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Yass-Marie Rutty
BHP Billiton

Dan Payne
BHP Billiton

Adam McKenzie
BHP Billiton

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THE EVOLUTION OF PRE-DRIVEN RECOVERY ROADWAYS AT CRINUM MINE

Yass-Marie Rutty¹, Dan Payne² and Adam Mackenzie³

ABSTRACT: Historically, the Crinum mine has experienced significant falls of ground when longwall production slowed down in preparation for recovery in weak roof areas. These conditions continue through the recovery process and result in both safety concerns and delays. When mine plans and exploration revealed that most of the future longwall recoveries were located in weak roof areas, a decision was made to try pre driven recovery roads as a solution to the problem. After completing eight pre-driven recovery roads with varying degrees of success and numerous lessons, Crinum North Mine now utilises a modified Pre-driven Recovery Roadway (PDRR) to improve the longwall take off process in weak roof areas. During mine development a standard roadway is driven where the final recovery location of each longwall is planned. After the installation of secondary support, the PDRR is backfilled with a cement-flyash mix to provide support to the roof, and confinement to the ribs and floor of the roadway. The method has been refined over the last four years to provide greater strata stability and improved operational and safety performance compared with conventional takeoffs at Crinum, and has resulted in a site record of longwall relocation in 11.5 days (pull mesh to picks in coal). This paper describes the evolution of the PDRRs from Crinum East to Crinum North including lessons from initial attempts and changes to; the secondary support regime, the operational approach during the final stages of retreat, the backfill strategy and also describes plans for the future.

INTRODUCTION

The Crinum Mine is the underground component of BHP Billiton Mitsubishi Alliance's (BMA) Gregory Crinum Mine located north-east of Emerald, Queensland (Figure 1).

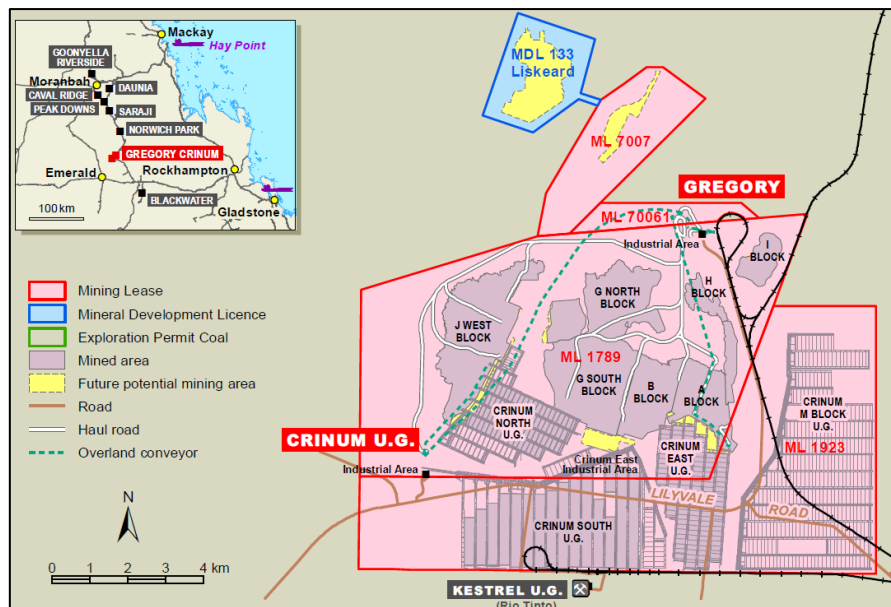


Figure 1: Gregory Crinum Location

¹ Specialist Mine Planning, Goonyella Riverside, Email: Yass-Marie.Rutty@bhpbilliton.com, Tel: +61 0459444464,

² Manager Geotechnical Services, BHPBilliton, Brisbane, Email: Dan.Payne@bhpbilliton.com, Tel: +61 0417684021,

³ Contractor Specialist Engineering, Broadmeadow Mine, Email: Adam.Mackenzie@bhpbilliton.com, Tel: +61 0429011390,

The Crinum mine has a history of roof control problems coming into and during longwall recoveries. Weak roof, combined with the slow mining, which is a consequence of preparing for equipment recovery, pulling mesh (which also creates tip to face issues), and the lengthy bolt up process, often results in loss of immediate roof and subsequent roof falls. In fact, approximately 50% of the first 13 longwall recoveries experienced roof fall delays, the longest of which took four months to mine the last pillar and recover the longwall. This recurring problem prompted the mine to investigate options to reduce or eliminate the problem.

The most obvious option, which had been used with some success in the US, but only 11 times in Australia with very little success (including one on which the Crinum Longwall Superintendent experienced the terrible conditions), was pre driven and supported recovery roads. These roadways are driven where the longwall will stop for recovery, reinforced with secondary support, and then mined into. After assessing the cost to drive, the cost to pre-support, and predicting the production/financial benefit of the reduced bolt up time in the recovery, it was assessed as being cost neutral (compared with a traditional recovery with no roof fall delays) and still had the risk of premature fender and roof failure being just as high as a traditional recovery (given recent experience in Australia). The mine plan was also reviewed at the time and it was decided:

1. Development could not come back and drive LW 14 pre-driven due to ventilation and conveyor locations
2. Development had not advanced enough to allow the additional driveage required
3. Longwall 15 could be recovered two pillars early to avoid a weak roof area, and longwalls 16-19 in Crinum East would be in good roof.

