ACARP

Australian Coal Association Research Program

FINAL REPORT

Rapid Roadway Development

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ACARP

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EXPLORATION AND MINING

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ACARP Project C8014
Rapid Roadway Development

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1 OVERVIEW

1.1 Introduction

CSIRO and JCOAL signed an umbrella agreement for investment in productivity related research projects for the Australian underground coal industry in July 1997. Under the agreement, JCOAL agreed to jointly fund critical areas of research and development that would result in a direct improvement of Australian productivity. Funding from Australia and Japan would be approximately equally shared. The subject of the first study or "pilot project" was improvement of underground roadway development rates. A $160,000 scoping study was completed in March 1998 and formed the basis of the 5year Rapid Roadway Project commenced in December 1998.

This project aims to ***design***, ***build***, ***provide systems support*** for and ***test run*** an integrated, ***automated coal conveying/bolting module*** that may sit between a variety of production machines and coal haulage options. The full project is scoped over five years, and JCOAL have committed $A5.4M out of a projected total budget requirement of $A10.7M. ACARP has supported the first year of activities within this project and has recently awarded an extension of support to the second year's activities. This report details the first full years activity of the ACARP/CSIRO component of the RRD project.

1.2 Project Outcomes

Substantial progress has been made in all areas of the RRD project over the last twelve month period. The major milestone for the year, the trial of a combined autonomous feed and bolting prototype has been achieved. Other substantial milestones in strata control, control systems, systems development and machine layout have also been accomplished. Challenges remain, as highlighted in the next section, but progress to date can be accrued to the depth of talent and motivation of the RRD team, including the monitors and support groups.

Up to the end of March 2000, the following outcomes have been completed for the RRD project.

1.2.1 Auto Roof Bolting System.

A prototype autonomous feed and bolting system has been constructed and successfully trialled. A feed system was designed and constructed by IHI in Japan and demonstrated during the October technical meeting in Nagoya. It was then modified and a second prototype was constructed and transported to Australia. The feed system is a mechanical underfeed system that does not depend upon robotics for bolt selection.

The bolting system has been developed to a remote controlled version by Hydramatic Engineering and BHP in a parallel, collaborative project outside the RRD project. During this development the new consumable, the BHP self-drilling bolt, and a new bulk chemical system have been combined to result in a completely hands off bolt installation process.

The two systems have been combined in a prototype trial to produce a fully autonomous feed and bolting unit. Bolt transfer via three bolt carousel on either side of the ACBM allows for either a 4 or 6 bolt pattern to be installed with some independence from the feed unit. The production unit will have bolt boxes with a capacity of two hundred bolts on either side of the machine, a total live feed capacity of four hundred bolts. Cycle times of 75 seconds per installed bolt per side will result in advance rates of up to 15 metres per hour with a four bolt pattern.

The rib bolt system will be similar in concept to the bolt feed system, except that the bolt will be fed directly into the bolter and not via a carousel. Only conceptional drawings have been completed at this stage.

1.2.2 ACBM Platform.

A specification for the platform detailing its functionality, environmental constraints including maneuverability has been completed. An industry survey was used to assist in this process. Mitsui Miike has prime responsibility for the design and construction of the platform. The have completed a series of drawings for a conceptional design (Appendix 2). Discussions at this time (April 2000) are being carried out to fine tune the design and reduce overall dimensions as much as possible. Detailed discussions are also ongoing on the subsystems component design and integration (autonomous feed and bolting, hydraulic, electrical, tramming, conveying, control etc). The CSIRO has completed concept drawings and incorporated this into 3D visualisation that has proven useful in the design development.

1.2.3 Strata Control

One of the key components of the RRD project is to determine suitable geological and geotechnical conditions and roadway support design methods for the new RRD system. To date, preliminary field monitoring and numerical modelling work has been carried out to determine effects of the unsupported span length and time.

A 2D Cosserat Finite Element code has been incorporated into a finite element package called AFENA, to predict the stability of the roadway involved, and study effects of the unsupported span length in strata with highly anisotropic deformation characteristics. The modified code is now capable of modelling elastic-plastic behaviour of both the lamination or bedding planes and rock layers involved more realistically than widely used conventional elasto-plastic models. The code is being calibrated against actual field monitoring data.

To provide a simple and easy-to-use predictive tool for the initial evaluation of the unsupported roadway span stability, an analytical model, the Bedded Span Stability Model, has been developed. The model is based on the previous CSIRO model for highwall mining span stability (Shen and Duncan Fama, 1996), and it takes into account the delamination and breakage of roof strata.

As a first attempt to monitor unsupported roof behaviour, a joint monitoring program has been completed at Moura Mine between CSIRO Highwall Mining Project and RRD Project Teams. Extensometer results have been analysed using UDEC and the new Cosserat model. Microseismic analyses have been completed.

A second underground site at Central Colliery has been completed. The study focused on the influence of roof beams, structure and stress direction on cutout distances achieved and stand up times.

1.2.4 Remote/Automatic Control Systems

The specification and acquisition of Miner Remote Control System has been completed. The conceptual design and preliminary specification of supervisory and bolting platform control system and detailed definition of the functionality of system components has also been completed. Work on sensor acquisition and definition of sensor development requirements and specifications is underway. A result has been the successful trial of a laser sensor through Perspex for roof and rib profiling. This will enable the sensor to be housed in a flameproof enclosure. Further evaluation of the laser distance measurement system for rib and roof profiling has also been undertaken with good results.

The data communications system between the miner and the ACBM, including a two-channel video link has been specified and ordered. Design work has progressed on the flameproof instrumentation enclosures to be mounted on the ACBM.

There has been some issues regarding electrical installation and a quotation from AT Flameproofing has been sourced to help resolve these requirements.

1.2.5 Systems Engineering

The Rapid Roadway Development project systems engineering component presented work in many areas of the overall mining system. This includes configuration details and specifications of the ACBM and the mining development system.

The ACBM conceptual model development section of the report presents the results of the mine survey, specification criteria developed based on this survey and details the current specifications of the ACBM and the mining system as they were agreed on through technical committee meetings. Lists of additional items that required to be clarified in the technical meeting discussions have also been included in the report.

The objective of the mine survey was to list design criteria that reflected the Australian environmental conditions, which the ACBM and mining system would be best suited to. A criterion for selection was to meet approximately 80% of the market. Specifications for the ACBM include, machine total length 11.0 metres, one metre advance support pattern of 4 roof bolts and one rib bolt per side installed in 4 minutes and the tail configuration of the ACBM should be similar in conceptual design to that on a continuous miner. The process of materials supply was highlighted under mining system criteria.

To assist in technical discussions and development of the design specification for the RRD system a number of 3D visualisation models of the ACBM were developed. The techniques used in the creation of 3D block models and some typical images from the visualisation are presented in this report. Flythrough movies of the RRD system are being presented at all the technical committee meetings. The models were used to demonstrate the size, configuration and interaction of moving components on the ACBM components.

The 3D visualisation is built in a three-stage process that starts in a CAD environment. The block diagram is currently held as a Solidworks model, and any design changes are made in this environment. The various components of the model are then exported as separate VRML files to go into the second stage of the modelling. After the animations have been added to the model, the VRML models are transferred into the JAVA control applet in the final stage. The applet used in this case is a small program that can run inside the web browser environment, and presents the user with a series of buttons which turn components ON/OFF and also control animations.

It is envisaged that the block components will gradually be replaced with fully detailed components as the project proceeds, with a fully detailed working 3D model being a deliverable out of the 3D visualisation work at the end of the project. It is also proposed to procure/develop equipment simulation capability in the next stage of the project.

The panel layout section details the theoretical development rates, panel cycle times, and results of sensitivity analysis. The mining cycle time calculations were developed utilizing the critical variables in the cycle time critical path. The two scenarios investigated were two heading development with 2 x 50 metre and 100 metre pillar panel configurations. The results showed that 100 m pillar layout is a better configuration for this Rapid Roadway Development system. A review of the Australian coal mining regulations to identify the critical issues to be addressed pertaining to the application of proposed rapid roadway development system has been completed. Regulations and issues concerning the introduction of new remote/automatic equipment have also been identified.

Ventilation alternatives for the ACBM and mining system were developed and presented to the technical committee. Different configurations of conventional gateroad ventilation techniques utilizing exhaust and forcing systems were discussed. The most effective design has ventilation ducting over the top of the conveyor, through the temporary roof support and beside the hopper arrangement. Cables handling and operator’s location issues were also discussed, as they need to be considered during design stage.

The interaction of the ACBM and the components of the RRD mining system had been itemized in the process interaction section. This study was conducted to detail the processes that could not happen simultaneously, and those that could operate independently on the ACBM. The ACBM cut out sequence control was also specified. An aim of this exercise was also to assist in the development of process controls that need to be employed in the programming of the ACBM functions and design of the mining system. The roles and responsibility of the mining operators was also itemized to highlight the processes that needed to be conducted.

1.3 Project Issues

Although one could enunciate several pages of challenges that lay ahead for project team, only a few require a special mention as being critical to continuance of the project. These include:

- Confirmed test site. Japanese interests are asking for a confirmed test site for the project to proceed. Australian interests will agree to a test site in principle, but won't commit to a site without something more tangible to consider. We are progressing this issue, but it is still a critical one to the project.

- Machine size. Although much progress has been made on machine functionality, there remains substantial work to integrate the systems into a practically sized machine. This is the main area of focus over the next months before engineering drawings are to be finalised.

- IP agreement. A draft agreement that was formulated by the technical group is currently under consideration by the company partners to the project. This has to be finalised before manufacturing progresses.

1.4 Program for 2000-2002

During the next two years, the ACBM will undergo final design, manufacture and initial field trials. The CSIRO responsibility includes support of this process in design and design approvals, manufacturing process, and arranging field trials and project management. In addition CSIRO has major responsibilities in automation control, systems engineering and strata control. Some unresolved issues remain regarding the process for design, approval and installation of power electrics and it is the requirement for front bolters, although firmly confirmed as a necessity, have not been fully scoped. The current detailed program for the ACARP/CSIRO components is shown below.

1.4.1 Automation and Control Component

1. Miner Remote Control
    - Acquire and commission laser-based miner heading control system
    - Develop miner control station on ACBM platform
- Commission Forced Potato "Simpson" radio remote control system including interfaces to miner-mounted horizon control and orientation sensors
    - Develop video monitoring system for coal cutting and forward bolting operations

  Milestones:
    - Heading control system operational (6 months)
    - Simpson control system operational (12 months)

  - Video monitoring system operational (12 months)

2. ACBM control system

- Design and acquire flameproof enclosures compatible with ACBM layout to house computer and sensor equipment
  - Design, implement and trial sensor systems to provide:
    Distance measurement to ribs, roof and miner
    Odometry on ACBM platform drive
  - Develop video monitoring system for hopper and ACBM belt
- Acquire computer hardware, install in flameproof enclosures and interface to external sensors
- Develop software to control overall system and interface to operators

  Milestones
  - Flameproof enclosures fitted out with computer equipment and operator interfaces (12 months)
  - Sensor systems for distance measurement and odometry operational (12 months)
  - Video monitoring system tested (18 months)
  - Control system software complete (24 months)

3. Forward bolting system
   - Provide interface in ACBM hardware and software for bolter data transmission
   - Design miner lighting and camera system to allow monitoring of forward bolting operation.

   Milestone
   - ACBM control system interface to forward bolting complete (24 months)

1.4.2 Systems Engineering Component

1. Systems – Sequences, Designs and Hardware requirements.
   - Plans of alternative mining sequences and auxiliary services' arrangements such as power, water, monitoring and communication systems through bolter will be developed. (6 months)
   - After analysis of the conceptual models and system components final designs and logistics of consumable supply, services extension and maintenance schedules will be developed (12 months)
   - Design and manufacture of supply cassettes, cable hangers, vent-tube/adapters and other required hardware for services. (18 months)
2. Gas and Ventilation Studies.
   - Field studies at selected mines to obtain gas emission data versus development rate. (12 months)
   - Setting-up and calibration of the gas emission model to estimate of gas emissions for different development rates and gas contents and seam permeability. (18 months)
   - Computational fluid dynamics model of the roadway constructed using actual machine configurations. This model will be used for simulating the effect of various parameters and design optimisation of the ventilation system for this remote miner and bolter combination. (18 months)
3. 3D Visualisation Studies.
   - Existing models will be updated when detailed plans are available. These will be used to simulate interactions between the components at various cutting stages. (6- months - ongoing)

- A full sequence simulation will also be developed to address interfaces between the machine components and logistics of services extension. (12 months – ongoing)

1.4.3 Strata Control Component

- Complete evaluation of the first two field sites for the effects of unsupported span length, time and bolting away from the face. (4 months)
- Complete development of numerical modelling tools to predict unsupported roadway roof and rib stability to determine appropriate support in given geological conditions (8 months)
- Carry out additional field geotechnical studies at other selected mines (12 months)
- Identify potential geotechnical hazards and risks involved in the new RRD system (18 months)
- Develop support design methods for the new system, including forward support from the miner (20 months)
- Coordinate underground field trials and calibration for the Japanese on-line rock monitoring system.(16 months)
- Undertake site specific geotechnical assessment and support design for the selected potential trials site for the new RRD system (18 months)
- Monitor first field site (24 months)

2 ACBM PLATFORM DESIGN

The ACBM platform design responsibility resides with Mitsui Miike Machinery although practically there has been input from all parties involved in the Rapid Roadway Development project. Responsibility of components on the ACBM includes Hydramatic Engineering with the manufacturing of the automatic rib and roof bolters, IHI design of the automatic bolt feeding system and CSIRO has designed the control systems. Input from CSIRO has also assisted the development of the individual component areas above.

2.1 Operational Environment Functionality

The ACBM is presently being designed according to the specifications outlined by the Rapid Roadway Development technical team to operate in an underground coal mine under the following conditions:

- Fit and operate in coal mine heading profile
    - 2.8 to 3.5 metres height
    - 4.8 to 5.5 metres wide
- Navigate turns in this heading profile range that have a minimum turning radius of 5 metres
- Navigate dips and rises up to +/- 7 degrees
- Maintain passage clearance of 600 millimetres for the mine operators beside ACBM and rib line whist operating
- Manoeuvre behind continuous miner to receive coal
- Receive and deliver coal at the same delivery rate of a continuous miner

The function of the ACBM is to autonomously support the coal mine heading profile (roof and ribs) whist receiving coal from a continuous miner and delivering via a through conveyer. The operation of the ACBM performs the following functions whist in this normal operation mode:

- Tramming of the ACBM forward a predetermined distance – manual tramming will be assisted through the intelligence of the heading positioning system. A display screen will indicate the position for the next line of support to be installed and the required distance to be moved. Constant feedback will be provided to the operator to assist with manoeuvring the ACBM into the support line location.
- Setting the Temporary Roof Support to roof and stabilising jacks to the floor – once the next support line position is reached, the rear stabilising jacks and front Temporary Roof Support floor jacks detract to the floor to level the ACBM. After levelling the Temporary Roof Support roof jacks set to secure the ACBM in the mine heading ready for the support installation process.
- Installation of the rib and roof support – the ACBM has the capability to install a 6-roof bolt and 1 rib bolt per side support pattern. Both rib and roof bolts process can happen

simultaneously. The centre roof bolts are installed first and then the outer bolts. The automatic bolt feed systems for the rib and roof work in unison with the total system, loading bolts when not engaged in the bolt installation process (covered in detail in the next section)

- Conveyance of coal through the ACBM - the front hopper has a chain conveyor in the base which continues through the centre of the ACBM to a 3 metre articulated discharging tail.

2.2 ACBM Platform Design

A survey was conducted of Australian underground coal mines to assist with the final design specifications. From the results of the survey, the mining environment that the ACBM will operate in was described above. The proposed peak development rate of 15 metres/hour is a design criterion of the ACBM. The design of the ACBM platform incorporates many individual components and systems to achieve this mark.

The components and operating systems on the ACBM include:

- Manoeuvrability of the ACBM – the ACBM will match the manoeuvrability of a conventional continuous miner. This is achieved by the continuous miner type track profile and layout.

- Temporary Roof Support – provides hydraulic support to the floor and roof around the installation line behind the hopper.

- Automatic Roof Bolt Feed System – the roof bolts are ejected from the bolt box and traversed to the bolting rigs were the bolt is rotated vertically. (See photo of prototype)

- Roof Bolt Carousel – the vertical roof bolt is grabbed by a 3-bolt carousel and rotated into position for the bolting cycle. (See photo of prototype)

- Automatic Roof Bolter – the roof bolter picks up the roof bolt from the 3-bolt carousel and begins the bolting cycle described in the section following. (See photo of prototype)

- Automatic Rib Bolt Feed System – the rib bolts are feed to the rib bolter via a mechanism that transfers the bolt form the rib bolt box to the rib bolt chuck in the horizontal plane.

- Automatic Rib Bolter – once the rib bolt is in the chuck the rib bolter begins the bolting cycle described in the section following. This involves positioning of the rib bolter to the rib line via a telescopic arm and laser profiling system.

- Materials supply on/off the ACBM – materials are contained in custom-made boxes that incorporate the bolt ejection mechanism. The rib and roof bolts have separate boxes on the ACBM. The desirable final design of the material supply box will also include the chemical resins for anchoring the bolts. The ACBM would have connecting hoses to the chemical storage tanks in the bolt box.

- Chemical injection system – rib and roof bolts are anchored by the chemical injected up the centre of the bolts once drilled into position. The chemical injection system injects mastic and catalyst chemical resins at the point of injection.

- Coal Transport – articulated hopper at front (vertical axis) and through chain conveyor are responsible for the transportation and delivery of the coal. (The hopper design includes the bash plate and ventilation ducting.)

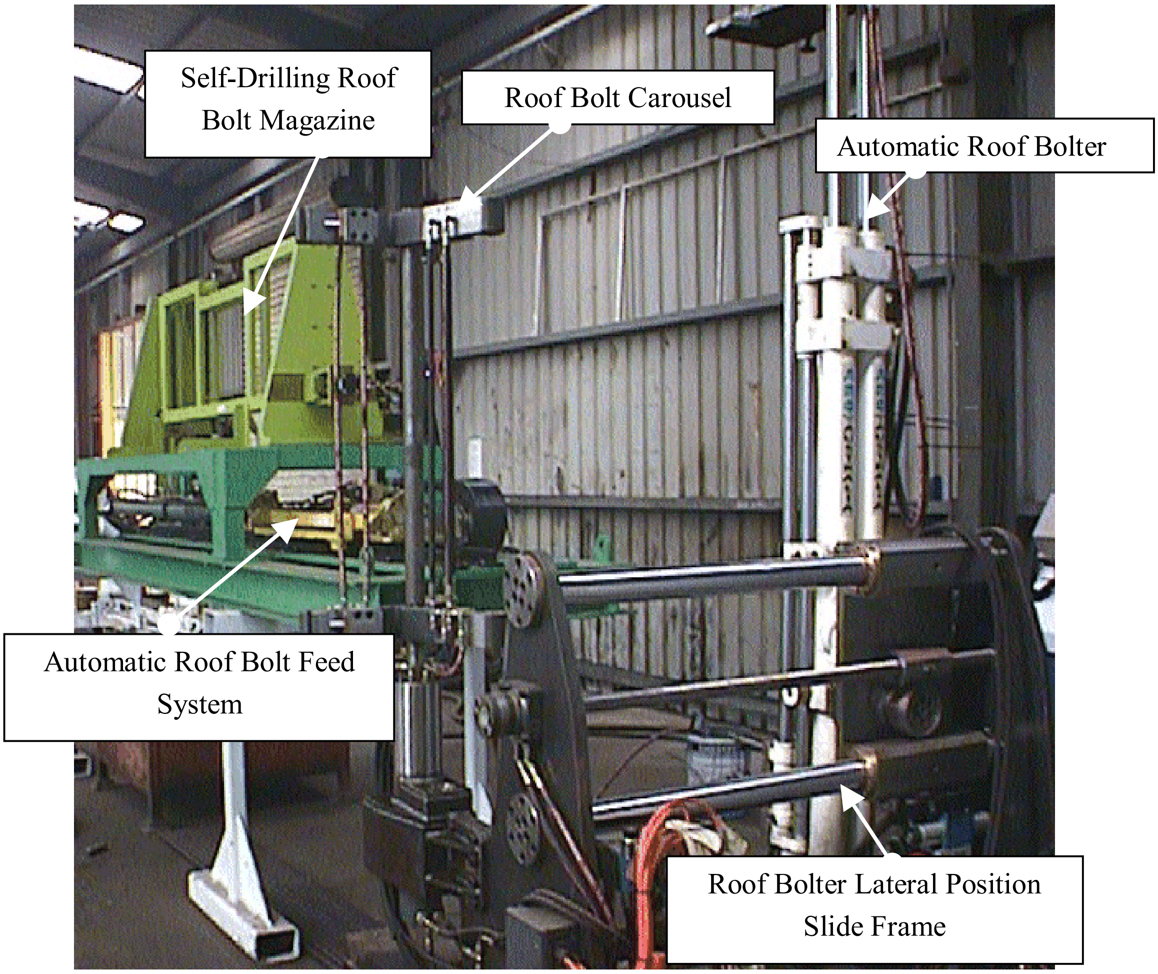


Figure 2.1 – Prototype of Autonomous Feed and Bolting Unit

- Operator Platforms – the platforms along the sides of the ACBM are design fold down and up depending the on the task at hand. The platforms in the bolting rig area are to assist the operator if interaction in the bolting cycle is required

- Laser Profiling System – profiles the mined heading at the support installation line to optimise the placement of bolts.

- Operator Display Screen and Control Panel – the operator has a display screen that itemises all operating processes and their progress. Cameras are located on the bash plate and over the central conveyor to provided visual monitoring. Manual control buttons/keyboard are also located in this area.

- Lighting – the ACBM will luminate forward of the ACBM over the hopper and continuous miner. Low-level lighting will also be provided around the operator controls.

- Ventilation – the ACBM ventilation duct is connected to the main auxiliary ventilation ducting via an Elephant trunk type ducting. The ducting on the ACBM is centrally located above the conveyor up to the bash plate. The ducting splits into two sections were it is incorporated into the bash plate/hopper structure venting along the under side of the hopper. (An earlier conceptual design of the ventilation ducting shown beside)

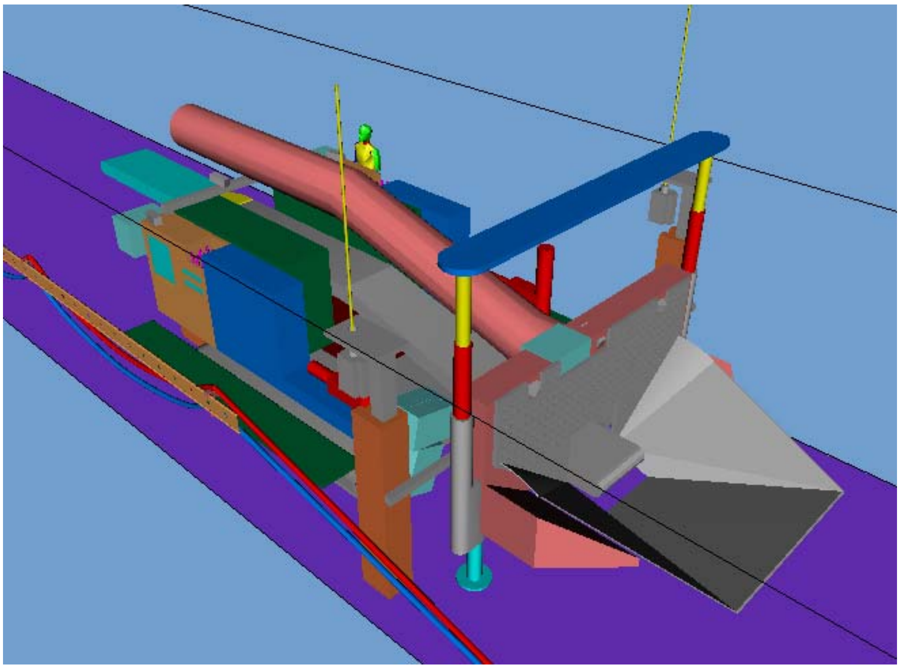


Figure 2.2 – 3D Visualisation representation of ACBM

The platform design conceptually has evolved as a consequence of the operations functions that each component/system needs to perform to reach the development rate goal. The layout of the ACBM platform has been refined over the four technical meetings held with the view of integrating as many components and systems as practically possible to simplify the machine.

3 ACBM - ROOF AND RIB BOLTING SYSTEMS OPERATION

Once the heading positioning system has guided the ACBM to the next support line location the ACBM autonomously installs the required support into the roof and rib line strata. The rib and roof bolts are contained in individual material supply boxes. At this stage in the project, the roof bolt supply box is loaded onto the ACBM from the rear and the rib bolts are loaded from the side.

3.1 Installation of a Self Drilling Roof Bolt

The installation of a roof bolt involves the following stages:

1. Roof Bolt Ejection – the first stage of the installation process involves the ejection of a roof bolt from the storage magazine. A series of hydraulically activated pins that operate in turn assists the ejection process. The result is a roof bolt is dropped into the jaws of the bolt transverse device.

2. Roof Bolt Transverse – the bolt transverse device transfers the horizontal roof bolt from the magazine to the 3-bolt carousel with the use of a hydraulic jack.

3. Roof Bolt Vertical Placement – once at the carousel a small hydraulic jack and clamp arrangement rotates the roof bolt vertically.

4. Carousel Interaction – Once vertical the carousel rotates so the gripping jaws come into contact with the roof bolt. The spring-loaded jaws grip the bolt and the carousel may rotate to load another roof bolt if required.

5. Roof Bolter Loading – With the roof bolt located in the 3-bolt carousel, the roof bolter may position the chuck under the end of the roof bolt in the carousel. The roof bolter then extends the drill motor up so the roof bolt sits in the chuck. Once the roof bolt is seated, the carousel releases the grippers on the roof bolt so the roof bolter can assume the next roof bolt installation position.

