation. In many cases, several milestones for each section were inspected and signed off before it progressed to the next phase. For example in the decline, after the design phase was completed highlighting the ground support required and any specific safety concern, the services were removed, the area rescaled by hand or mechanically scale and then hydroscaled. The engineer would inspect and ensure the area's hydroscale was complete and adequate to provide superior bonding surface. Then the area was fibrecreted with the engineer inspecting for any under specified sections and signed off before it was allowed to be bolted. After bolting the final inspection occurred to remediate any non-conformance issues before it was released back to mine operations.

5 Difficulties encountered and learning's during the project

Large projects always suffer from obstacles and barriers that need to be overcome to ensure a high quality and timely project. With ground support rehabilitation of almost 24 kilometres in a period of 9–10 months while still producing was a difficult undertaking. There were two majority difficulties that were encountered that need to be addressed to meet these goals.

5.1 Procurement of consumables, ground support and logistics

The current resource boom in Australia and the world has created a shortages in both manufacturing capacity and skill shortages. One of the first constraints encountered was the sourcing of jumbos and jumbo operators, grouters and service crews for the contractor rigs. Three main contractors for the SZRP were chosen but they unfortunately were not fully manned during the early portion of the program and maintaining full crew levels during the project was difficult with various retention strategies put in place by the various contractors. Manufacturing constraints and transportation logistics affect the entire duration of the rehab project. The supplying of mesh saw only minor impacts since the supplier was able to use manufacturing plants all over Australia and then transported to the mine site. The remaining ground support and jumbo supplies were affected by manufacturing constraints. Due to the demand for galvanised ground support many items (Nuts, rock bolt plates, rebar etc) were constantly being delayed by 1–2 weeks awaiting galvanisation. Since the primary bolt type for the SZRP was Hybrid bolts they required multi-components which were supplied from some manufacturing sites offshore. These included rockbolt anchors from Africa and grouting domes from China. Shipping delays caused bottlenecks in the manufacturing of these bolts since they still required assembling once all of the components were delivered. On several occasions certain components were air-shipped at cost, to speed up delivery. Non-ground support items also created delays and shortages such as drill steels, bits, dolleys and couplers for the jumbos, grouting equipment and accessories such as grout couplers. Once the consumables were available delays were also encountered due to lack of transportation resources available. A typical shipment out of a Sydney manufacturing site had single trailer shipments to a staging area where it would wait for the second trailer. Once received, it would continue onto the triple B-train staging area; but it was delayed further waiting for another trailer being transported to that region of Queensland. Working closely with the suppliers and looking at alternatives, other manufacturing sites, using BHP Billiton's transportation agreements helped reduce the potential impact in this area.

5.2 Difficulties with ground support and accessories

During the initial use of the Hybrid bolts, a high rate of installation failures (30–40%) occurred. This was not due to one, but several design, equipment, and training and environmental factors which needed to be addressed to meet quality and timeline milestones. With the Hybrid bolts, any damage or severe twisting to the sleeve can prevent full grouting of the bolt. Many contributing factors were identified such as: long rails

(3.6 m–12 feet) – this affected the angle which the bolts would go into the bolt hole which would damage the sleeve when it rubbed against the side of the drillhole (Figure 8). The BHP Billiton rigs were refitted with 3 m (10 ft) rails and the contractor jumbos were specified for 3 m rails. Plates, especially butterfly plates which typically had thin sharp edges that the poly sleeves would get caught and tear against on installation. This was drastically reduced by using combination plates with both the Butterfly and rockbolt plate welded together as one plate with the hole in the butterfly portion flanged inward to remove the sharp edges. The different Hybrid bolts came with two different types of anchor shells, a two leaf and a three leaf design with different wedge profiles. It was determined that in the Cannington conditions the three leaf design was preferred since it had a larger overall expansion (up to 52 mm), and it expanded quicker for the amount travelled. This was an factor for several reasons: greater travel required to engage the anchor, the more spin required would increase the chances to damage the sleeve. Due to the early bit size issue and some of the breakout during drilling in poor ground, the extra millimetres made a different in engaging the anchor. From experience it was preferred by the operators since the consistency of the three leaf anchor gripping the drillhole improved. This preference was also influenced by the lack of worn drill bits available. Normally at Cannington a new Magnum bit had a diameter of 46.5 mm. These bits were used to bore the face during development drilling until the bit size was reduce to 45 mm. From 43.5 to 45 mm these drill bits are used for resin bolting for the jumbolts and for split sets. When the Southern Zone was shut down for rehab there were only two jumbos concentrating on drilling in the North Zone which could not generate enough worn bits for the rehab fleet of ten jumbos. Until all of the two anchor shells were replaced by the new three anchors the Magnum bits were grounded down to 45 mm to allow for better engaging by the two leaf anchors.