At this time a conscious decision was made to not employ pre-driven recovery roads at Crinum.

Two Fletcher panline bolters were purchased to minimise exposure of longwall operators to falling ground when bolting up during longwall recoveries and chutes were driven to deploy these bolters in longwalls 16-19.

However, the long term planners recognised that weak roof returned to longwall recovery locations for longwalls 20 and 21 in Crinum East and would be present for every longwall recovery in Crinum North, so a solution would still be required. Mine plans and schedules were developed to include pre-driven recovery roads for the remaining longwalls 20-28.

This paper will show that pre-driven recovery roadways can be used with success when proper care is given to their design and execution, and continuous improvement is sought, as has been the case at Crinum Mine.

THE CRINUM PDRR STRATEGY – SUPPORT AND RECOVERY

Crinum East

PDRR20

By the time the decision of whether to deploy a Pre Driven Recovery Road (PDRR) for Longwall 20 came around several parameters had changed:

- More development float was available and the decision was made when development was initially mining through the area
- Several more PDRRs had been employed and were successful in Australia
- The understanding of what support was required had improved
- All future longwalls were in weak roof

Longwall 20 PDRR was driven first pass (Figure 2), full seam leaving 200mm coal in the floor and taking a range of roof stone (varying between 200mm and 1m). Second pass (on the outbye side) widened the

roadway to 7.5m. A PDRR experienced consultant was commissioned to design the support, monitoring and Trigger Action Response Plans (TARPs), take part in risk assessments, and train crews. A project was run to install the support.

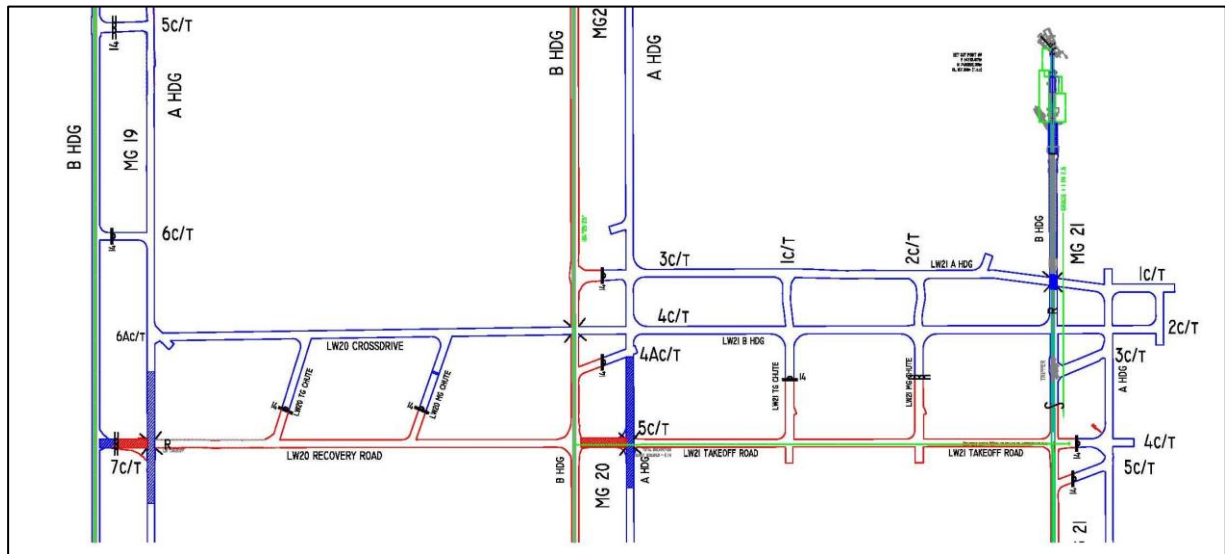


Figure 2: Crinum East Mine Plan, Longwall 20 and 21 PDRRs

Longwall 20 PDRR Support and Monitoring Design

Due to the variation in the amount of roof stone cut during development, and the concern of the longwall roof horizon upon entry, a decision was made to install a false roof in the first pass (inbye portion) of the PDRR. This false roof was made up of prefab concrete plates lifted and hung from roof bolts at the top of the coal seam horizon and then sealed and filled above with grout.

Primary roof support consisted of 8 x 2.1m long X-grade bolts per 1m during the first pass and 4 x 2.1 m long X-grade bolts per 1m during widening. Primary rib support consisted of 1 x 1.2 m and 1 x 2.1 m long X-grade bolts installed on the outbye rib and 3 x 1.2 m long fibreglass bolts per 1m on the inbye rib. The secondary support installed was; 3 x 7 m long Megabолts every 1m, 3 x 3 m long fibreglass dowels every 1 m on the inbye rib, 1 x 2.1 m long X-grade roof bolt and 1 x 1.2 m long X-grade roof bolts every 1 m on the outbye rib. As shown in Figure 3 standing support was made up of double rows of fibrecrete block cribs (with single rows for 30 m at the protected gate ends). To ensure a good flat base on which to install the fibrecrete blocks, 200 mm thick concrete plinths were constructed on the floor for every fibrecrete crib. This resulted in 1.4 MPa per metre of roadway (excluding the protected gate ends) which exceeded the required support as per the PDRR database (≥ 1.2 MPa).