    - The roof bolt feed system, stages 1 to 4, may operate at any time while the roof bolter is at not the carousel or the roof bolter position interferes with the vertical rotation of the roof bolt

6. Installation Position – the loaded roof bolter assumes the next installation position with the assistance from the strata profiling system, used to survey the strata profile for optimum bolt placement in the support pattern being installed.

7. Installation process:

- The roof bolt plate magazine located on the side of the bolting slide frame ejects a plate on top of the head plate using the same "staple ejection principle" as a paper stapler.
- The head plate of the bolter extends up to the roofline, with roof bolt plate, to secure the bolter to the roof strata.
- Drill rotation and drill feed commence and operate under monitored rates to ensure optimum drill performance.
- Once the Self-drilling roof bolt has been drilled, a set amount of chemical resin is injected.
- The chemical resin is allowed to go off (10 seconds) before the drill head rotates to apply torque to the bolt nut.

8. The chemical injection system comprises of two epoxy resin chemicals, a mastic and catalysis. The two chemicals are stored separately. The resin injection process requires the stored chemical to be loaded into two separate injection cylinders. This is achieved when the hydraulic piston on top of the injection cylinders retracts, sucking both chemicals from the storage tank into the respective injection cylinders. The large and small sized injection cylinders are designed to cater for the different quantities of chemical required for anchoring the roof bolt. With the system primed, the hydraulic jack extends forcing the chemical into the roof bolt via the multifunctional drill head chuck. The chemicals are mixed on the point of injection in the roof bolt base with the use of a static mixing device.

9. The drill head retracts down the bolt slider and head plate retracts of the roof line.

10. Reload Roof Bolter – the roof bolter returns to the carousel where the bolter docks in position to load the bolt

3.2 Installation of a Self Drilling Rib Bolt

The installation of a rib bolt involves the following stages:

1. Rib Bolt loading - a rib bolt is loaded horizontally into the rib bolt chuck from the rib bolt supply box. The feed system for the rib bolter is still under conceptual design.

2. Rotation – the rib bolter rotates 90 degrees towards the rib line for positioning into the rib.

3. Positioning - Once loaded chunk the telescopic arm of the rib bolter extends the rib bolter to the rib line for installation. This is assisted with the use of the strata profiling intelligence.

4. Installation process – this is the same as step 7 in the Roof Bolt Installation section.
5. Once the application of torque is complete, the rib bolter retracts the telescopic arm, rotates 90 degrees into position to receive another self-drilling rib bolt.

4 STRATA CONTROL

4.1 Executive Summary

An effective strata control system is one of the key features of the rapid roadway development (RRD) systems. The main objective of the research is to develop effective assessment techniques to determine the roof and rib stability, reinforcement requirements and design for the safe and productive application of the new rapid roadway development technology.

The same techniques can also be applied for strata control management in place changing and other conventional roadway development and mining methods.

The principal tasks of the first year of the five year research program are as follows:

- carry out site investigations into the effects of span width, time, roof strata conditions and stress conditions on the stability of unsupported spans;
- complete preliminary developments of analytical and numerical methods for a systematic study of the stability of unsupported spans.

Progress made up to March 2000 in the above two areas is summarised as follows:

4.1.1 Site Investigations

Moura Mine

Unsupported highwall mining spans were monitored with 3 deep-hole surface extensometers during June-August 1999 at Moura Mine in Central Queensland as part of an ACARP project in collaboration with the current project. Two unsupported highwall mining spans of 3.5m were monitored for roof deformation during and after mining. It was found that:

- The spans were stable 2 months after mining with limited deformation in this case;
- The deformation occurred in two phases, the initial deformation occurred immediately after the entry was cut and significant increase in deformation also occurred during the two months after mining.

Central Colliery

Central Colliery in Central Queensland was selected for another site for detailed investigations and monitoring. The place change method has been used at Central Colliery and various roof conditions have been encountered. As the first part of the site study, a geological and geotechnical investigation, including an underground mapping and roadway performance review, was carried out during October-December 1999. The initial findings are as follows:

- The orientation of the horizontal stress had a substantial effect on the roof instability. The roadway headings in the East-West direction suffered more roof falls and damage than the cut-throughs in the North-South direction.
- The mining sequence also had an effect on the roadway stability. The first heading developed in the area suffered more extensive damage than subsequent headings.
- Joint conditions had affected the size and depth of roof falls. Many roof falls were bounded by joints. The roof falls in the non-jointed areas consisted of shallow oval shapes with the shorter axis in the NNE direction.
- The standard cutout distance of the roadway headings was 6m at Central Colliery. However, this distance was reduced to 2-4m in areas where bad roof conditions were encountered, e.g. 49E-52E headings.
- The Coal Mine Roof Rating Classification method (CMRR), developed by the US Bureau of Mines, was also used for the evaluations of roadway roof stability. The CMRR rating of the roadway roofs in the area studied is consistent with the roof instability recorded at Central Colliery.
- The previous extensometer data in the area indicated that the maximum roof displacement was proportional to the cube of the span width.

4.1.2 Analytical Model Development

To provide a simple and easy-to-use predictive tool for the initial evaluation of the unsupported roadway span stability, an analytical model, the Bedded Span Stability Model, has been developed. The model is based on the previous CSIRO model for highwall mining span stability (Shen and Duncan Fama, 1996), and it takes into account the delamination and breakage of roof strata. This model is designed to predict the roof failure caused by roof delamination and snap-through.

According to the bedded span stability model, the maximum stable span of underground roadways is a function of: in-situ and mine induced stresses (σ_v and σ_H)

- intact rock strength (σ_t and σ_c) and Young's modulus (E)
- roof layer thickness (t)
- bedding strength

The model is applied to a simple example case. The prediction results for this example case showed a reduction of roof Factor of Safety with increasing vertical and horizontal stress level. Further verification tests are needed once further site monitoring data becomes available.

4.1.3 Numerical Model Code Development

Efficient numerical models are needed for span stability prediction in complex cases for this project. Two areas that existing numerical codes need improvements are their ability to handle the bedding, and the excessive calculation time required.

An advanced numerical code, using the Cosserat theory, has been developed to simulate the stability of bedded and laminated roof of underground roadways. It has been coupled to a time-dependent visco-plastic model, in two or three dimensions, to study the stand-up time of an unsupported roadway span.

When applied to an example case with a square roadway, the code has showed a reducing stand-up time as the roadway size increases. Some issues such as the mesh element size dependency are still to be addressed with the new code.

4.2 Introduction and Background

Key areas of research for the new Rapid Roadway Development (RRD) systems are the assessment of roadway stability and the design of strata control systems. The main objective of the research is to develop effective assessment techniques to determine the roof and rib stability and reinforcement design for the safe and productive application of the new rapid roadway development technology.

The same techniques can also be applied for strata control management in the place changing and other conventional development and mining methods.

The principal tasks of the five-year research are as follows:

- carry out geotechnical risk assessment of the new rapid roadway development (RRD) systems; through evaluation of effects of unsupported span length, effects of unsupported time and delayed bolt installation away from the face in various geological environments;
- develop rock bolt design criterion and support methods under such conditions;
- develop and apply a suitable rock monitoring method

The major tasks of the first year of the five year research program are:

- carry out site investigations into the effects of span width, time, roof strata conditions and stress conditions on the stability of unsupported spans;
- complete preliminary developments of analytical and numerical methods for a systematically study of the stability of unsupported spans.

This report describes the progress up to March 2000. This progress includes field investigations at Moura Mine and Central Colliery in Central Queensland and development of analytical/numerical models for span stability assessments.

4.3 Field Investigations

4.3.1 Roof Monitoring at Moura Mine

The work discussed in this section was carried out as part of ACARP (Australian Coal Association Research Program) Project C8033 in collaboration with the current project. The entire monitoring program including microseismic monitoring is reported in Shen et. al. (2000).

Highwall mining has been undertaken at Moura Mine in Central Queensland. A highwall mining entry is 3.5m wide and usually has a cover depth of 60-100m. The highwall mining entries are designed to be unsupported during and after the mining. This provides a good opportunity to monitor the natural reaction of the roof to the excavation of coal in the entry for an unlimited period. The highwall entries are not accessible by people for the installation of monitoring instruments inside the entry. However, the relatively shallow cover depth makes it feasible to install measurement devices in the immediate roof from the surface through vertical boreholes.

The coal seam being mined is the DU seam. The immediate roof overlying the DU seam varies. Normally the DU overburden is conformable with the coal and coarsens upwards from an overcoal mudstone unit (DU0) into siltstone interbedded with fine sandstone (DU1), to an overlying unit of medium grained sandstone (DU2), see Figure 4.1. The DU1 siltstone is the most common roof rock unit in contact with the DU Seam.

The DU1 siltstone is described as a grey, mostly moderately weak but occasionally moderately strong, siltstone with occasional sandstone laminae. The average estimated UCS determined from point load testing was 23 MPa, but ranged from 6.5 to 40 MPa. Three Brazilian tests gave tensile strengths in the range of 2.8 - 5.4 MPa. Two direct pull tests gave the tensile strengths of 0.3 and 1.2MPa along the bedding and a direct shear test indicated a friction angle of $\phi = 34°$.

Overlying the DU1 siltstone is the DU2 sandstone. The DU2 sandstone consists mainly of moderately strong pale grey, interbedded fine and medium grained sandstone with some interbedded siltstone. No strength testing was done on the sandstone but field logging indicates that its estimated UCS is in the range of 12.5 – 50 MPa.

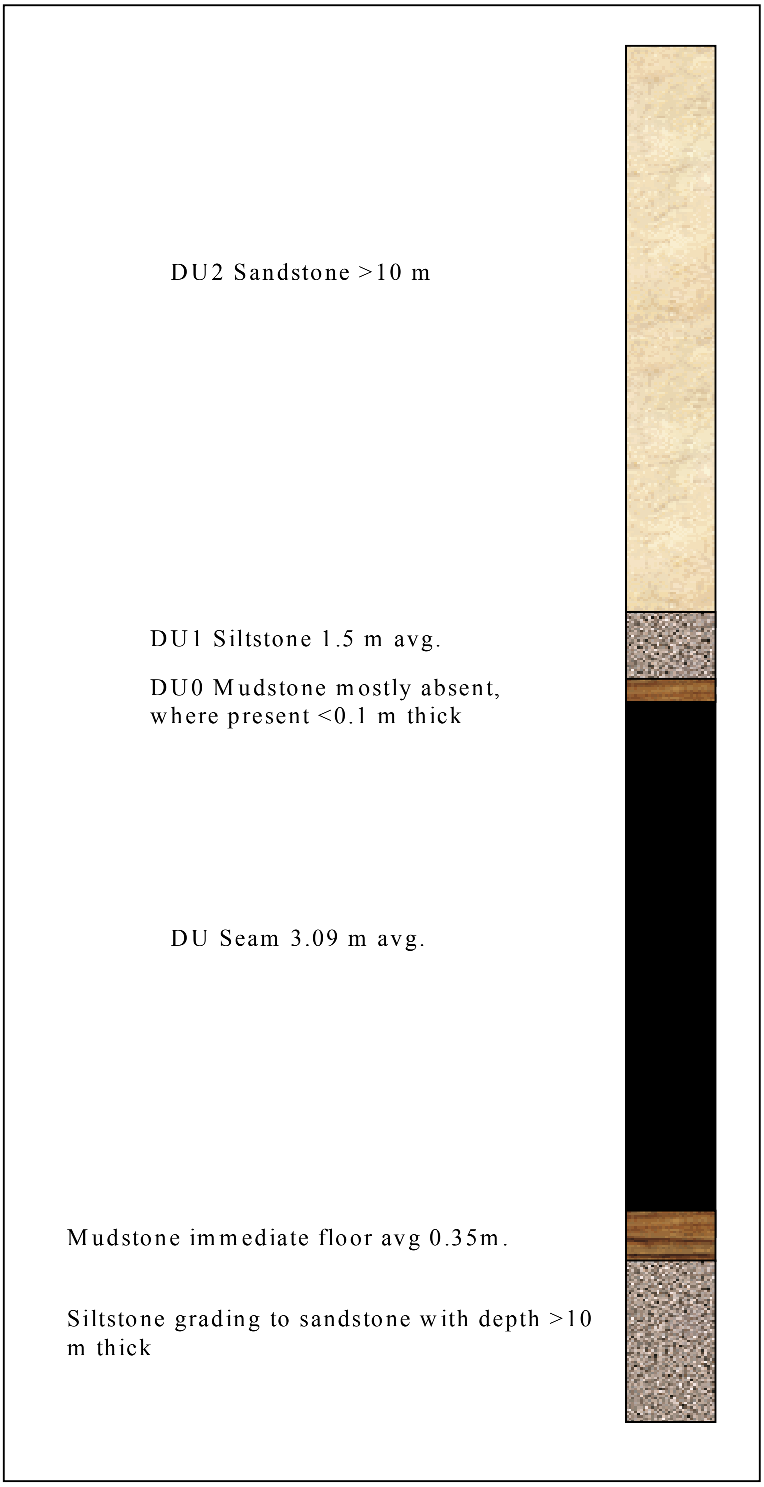


Figure 4.1 - Typical borehole section for the immediate geology above and below the DU Seam in the Pit 20DU (not to scale). (After Duncan Fama et al., 1999)

Subvertical joints are evident on the highwall face. There are two major joint sets with the average orientation of 80°/202° (dip/dip direction) and 90°/153°. The highwall face is orientated at 20° from North.

Three surface deep-hole extensometers were installed in the roof of two highwall mining entries in Pit 20DU, Moura Mine, see Figure 4.2. Each extensometer had 15 measurement points (anchors), spaced to cover the whole length from the immediate roof to the surface. Roof vertical displacement was recorded during entry excavation as well as after the excavation for a period of two months.

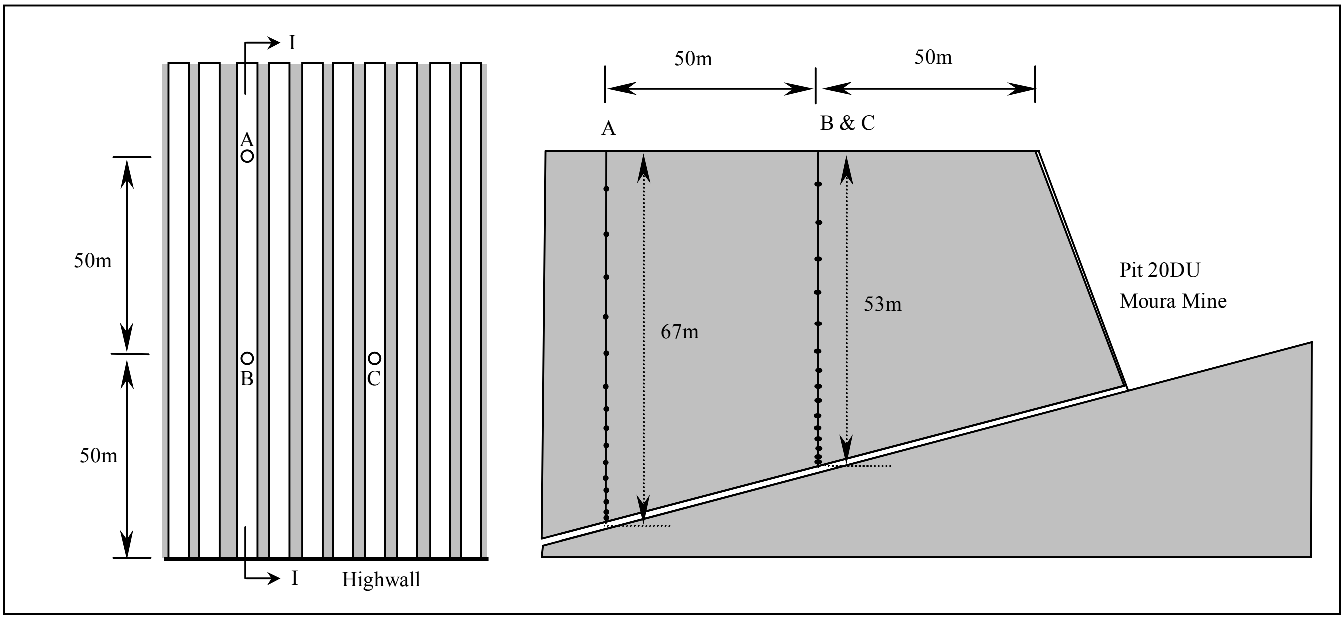


Figure 4.2 - Location of extensometers in Pit 20DU, Moura Mine

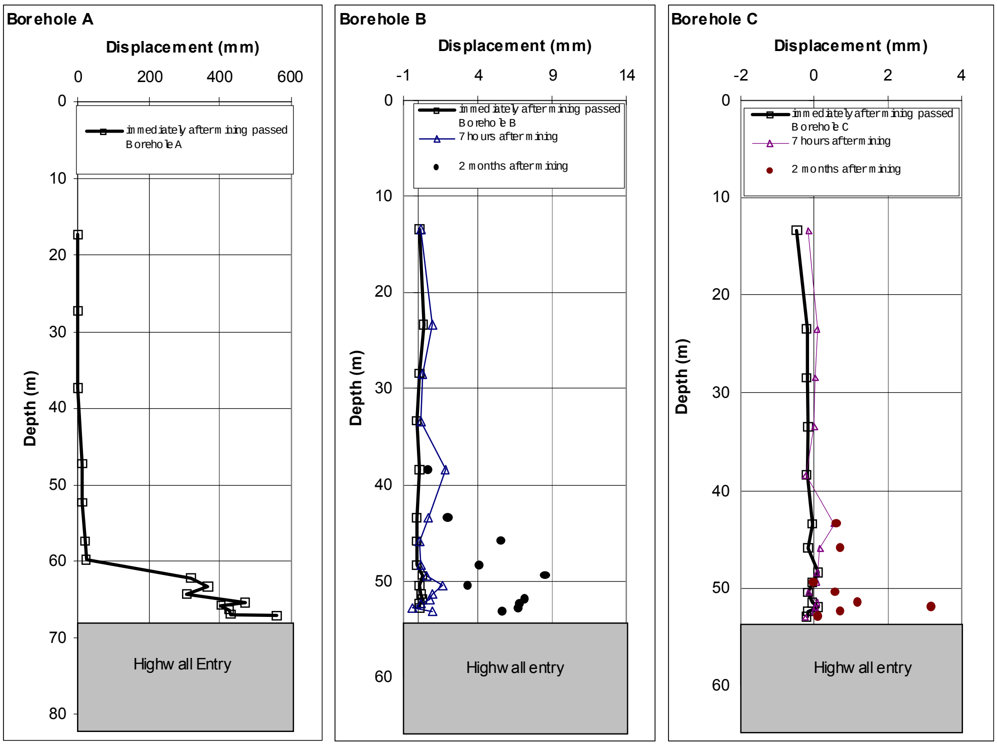


Figure 4.3. Measured roof displacements relative to the ground surface. Positive values represent downward movement.

The measured displacements are shown in Figure 4.3. A significant roof movement was obtained in borehole A (>550mm) immediately after the mining passed this borehole. It is believed that the large displacement was caused by a local roof fall. Small movements were recorded in boreholes B and C, with the immediate response of the roof to mining being only a few millimetres. Two months after mining, a further 1-10mm roof movements were obtained at different locations. The measured displacement also showed significant variation and irregularity along the depth of the boreholes B and C, possibly due to the well-developed joint sets and limited accuracy of the device in measuring a few millimetre displacements. The position of the boreholes relative to the entry span, particularly borehole C, is uncertain due to the entry deviation during mining at depth. It could be possible that borehole C was located above the pillar rather than in the mid-span of the highwall mining entry.

Apart from the possible local roof falls at borehole A, the monitoring results at both boreholes B and C showed the roof was stable. Because of the limited accuracy of the instrument, the elastic roof deformation of a few millimetres can not be accurately measured and analysed.

The monitored highwall entries were studied using a numerical code, UDEC (Itasca, 1996), as well as an in-house Cosserat code (Adhikary and Dyskin, 1998). Both numerical models used idealised roof geology as shown in Figure 4.1. The numerical modelling predicted maximum roof displacements of about 2-3mm, see Figure 4.4. This value is in the same order as those measured in boreholes B and C immediately after mining of the monitored entries.

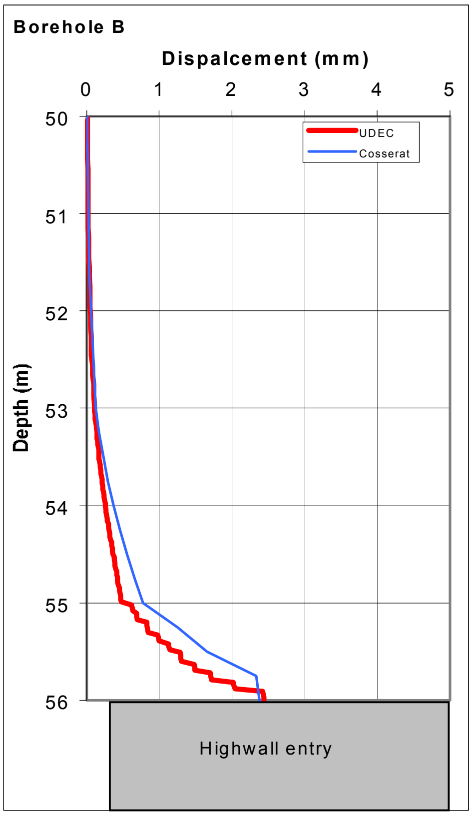


Figure 4.4. Numerical prediction of roof vertical displacement.

As part of ACARP Project C8033, microseismic monitoring was also carried out at Moura Mine to map roof fracturing associated with highwall mining in the same area of the extensometer monitoring. A report of the Project C8033 is currently in preparation. It appears that the located microseismic events were related to the highwall mining panel stress re-distributions.

There are two groups of the microseismic events located. The first group were located within 25 m above the coal seam being mined, and appear to be associated with the boundary position of the completed highwall mining entries. The second group was located between the highwall and a major fault. Many of these events were located in the floor of the seam being mined near the highwall toe. They appear to be controlled by the floor stress concentration near the highwall toe.

Microseismic events related to the highwall entry roof delamination are relatively weak and further work would be required to locate these weak events.

4.4 Central Colliery

Central Colliery, located in Central Queensland, has used the place change method for part of its roadway development. The width of the roadway is 5.2 metres and the standard cutout distance is 6 metres. Both stable and unstable roadway roof conditions have been encountered. The roof condition at Central Colliery is typical of many underground mines in Australia, and has been selected as one of the sites for a detailed investigation for roadway stability and mining performance.

The study at Central Colliery is to assess and select suitable roof geotechnical characterisation methods and criteria to determine maximum cutouts and unsupported time for place change operations.

The following tasks have been planned:

- collate cut-out performance data for the place change roadway development to date;
- collect relevant geological and geotechnical data for selected representative areas;
- map roadway roofs and drill and collect roof cores;
- monitor roof deformation and identify the roof failure process;
- carry out numerical modelling of the unsupported roof failure process and estimate effect of unsupported span length;
- critically review the effectiveness of existing methods such as RMR and CMRR.

To date, geological and geotechnical data in the area of place change operations have been collected, the roadway roofs have been mapped, and the previous mining performance has been studied. The roof monitoring and roof coring will be carried out once the place change operation recommences. Numerical modelling of the unsupported roof stability will be carried out after the first set of monitoring data is available.

4.4.1 Roof geology

Geological data of 7 cored holes in the vicinity of the place change operations were collected. The locations of the boreholes are shown in Figure 4.5 in the E-W vertical cross section. The area where the place change method was utilised lies in between boreholes DDH145 and DD0422. There were no boreholes drilled directly in this area. However, based on the above borehole information, the geology of German Creek Seam, roof and floor in Central Colliery were found to be fairly consistent, and the geology near the place change operations was inferred by interpolation. Based on laboratory tests, sonic interpretation and point loading tests, both the roof and the floor were found to be competent siltstone/sandstone. In the roof, the rock unconfined compressive strength (UCS) ranged from 41MPa to 68MPa with an average of 54MPa. In the floor, the rock UCS ranged from 32MPa to 61 MPa with an average of 50MPa.

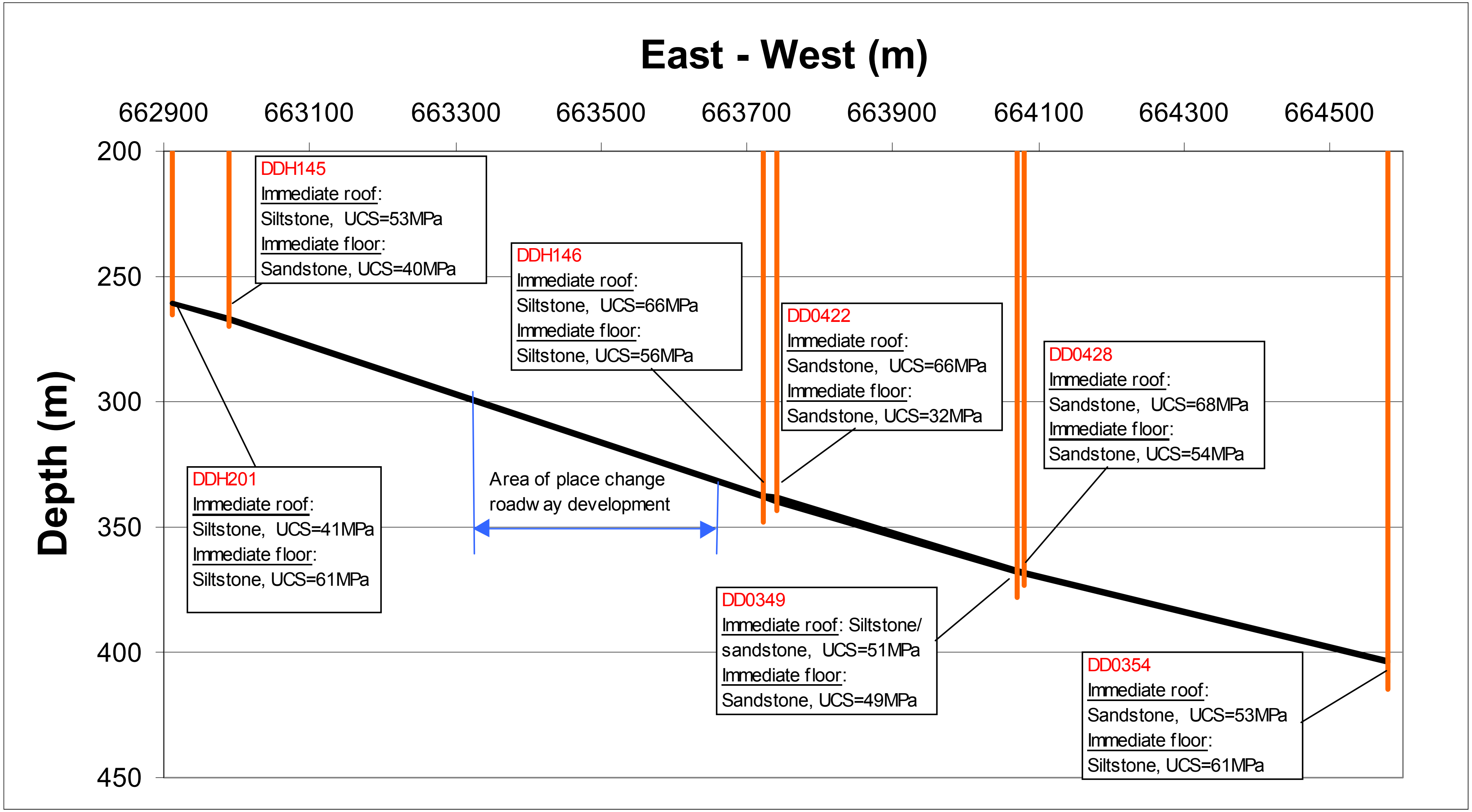


Figure 4.5 – Location of drill holes in the vicinity of the place change operations. Rock Strength of the immediate roof and floor were determined from laboratory compression tests, point load tests and sonic logs.