The sleeve length was also modified to ensure that if the nut at the collar broke-out early and travelled prematurely (instead of tension up the plate), the extra travel at the anchor end to tension the plate, would not block the end of the poly sleeve and prevent grout from passing into the borehole. The breakout device did not reliably break when required and appeared to be potentially affected by the galvanisation of the bolt (extra thickness on the threads). Galvanisation of these bolts was unique in mining. The mining application of these bolts before had used only ‘black’ hybrid bolts. Applying galvanisation to these bolts did create problems in the early period mostly with the fine M24 threads on the anchor end. Some of the early batches did not account for the extra galvanisation thickness and the anchors would not turn. This was fixed with later batches by cutting deeper threads into the bar. Later batches were also affected by fine ‘contaminants’ of zinc galvanisation on the threads. This was resolved by the manufacturer wire brushing the threads during assembly and spinning the anchor partially down the rebar. Training had a large impact on the failure rates, especially for operators from Western Australia who were use to installing simple split sets that could be installed at an angle to the hole without damaging the rockbolt. Many training sessions with the manufacturers and daily checks by the geotechnical engineers and the BHPB operational staff made the difference. Ensuring that the holes were well clear of rock fragments, and the operator had optimum water, air and feed pressure for the ground conditions was important. Preventative maintenance on the jumbo especially the boom hydraulic cylinders were essential to maintain the correct dip and angle to the hole while spinning was require reducing the damage to the sleeve. Finally, the geotechnical engineers also placed a minimum rock mass quality limit on what ground that the Hybrid would be installed in. Near the end of the program the Hybrid bolts were being installed daily at between <4% failure rate.

In some of the very poor ground areas where Hybrid bolts could not be installed successfully and it was difficult to bolt with cablebolts or it was inadequate due to the angles, CS bolts were used. These were 24 mm bolts that would be installed into pre-grouted drillholes. One safety concern was the weight and consistency of the grout from the various grouting crews. It could not be always assumed that the grout would hold the weight of the 2.4 m rebar with the additional weight of the plate. To engineer a solution, rigid wire spring clips were devised to spin onto the end of the bolt that when pushed up into the hole would spring out and hold the bar safety in the hole while the grout cured. Several proto types were designed until the optimum length, width and rigidity was determined. These were used in the DRP, SZRP and the air leg Boutique rehab where resin or postgrout rockbolting could not be confidently accomplished.

Cement strengths were a concern especially with the use of low heat blended cements during the winter months. With several contracting and BHP Billiton grout crews, some with very little grouting experience, maintaining a consistent mix design was essential. The use of the right type of high pressure grout pump was essential to pump thick grouts for the best attainable strengths. To improve on grout strengths there was an education campaign to reduce the amount of water used. To help with the pumpability, the onsite experience with cement chemical admixtures was handy by using superplasticisers to reduce the water: cement ratio and increase the early and final strengths of the cement.

In areas of very poor ground where the stability of the fibrecrete shell was crucial for the long term stability of the drive or intersection, rings of prefabricated arch sections were overlain together and bolted to the back and walls and down to the floor.

Figure 8 Damage poly grouting sleeve on a hybrid bolt

6 Conclusions

BHP Billiton's Cannington Mine had matured after ten years of exploration, delineation and mining. Previous historical ground support practices, bolt design and environmental issues started to impact the safety and production aspects of the operation. To prepare the mine for the next stage of its life an extensive 24 kilometre ground support rehabilitation program was undertaking to secure the future. Many difficulties were encountered and solved during the 9–10 months of the project. Since the project was complete the Cannington mine has return to a predicable ground response to the mining activities at Cannington. This is an example of Cannington's overriding commitment to safety and sustainable development.

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