Instrumentation consisted of Gel extensometers and roof to floor and rib to rib convergence monitoring using rotary potentiometers every 20 m cabled back to a junction box in the maingate chute road. Hydraulic stress cells installed at various depths into the fender and barrier pillar with gauges located in the barrier pillar along the maingate chute road rib. The instrumentation layout is shown in Figure 4. Geotechnical engineers were put on shift to monitor instrumentation during holing. These units were installed to monitor strata behaviour leading up to and during the final stages of longwall retreat.

Longwall PDRR 20 – Outcome and Lessons

Unfortunately, despite all the work done to give the Longwall 20 PDRR the best chance for success one factor was not properly accounted for. Standing support was designed to the required 1.4 MPa, however it was done using fibrecrete cribs with a capacity of 15 MPa and then built on a floor at Crinum which was approximately 4 MPa.



Figure 3: Fibre-cribs in PDRR 20 prior to floor heave event

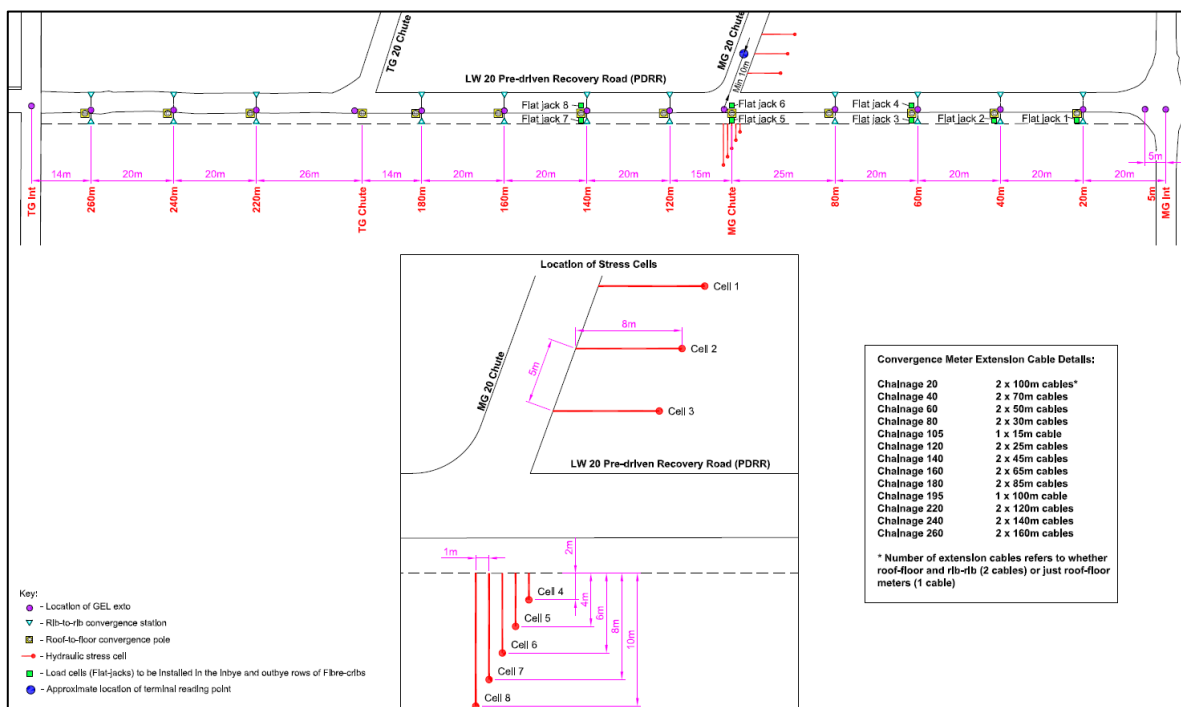


Figure 4: PDRR 20 monitoring locations

Mesh was pulled on the face when the fender was 8m thick with no issues. However, just prior to holing, when the fender was 2.5 m thick (Figure 5), the concrete plinths fractured at the edge of the base of the fibrecrete cribs and the cribs punched into the 4 MPa floor (Figure 6). A large crack opened up in the roof outbye the fibrecrete cribs. The longwall was stopped, and timber cribs were installed in the PDRR under the crack in the roof. Due to the damage to the floor (and concern of trying to bring the shield pontoons into the severely damaged floor), as well as the general roof instability, it was decided not to

try to remove any more of the fender until the PDRR could be backfilled with cement. Boreholes were drilled from the surface and the PDRR was fully backfilled. Three to four shears were taken to get enough space to pull shields (revealing the amount of floor punch (~1 m) and floor damage) (Figure 7) and the longwall was recovered.

At this time a few major decisions were made;

1. As Longwall 21 PDRR was already driven it was decided to learn from Longwall 20 and try again
2. It was decided not to widen Longwall 21 PDRR but to leave it at 5m wide
3. It was decided not to use fibrecrete cribs but to fully backfill the roadway.