A thin Rider Seam exists above the immediate siltstone/sandstone roof. The separation between the Rider Seam and the German Creek Seam was found to increase with depth. In the area of place change operations, the estimated depth of cover was around 325m. The rider seam was estimated to be 1.1m above the German Creek Seam.

4.4.2 In situ Stresses

Stress measurements were made by Charleson, et al. (1999) in a number of boreholes in an area covering both Central Colliery and Southern Colliery. Two measurements were made near the place change roadways in Central Colliery in Boreholes DD0428 and DD0429. Borehole DD0428 was marked in Figure 4.5 Borehole DD0429 was located parallel to roadway 48 cut-throughs but about 100m south of intersection 48E (see Figure 4.6 for the roadway ID). Overcoring techniques were used to determine the magnitude and orientation of principal horizontal stresses. Three successful measurements were conducted in each of the two boreholes, two measurements in the roof and one in the floor. The measurements are summarised in Table 4-1.

Table 4-1 - Stress measurement results in Boreholes DD0428 and DD0429, after Charleson et. al. (1999).

Borehole ID	Depth (m)	Distance from Roof/ Floor (m)	Major horiz stress σ_H (MPa)	Minor horiz stress σ_h(MPa)	Orientation of σ_H (°)
DD0428	357.04	8.72 (roof)	17.75	13.51	11.89
	360.04	5.72 (roof)	16.46	5.1	6.14
	368.81	0.83 (floor)	13.58	6.46	2.45
	Average		**15.93**	**8.36**	**6.83**
DD0429	306.07	8.13 (roof)	12.09	6.09	1.87
	311.87	3.13 (roof)	9.65	4.47	16.96
	317.87	2.87 (floor)	12.65	10.77	35.77
	Average		**11.46**	**7.11**	**18.2**

The stress measurement results in Borehole DD0429 are believed to be more representative for the area of place change operations since they were carried out at a similar depth. The principal stresses obtained from Borehole DD0428 were higher than those from Borehole DD0429, reflecting the effect of increasing cover depth.

4.4.3 Roof Mapping

Approximately 4.8 km of roadway were mapped during November 1-3, 1999 as a part of the investigation, see Figure 4.6. The mapped area includes roadways from 40C/T to 52C/T, covering roadways developed by both the conventional method (40C/T – 47C/T) and the place change method (47C/T – 52C/T). Joints and roof falls observed in this area are plotted in Figure 4.6.

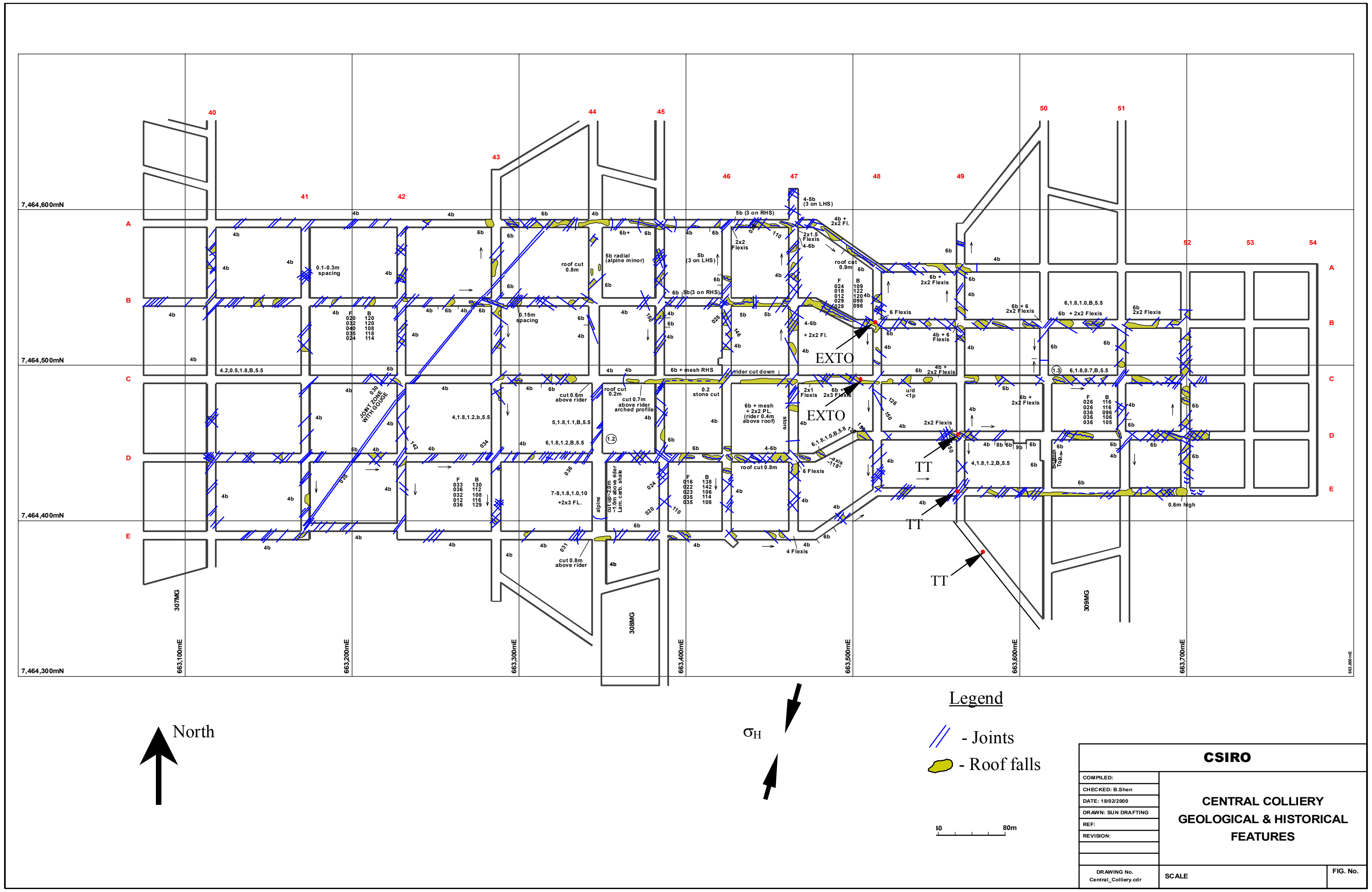


Figure 4.6 – Joints and roof falls observed in the roof of the roadways.

Roof structure primarily consisted of sub-vertical planar joints. Three main sets were evident:

J1 - Northeast set: 029°-045°, mean = 037°, evident in all areas

J2 – Southeast set: 104°-139°, mean = 125°, appeared to be clustered

J3 – Southeast set: 151°-159°, evident in zone from 44B to 49E

The following features of roof instabilities were noted from the roof mapping:

- The roof falls or damages had a strong dependency on the roadway direction. The roadway headings in East-West direction suffered more roof falls and damage than the cut-throughs in North-South direction.
- Roof guttering was common and widespread. It appeared to be the trigger for many roof falls experienced during and after mining.
- Roof guttering occurred mostly in the southern side of roadway headings as would be expected from the stress orientation.
- Many roof falls were bounded by joints. Other roof falls in the non-jointed areas consisted of shallow oval areas with the shorter axis in the NNE direction.
- In the roadways from 49E to 52E, roadway heading E suffered more extensive damage than other headings. This seemed to relate to the fact that the E heading was developed ahead of other headings in this area. It appeared that the orientation of the horizontal stress had a substantial effect on the roof instability.

Based on the directional features of the roof falls and roof gutters, Keith Rixon of SCT made an independent estimate of the orientation of the horizontal stresses. His estimate showed that the major principal horizontal stress σ_H had a direction of 019°. This orientation was close to the measured average orientation of 018° by Charleson, et al. (1999) in Borehole DD0429.

4.4.4 Cut-out Distance and Stand-up Time

The standard cutout distance of the roadway headings was 6m. However, based on the mining records, this distance was reduced to 2-4m in areas where severe roof falls were experienced such as in 49E-52E heading. The short cutout distances were described in the mining record as due to bad roof conditions. Unfortunately, the available mining records were not detailed enough for a statistic analysis of the actual cutout distance at Central Colliery.

The cutouts were usually supported during or soon after mining (within 2-3 hours). The stand-up time was therefore estimated to be mostly in the range from 0-3 hours. There were no specific records of the time before roof bolting after each cut.

4.4.5 Roof Displacement Monitoring

Two roof extensometers (EXTO) and three telltales (TT) were installed by Central Colliery in the area around 48CT – 49CT, see Figure 4.6 for locations. One of the two extensometers was located at the centre of 48B intersection and installed shortly after the intersection was cut and bolted. The roof displacements obtained from this extensometer covered a period of one month after mining. The time effect on the roof displacement appeared to be significant, see Figure 4.7. The maximum roof displacement doubled from 8 mm on December 17, 1998 to 17 mm on January 18, 1999.

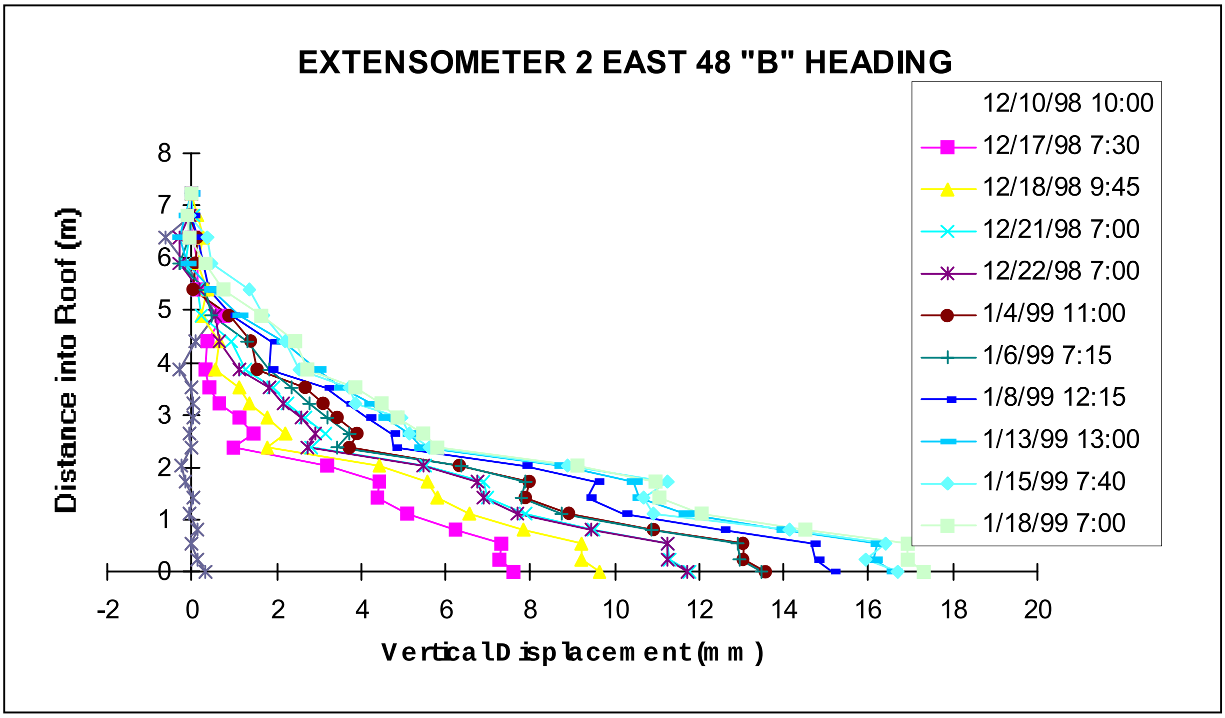


Figure 4.7 - Monitored roof displacement at the mid-span of roadway B heading.

The other extensometer was located in C heading between 47 and 48 cut-throughs. A maximum displacement of 8 mm was recorded 4 months after mining. Time effect again seemed to be significant. Note that this extensometer was not located in the centre of the roadway. The extensometer reading was therefore not the maximum displacement of the roof in the mid-span. Data from only one telltale (located at 49D intersection) was available, and it gave a maximum roof displacement of 17mm 2 days after mining.

Five extensometers were also installed in roadways outside the place change area. The monitored roadways were developed using the conventional method. They were cut initially to a width of 5.2m, and later widened to 8.0m.

Table 4-2 summarises the maximum roof displacement recorded from the extensometers and telltales in the 5.2m roadways and the 8m roadways. In Table 4-2, the maximum roof displacement of the 5.2m roadway ranged from 10mm to 28mm with an average of 18mm, whereas in the 8.0m roadway, it ranged from 47mm to 88mm with an average of 67mm. A significant "jump" in roof displacement was observed after the roadways were widened from 5.2m to 8m.

The average maximum roof displacement appeared to be proportional to the cube of the span width.

$$\frac{67mm}{18mm} \approx \left(\frac{8m}{5.2m}\right)^3 \text{ (average displacement from seven holes)}$$

Table 4-2– Maximum roof displacement obtained from extensometers and telltales.

Extensometer/Telltale ID	Roof displacement (mm)	
	5.2m roadway	8.0m roadway
TT 2E 49D heading	17	-
EXT 2E 48B heading	17	-
EXT 2E 47-48B heading	8	-
EXT 308 INSTRD 22m	20	68
EXT 308 INSTRD 100m	21	88
EXT 308 INSTRD 140m	10	66
EXT 308 INSTRD 180m	12	47
EXT 308 INSTRD 220m	28	65
Average *(exclude EXT 2E 47-48B heading)*	***18 mm***	***67 mm***

4.4.6 Coal Mine Roof Rating Classification

In addition to roof mapping at Central Colliery during November 1-3, 1999, a roof rating based on the US Bureau of Mines method was attempted in the roadways from 40C/T to 50C/T (Appendix 1). The coal mine roof rating classification (CMRR) was developed by the U.S. Bureau of Mines as an engineering tool to quantify descriptive geologic information for use in coal mine design and roof support selection (Molinda and Mark, 1994; Mark, 1999). The CMRR simply combines the results of geologic ground control research with worldwide experience of rock mass classification systems. The CMRR is based on the structural competence of the mine roof rock, which is determined primarily by the discontinuities that weaken the rock fabric. The data collected by the US Bureau of Mines method was partitioned into three broad regions: Weak (0-45), moderate (45-65) and strong (65-100).

Table 4-3– CMRR rating of roadway roofs at Central Colliery

Location	Exposure	Unit Rating	
B40CT	2m towards C Heading from SE corner	43.5	Weak
B42CT	1.5m towards C Heading from SE corner	47.0	Moderate
B44CT	0.5m towards C Heading from SW corner	43.5	Weak
B46CT	2.0m towards C Heading from SW corner	43.5	Weak
B48CT	0.5m towards C Heading from SE corner	39.5	Weak
B50CT	5.0m towards C Heading from SE corner	49.5	Moderate
D40CT	1.0m towards E Heading from SE corner	46.0	Moderate
D42CT	1.0m towards E Heading from SE corner	38.5	Weak
D44CT	1.0m towards E Heading from SE corner	46.0	Moderate
D46CT	2.0m towards E Heading from SE corner	39.0	Weak
D48CT	towards E Heading from SE corner	48.0	Moderate
D50CT	along D heading about 5 m from SW corner	42.0	Weak

The CMRR rating of roadway roofs at Central Colliery is listed in Table 4-3. In general, the roadway roofs in the area studied in Central Colliery are classified as weak to moderate. According to Mark (1999), the critical CMRR value for 5.2m roadways is 46. For place change operations, roadway roofs with CMRR less than 46 are unstable. This agrees in general with the roof instability recorded at Central Colliery.

4.4.7 Future Work

Further roof monitoring and roof coring are planned. The roof monitoring will be conducted using both SCT Sonic extensometers and GEL remotely readable extensometers. The monitoring will be conducted at five locations, two in roadway headings, two in intersections and one in cut-throughs. The monitoring will commence once the place change operations resume.

4.5 Analytical Model Development

Accurate prediction of the stability of an unsupported roadway span is crucial for mine design. A simple and easy-to-use predictive tool is helpful for a quick assessment for a given geometrical and geological condition. The simple tool, however, needs to capture the controlling factors for span stability in the environment of underground roadway development.

Span failure mechanisms are controlled by a number of factors including rock strength, *in situ* stresses, joints, lithology, sedimentology, and excavation geometry. In general, failure mechanisms can be divided into four main types. They are:

- Intact rock shear failure
- Block fall
- Span buckling
- Span delamination and snap-through

A laminated span failure model (LSFM) was developed by CSIRO (Shen and Duncan Fama, 1996) to predict the snap-through type of failure for highwall mining spans. In the current study, this model has been modified and extended to underground roadway spans. In the modified model, the roof is considered to be an assembly of horizontal layers. Each layer is considered as a beam. When the roof reaches critical stability stage, the disturbed roof can be divided into two regions (Figure 4.8):

Region 1 - immediate roof beams. They have been fractured at the mid-span and the ends of the span. The beams behave as cracked beams and may fall due to snap-through failure at the mid-span or due to compressive failure at the ends of the span. The mode of failure depends upon a number of factors, noticeably the horizontal/vertical stress ratio, span width /layer thickness ratio and the compressive strength of the roof rock. High horizontal/ vertical stress ratio and low rock strength enhance the compressive failure (guttering), whereas high span width/layer thickness ratio often leads to the snap-through type of failure.

Region 2 – beams at a distance above the roadway. In this region roof delamination has occurred and each beam deforms elastically as a fix-end beam.

It is assumed that the vertical displacement of the beams in Regions 1 and 2 each follows a linear relation (Figure 4.8). The beam assembly in the two regions together supports the insitu vertical stress applied to the top boundary of Region 1.

Based on the theory of fix-end beam and cracked beam, the maximum roof displacement (d_0) of the immediate roof layer can be calculated for given insitu stresses, roof layer thickness, roof rock strength and elastic modulus. The bedding strength is considered indirectly by varying the depth of roof delamination. After knowing the maximum roof displacement (d_0), the stability of the immediate roof layer can be evaluated. If d_0 is found to be greater than the critical vertical displacement for a snap-through failure of the cracked beam, or if the compressive stress caused by this displacement at the end of the beam is greater than the rock compressive strength, roof falls either due to snap-through or due to guttering are predicted. In general, the maximum stable unsupported span of underground roadways (S_{max}) is given by

$$S_{\max} = f(\sigma_v, \sigma_H, E, t, \sigma_c, \sigma_t, k)$$

Where σ_v and σ_H – vertical and horizontal stresses

σ_t and σ_c - intact rock tensile and compressive strength

E - Young's modulus

t - roof layer thickness

k - factor incorporating roof bedding strength

Figure 4.9 shows the effect of the overburden stress on the predicted maximum stable span width in an example. In this example, the roof rock was strong and the roof layers were relatively thick. The maximum unsupported stable span at an overburden depth of 200m (σ_V=5MPa) is predicted to be 8m, whereas at the depth of 600m it is predicted to be only 4m (σ_V=15MPa). Figure 4.9 also shows that, at a shallow overburden depth (<160m, σ_V<4MPa), the final roof failure will be dominated by snap-through mainly due to the high ratio of the maximum span width to layer thickness and the low magnitude of stresses. At an overburden depth greater than 160m, however, the roof falls will be dominated by compressive failure (guttering) because of the low span width/layer thickness ratio and high stresses.

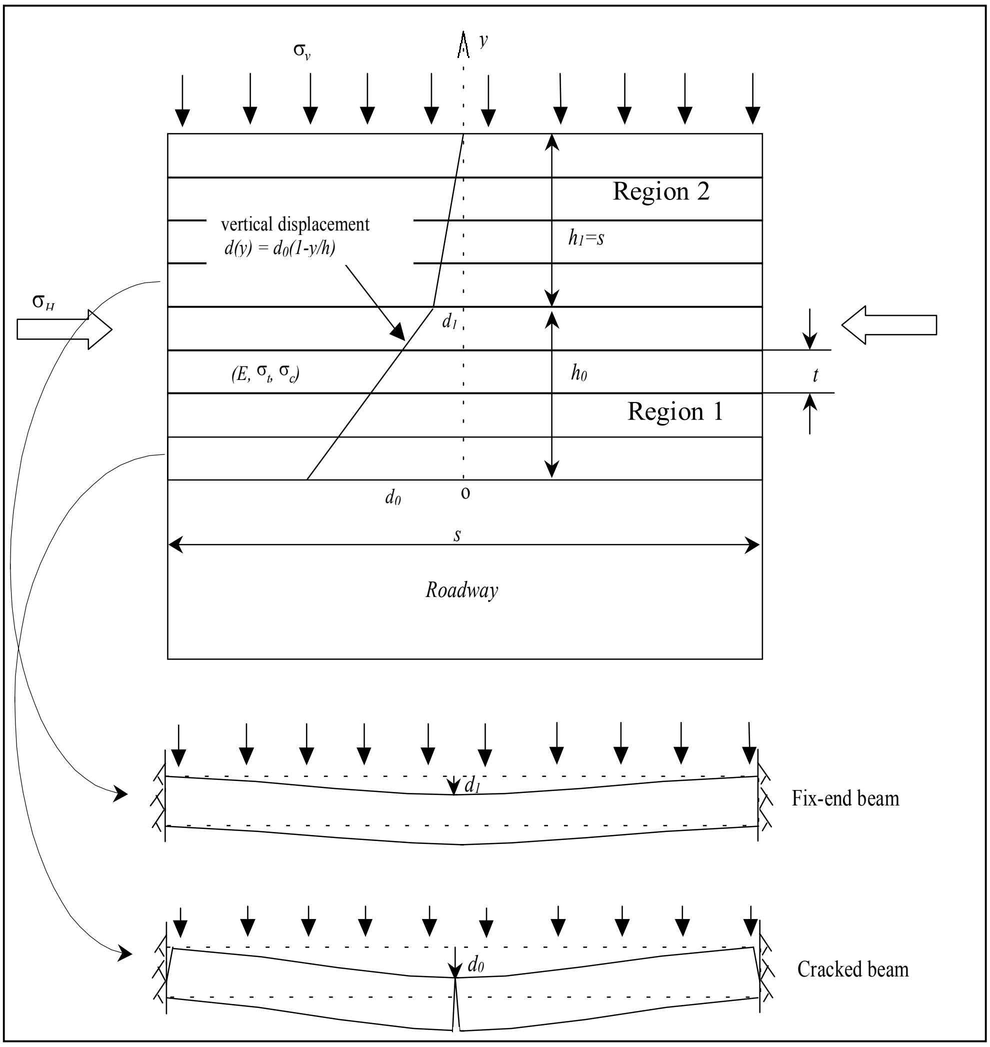


Figure 4.8. A bedded span stability model for unsupported roadway span stability assessment.

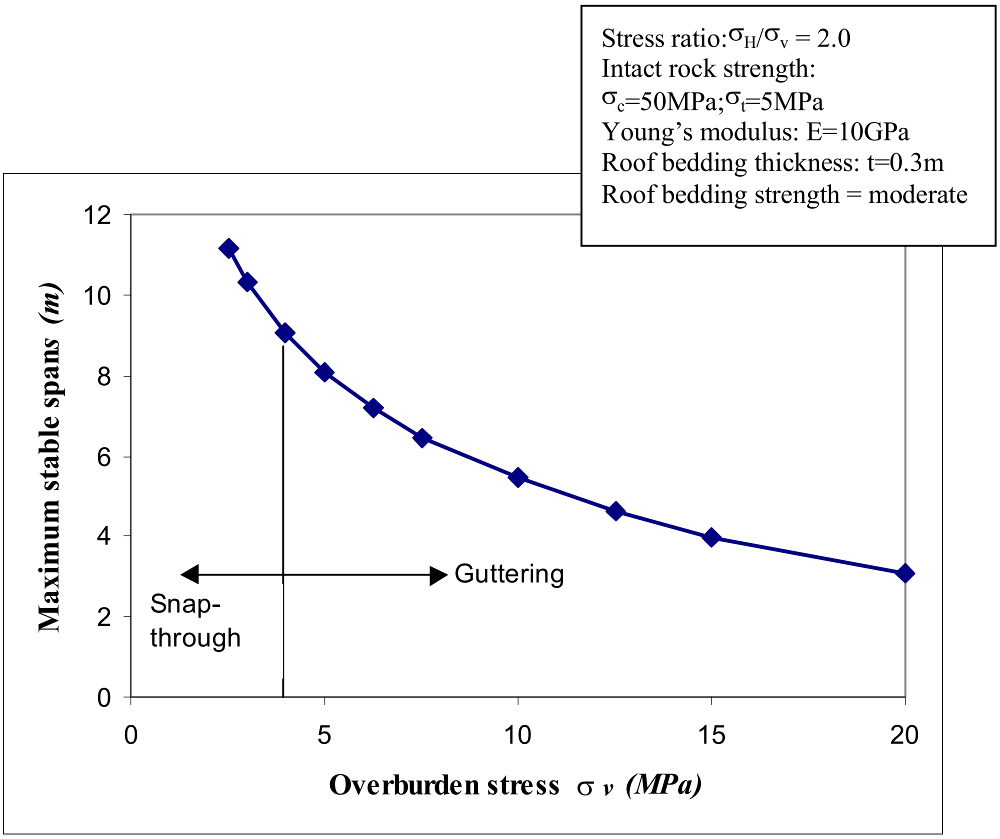


Figure 4.9. Effect of the overburden stress on the maximum stable span in an example case, predicted by the bedded span stability model.

4.6 Numerical Model Development

Although analytical methods can give a quick and indicative assessment on the stability of an unsupported roadway span, it is often limited to the cases with simple geology and stress conditions. For more complicated cases, numerical methods are needed. A number of existing continuum and discontinuum numerical tools have been examined for simulation of roadway span stability. However, the nature of coal roof strata (often closely bedded and laminated) makes most of the existing tools difficult to apply, either due to their incapability in handling the bedding or due to the impractical calculation time. To simulate the stability of roadway spans, one needs a continuum code which is capable of simulating the mechanical response of a layered rock mass; such as layer delamination, inter-layer sliding, layer bending and associated shear or tensile failures. Such a continuum code can in principle reduce the computer time considerably. The Cosserat Model has recently been shown to have the necessary capability to simulate the response of a layered rock mass accurately (Adhikary and Dyskin, 1997 & 1998).

The Cosserat model provides a large-scale (average) description of a layered medium. In this model, inter-layer interfaces (joints) are considered to be smeared across the mass, i.e. the effects of joints are implicit in the choice of stress-strain model formulation. An important feature of the Cosserat model is that it incorporates bending rigidity of individual layers in its formulation and this makes it different from other conventional implicit models. A distinctive advantage of the Cosserat model is that in the process of numerical modelling the problem region can be discretised with a coarser mesh (i.e. subdivided into fewer finite elements) than in explicit schemes where the size of the finite elements cannot exceed the layer thickness. Thus, in this scheme, the size of the finite elements is solely dictated by computational needs.

In the first stage of numerical code development, 2D and 3D Cosserat Finite Element Models have been developed. Figure 4.4 presents a comparison of numerical predictions of vertical displacements along a vertical cross-section above a highwall entry obtained using the 2D Cosserat Finite Element code and a Distinct Element code UDEC. The Cosserat code took only about 1/20 the time to execute compared with UDEC. This clearly shows the advantages of using continuum based Cosserat model over discontinuum based models such as UDEC in modelling the coal roof strata. The execution time is a limiting factor with 3D models.

In the second stage of model development, time is considered as an extra variable since in most of the cases and the response of a rock mass is found to change with time. Time dependency of the rock mass is of paramount importance in studying the stand-up time of unsupported roadways. However consideration of time effects in modelling adds another dimension to an already complicated 3D-rock mechanics problem. Hence it is desirable that a simple yet robust time dependent model is formulated, such that the developed model firstly is easy to calibrate against the field data and secondly is able to capture the essential features of time response. Such a rheological model capable of simulating the effect of time on the response of a rock mass has recently been developed and incorporated with the Cosserat Finite Element Models. Figure 4.10 presents a schematic representation of this rheological model that consists of a system of a spring and a slider connected in series. This part of the model will represent an elastic-plastic behaviour of a rock mass. This spring-slider system is further connected in series with a system of a dashpot and a slider arranged in parallel, which is included in the model to represent the time dependent response of the rock mass.

The computer program has been demonstrated to study the effect of time in a hypothetical 2D problem. A square roadway of 2m × 2m, 3m × 3m, 4m × 4m, and 5m × 5m respectively is driven through a prestressed rock mass. The insitu vertical and horizontal stresses were assumed to be 10 MPa and 25 MPa respectively, representing a roadway driven at a depth of about 400m in a rock mass with in situ stress ratio of 2.5.

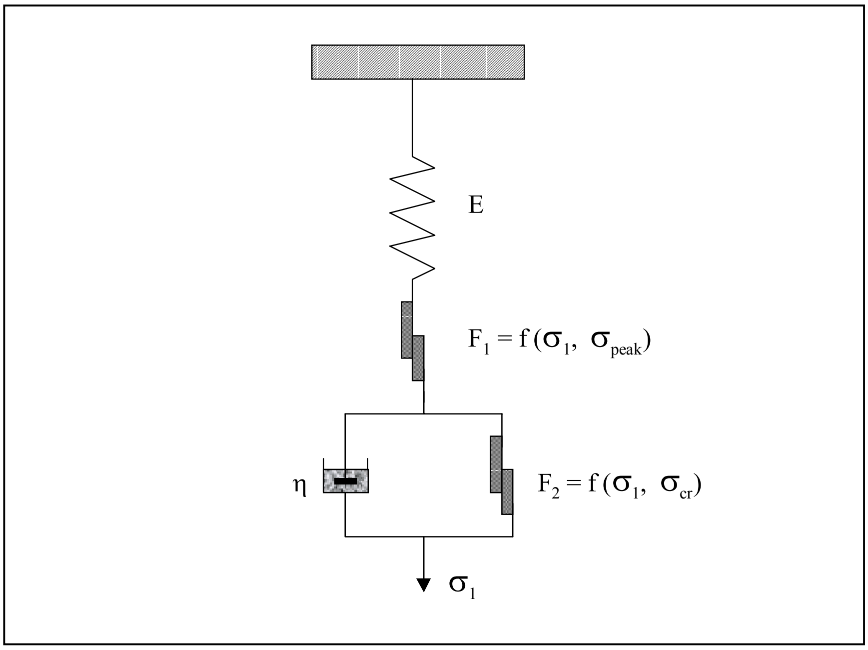


Figure 4.10. A schematic of the rheological model

The following properties for the rock mass were assumed:

Young's modulus = 10 GPa

Poisson's ratio = 0.21

Peak Cohesion = 1.2 MPa

Peak friction angle = 30°

Dilation angle = 0°

Peak tensile strength = 4 MPa

Residual cohesion = 0.

Cohesion softening rate =0.001

Residual friction angle = 20°

Friction softening rate = 100

Residual tensile strength = 0.

Tension softening rate = 0.001

Rock viscosity = 10-19 MPa sec

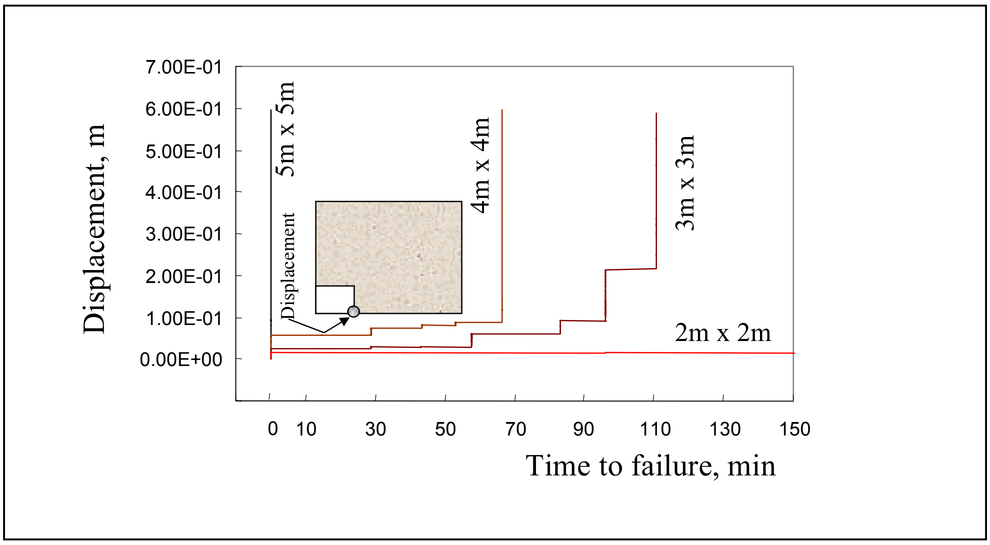


Figure 4.11. Displacement time history plot for roadways with different sizes

Figure 4.11 presents a plot showing displacement history versus time for each roadway size. It can be seen that a 5m by 5m roadway collapses instantaneously, where as a 4m by 4m and a 3m by 3m roadway takes about 60 minutes and 120 minutes to collapse respectively. A 2m by 2m roadway is observed to be stable beyond 200 minutes. Even though these preliminary model simulation results seem quite encouraging, there are some issues that need to be tackled in the future.

One of the issues is the dependency of results on the size of the finite elements used. We are dealing with a strain softening model (i.e. the strength of rock reduces as it fails) which is known to produce numerical results that are dependent on the element size. Hence the effect of excavation size on collapse time as observed above could well be a consequence of size effect introduced by the strain-softening model. In order to be able to eliminate the element size dependency inherent within the strain-softening model, it is desirable that the element size be properly calibrated against the available field data. Once such a mesh calibration is achieved, then true size effect of roadways in their collapse time can be studied which with further calibration against the field data may help produce a design chart showing the roadway span and stand-up time.

4.7 Conclusions

This report describes the progress made to date for the first year of the five-year research program. The achievements include:

- Roof deformations of two 3.5m unsupported highwall mining spans were monitored at Moura Mine as part of another project in collaboration with this study. The spans were observed to be stable during and after mining. The extensometers showed only 2-3mm roof displacement.

- Site geological and geotechnical investigation and roof mapping have been performed at Central Colliery for roadways developed by place change method. The review of the mining performance yielded a number of interesting findings, such as the dependency of the roof stability on mining sequence, roadway orientation and joints density.

- An analytical model for the stability assessment of unsupported spans in underground roadways has been developed. It is based on the previous CSIRO model for highwall mining span stability. This model yields plausible results with artificial examples, but will need to be verified and/or modified during applications to real roadway stability/instability cases.

- An advanced numerical code, using the Cosserat theory, has been developed to simulate the stability of bedded and laminated roof of underground roadways. It has been coupled to a time-dependent visco-plastic model, in two or three dimensions, to study the stand-up time of an unsupported roadway span.

A number of tasks are still to be carried out in the near future. They include:

- Monitoring the roof behaviour of underground roadways at Central Colliery. It has been planned that extensometers will be installed at five locations in the future roadways to monitor the roof deformations. Roof coring and laboratory tests will also be carried out. The place-change roadway development at Central Colliery is currently stopped due to gas problems, and there is no firm date when it will restart. The installation and monitoring will commence once the place change operations restart at Central Colliery.

- Additional site roadway stability studies at other selected mines. The analytical and numerical tools will need to be refined and verified against the additional site data. A number of issues in the numerical model, such as element size dependency will be investigated.

5 REMOTE AND AUTOMATIC CONTROL SYSTEMS

5.1 Introduction

This chapter of the report describes the activities and the outcomes of work done according to the Remote/Automatic Control Systems scope contained in the proposal document covering:

- Design of overall communications and control structure
- Definition of computer systems and communications protocols
- Specification of hardware and software for the overall control system

This has included the purchase of a Forced Potato "Simpson" control system and has involved liaison with the Inspectorate and equipment manufacturers regarding the flameproof enclosure design as outlined.

There has been one change to the project plan. During the course of the project a decision was taken by the Project Technical Committee not to control the miner from a remote operator station. Instead the miner will be operated by a conventional radio remote system.

The functions that each rapid roadway development system element is required to perform are considered and the approach taken to either manually operate, teleoperate or fully automate the functions of each system component are described below. The elements covered are:

- Continuous miner (CM)
- Hydramatic Roof and Rib Bolting Rig
- IHI rib and roof bolt storage and delivery system
- Mitsui Miike ACBM platform
- Forward Bolting Unit
- Control System

An overview of the architecture of the control system is presented and the tasks to be performed by the major subsystem controllers are discussed. Figure 5.1 shows a block diagram of the arrangement of the system components.

5.2 Continuous Miner

5.2.1 Methane Monitoring

Methane monitoring will be carried out on the CM and the readings transmitted to the ACBM. The methane monitor will also have independent control over the miner electrical system. The mode of operation of gas detection systems on remotely controlled mining systems, particularly with regard to resetting after a trip is an important issue. Operators will not be permitted to approach the RRD miner under unsupported roof to reset power systems locally after a methane trip. This problem can be solved with IS methane sensors that are able to self-reset after a trip and re-establish pilot circuits so that continuous miner power can be restored remotely.

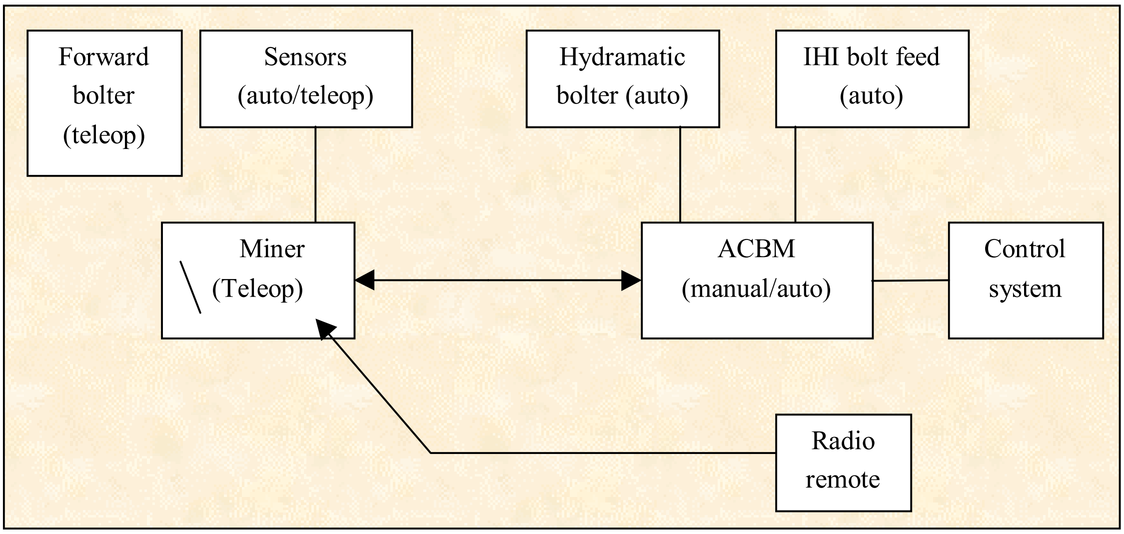


Figure 5.1. Rapid Roadway Development system elements requiring manual, teleoperation and automatic control.

5.2.2 Remote Control System

The continuous miner will not be automated. It will be remote controlled from an operator station on the ACBM (see later) using a *Simpson* remote control system from Forced Potato. The miner can therefore be operated from anywhere within radio range permitting independent operation of the miner separate from the ACBM. This mode of operation will be required during system maintenance and setup/withdrawal. When the miner is operating with the ACBM the miner operator will be located on a platform at the rear of the ACBM.

Given the dimensions of the system the miner operator will be located no closer to the machine than approximately 15-20m from the cutter drum, with a large structure between him and the miner. Visibility will be poor so guidance of the machine both for heading and horizon control will require enhancement through sensors.

Teleoperation relying on vision from cameras will be required for CM control. Experience in highwall mining suggests that to control the cutting action, two cameras could be required. One would be mounted on the top of the miner body covering the active area of the cutting drum. The other camera would be mounted to the side of the miner facing forwards to observe the drum vertical position. This helps in cutting the floor. In this case there will be instrumentation to measure the arm angle so the second camera might not be required.

The forward bolting system, described later in this section, will require monitoring by camera so two cameras could be mounted on each side of the CM so that the full width of the drum and the forward bolting system can be observed simultaneously.

At least two lights will be required to illuminate the face area. Flameproof enclosures exist to house the required lights. Because of glare no lights will face outbye where they would dazzle both operators and cameras.

5.2.3 Sensing and Horizon Control

The type of sensor for horizon control will depend on the mine-specific roof and floor strata. Natural gamma-based sensors (NGR) are being used in a number of locations in Australia for direct coal interface detection and provision is being made to incorporate NGR sensors on the miner. In the absence of real-time thickness measurements if the strata are not suitable, a memory cut approach will be taken whereby the miner cuts to predetermined horizons which are modified periodically through observation of the roof and floor at the bolter. Inclinometers to measure the attitude of the miner body and cutter boom will be fitted.

5.2.4 Heading Control

Several alternatives for lateral guidance (heading control) of the miner exist.

The preferred approach is to use conventional underground survey methods, coupled with a laser targeting system. This method depends on being able to have a clear path for the reference laser beam originating from a station some distance from the face. It is unclear at this stage of the project whether such an optical path will exist through the bolter structure.

An alternative may be to place the laser target on the bolting module, and use the known orientation of the miner with respect to the bolter to infer path corrections for the miner.

Inertial navigation (INS) can be used. The advantage of this method is that it is self-contained on the miner requiring no external sensors. It has two disadvantages. The first is cost to provide an INS with sufficient accuracy and the second is the accuracy achievable in the long term. If INS is used, the mining sequence will require allowance for periodic recalibration of the inertial system.

The selection process is ongoing and INS will be considered only if conventional (automated) laser-based underground navigation techniques are found to be unsuitable due to problems caused by the structure of the ACBM in allowing sensing of the laser on the CM.

5.2.5 Communications Connection

As mentioned there will be no physical connection between the CM and the ACBM. Options for communications are either direct radio link or cable-based communications looped from the

CM to the ACBM through the gate-end box. Two independent radio communications systems will be developed, based on Forced Potato products. One will be unidirectional, carrying two video channels from the miner to display screens on the ACBM and the second will be bi-directional, allowing management of the sensors mounted on the miner. The system is shown in block diagram form at the end of this section.

5.2.6 Forward Bolting System

A bolting system will be required on the CM to install a degree of support ahead of the ACBM. The development of this system will be required within the two to three year scope of the RRD project. However, control system architecture under consideration now includes provision for forward bolting.

The forward bolting system will be teleoperated from the ACBM. Video cameras and lights as described above will be used in the teleoperation system. The forward bolting system will include drill monitoring. The control system will require the capacity to communicate with this system.

5.2.7 CM Coal Flow Monitoring

This will be achieved using a camera and lights on the ACBM mounted on the bash plate facing the miner. Results of previous ACARP outburst mining remote control project will be utilised to examine methods to determine coal level in hopper.

5.2.8 CM Control System Overview

Figure 5.2 shows an overview of the control and communications system for the continuous miner. Solid bordered blocks are part of the Simpson miner remoter control system. Dotted blocks are elements of the prototype communications system of 1.2.5. The two systems will share common components.

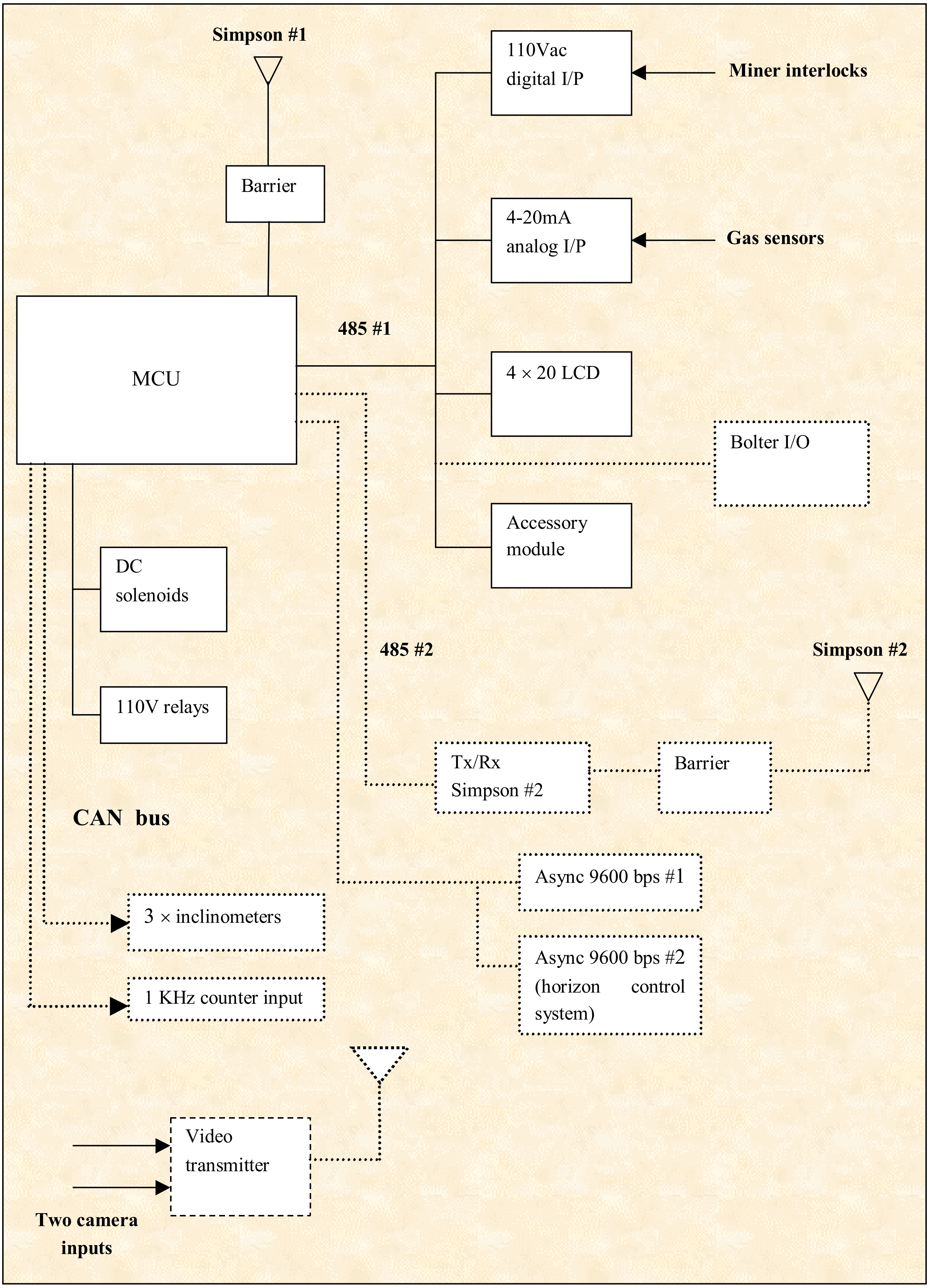


Figure 5.2. Forced Potato Control Equipment – Miner Component

5.3 ACBM

The ACBM consists of three physical components:

• ACBM Platform	Mitsui Miike
• Bolting System	Hydramatic
• Bolt Storage and Delivery	IHI

5.3.1 ACBM Automation Components

Because different manufacturers are constructing parts of the ACBM, the automation tasks and responsibilities have been split into four main areas:

Component	Responsibility
ACBM Platform	MMM - CSIRO
Bolting System	Hydramatic
Consumable Storage	IHI
Overall System Control	CSIRO

5.3.2 ACBM Platform - Autonomous Functionality Requirements

The general high-level autonomous functionality requirements of the ACBM platform are as follows:

- Occupy designed position in drive during each transverse bolting activity
- Form rigid support for bolting rigs
- Accept external command to set up for next bolting activity
- Tram on specified path
- Tram specified distance

5.3.3 Sensing Requirements

Sensing requirements to achieve the desired autonomous functions are:

- Distance measurement to ribs
- Distance measurement to roof
- Distance measurement to continuous miner (3m maximum distance, minimum distance is touching the bash plate)
- Odometry for bolt spacing (100mm resolution)
- Tracking of continuous miner (distance and angle)

In addition video monitoring of front hopper and ACBM belt are required for operator teleoperation functions.

5.3.3.1 Scanning Laser Rangefinders

A significant outcome of the project so far has been the successful application of the Sick LMS scanning laser rangefinder to all the distance measurement tasks identified above. The basic LMS unit is not an intrinsically safe device and so will require to be housed in a flameproof enclosure for underground use. A significant unknown was whether the laser beam would pass through a flameproof window. Tests showed that this could be achieved and in addition, coal and sandstone material produced viable echoes under these conditions.

5.3.4 Basic ACBM Control Functions

Tram control is the only function of the ACBM platform that requires computer control to execute the autonomous functions identified above. Two-speed, forward and reverse functions for each track will be provided.

As well as being under the control of the autonomous controller, manual/automatic selection will be available. The operator will be able to manually tram the ACBM and the sensing systems will provide feedback on such parameters as distance to the CM, ribs, tramming distance covered etc.

5.4 Bolting System – Automation Requirements

Automation for the bolting system is the responsibility of Hydramatic. It will be a stand-alone system receiving roof and rib bolts from the IHI storage and delivery system and hydraulic and electrical power from the ACBM platform. It will also have a communications interface to the system controller.

The Hydramatic unit consists of:

- Temporary roof Support (TRS) system
- Two automatic roof bolting rigs
- Two automatic rib bolting rigs
- Supporting mechanism to deploy/articulate the rigs and to mount on the ACBM Platform
- Interface to the IHI consumables unit

It will have local manual controls for each of the rigs. These manual controls will be implemented through mechanical overrides on the solenoid valves.

It will have an intelligent controller HYDRA which will reside in an instrumentation flameproof on the ACBM platform.

5.4.1 Additional Bolter Sensing Requirements

Proximity sensing for cables/hose against rib is required. Similarly, rib profile is required for the rib bolting system.