Figure 5: Longwall 20 fender 2.5 m thick



Figure 6: Fibrecrete cribs starting to punch into weak floor



Figure 7: Fibre-cribs mid-shear (after PDRR 20 was backfilled) and two shears were taken into the failed pre-driven recovery road

PDRR 21

Longwall 21 PDRR Support and monitoring design strategy

Due to the failure of PDRR 20, back analysis of the roadway was conducted by a second engineering company using FLAC 3D which modelled the failure observed. Additionally, a third consultant undertook 2D and 3D modelling of a scenario where backfill was included. They found that the fill may carry up to 50% of the induced stress as it transfers outbye, it could be assumed that a 50% reduction in floor heave would occur in LW21 when compared to LW20, all other things being equal. Their modelling suggested that PDRR21 was feasible if backfilled and would improve mining conditions.

Taking these findings into consideration, the roadway was left at 5m wide and backfilled with a flyash-cement mix of approximately 7MPa strength via a surface to seam borehole delivery system. During development of the roadway 8 x 2.1 m long X-grade bolts were installed every metre. The secondary roof support installed comprised of 1 x 6 m fully grouted Megabolt per metre near the inbye ribline and two rows of Megabolts angled over the pillar every 1.5 m on the outbye rib side. Secondary rib support was installed on the inbye rib only; 3m and 6m fibreglass dowels were installed and angled up into and above the fender at 1 m spacings. Roof mesh was also suspended from the roof at 100-200 mm below the development roof horizon (which was similar to PDRR20) to create a false roof and protect the tails of the installed secondary support (Figure 8).



Figure 8: Photo of roof mesh hung to create 'false roof' in PDRR21

The monitoring regime implemented for PDRR 21 had three main components (Figure 9):

- 5 hydraulic stress cells installed in the fender at depths of 2-10 m
- 3 hydraulic stress cells installed in the barrier pillar at depth of 5, 10 and 15 m
- 7 load cells and 3 hydraulic stress cells located within the backfill material.

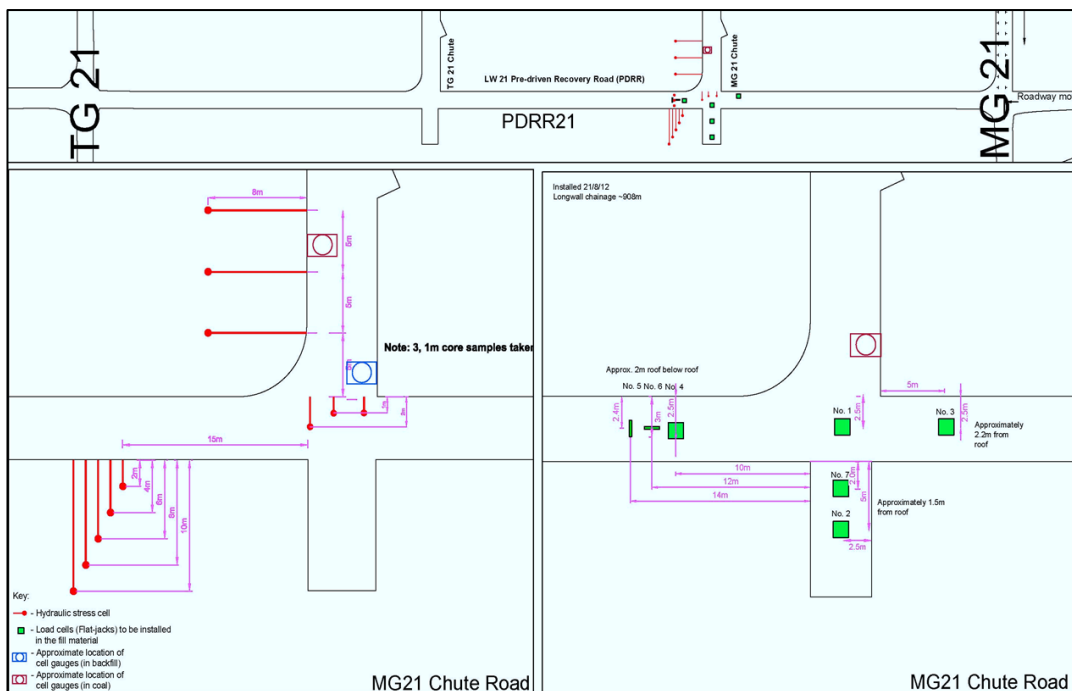


Figure 9: PDRR21 Monitoring locations

Longwall 21 PDRR outcome and lessons

In line with the modelling outcomes, by maintaining a 5 m roadway width and backfilling the roadway, conditions were significantly improved during the longwall 21 recovery process from those experienced

at PDRR20. The backfill provided sufficient confinement to the fender and PDR roadway during the final stages of retreat. Operationally, the backfill presented a number of hazards;

- It was difficult to achieve satisfactory horizon control due to the seam dip
- The backfill material was sharp and angular when it failed
- When the backfill material mixed with water during recovery, trafficability was compromised.

It was also decided that hanging roof mesh to create a reinforced false roof did not achieve the intended outcome due to horizon control issues and would not be continued.