For autonomous bolter operation it will be necessary to measure the roof profile for the following reasons:

- To ensure that general roof height is within the operating range of the equipment.
- If necessary to select relatively flat places on the roof line for bolt spotting

Roof bolting rig transverse motion must be sensed so that the desired bolting pattern can be achieved. Fortunately these sensing functions will be provided by the laser rangefinding system mounted on ACBM platform.

5.5 IHI Consumables Storage System

Automation of the consumables storage system will be the responsibility of IHI. For the automation model it is assumed that the consumables storage system will require no direct communication link to the system controller. It is expected that all communications to this unit will be through the Hydramatic system. The definition of this interface is the joint responsibility of IHI and Hydramatic.

5.6 Overall Control System

The overall control system is the responsibility of CSIRO. In order to execute the bolting process automatically, the major components of the system will require remote control and/or autonomous operation capability. A development process control system must be superimposed over the four major equipment subsystems to achieve this. The computer hardware required for the overall control system has been acquired and is based on a PC104 format industrial PC. The various software functions are described below.

5.6.1 Development Process Controller (Big Brain)

The function of the development process controller (BIG BRAIN) is to interpret the high level bolting pattern design and to issue commands to the various subsystems to execute the bolting pattern, and to monitor the performance of the entire system.

The definition of the overall bolting program is in early stages and will evolve as the capabilities of the various subsystems become known from the "bottom up" and the requirements of the drivage concept crystallise further from the "top down".

The BIG BRAIN will have a repertoire of commands to initiate and monitor various tasks carried out by the subsystems.

5.6.2 MMM

MMM will be a process running in BIG BRAIN hardware. Its function is to execute the autonomous functionality outlined earlier in this section.

5.6.3 HYDRA

HYDRA is the intelligent controller embedded in the Hydramatic bolting system. It will enable autonomous operation of the bolting system. It will also supervise the operation of the IHI storage and delivery system. The HYDRA intelligent controller will be implemented as a Mitsubishi PLC.

5.6.4 IHI

IHI is the processor responsible for the operation of the bolt storage system. This control process will be implemented as a process running on the HYDRA PLC.

5.7 ACBM Control System Overview

Figure 5.3 shows an overview of the ACBM component of the control and automation system hardware.

5.8 Future Work

The work program for the next year of the project will concentrate on assembly of the control system and integration into the remainder of the RRD equipment. Specific tasks to be carried out are:

Miner Remote Control

- Acquire and commission miner heading control system
- Develop miner control station on ACBM platform
- Commission Forced Potato "Simpson" radio remote control system including interfaces to miner-mounted horizon control and orientation sensors
- Develop video monitoring system for coal cutting and forward bolting operations

ACBM control system

- Design and acquire flameproof enclosures compatible with ACBM layout to house computer and sensor equipment
- Design, implement and trial sensor systems to provide:
    Distance measurement to ribs, roof and miner
    Odometry on ACBM platform drive

- Develop video monitoring system for hopper and ACBM belt
- Acquire computer hardware, install in flameproof enclosures and interface to external sensors
- Develop software to control overall system and interface to operators

Forward bolting system

Provide interface in ACBM hardware and software for bolter data transmission
Design miner lighting and camera system to allow monitoring of forward bolting operation.

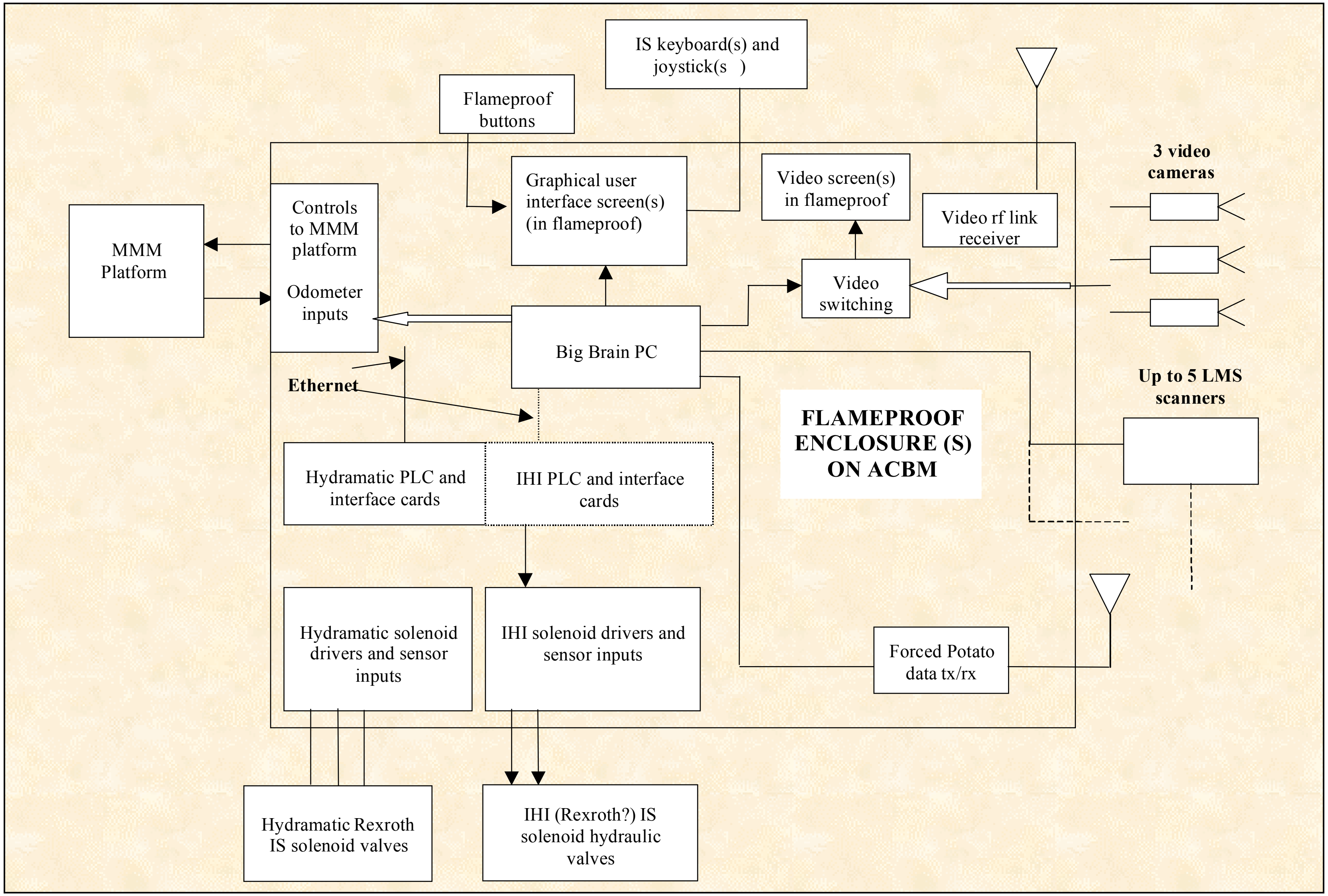


Figure 5.3. ACBM Computer Control Schematic

6 SYSTEMS ENGINEERING

6.1 Introduction

The systems engineering component of the RRD project looks at several aspects of the total project to provide linkage between different system components. The studies conducted in this year include: ACBM conceptual models, systems requirements, 3D visualisation models, panel layouts, ventilation arrangement and process interactions. This chapter presents the results of these studies in the following sections.

The ACBM conceptual model development section summarises the results of a mine roadway survey conducted across Australia to help in the process of specification development. The current specifications of the Automatic Conveyor Bolting Module (ACBM) and system requirements are presented in this section.

A number of 3D visualisation models were developed during the course of the project and the results of the current model are presented in this report.

The panel layout and mining system section has a breakdown of the theoretical panel development times for 50 m and 100 m pillar lengths. Ventilation alternatives are discussed and single heading development diagrams are presented.

In the Process Interaction section, the ACBM and the mining system parameters have been itemised and correlated to determine process interaction issues. The roles and responsibilities of the mine operators are also covered in this section.

6.2 'ACBM' Conceptual Models

From the onset of the Rapid Roadway Development project the specifications of the ACBM and the mining system have been reviewed and in some cases altered with the presentation of new information. A survey was conducted of underground coal mines in Australia. The report detailing the survey results was completed and a summary of this information is presented below.

The systems requirement section presents the list of items, which were discussed and finalised during the course of the project, and through technical committee meetings. After the 2nd technical meeting, Brisbane Australia, a table was prepared with details of those items that were decided on. This list was also used to generate the clarification lists that were used as a guide for discussion at the Nagoya 3rd technical meeting.

6.2.1 Results of Mine Survey

A survey was conducted of all underground coal mines operating in the New South Wales and Queensland. The purpose of the survey was to identify practiced roadway development standards that may be used in the final design considerations of the ACBM before commencing final engineering design plans. It is an aim of this exercise to ensure final designs target around 80% of the coal mines surveyed. Of the 38 longwall coal mines in Australia conducting gateroad heading development, 23 were surveyed.

The survey questionnaire was categorized under the following headings.

1. Coal Seam, Depth and Thickness
2. Development Panel Layout
3. Development Sequence Details
4. Support Density in Rib and Roof
5. Development Heading Cut-out Distance
6. Roof and Floor Conditions
7. Stress Conditions Around Development Heading
8. Mining Equipment
    a) Coal Cutting Equipment
    b) Coal Haulage Equipment
    c) Coal Flow Clearance
9. Ventilation of Development Panel
10. Gas Issues that Impact on Development Rates
11. Materials Supply to Development Mining Panel
12. Operator Location During Mining Sequence
13. Coal Clearance - Conveyor Belts
14. Budget Metres Per Shift
15. Issues Impacting on Development Rates
16. Shift Roster

Results of the survey are summarised in the Figure 6.1to Figure 6.5.

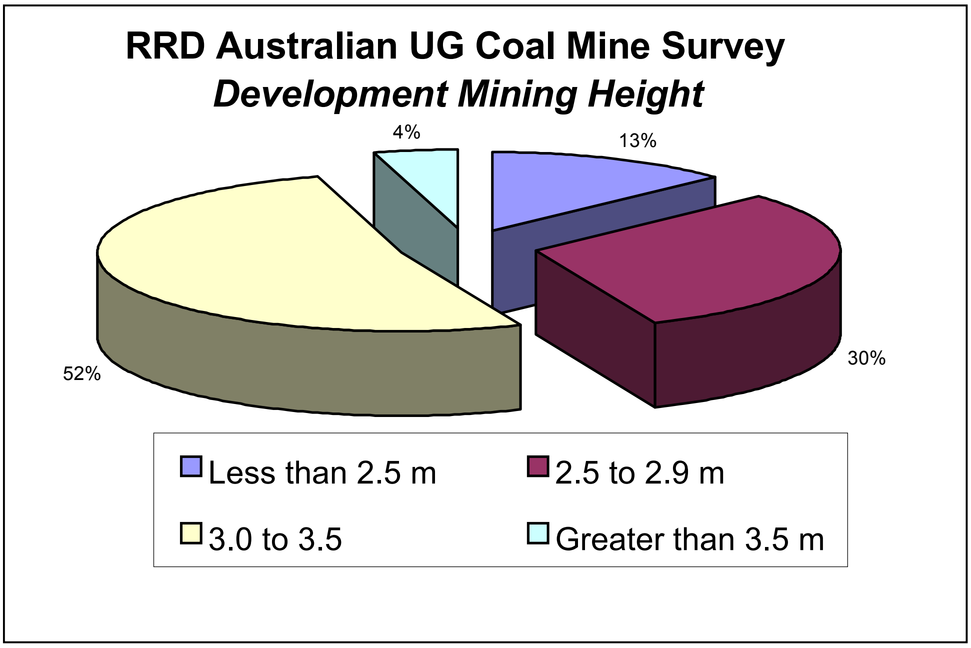


Figure 6.1. Mine survey result – roadway height distribution chart

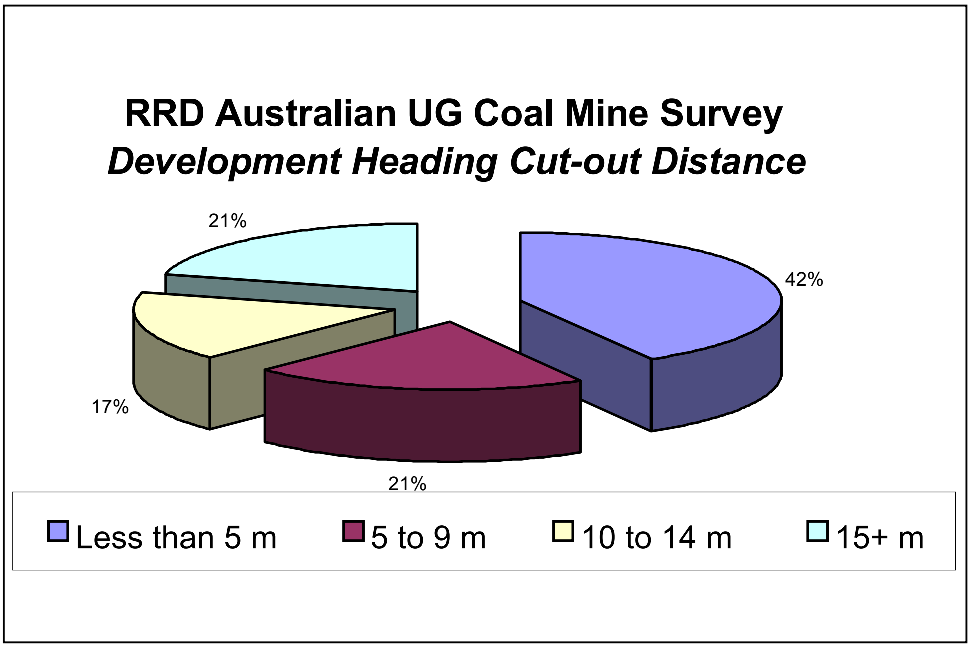


Figure 6.2. Mine survey result – heading cutout distance distribution chart

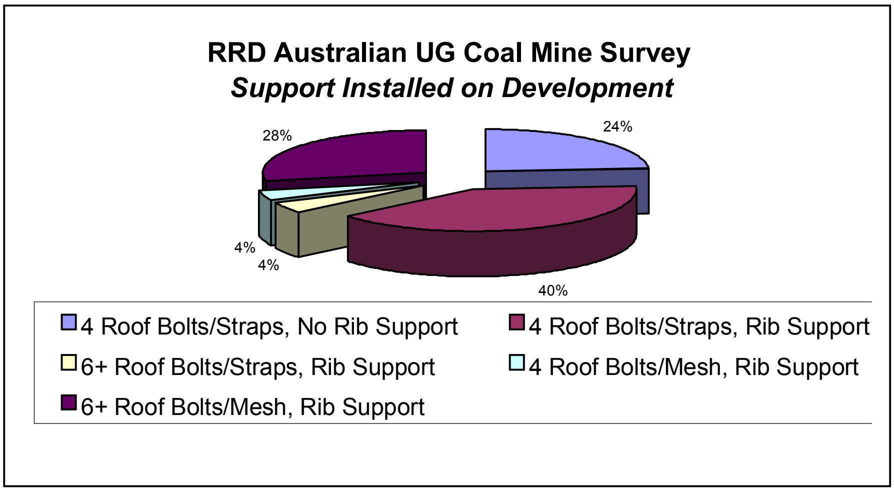


Figure 6.3. Mine survey result – support density distribution chart

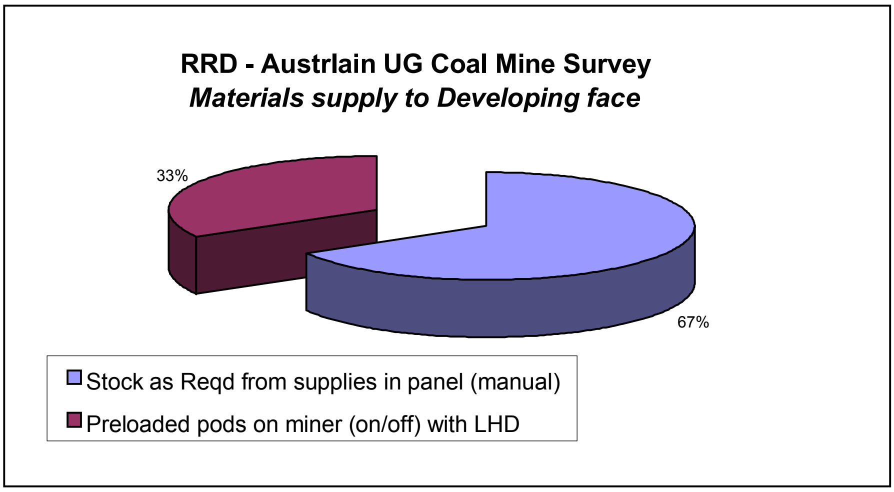


Figure 6.4. Mine survey result – material supply system distribution chart

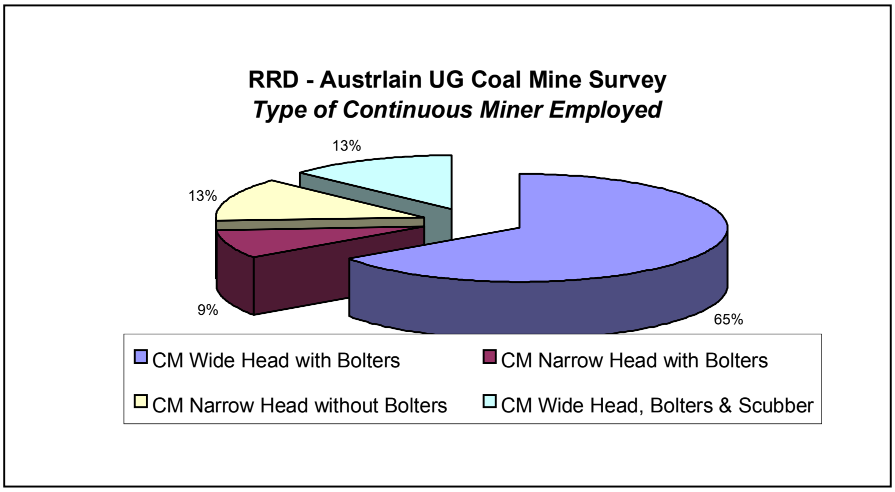


Figure 6.5. Mine survey result – continuous miner type distribution chart

6.2.2 ACBM Final Design Specification Criteria

From the results obtained in the survey, the following design specifications were developed to meet approximately 80% of the underground coal mine market conducting gateroad heading development.

1. The ACBM final design should be able to support a roadway heading with the dimensions 2.8 (h) x 4.8 (w) to 3.5 (h) x 5.5 (w) metres.

   Implication to ACBM specification

   a. Total length of the ACBM including tail, should be no more than 11.0 metres, (8 m body + 3 m tail = 11 m).
   b. The desirable width of the ACBM is 3.1 metres with an absolute maximum total width of 3.5 metres.
   c. Maximum tramming height of ACBM 2.3 metres will be required to navigate dips and humps in seam floor. This will be made possible with the entry and exit angles of the ACBM at 15 degrees.

2. The ACBM final design should be capable of installing 6 x 2.0 metre roof bolts and 1 x 1.5 metre rib bolt (per rib) per metre of heading developed.
   - The bolting pattern should have the flexibility to install bolts in varying rib and roof profile conditions.

   - The automatic bolting system should be capable of installing one complete line of support within 4 minutes. This includes, tramming to support installation position, bolt feed system operation, the installation of 4 roof and 2 rib bolts (drill, encapsulate and tension) and retraction of TRS ready for next line of support.

3. The ACBM final design of the coal delivery tail section should have the same function and movement as that on a continuous miner. Specifications obtained from a manufacture show, lateral movement in plane is 45 degrees off the centre line and the vertical movement 20 degrees from the horizontal. The ACBM coal clearance system should be compatible with the continuous miner loading rates.

4. Typical continuous miner loading rates are up to 36 tonnes/minute, with a conveyor speed of 2.3 metres/second. The conveyor discharge width in this case was 762 millimeters.

5. Operators should be able to have the provision to stand on the ACBM to observe and manually conduct the bolting process, if required.

6.2.3 Panel Layout Specification Criteria

The Rapid Roadway Development Mining System panel layout configuration should encompass the following design criteria.

- Depth of cover
- Inherent mine environment – Gas, ventilation
- Coal cutting machine selection
- Coal haulage alternatives
- Sequence of heading development
- Materials supply system

Attention should be given to the following items when considering the overall success of the Rapid Roadway Development Mining System.

1. The depth of cover is a factor when considering panel layout design.
2. Ventilation – gassy mines reported to require 6-8 cubic metres per second at the developing face.
3. Coal cutting machine – continuous miner type with remote control and wide head for single pass drivage.
4. Coal flow process, development critical path is on the haulage from ACBM to conveyor belt.
5. Sequence of development – optimal solutions available once machine selection and geological factors are considered
6. Material supply to developing panel – this is dead time, should be conducted in an efficient and effective manner. Design of a complete material supply system from manufacture to coal face may be required.
7. Panel cycle extensions – belt moves and service extensions, careful consideration should be given to the sequence of this operation.

6.2.4 RRD System Requirements and Specifications

The following items were considered for discussions during various technical meetings. Some of the issues were finalised during the meetings and decision on the remaining items will be finalised very soon in the following technical committee meetings. Details of the discussion and outcomes are presented in minutes of the Technical committee meetings. Current specifications of the ACBM that were agreed upon by all the parties and other specifications that need to be modified are given in the Table 6-1. Current design drawings are attached in minutes of the 4th Technical committee meeting.

Roof and Rib bolt sizes, spacing

- What is the roof bolt size to meet 80% of the Australian market
- What is the rib bolt size to meet 80% of the Australian market
- What is the spacing for roof bolts and rib bolts

ACBM dimensions

- What are the maximum dimensions for ACBM
- Do we need a hopper
- Do we need protection behind the hopper
- Sizes of various supply boxes

Autonomous bolters

- Development of the system
- testing – both in workshop and in field
- cycle times

Bolting system on ACBM

- How many roof bolters are required on the ACBM
- Location of roof bolters
- How many rib bolters are required

Autofeed system for bolts

- What type of autofeed system – robot arm or some other
- Maximum cycle time for supplying one roof bolt
- How many feed systems we need on the ACBM
- Does the feed system allow manual operator control?
- Roof bolt to be supplied to position in space
- The roof bolt rotation must not exceed a height of 2.5 metres
- How will the feed system operate?

Automatic roof bolting rigs placement

- What is the actual distance between the roof bolter and front of carrier:
- Where is the docking position located?

Automatic rib bolting rigs placement

- What is the actual distance between the rib bolter and roof bolter feed system:
- Where does the rib bolter pivot on the ACBM?

Chemical resin pumps and resin storage design

- What quantity of chemical is required to install 200 roof bolts and 100 rib bolts:
    - epoxy resin?
    - catalyst?
- How many resin and catalyst reservoirs are required?
- How many chemical injection pumps are required?
- Can multiple chemical injections occur at once?

Roof bolt supply box design

- Size
- Loading and unloading of bolts – manual or module box replacement
- Will the computer support installation system know the bolt box has had a bolt removed or replaced manually?
- loading /unloading of bolt supply box onto/off ACBM

Rib bolt supply box design

- Size nominate
- Loading and unloading of bolts -
- operation

Bash plate design

- Holes ? X ? May be required to cut into bash plate for ventilation purposes!
- Fine mesh screen may be placed on the bash plate to prevent coal projectiles!
- Limited closed height of 2225 mm not to be exceeded
- Is the bash plate required to be extendable during mining?
- Where are the mounted water sprays on bash plate located?

ACBM coal hopper design

- Volume capacity required (match 12CM20 output-30 t/min)!
- Shape of final design!
- Need to have the ability to pivot hopper up/down!
- Conveyor placement, not to impinge on hopper tilting!

Conveyor design

- Width of outer specification,
- Capacity required to suit 12CM20-type miner - approx. 30 tonnes/min
- How far into the hopper does the conveyor extend?
- What is the actual movement range of the ACBM tail?
- Where is the drive motor located?

Operator location

Installation of support

- barriers, lock outs required, sensors!

- Tramming ACBM

Operator platforms

- 525 mm wide
- Are the platforms retracted up for ACBM tramming?
- Do the ACBM, Continuous Miner operators stand on the platforms whilst supporting and cutting?

Control systems

- Control systems for various components
- Integration of all control systems
- Monitoring systems required

Flameproof electrical enclosure and operator console

- ID for Flameproof enclosure
- What electrical components are required to be located in the FLP enclosures?
- What will be the size of the door on the flameproof enclosure?
- Where will the operator consol be on located?

Temporary roof support

- Will the temporary roof support have one or two roof bearing plates?
- What is the size of the roof/floor bearing plates?
- What is the capacity of the temporary roof support?

Lighting

- How many lights will be required on the ACBM?
- Where will the lights be located and what are the beam directions?

Surveillance system

- How many cameras are required on the ACBM?
- Where will the cameras be located and what is their direction of view?
- How many display screens will be located on the ACBM?
- Where will the display screens be located on the ACBM?

Water spray system

- ACBM - Hopper bash plate, forward facing
- Manual or automatic operation?
- How many water sprays will be required?