Grout was pumped into the relatively flat PDRR21 via one surface borehole and a poly pipe delivery line. This made achieving grout contact with the PDRR roof difficult and labour intensive. Several grout-to-roof voids were discovered during the longwall breakthrough. It was estimated the grout achieved approximately 90% roof contact. Multiple grout delivery boreholes were agreed for PDRR22.

The stress cells located in the fender and adjacent pillar indicated that the abutment load picked up when the face was 15 to 20 m from the cell, and the softened zone was seen to be 6 to 8 m in front of the face. The chute road took weight from 3 to 5 m outbye. A high angle shear along the outbye rib near the chutes caused the Breakerline Supports (BLS) to become iron bound during shield recovery. None of the load and stress cells located in the backfill recorded any measureable stress increase. Based on this data it was decided that vibrating wire type instrumentation would be used where possible (the hydraulic load cells would no longer be used exclusively) and strain gauges would be introduced.

Although the support design and backfill characteristics were still being refined, four days were saved during the bolt up cycle and ten days were saved on recovery time – this justified the decision to backfill future pre-driven roadways.

Crinum North

Crinum North had two key differences from the previous two underground mining areas (Figure 10); the orientation of longwalls, and the longwall width of 304 m (increased from 270m). The coal seam was also thicker on average which allowed 0.5-1 m of coal to be left in the floor to provide protection from the soft floor that existed at Crinum South and East.

By the time longwall mining began in the Crinum North domain, the fundamental design for the pre-driven recovery road method at Crinum had already been established. With each additional PDRR utilised for longwall recovery, new lessons were realised prompting slight refinement to the strategy for each subsequent recovery roadway.

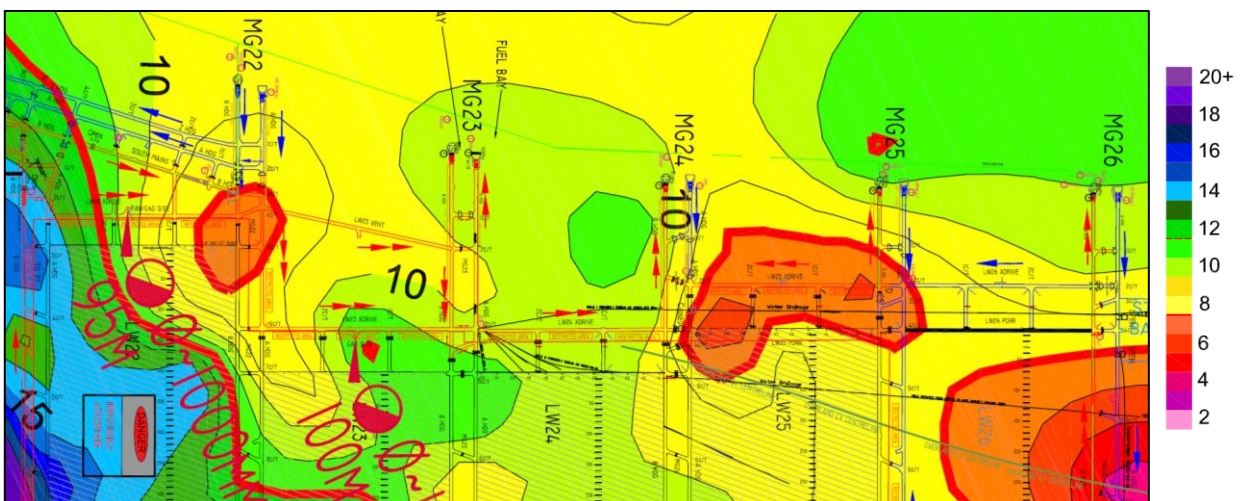


Figure 10: Crinum North roof uniaxial compressive strength (MPa)

PDRR22

Longwall 22 PDRR support and monitoring design strategy

Given the success with PDRR 21, the same strategy was employed for PDRR 22. The roadway was 5m wide and 3.4 m high with the roof cut to 200-300 mm above the top of coal horizon. This would allow the longwall to retreat into the recovery road at their standard horizon without compromising the installed support (cable bolt tail lengths required to be ≤ 300 mm) and became the standard cut height for the remaining PDRRs at Crinum North. No hanging mesh or false roof was planned; the grout was anticipated to fall out after each cut, or be supported by additional bolts as required. The cement content in the backfill was reduced from 12% to 10% from PDRR 21 to PDRR 22 to produce a material with an Unconfined Compressive Strength (UCS) closer to that of the surrounding coal, and to allow the grout to be cut more easily and reduce the slabbing effects seen in PDRR21.

A standard eight bolt pattern of 2.1 m bolts in the roof and 1.2 m rib bolts were installed during development of PDRR 22. The secondary support regime consisted of 1 x 8 m cable bolt every 2m (or every 1 m in weaker ground) near the inbye rib, angled over the fender and two offset rows of 8m cables at 2 m spacing, both angled over the pillar. 6 m S-grade rebar bolts were installed at a shallow angle above horizontal, across and over the fender (Figure 11). 8m cable bolts were also installed in the chute roads at a density of 3 x 1 m for the first 10 m then 2 x 2 for another 20 m outbye. These cables (and a number of tin cans) were added to the plan as a result of the shearing experienced along the span of the chute roads during the removal of shields in Longwall 21.

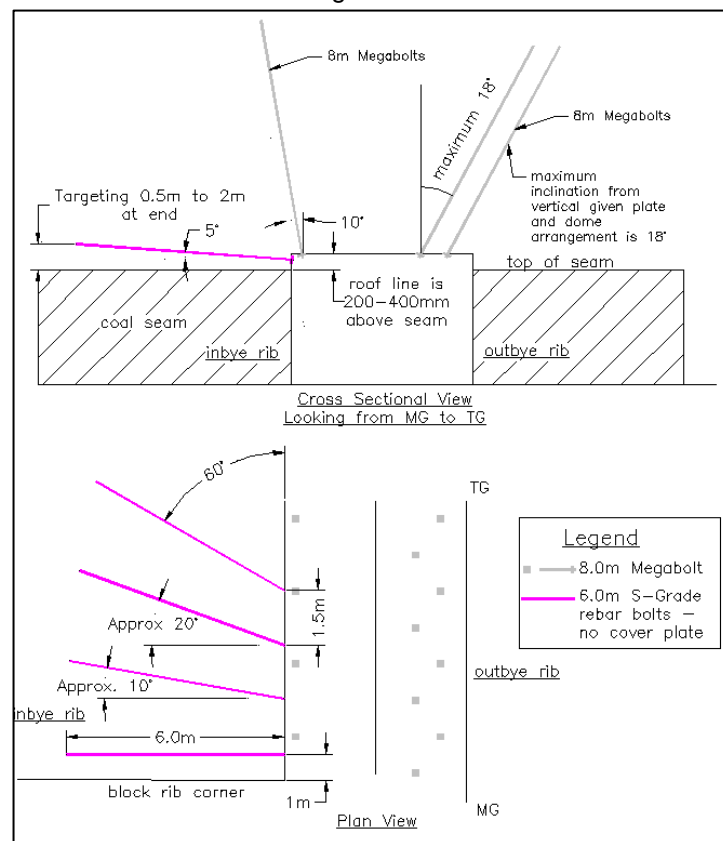


Figure 11: Cable bolt and rebar location, PDRR 22

Two vibrating wire stress cells, five hydraulic stress cells with vibrating wire transducers and three concrete embedment strain gauges were utilised to monitor stress and strain changes during longwall retreat. These cells were located around the Tailgate chute road and PDRR intersection. Additionally, four hydraulic cells were installed into the coal fender at 5 m, 2 m, 2 m and 0.3m, and one was installed at 8m into the coal pillar (Figure 12).

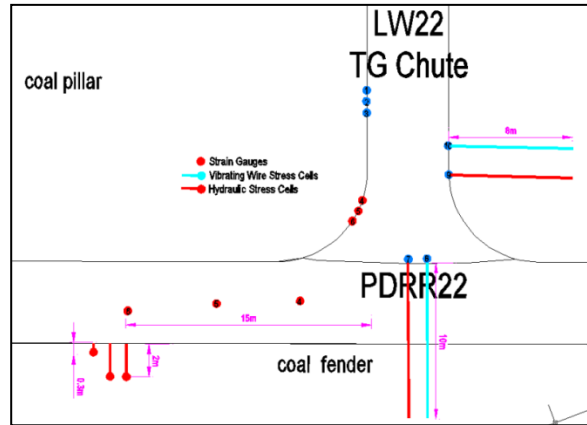


Figure 12: Monitoring regime, PDRR 22

Longwall 22 PDRR outcome and lessons

A major roof fall occurred 9 m outbye PDRR 22 when the face was left open for a clean-up run prior to pinning the Huesker mesh. It was recognised that leaving the face open with an increased tip to face distance was not possible without additional support being installed due to the weak roof conditions (was the original reason for PDRRs and again validated the use of PDRRs). As a result, a bolt up cycle prior to pulling and pinning of the Huesker mesh was implemented for the remaining PDRRs. Cavity fill and Polyurethane (PUR) was required leading up to the PDRR. Once the affected area was consolidated, the presupported stability of the PDRR allowed the longwall to retreat safely into PDRR22 without further roof control problems which would have undoubtedly occurred given previous experience at the mine.