Table 6-1. Current specifications of ACBM

Item	***Size***	***Location***	***Remarks***
Roof Bolt length, type, spacing	2.0/2.1 m, self drilling spacing capacity 1.0 m		To be finalised
Rib bolts length, type, spacing	1.2 –1.5 m, self drilling bolt 1 bolt per 2 m per side		May be modified
Bolting System	- 2 roof bolters - 2 rib bolters - 2 grout pumps Tank + pump size - 960 x 915 x 915 - one each side		Agreed
Plate feed	Yes, 150 mm	On side of bolter	Agreed
Bolt magazine	Yes, 3 bolt magazine		Agreed
Bolting feed			
- Bolt Storage		mid/rear section of ACBM. Position to be easily accesssed for material re-stocking.	To be modified (Boxes may be attached)
- Roof bolts	For 200 + 200 roof bolts - 950(h) x 540(w) x 2.1m		
- Rib bolts	For 100 + 100 rib bolts - 950 x 300 x 1.2m		
- Feed system	Roof bolt – vertical Rib bolt – horizontal Feed - one by one		Agreed
- Rotation unit	Hydraulic ram		Agreed
- location	650 mm from centerline 617 from trach base		
Drill bit	Design not yet decided		Required for bolt cassett design
Chemical storage box	Around 400 to 600 litres	Behind bolt box	
Cycle time for bolts autofeed system	50 sec for one bolt		Agreed
ACBM total size	L – 13. 5 m W – 3.2 m H – 2.2 m		Length to be reduced
Platform + traction	-Low profile track system (similar to Joy12CM track) -Jacks for horizon control -10 degrees max. dip		Being finalised May be reduced
Spacings	600 mm for bolters		Agreed
ACBM Entry and Exit angles	+/- 7 degrees		

Hopper	About 2.0 m3 Tilt provision - +/- 15 deg.	Front	To be finalised
ACBM Conveyor	Should be capacity of 12CM12 output – 30 tonnes/min 750 width x 400 height plus return, speed 120 m/min	Central - low set in Bolting Module, curved up at tail	To be finalised
Hydraulic sytem - Tank - Pump - Motor	To be determined for bolting requirements - 360 lt/min @ 210 Bar, feed system - 100 lt/min @ 140 Bar	Most likely under conveyor in between tracks, accessibility for motors and pumps	To be finalised
Electrical System - Main Controller - Lighting - Computer system	1100 / 440 volts, 50 Hz controls – 110 v 75kw x 2; + 30kw x 2; + 15kw x 2	Easily accessable, most likely at the rear	To be finalised - Australian standards to be followed
FLP boxes	FLP box size - ID 300(h)x600(w)x400(d)	”	FLP - to be made by contractor
Ventilation Tube	600 diametre area eqivalent	-over conveyor - next to hopper at the front	To be finalised
Operator Location - Continuous Miner - Bolting Module supervisor	525 mm wide platform	On platforms with control console either side.	Agreed
S/car Stopper		200 x 300 around back of Bolting Module 0.5 m off the floor height	Agreed
Fire Fighting Equipment		Extinguihers on Bolting Module boom	Agreed
Temporary roof support (TRS)	Two 30-40 tonne props with 400 mm bearing plate between them.	In front of roof bolting rigs	To be integrated with bash plate
Bash Plate	10-15 mm steel plate with 50x50 mesh, thin 5x5 mesh to go behind plate	Behind hopper, it has a section cut for the conveyor, 400 height	To be integrated with TRS

6.3 3D Visualisation Models

The research work carried out for the Rapid Roadway Development project in the area of 3D visualization has centered on two areas: the creation of an interactive 3D model for collaborative design work, and scoping research into simulation software for use in the next stage of the project. This section details the techniques used in the creation of the 3D model, and also presents images from the visualization. There is also a discussion of the findings of the simulation software research.

6.3.1 3D Model Development

The 3D model was first presented at the third technical meeting in Japan, and was updated with new components for the fourth technical meeting in Newcastle. The model is currently being used as a collaborative design tool, with still images and flythrough movies being presented at the meetings. The VRML delivery system allows the model to be viewed interactively on a PC, which greatly enhances its usefulness in a meeting context.

The model is essentially a block diagram at the moment, showing component placement and interactions. It is envisaged that the coarse block components will gradually be replaced with fully detailed components as the project proceeds, with a fully detailed working 3D model being a deliverable out of the 3D visualization work at the end of the project.

The model is built in a three-stage process, which starts in a CAD environment. The block diagram is currently held as a SolidWorks model, and any design or drafting changes are made in this environment. Once the design has been approved, the various components of the model are exported as separate VRML files to go into the second stage of the modeling process.

Before the next stage of the process is explained, some background on VRML may be useful. VRML is an acronym for “Virtual Reality Modeling Language” - an ISO standard for Internet-based 3D visualisation. VRML content is viewed from within a standard web browser such as Netscape Navigator or Microsoft’s Internet Explorer, and is a very flexible and efficient way of building 3D visualizations. Content can be shown from a laptop in a meeting, or served over the Internet to anywhere in the world.

VRML’s standardization has meant that it is supported by many CAD tools as an interchange format. The content from SolidWorks is imported into a suite of VRML authoring tools where further work is done to animate the moving parts. The ability to animate the moving parts in the model is one of the primary appeals of VRML; displaying the components as moving parts is particularly useful during the design process. A major part of the design review is to check the range of movements and sequences which the machine must perform, and VRML allows a collaborative design team to drive the various parts of the model through their range of movements to test their operation months before a physical prototype is constructed. Any design changes to be made are vastly cheaper when the equipment is still in electronic form.

After the animations have been added to the model, the VRML content is ready to go to the final stage of the model building process – the control applet. There are a large number of separate components in the VRML model, and it is usual to only review a subset of them at any one time. To provide the facility to turn off the components which are not being reviewed a Java Applet is used to control the VRML content inside the web browser.

Java is a platform-independent programming language originally developed by Sun Microsystems, and is now in widespread use in Internet applications. The applet used in this case is a small program that can run inside the web browser environment, and presents the user with a series of buttons which turn components on or off and also control the animations.

The applet is updated with new or refined controls to suit the new VRML components that have been added, and the model is ready to release.

6.3.2 3D Model Results

Figure 6.6 shows the current block model of the ACBM in the VRML environment. The purple gridded section under the ACBM is 5.2m wide, and is marked with gridlines at 0.5m intervals. The black wireframe represents a heading 3.6m high.

Figure 6.7 shows the ACBM after the roof support has been set and bolters extended. The movement of these parts is fully animated in the VRML model, and illustrates the bolting sequence as it would happen in operation.

A typical configuration for the ACBM is shown in Figure 6.8 – behind a continuous miner and with a shuttle car behind the ACBM. The extra arm protruding from the side of the miner is used to keep the services cables down in the corner of the roadway to avoid fouling the rib and roof bolting drilling process on the ACBM.

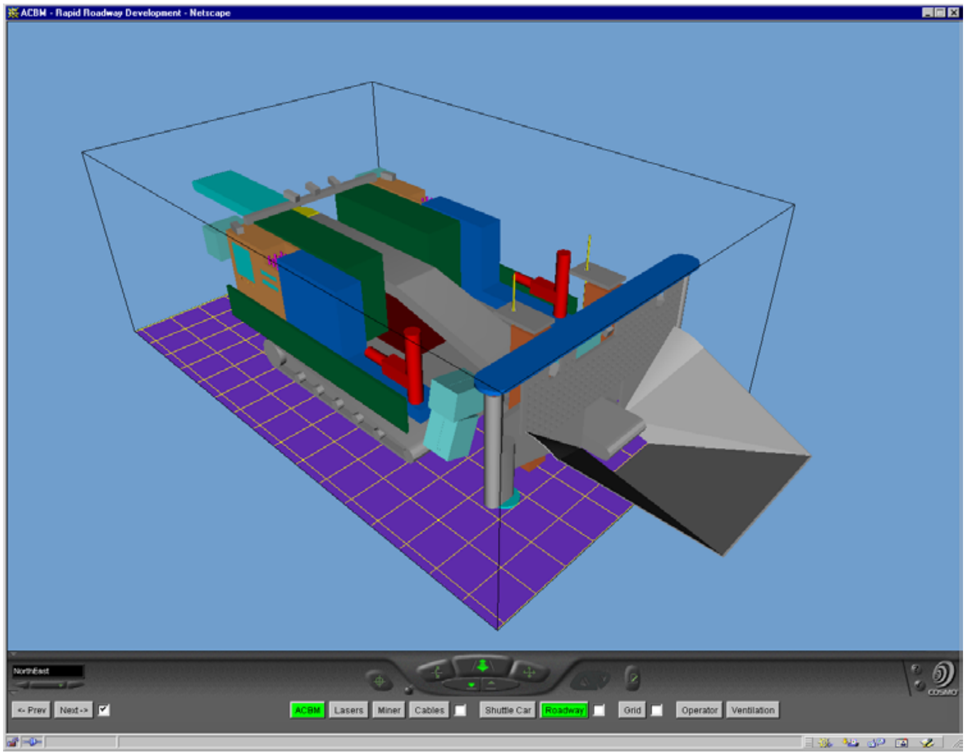


Figure 6.6. Default view showing the ACBM and the Java controls at the bottom of the image

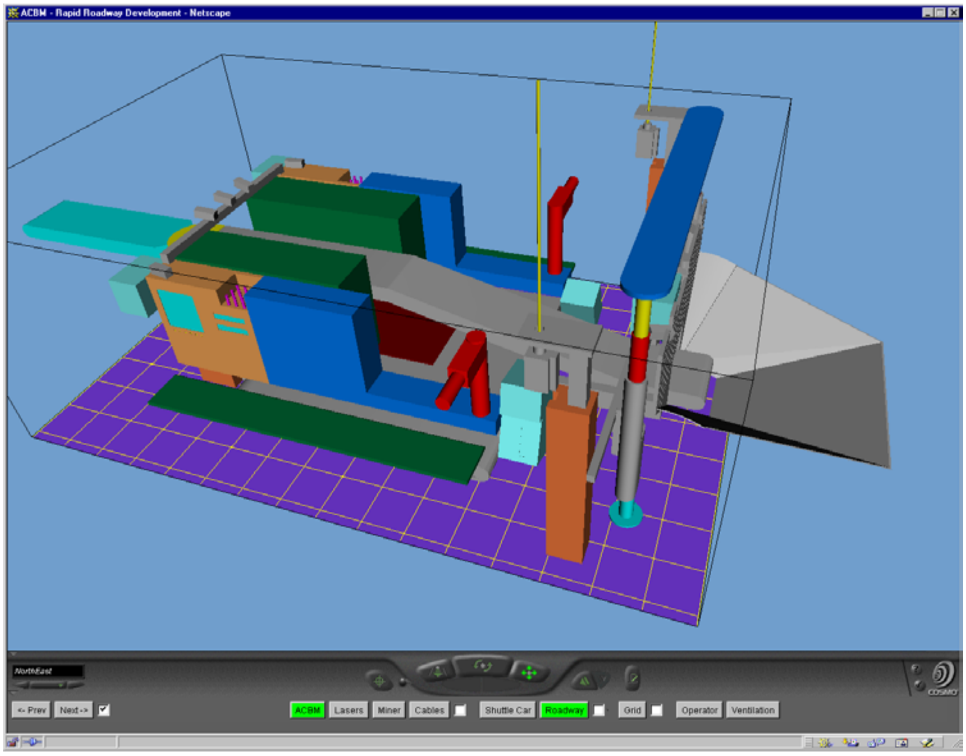


Figure 6.7. The ACBM with roof support set and bolters extended

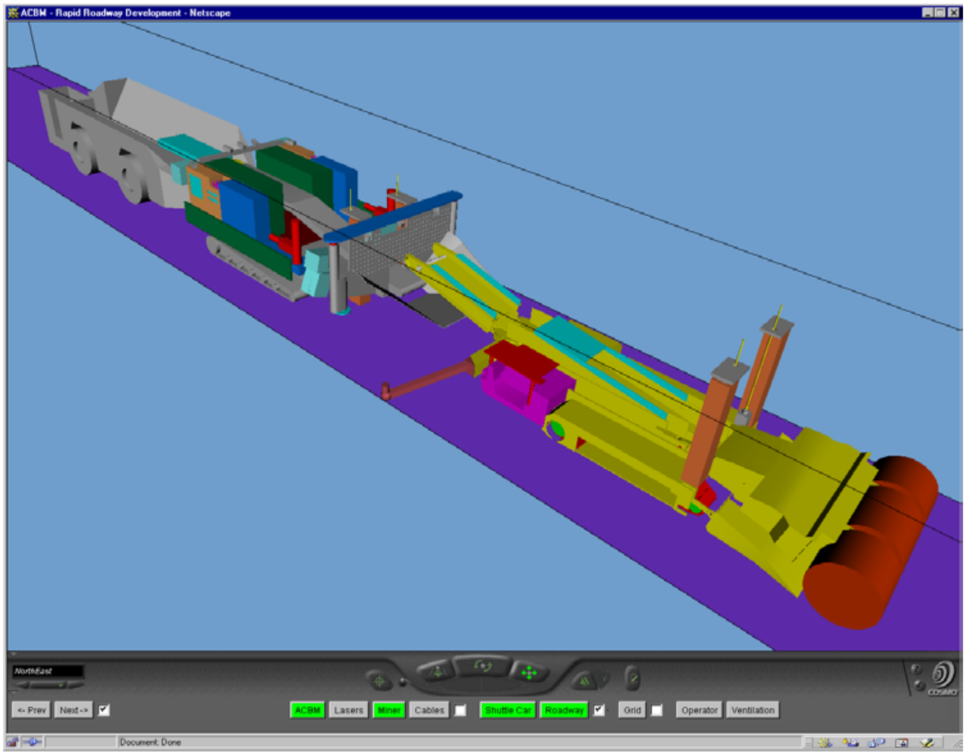


Figure 6.8. ACBM in typical configuration, with a continuous miner ahead and a shuttle car behind

These cables have provided an opportunity to test the interaction between the components in the system using the 3D model. The model update produced for the last technical meeting allows clearance between services cables passing by the ACBM to the continuous miner and the rib bolts being driven by the ACBM to be checked.

Figure 6.9 shows the clearances between the cables using two different configurations of strata strapping. The position of the miner has been animated, and the cables extend realistically as the miner moves forward. Careful scrutiny of the model around the cables and the rib bolters shows that both configurations will allow the cables to pass without interfering with the rib bolts, but that the configuration where the cables attach near the rear of the ACBM allows for a wider range of rib movements for the bolt to work into.

The proposed ventilation arrangement is shown in Figure 6.10. This arrangement has been refined over several iterations. The first design brought the ducting over the head of the operators in the corner of the roadway, but the 3D model showed that the duct would interfere with a typical 180cm miner standing on the platform. The current bifurcated duct arrangement was decided on from a number of other alternatives.

Figure 6.11 shows a typical position for the operator. It is envisaged that further development work will be undertaken to test visibility for the operator from this position, and to perhaps perform ergonomic testing of the control layout once the design is further refined.

Figure 6.12 shows the sweep patterns for the laser range scanners attached to the ACBM. These scanners can sense the profile of the heading, and their scanning information is provided back to the control system in the ACBM to assist in determining the bolting pattern to use.

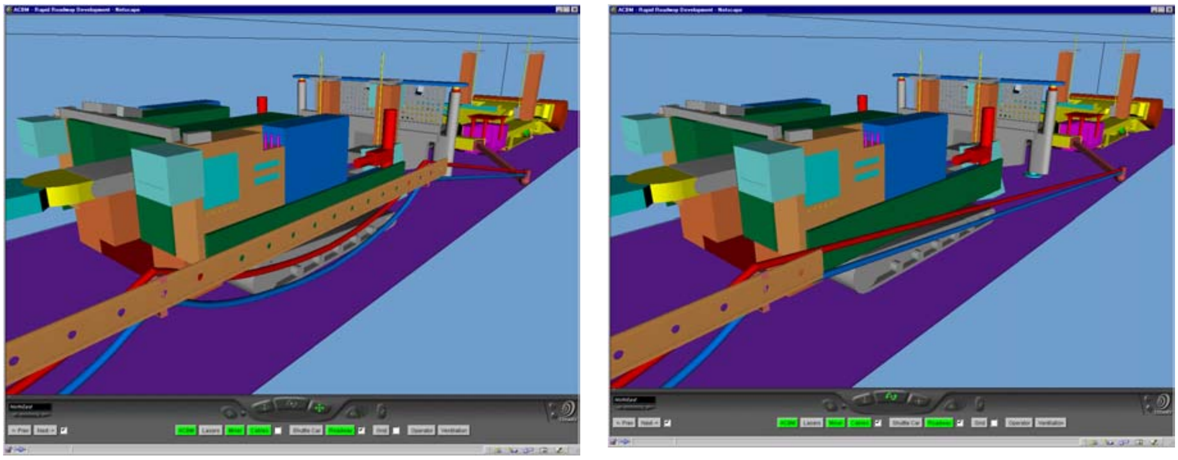


Figure 6.9. Two options for continuous miner services cables

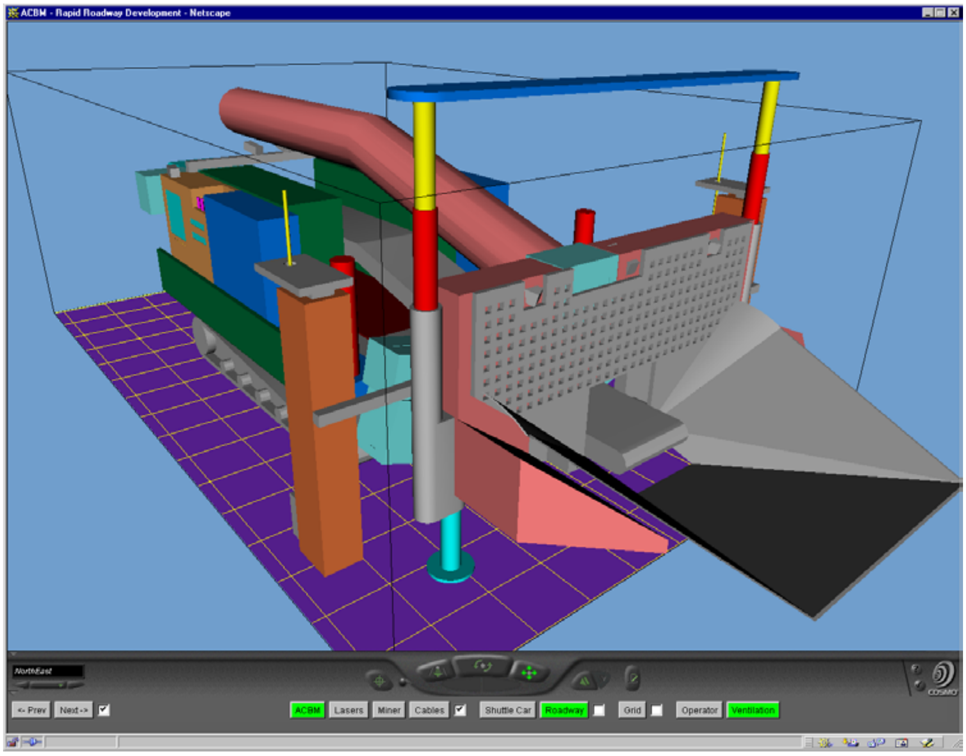


Figure 6.10. Proposed ventilation arrangement

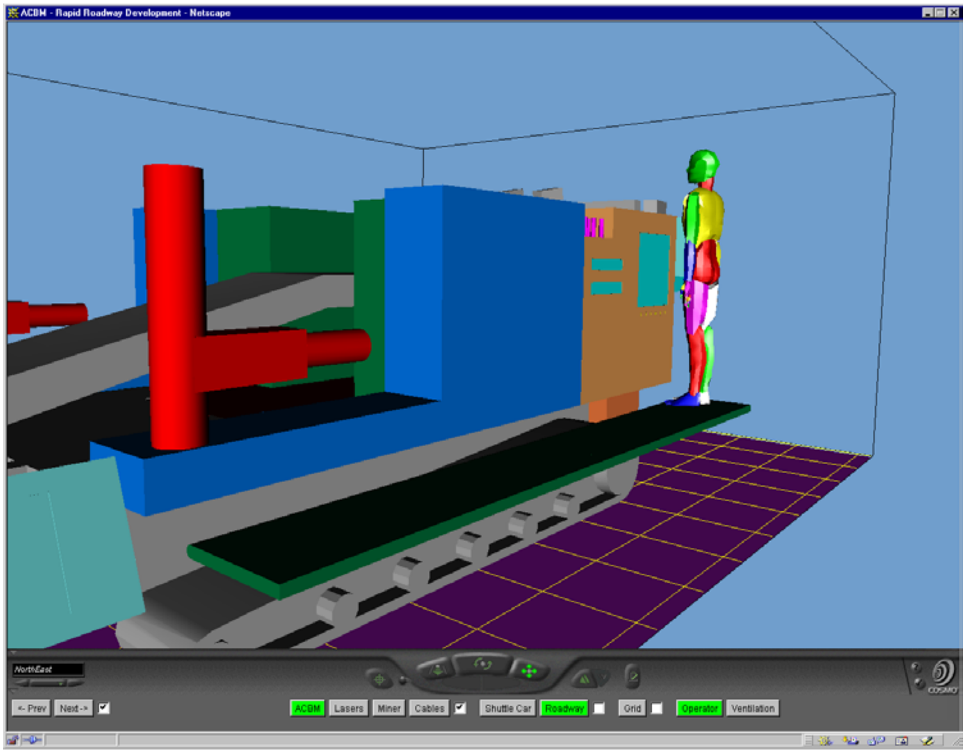


Figure 6.11. Operator position

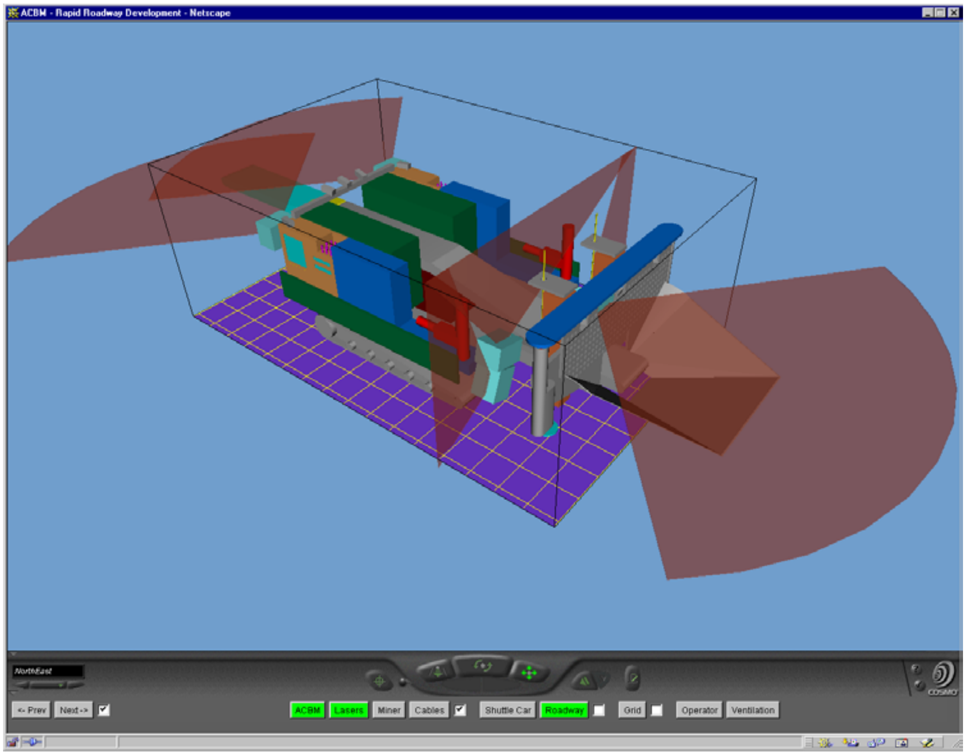


Figure 6.12. Red “fans” showing laser range scanning of heading profile

6.3.3 Simulation Software

The use of simulation software in the mining industry is well established for scheduling of equipment, but the Rapid Roadway project allows the chance to push mining equipment design in a new direction by simulating the actual operation of the machine in its environment.

It is important to discriminate between the terms *process* simulation and *equipment* simulation. These terms are frequently used interchangeably in mining simulation, but the Rapid Roadway project treats them as two distinct areas. Process simulation is the prediction of the efficiency of a mining process by using discrete event simulation. Discrete event simulation packages used for process simulation accept inputs such as vehicle speed, load carrying capacity and a set of arbitration rules for controlling the process. Discrete event simulations can accurately predict the throughput of a process based on these types of inputs.

Equipment simulation, on the other hand, is the physical simulation of complex mechanisms in equipment designs, and has its closest links to CAD systems. Equipment simulation will be able to predict, for example, what radius a continuous miner will be able to cut corners based on the physical design of the machine. Software packages for equipment simulation will commonly also allow testing for collisions between different parts of the model to be tested.

Process Simulation Software

Although discrete event simulation software has been around for at least thirty years, it is only in the last couple of years that visual output from these systems has become commonly available. There are perhaps a dozen discrete event simulations packages in widespread use, but only two or three of them can produce visual output directly. These packages have been researched further.

The two packages suggested as being suitable are AutoMOD by AutoSimulations and QUEST by Deneb. Both packages allow highly complex processes to be simulated and visually represented. Of the two, AutoMOD has a longer history, a more attractive licensing agreement and a better price. The next step with both packages is to request a trial to test their applicability to this project.

Equipment Simulation Software

This area is fairly sparse in terms of commodity-priced simulation packages. There are a number of very expensive proprietary systems – the ADAMS package for example – but very few which could be considered affordable. In fact, the only affordable mechanical simulation package found is Working Model from MSc Software. Its pricing of around $5k makes it reasonable to consider, and it is quite powerful in terms of being able to simulate complex mechanisms and linkages. It is less capable in being able to test the interaction equipment within an environment, so the research has widened its scope a little.

There are a number of computer animation packages that offer tools that could be adapted for use in equipment simulation. Their results of their adaptation would not produce numerical results for forces on components, but they will certainly provide excellent visualizations of the equipment in operation and have much better tools for testing for machine-to-machine collisions. Use of packages such as 3D Studio Max from Kinetix or Maya from Alias|Wavefront is becoming increasingly common in equipment design.

These simulation tools offer compelling benefits for promoting the performance and operation of new equipment such as the ACBM to a marketplace already crowded with mining equipment. If the ACBM can be released with a comprehensive process and equipment simulation study proving its efficiency over other roadway development methods, its acceptance as a worthy alternative must surely be easier to achieve.

It is expected that the Rapid Roadway project's progress during the next twelve months will help to guide the directions in which further process and equipment simulation will be taken.

6.4 Panel Layouts and Mining Cycle

The Rapid Roadway Development system of mining is designed to increase gateroad development rates to ensure longwall continuity, and hence maintain a reliable supply of coal to consumers. The mine panel layout adopted to calculate the mining sequence cycle time is a conventional longwall two heading gateroad development panel, with the parallel headings at 40 metres apart. The two scenarios presented for analysis in this report include pillar lengths of 50 and 100 metres respectively (Figure 6.13).