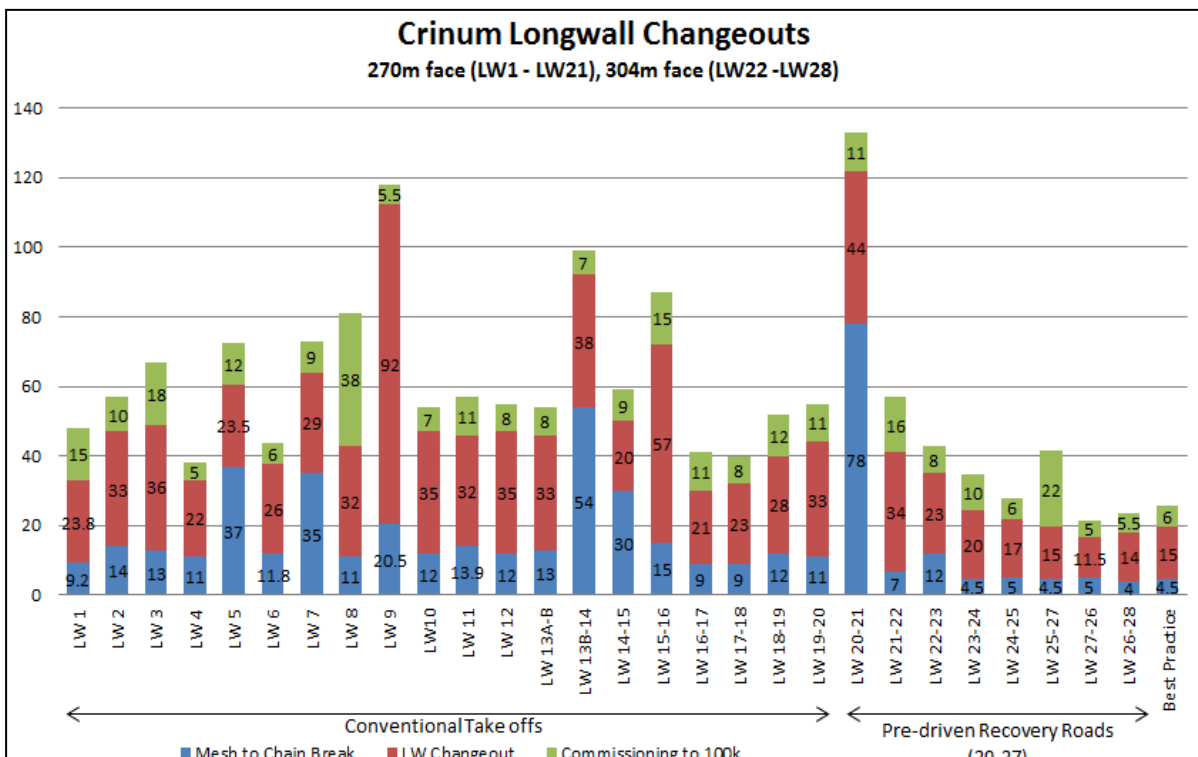


Figure 13: Crinum Longwall Changeouts, 1-27

Stress redistribution around the PDRR was as expected within the coal fender (although greater stress changes were anticipated). The rise in stress followed by a drop (yield) immediately before the longwall hit the cell was as expected. Noticeable stress increases were shown when the wall stopped for three

days at 42 m from PDRR22 and when the initial fall occurred. Stress changes were also evident on resuming retreat after a period of the longwall standing. It was recognised that having a data logger or continuous monitoring to the surface would have enabled a more effective analysis of stress changes. PDRR22 achieved a 'tight' grout to roof fill via pumping from surface through 10 boreholes to allow for gradient and high points in the roof. This filling technique was adopted for all future PDRRs at Crinum.

Although a number of days were lost due to the fall recovery inbye PDRR 22, Figure 13 shows that the overall longwall move time was reduced, with the longwall shield recovery shortened by nine days.

PDRR23 Overview

The primary and secondary support remained largely the same as for PDRR 22. The key changes to the strategy were:

- The addition of a bolting cycle (in sections) prior to pulling and pinning the Huesker mesh
- The length of spiles over the fender was increased to 10 m (strands introduced to replace rebar)
- Application of a material to the roof and rib to allow the backfill material to detach from the strata; in situ trials of Tekflex and black plastic material were applied in separate areas of PDRR 23
- Due to flyash shortages from the previous supplier, a different flyash was used for PDRR23. This resulted in a 10MPa grout at LW breakthrough
- Grout was pumped up to 1km from the batch plant to PDRR 23. This resulted in valuable grout flowability and water content/grout strength lessons for future PDRRs.

The addition of the bolting cycle prior to pinning mesh was successful, reducing the previous time taken to complete "mesh to break chain" from 7 (LW21) and 12 (LW22) to just 4.5 days. The Tekflex was not successful as it did not allow the grout to fall away from the roof (Figure 14 and 15). The black plastic minimised the amount of grout remaining on the roof but prevented the longwall operators from choosing appropriate hole locations when installing 1.2 m bolts (to pin the Heusker mesh) within the PDRR. Failure of the outbye rib occurred around the maingate chute road during longwall shield recovery. The 1.2 m bolts installed during development did not provide adequate support due to the loading that occurred during the shield removal process, especially in the vicinity of the chute roads. Some 10 m spiles appeared in the face and presented an additional hazard by wrapping around the shearer drums. Inclinometers were provided to the spiling crews to improve the angle of the spiles at the collar of the drillholes.



Figure 14: Cutting into PDRR22



Figure 15: Cutting into PDRR23

PDRR24 Overview

The key changes from PDRR 23 to PDRR 24 were:

- 6m point anchored strands were installed by the continuous miner during development (2 x 2m vertically using the inner rigs). This allowed the second outbye row of cables to be omitted
- A combination of 2.1 m bolts and 4 m post-grouted strands (between chute roads) were installed on the outbye rib to prevent failure during shield retrieval
- Clear plastic was attached to the roof to act as a barrier between the backfill material and the roof

The longwall 24 take off process and PDRR were generally successful, though some of the same issues encountered in PDRR23 were not resolved. There was another rib fall outbye of where the 4 m cables stopped – this required cavity fill and PUR to be pumped prior to recommencing shield recovery. A number of 10 m spiles were either not installed at the correct horizon and presented in the face or bent down onto the face where blocks of roof were not supported ahead of the face. The clear plastic was not as effective due to grout from the backfill delivery boreholes breaching the roof-plastic interface.