The Rapid Roadway Development mining system incorporates the use of a conventional continuous miner cutting machine and two shuttle cars along with the developed Bolting Module. The configuration of the equipment will consist of the Continuous Miner at the advancing cutting face, behind which the Bolting Module will operate to support the newly exposed roof whilst loading the shuttle cars via the coal clearance conveyor unit situated through the centre of the Bolting Module. The effect of the Bolting Module on mining cycle time to complete 100-metre gateroad panel advancement, with pillar layouts outlined above, is calculated. Results of the mining cycle sensitivity analysis carried out to quantify the effect of various parameters are presented in section 5.4.1. Details of the calculations and various sequences are given in the CSIRO internal report. Mining systems and sequences for a 100-metre pillar are reported in section 5.4.2. Proposed ventilation configuration during various mining sequences is shown in the section 5.4.3.

Mining Layout and Cycle Assumptions

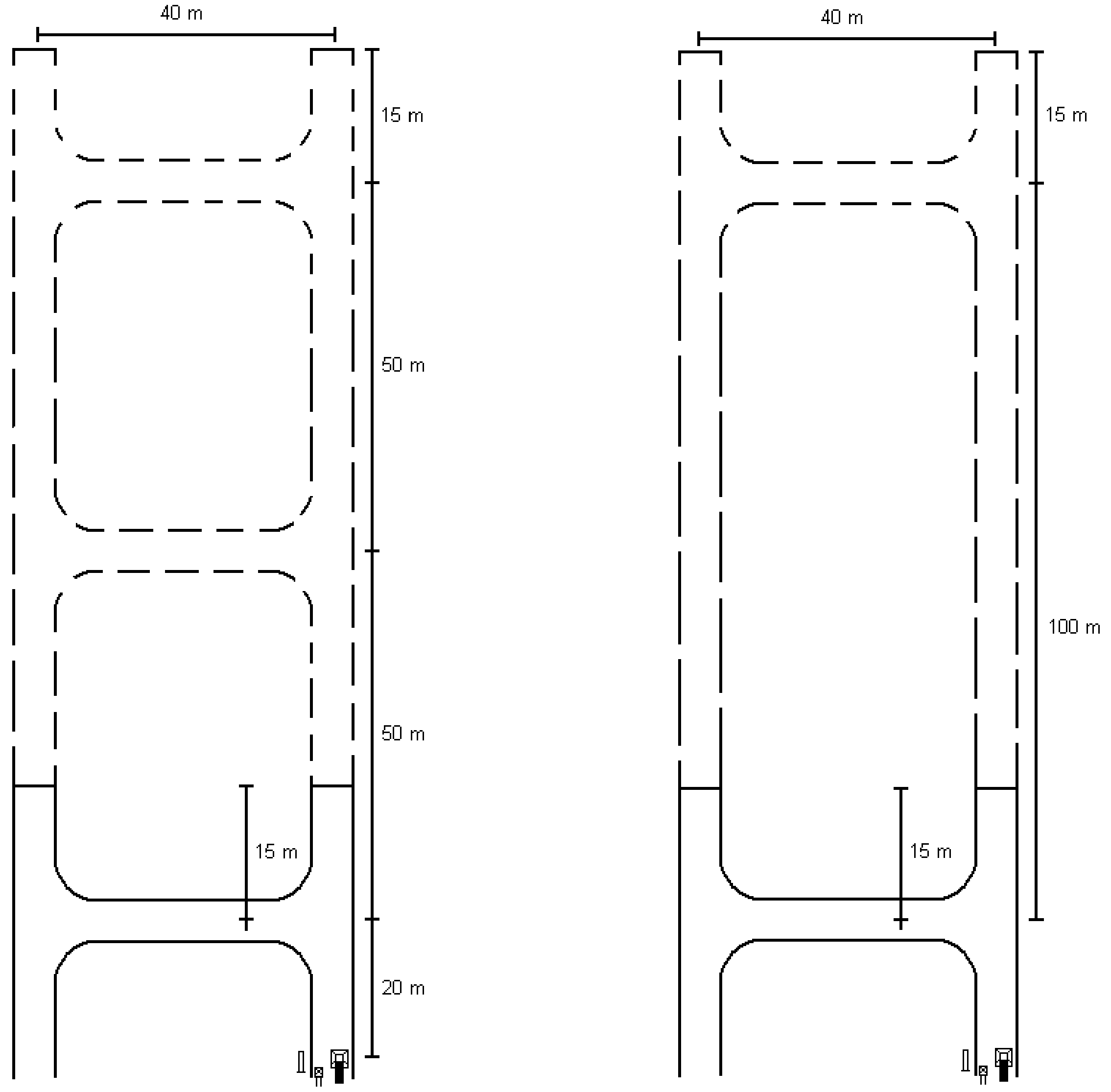
Item	**Assumptions**
Specific Gravity of Coal	1.4
Number of bolts per 1.0 metre advance	4
Support installation time	4 mins
Shuttle car speed	1.8 m/sec (variable)
Time lost on every intersection (SC operation)	5 sec
Shuttle car capacity	11.5 tonnes
Distance of cut-through to boot end	15 metres (variable)
Radius of curvature at break-away	7.0 metres
Total production time in a shift (uptime)	5.2 hours (variable)
(Based on 12CM3 + 2 Shuttle cars)	
Unloading Rate of S/C, incl. Docking	80 sec (variable)
S/C filling time	120sec (variable)

Pillar and Heading Dimensions to consider

1. Pillar size – 50m pillar length @ 40 metre centres
2. Pillar size – 100m pillar length @ 40 metre centres

Heading Dimension (metres)

5.5 x 2.5 - 19.25
5.5 x 3.0 - 23.1 Base Case
5.5 x 3.5 - 26.95
5.0 x 2.5 – 17.5
5.0 x 3.0 – 21.0
5.0 x 3.5 - 24.5



50 x 40 m pillar

(b) 100 x 40 m pillar

Figure 6.13. Typical layouts considered for cycle time analysis

6.4.1 Mining Cycle Sensitivity Analysis

Table 6-2. Effect of Up-Time on the 100m panel cycle and 2km Gateroad panel completion – 2x50-metre Pillar

Variable		**Hours**	**Days**	**Weeks**
% Shift (8)	**Up time (hrs)**	**2x50-metre Pillar**	**2 km (50) Gateroad**	
		49.6	61.3	12.3
50%	4	61.6	71.4	14.3
55%	4.4	56.9	67.4	13.5
60%	4.8	52.9	64.1	12.8
65%	5.2	49.6	61.3	12.3
70%	5.6	46.7	58.9	11.8
75%	6	44.3	56.9	11.4
80%	6.4	42.1	55.1	11.0
85%	6.8	40.2	53.5	10.7
90%	7.2	38.5	52.1	10.4
95%	7.6	36.9	50.8	10.2
100%	8	35.6	49.6	9.9

Table 6-3. Development Rates metres/sequence hour – 2x50-metre Pillar

Up time	Up time (hrs)	Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	Sequence 6	Sequence 7	Sequence 8
		7.5	7.4	7.5	8.4	7.5	6.2	6.6	5.9
50%	4	5.8	5.7	5.7	6.4	5.8	4.7	5.1	4.6
55%	4.4	6.3	6.2	6.3	7.1	6.4	5.2	5.6	5.0
60%	4.8	6.9	6.8	6.9	7.7	6.9	5.7	6.1	5.5
65%	5.2	7.5	7.4	7.5	8.4	7.5	6.2	6.6	5.9
70%	5.6	8.1	7.9	8.0	9.0	8.1	6.6	7.1	6.4
75%	6	8.6	8.5	8.6	9.6	8.7	7.1	7.6	6.9
80%	6.4	9.2	9.1	9.2	10.3	9.2	7.6	8.1	7.3
85%	6.8	9.8	9.6	9.8	10.9	9.8	8.1	8.6	7.8
90%	7.2	10.4	10.2	10.3	11.6	10.4	8.5	9.1	8.2
95%	7.6	11.0	10.8	10.9	12.2	11.0	9.0	9.6	8.7
100%	8	11.5	11.3	11.5	12.9	11.6	9.5	10.1	9.1

Table 6-4. Effect of Up-Time on the 100m panel cycle and 2km Gateroad panel completion – 100-metre Pillar

Variable		**Hours**	**Days**	**Weeks**
% Shift (8)	**Up time (hrs)**	**100-metre Pillar**	**2 km (100) Gateroad**	(5 Day)
		44.2	58.5	11.7
50%	4	55.5	67.9	13.6
55%	4.4	51.1	64.2	12.8
60%	4.8	47.3	61.1	12.2
65%	5.2	44.2	58.5	11.7
70%	5.6	41.5	56.3	11.3
75%	6	39.2	54.3	10.9
80%	6.4	37.1	52.6	10.5
85%	6.8	35.3	51.1	10.2
90%	7.2	33.7	49.8	10.0
95%	7.6	32.3	48.6	9.7
100%	8	31.0	47.5	9.5

Table 6-5. Development Rates metres/sequence hour – 2x50-metre Pillar

Up time	Up time (hrs)	Sequence 1	Sequence 2	Sequence 3	Sequence 4
		6.4	5.1	7.1	5.0
50%	4	4.9	3.9	5.4	3.8
55%	4.4	5.4	4.3	6.0	4.2
60%	4.8	5.9	4.7	6.5	4.6
65%	5.2	6.4	5.1	7.1	5.0
70%	5.6	6.9	5.5	7.6	5.3
75%	6	7.4	5.9	8.2	5.7
80%	6.4	7.9	6.3	8.7	6.1
85%	6.8	8.4	6.7	9.3	6.5
90%	7.2	8.9	7.1	9.8	6.9
95%	7.6	9.4	7.5	10.4	7.2
100%	8	9.9	7.8	10.9	7.6

Table 6-6. Effect of Extended Panel/Gateroad Service Extension

Variable				
Gateroad - work	**Days**		**Days**	
Uptime (hrs)	**2 km (50) Gateroad**	**Weeks**	**2 km (100) Gateroad**	**Weeks**
5.2	61.3	12.3	58.5	11.7
12	61.3	12.3	58.5	11.7
14	64.7	12.9	61.8	12.4
16	68.0	13.6	65.2	13.0
18	71.3	14.3	68.5	13.7
20	74.7	14.9	71.8	14.4
22	78.0	15.6	75.2	15.0
24	81.3	16.3	78.5	15.7

Panel layout analysis summary

- The tramming and reduction in shuttle car waiting time advantages of the 50-metre pillar layout are absorbed by the need change and re-figure the panel services to start the next mining sequence on two occasions as opposed to one with the 100-metre pillar layout.

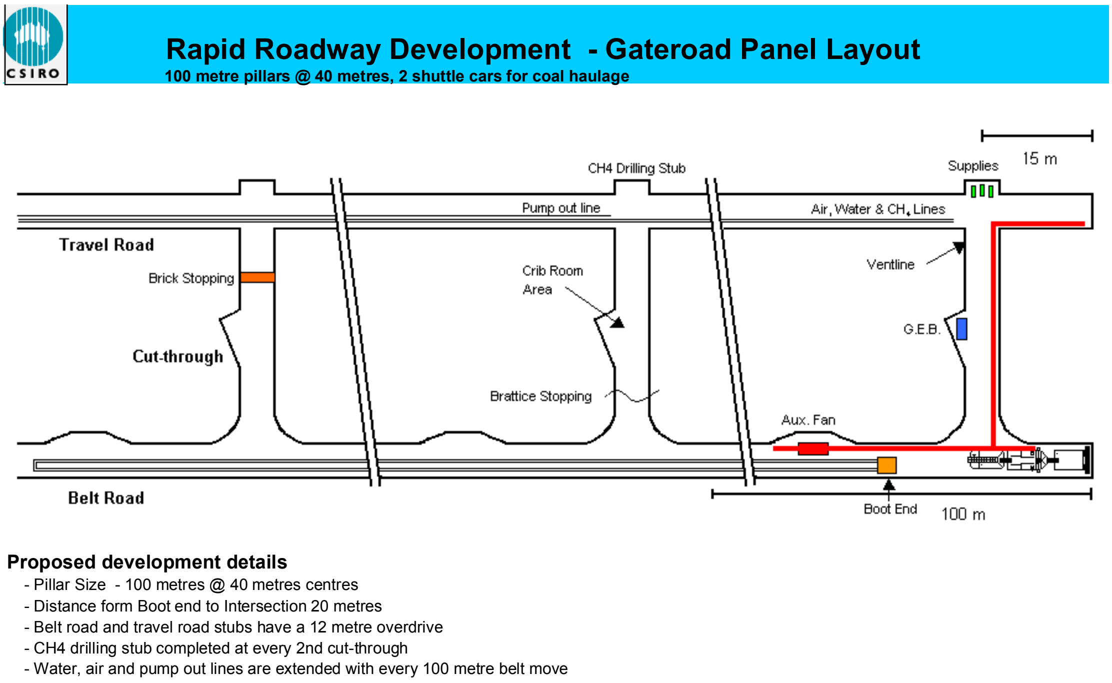
- There is a considerable lead-time advantage gained with the opportunity of starting panel preparation for the next service/belt extension in the 100-metre pillar over the 50-metre pillar design after completion of supporting sequence 2 of the 100-metre pillar layout.

- The 100-metre pillar panel layout seems to be the better configuration for this Rapid Roadway Development system.

6.4.2 Mining Systems and Sequences

The system has been designed to accept a number of combinations of cutting units in front and haulage units behind. In particular the arrangement is well suited to a TBM as a mining unit and continuous haulage. The base case of a shuttle car is designed to keep project focus (and funds) on the ACBM and the overall system. Previous projects that have tried to provide a complete system have had issues with the extensive engineering scope that diluted the focus on the new part of the technology. In this project, we have tried to keep the systems issues and the new technology in focus without unnecessary effort on mining or haulage options.

The independence of the ACBM to the mining machine in terms of power and control allows a large amount of flexibility in its operation. The remote for the miner can be separated from the ACBM control station and used independently. This allows the ACBM to be used either in series with the miner or independently as a place changer-bolting unit, thus allowing break-offs and stubs to be adequately supported (Figure 6.14 to Figure 6.22). It also allows a reversion to a short cutout place changer unit operations if ground conditions dictate. Predicted mining rates for the standard 100m sequence are 9.1m/hr per 100 metre pillar. Mining rates for 200 metre pillars with continuous haulage increase to 9.3m/hr per 200 metre pillar.



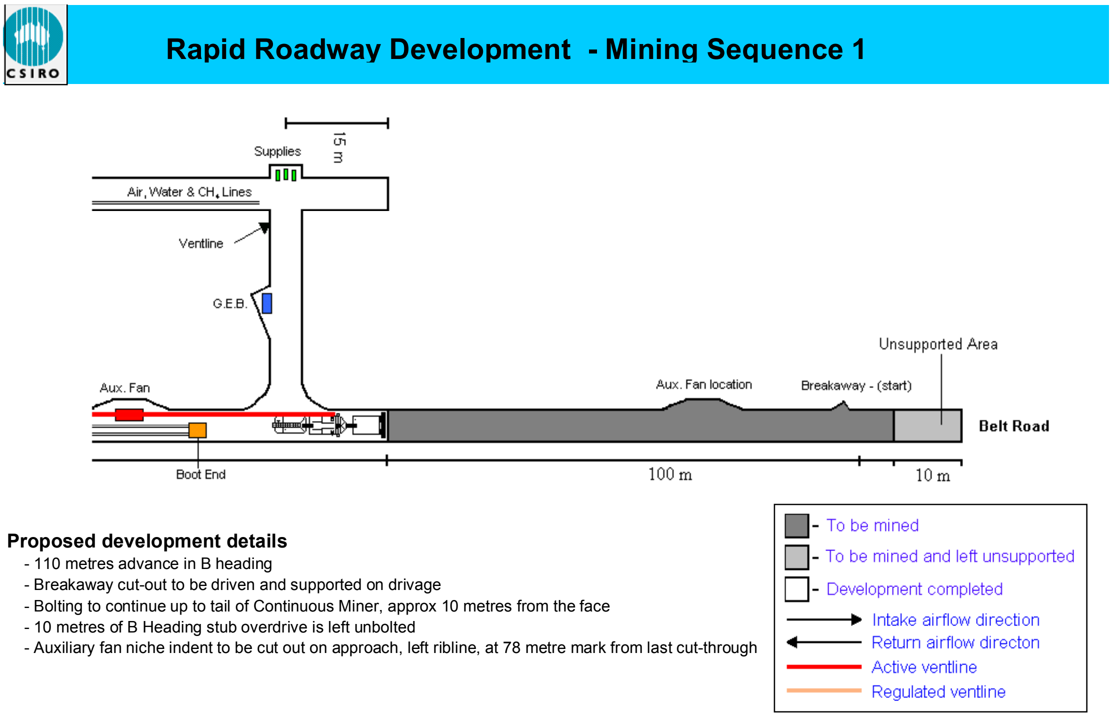
Rapid Roadway Development - Gateroad Panel Layout

100 metre pillars @ 40 metres, 2 shuttle cars for coal haulage

Proposed development details

- Pillar Size - 100 metres @ 40 metres centres
- Distance form Boot end to Intersection 20 metres
- Belt road and travel road stubs have a 12 metre overdrive
- CH4 drilling stub completed at every 2nd cut-through
- Water, air and pump out lines are extended with every 100 metre belt move

Figure 6.14. Gateroad Panel Layout (2 shuttle cars for coal haulage)



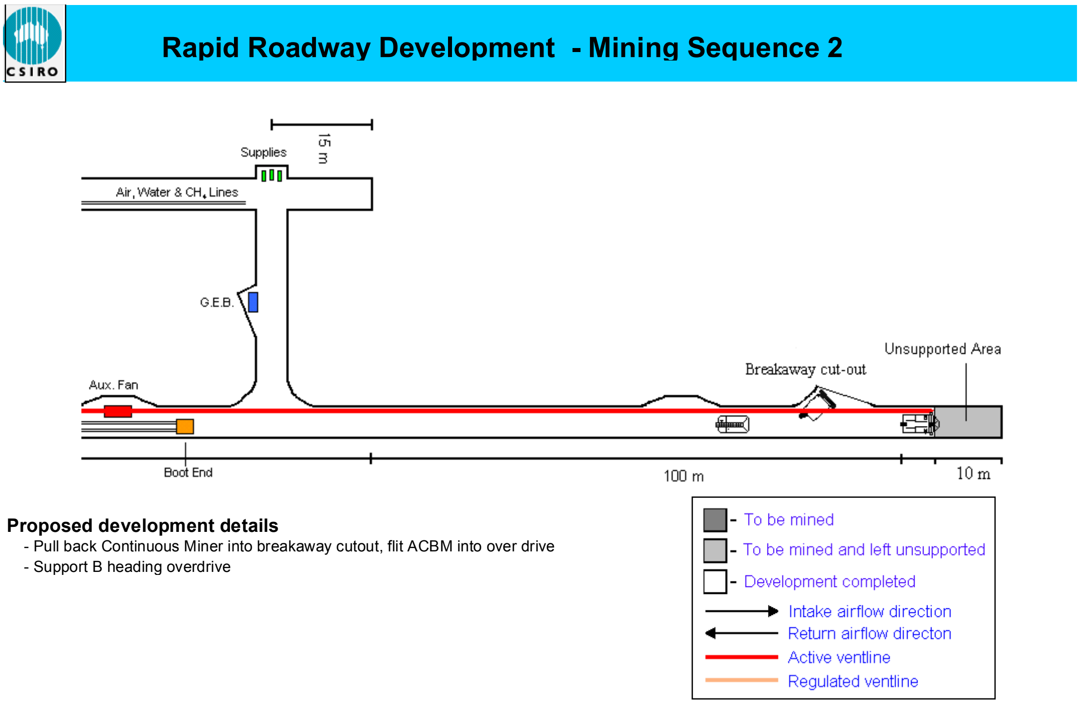
Rapid Roadway Development - Mining Sequence 1

Proposed development details

- 110 metres advance in B heading
- Breakaway cut-out to be driven and supported on drivage
- Bolting to continue up to tail of Continuous Miner, approx 10 metres from the face
- 10 metres of B Heading stub overdrive is left unbolted
- Auxiliary fan niche indent to be cut out on approach, left ribline, at 78 metre mark from last cut-through

■ - To be mined
▨ - To be mined and left unsupported
☐ - Development completed
→ Intake airflow direction
← Return airflow directon
━ Active ventline
━ Regulated ventline

Figure 6.15. Mining Sequence 1

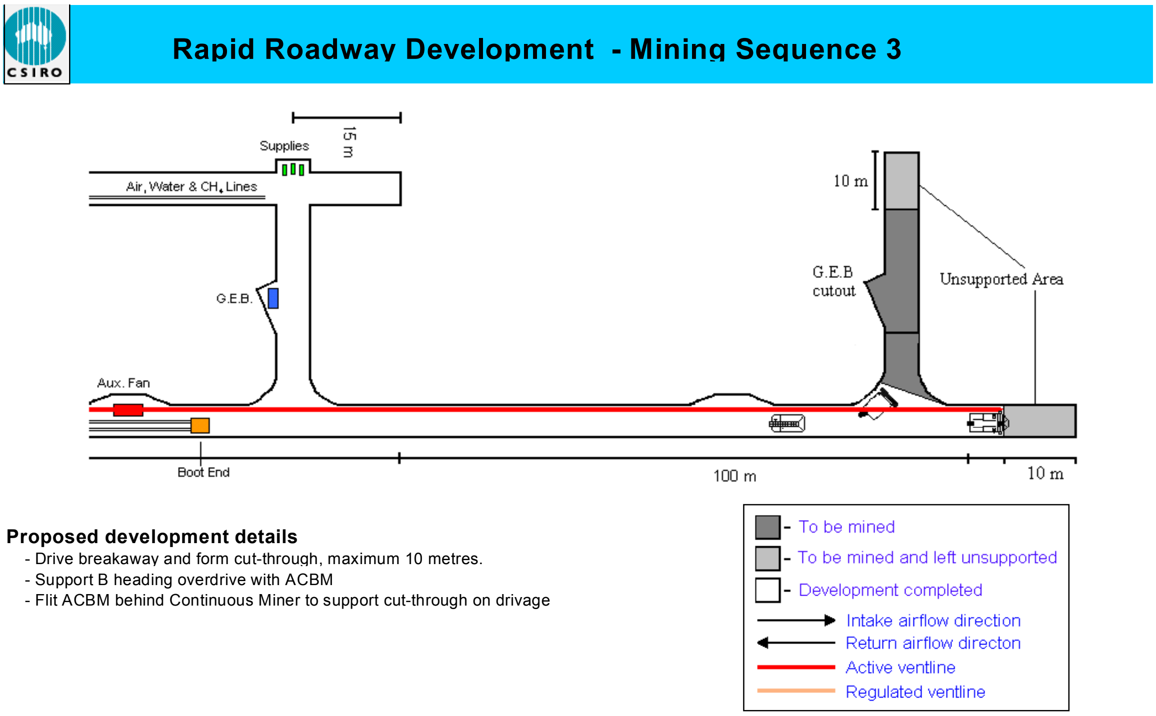


Rapid Roadway Development - Mining Sequence 2

Proposed development details

- Pull back Continuous Miner into breakaway cutout, flit ACBM into over drive
- Support B heading overdrive

Figure 6.16. Mining sequence 2

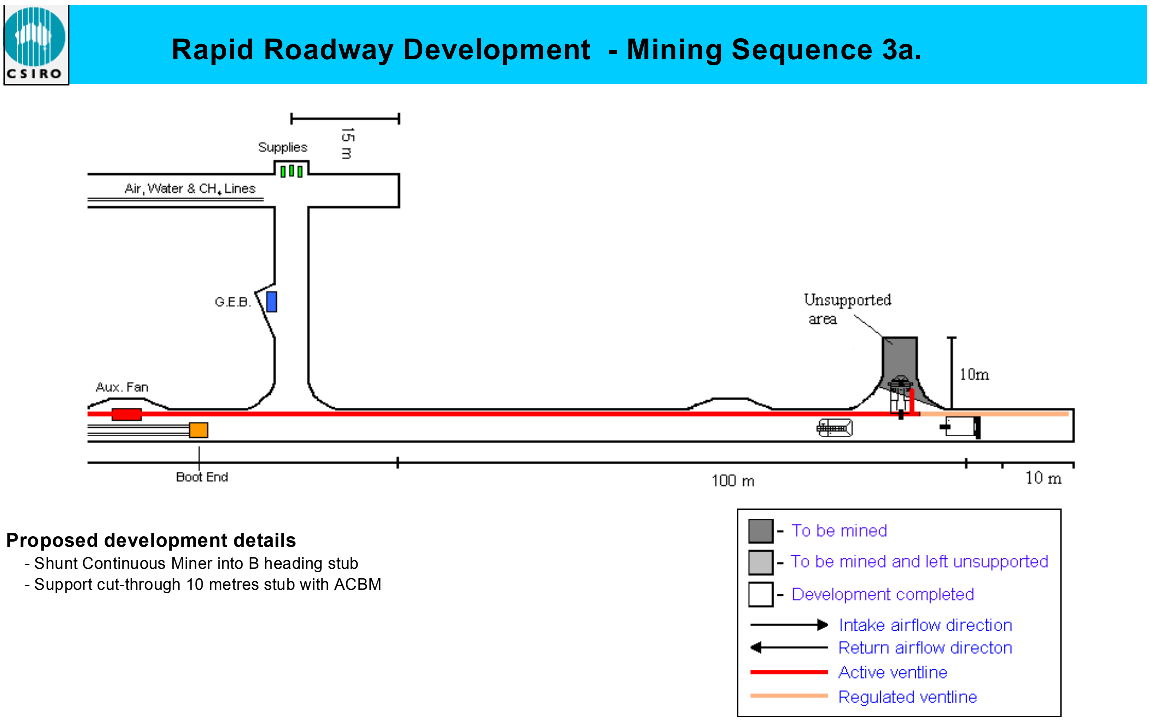


Rapid Roadway Development - Mining Sequence 3

Proposed development details

- Drive breakaway and form cut-through, maximum 10 metres.
- Support B heading overdrive with ACBM
- Flit ACBM behind Continuous Miner to support cut-through on drivage

Figure 6.17. Mining sequence 3



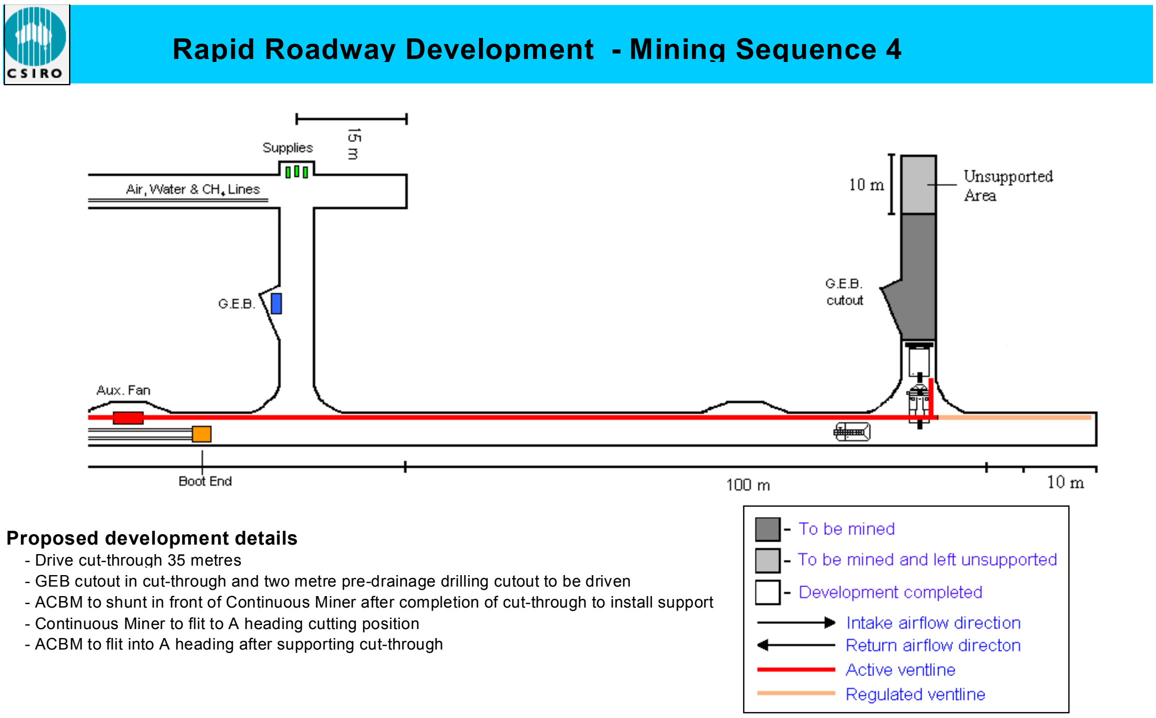
Rapid Roadway Development - Mining Sequence 3a.