BACKFILL STRATEGY AND RESULTS

Prior to grout filling PDRR21 substantial time and money was invested in differing grout mixes to achieve the required strength and flowability specifications. Grout mix considerations included:

- Flyash supplier – multiple flyash sources were trialled
- Grout composition – differing cement/flyash content
- Water content – achieve required grout flowability
- Water quality – salts and Total Dissolved Solids (TDS) will impact grout strength
- Curing times – cost benefits achieved by reducing cement content and allowing longer curing time.

The original trial data combined with the developed strategy after multiple PDRRs has resulted in the following decisions being made:

1. The flyash now used at Crinum (and since adopted at Broadmeadow Mine) consists of a light fine grained ash of consistent size and composition. This provides grout strength predictability, ease of pumping and consistent water requirements
2. The original 7 MPa grout specification has increased to 10-14 MPa. While a harder grout has the potential for brittle/sharp edges during cutting it generally shears away from the roof better and has improved qualities through the coal processing plant i.e. less daughter particle creation
3. Water content can be altered and tested to achieve the required grout pumping distance (from plant to PDRR) without negatively impacting the grout strength
4. Water required to produce grout with predictable strengths must have known salts and TDS levels. Water containing high salts or TDS will make grout strength prediction difficult
5. By scheduling longer curing times prior to longwall breakthrough, cement contents can be reduced. This results in a cheaper grout that still achieves the required strength
6. Grout delivery via multiple boreholes is a quicker, less labour intensive and more cost effective filling technique that provides a tight filled PDRR (>95% filled). Subject to borehole depth and casing, the cost of 10 grout delivery boreholes is less than one borehole with an underground network of delivery pipes and pipe install/ fill supervision labour
7. Consideration and some trials using other 'filler' materials other than flyash have been undertaken to further reduce PDRR costs e.g. fine coal tailings, aerated grouts.

PDRR 27 – THE FINAL ITERATION AT CRINUM MINE

All pre-driven recovery roadways for the life of mine at Crinum have been developed, supported and backfilled. The final PDRR to be prepared at Crinum is longwall 27. Though not yet mined, this roadway represents the final iteration of the method to be applied at the mine.

The 10 m JSS cables over the fender were replaced with 9 m length self-drilling bolts made up of 5 x 1.5 m hollow steel bolts coupled to 1 x 1.5 m hollow fibreglass bolts at the collar of the hole. The ability to couple of self-drilling bolt components not just with like materials (steel coupled with steel) but also steel and fibreglass has enabled the mine to remediate the issue of variable longwall horizon immediately prior to breaching the roadway. Another advantage of this system is that due to the much stiffer nature of the self-drilling bolts as opposed to the strands, they are not anticipated to present the same hazard experienced in previous pre-driven roadways where the ductile strands have wrapped around the shearer drums and provided little or no reinforcement to the roof once partially exposed. Advantages were also seen in the ease and quality of installation of these bolts.

The approach during the final stages of longwall retreat will remain largely the same utilising a pre-bolt up cycle (two rows 2.1 m bolts) and three rows of 1.2 m bolts to pin the Huesker mesh within the PDRR. The Huesker mesh will continue to provide protection during shield recovery by catching any small slabs of backfill material that remain on the roof after the final shear has been taken. Longer lengths of Huesker mesh may also be ordered so it can continue down the face and be pinned in place using bolts and/or straps where backfill material is unable to be removed from the final ribline.

CONCLUSIONS AND RECOMMENDATIONS

Significant progress has been made at the Crinum mine in the application of pre-driven recovery roads as evidenced by the evolution of the support regime, approach strategy, and backfill composition, as well as improved safety and recovery time. There are still a number of improvements to future PDRR design and implementation that should be considered.

1. Silent seal, or the like, the face rib so that the grout comes away from it and doesn't hold on to the mesh and bolts temporarily, and subsequently fall away during shield recovery
2. Install a trial of standing support like fibrecrete blocks or pumpable cribs and backfill the roadway to ½-¾ height. This allows the floor bearing capacity required, the roof support required, the rib confinement and fender support required, the floor heave control required, and then delivers a clean bolted roof as the backfill doesn't hang on to roof bolts and mesh and fall away later. Crinum was planning to do a 50 m trial section to prove the concept but ran out of longwalls
3. A full width PDRR (14 m) to eliminate the requirement to put up additional bolts
4. Evaluate the results of utilising a combination of steel and cuttable support above and within the fender
5. Continuous improvement of the backfill strategy – consideration and trials using 'filler' materials other than flyash to reduce cost, refinement of strength based on the strength of in situ strata.

The success of pre-driven recovery roadways at BMA's Crinum mine as compared to conventional longwall recovery within a weak roof environment has shown that when proper consideration is given to their design and execution, and continuous improvement is sought, PDRRs are a worthwhile and necessary strategy to ensure a safe and effective longwall take off.