Proposed development details

- Shunt Continuous Miner into B heading stub
- Support cut-through 10 metres stub with ACBM

■ - To be mined
▒ - To be mined and left unsupported
□ - Development completed
→ Intake airflow direction
← Return airflow directon
— Active ventline
— Regulated ventline

Figure 6.18. Mining sequence 3a



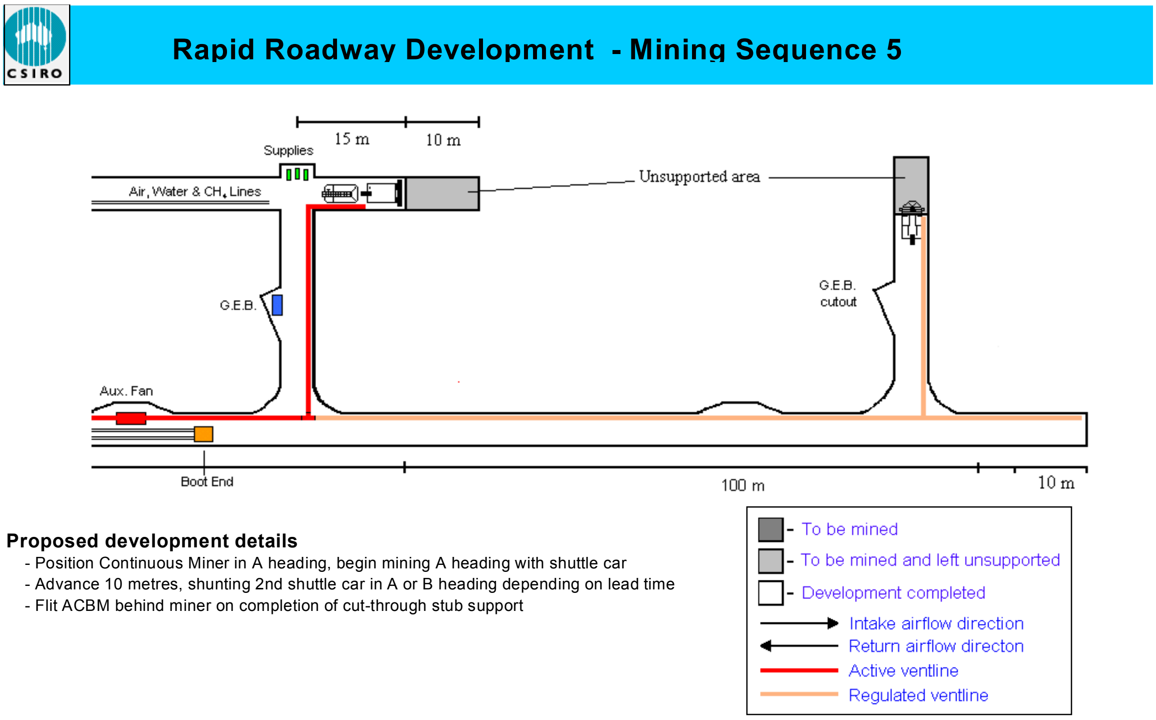
Rapid Roadway Development - Mining Sequence 4

Proposed development details

- Drive cut-through 35 metres
- GEB cutout in cut-through and two metre pre-drainage drilling cutout to be driven
- ACBM to shunt in front of Continuous Miner after completion of cut-through to install support
- Continuous Miner to flit to A heading cutting position
- ACBM to flit into A heading after supporting cut-through

■ - To be mined
▒ - To be mined and left unsupported
□ - Development completed
→ Intake airflow direction
← Return airflow directon
— Active ventline
— Regulated ventline

Figure 6.19. Mining sequence 4



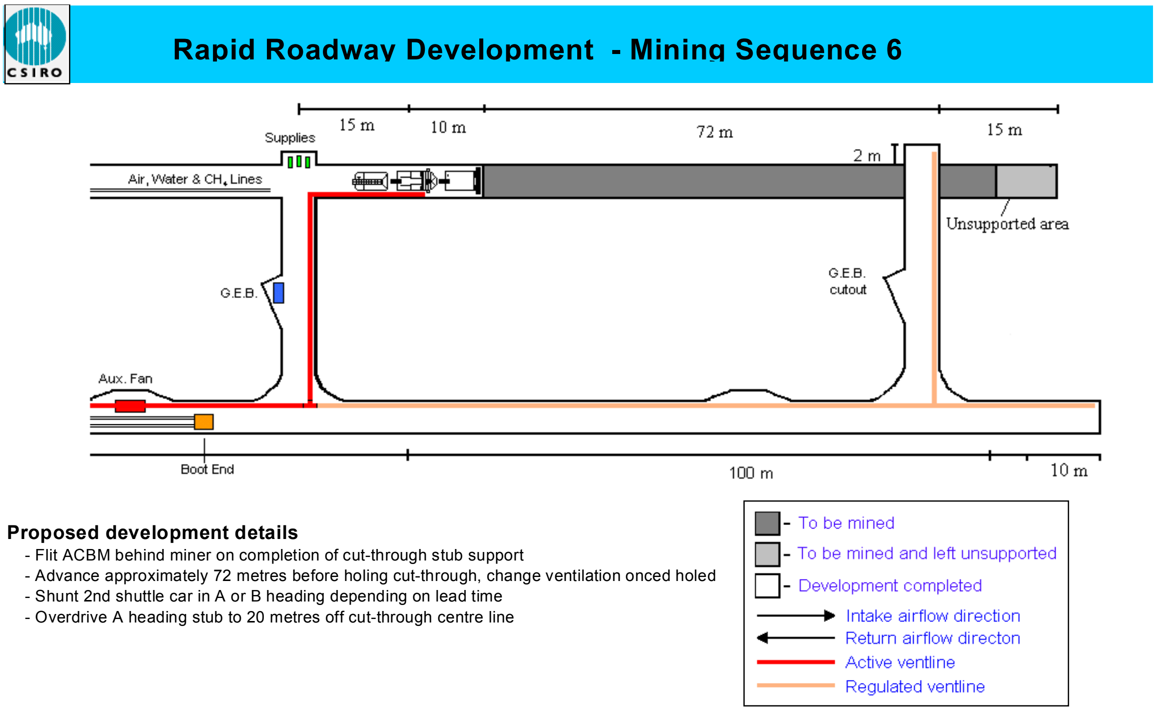
Rapid Roadway Development - Mining Sequence 5

Proposed development details

- Position Continuous Miner in A heading, begin mining A heading with shuttle car
- Advance 10 metres, shunting 2nd shuttle car in A or B heading depending on lead time
- Flit ACBM behind miner on completion of cut-through stub support

▨ - To be mined
▨ - To be mined and left unsupported
☐ - Development completed
→ Intake airflow direction
← Return airflow directon
— Active ventline
— Regulated ventline

Figure 6.20. Mining sequence 5



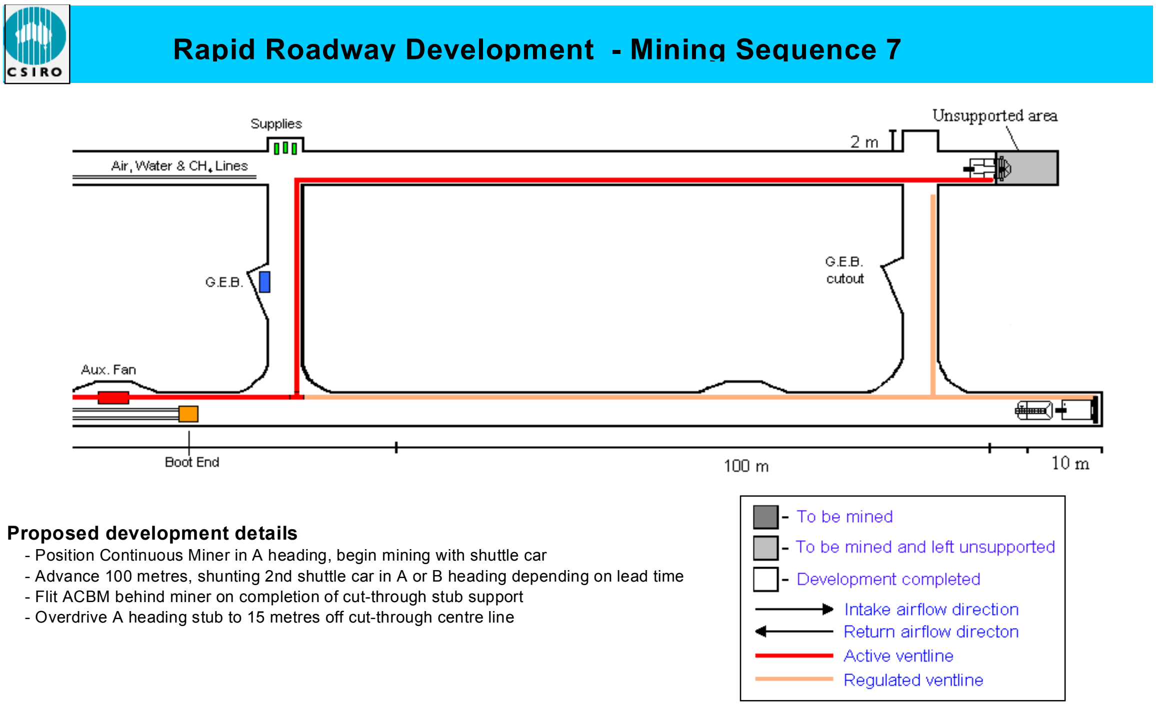
Rapid Roadway Development - Mining Sequence 6

Proposed development details

- Flit ACBM behind miner on completion of cut-through stub support
- Advance approximately 72 metres before holing cut-through, change ventilation onced holed
- Shunt 2nd shuttle car in A or B heading depending on lead time
- Overdrive A heading stub to 20 metres off cut-through centre line

▨ - To be mined
▨ - To be mined and left unsupported
☐ - Development completed
→ Intake airflow direction
← Return airflow directon
— Active ventline
— Regulated ventline

Figure 6.21. Mining sequence 6



Rapid Roadway Development - Mining Sequence 7

Proposed development details

- Position Continuous Miner in A heading, begin mining with shuttle car
- Advance 100 metres, shunting 2nd shuttle car in A or B heading depending on lead time
- Flit ACBM behind miner on completion of cut-through stub support
- Overdrive A heading stub to 15 metres off cut-through centre line

■ - To be mined
▨ - To be mined and left unsupported
☐ - Development completed
→ Intake airflow direction
← Return airflow directon
━ Active ventline
━ Regulated ventline

Figure 6.22. Mining sequence 7

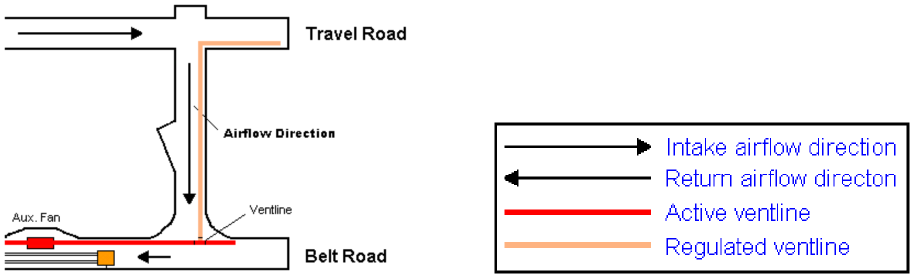
6.4.3 Panel Layout Ventilation Configurations

Panel Sequence

(a) Finish belt move

Ventilation Requirements

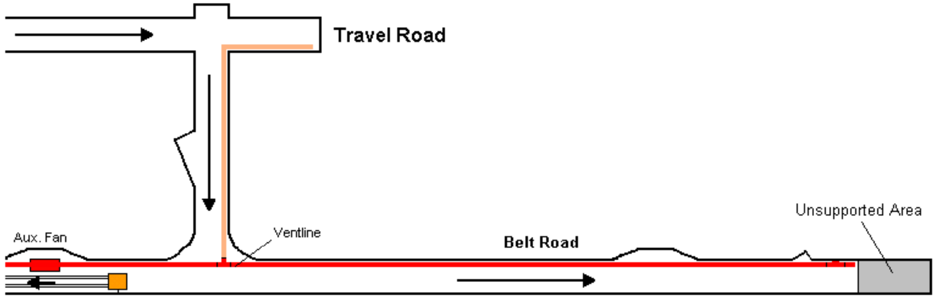
- Set up Fan in cut out niche
- Connect ventline for mining



(b) Mining sequence 1

- Mine belt road

- Extend ventline on development
- Install T-piece @ cut-through

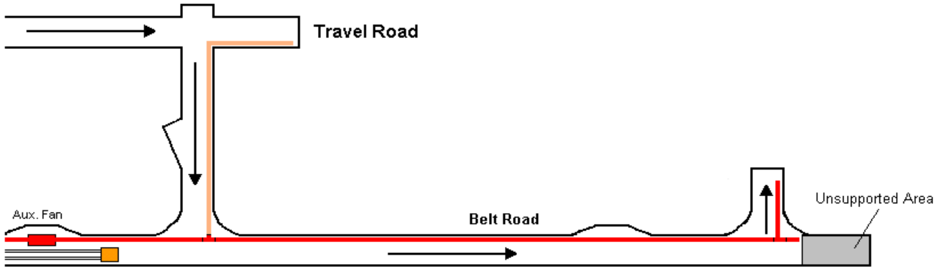


- Set up venturi blowers at stub

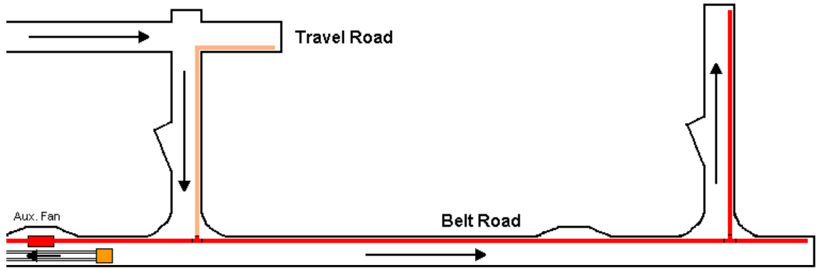
(c) Mining sequence 2 & 3

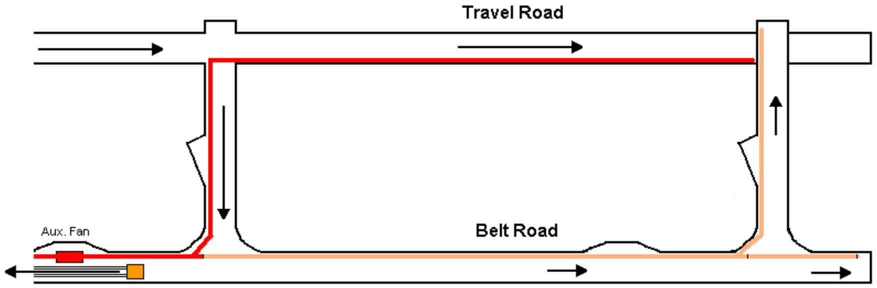
- Drive breakaway and form cut-through, 10 metres

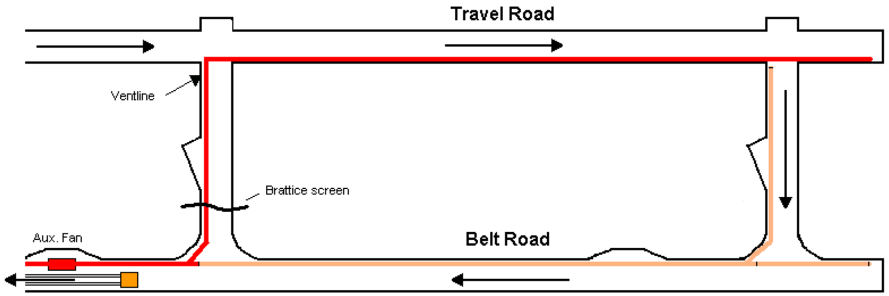
Extend ventline on development



Panel Sequence	**Ventilation requirements**
(d) Mining Sequence 4 - Cut-through development	- Extend ventline on development
(e) Mining Sequence 5-1. to cut-through	- Extend ventline on development - Regulate airflow in inactive
(f) Mining Sequence 5-2 - Hole through cut-through - Continue mining travel road	- Erect brattice screen in cut-through outbye the face







6.5 Services

6.5.1 Ventilation Options

Data obtained from Australian mine survey was used to finalise the ventilation option for Rapid Roadway Development system. Results of the mine survey with respect to ventilation are as follows:

- Airflow requirement 6 to 10 m^3/s
- Gas is an issue for 40-50% of the mines
- Most of the existing mines in Australia use exhaust system
- Ducting within 6 m from the face
- In place changing – ducting 6 to 18 m from the face
- Scrubbers used in most of the new mines

The ventilation options considered for this RRD system are

- No ducting on ACBM – with Exhaust system and its variations
- No ducting on ACBM – with Forcing system and its variations
- Ducting on ACBM – Exhaust system and its variations

The schematic layouts (Figure 6.23 to Figure 6.25) and issues involved with various options are presented below. Comparison of various alternatives is summarised in Table 6-7.

(a) No Ducting on ACBM with Exhaust System

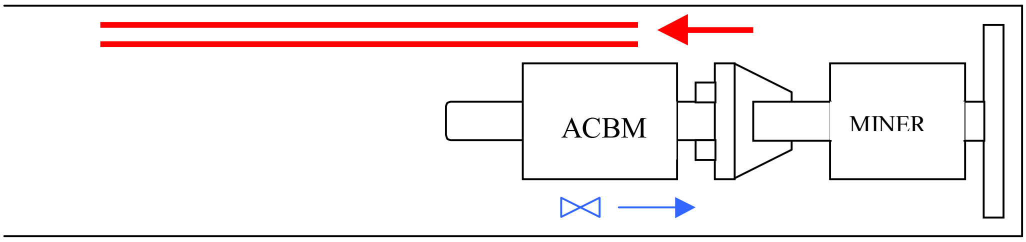


Figure 6.23. Ventilation schematic showing simple exhaust with no ducting on ACBM

Advantages

- Simple exhaust system
- No ducting work on ACBM
- May be OK in non-gassy mines (can be supplemented with venturis)

Disadvantages

- Duct 10 – 15 m away from the face
- Not suitable for gassy mines
- Duct may be an obstruction to ACBM operators
- Duct extension difficult – possible only out-bye of ACBM

(b) No ducting on ACBM with Forcing system

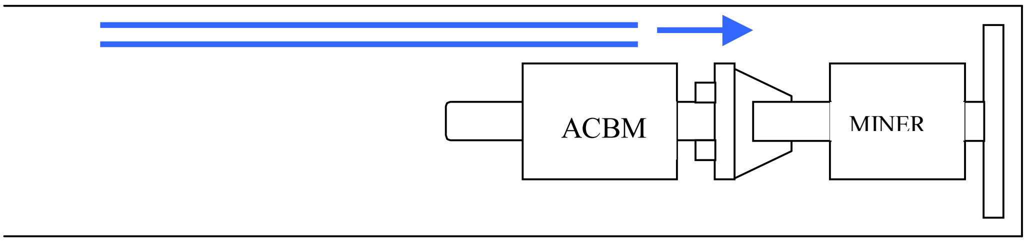


Figure 6.24. Ventilation schematic showing simple forcing with no ducting on ACBM

Advantages

- Simple Forcing system
- Duct to face distance – no problem up to 25 m from face
- Good for gassy mines and to solve heat problems

Disadvantages

- Not common in Australia
- Dust will be a big problem

(c) Ducting on ACBM with Exhaust system

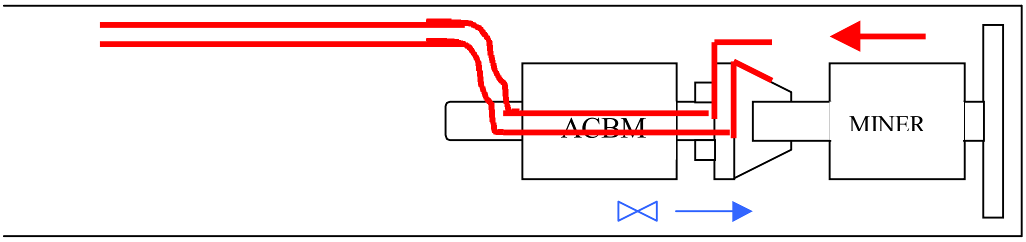


Figure 6.25. Ventilation schematic showing exhaust with ducting through ACBM

Advantages

- Duct always close to face

  (around 7 to 8 from face and very close to scrubber exhaust)
- Duct extension – no problem
- Duct not an obstruction to ACBM operators
- Simulates existing ventilation systems in 6 m cut-out place changing roadways
- Can be supplemented with venturis

Disadvantages

- Little bit more work on ACBM
- Space compromise on ACBM

(d) Comparison of various ventilation options

Table 6-7. Comparison of various ventilation options

	NO ducting on ACBM		**Ducting on ACBM**
Desirable criteria	Exhaust	Forcing	Exhaust
Non-gassy mine application	Yes	Yes	Yes
Gassy mine application	No	Yes	Yes
No dust problem	Yes	No	Yes
No obstruction to operator	No	**YES**	Yes
No duct extension problem	No	Yes	Yes
Close to existing ventilation system	No	No	Yes

Analysis of the above ventilation options shows that although ‘No ducting on ACBM’ option simplifies the work required on the new machine, it is difficult to ventilate the gassy mines with that ventilation arrangement. ‘Duct on ACBM’ ventilation option closely simulates the existing conditions and is applicable to a wide range of situations. Therefore, this option is being considered for use in the RRD system. It is also proposed to supplement to this ventilation system with venturis depending on the requirements at the field site.

Detailed studies on expected gas emissions for various development rates and the airflow requirements will be carried out in the 2nd year. Computational Fluid Dynamics (CFD) modelling studies of the airflow patterns will also be carried out in the following year.

6.5.2 Cables Handling

The following two options are available for cable connections in the RRD system.

- All cables through ACBM and coupled to continuous miner
- Independent cables to ACBM and continuous miner

The first option of connecting all the cables through ACBM reduces the risk of cable damage in the heading. This system also simplifies the data transfer between continuous miner and computers installed on ACBM for remote operation of the miner. However, this system is inflexible and is difficult to operate in two-roadway development system.

In view of the flexibility and other advantages offered it was decided to have independent cables for ACBM and continuous miner. This system introduces some minor risks such as possibility of automatic bolters hitting the continuous miner cables. To eliminate this risk, the following options are being considered:

- Spring loaded arm on the miner to keep cables at floor level
- Cable detection sensors and control mechanism on ACBM.

6.5.3 Location

A survey of the current practices revealed that most of the continuous miners are operated remotely, with operator standing behind the miner at a convenient location in the heading. In case of ABM-20’s the operators are positioned on the platforms of the equipment for better control of the bolting operations.

In this RRD system, operators are required to supervise the ACBM computer controls and operate them whenever necessary. It will be very difficult to operate those controls if operators are located behind the ACBM. Therefore it was decided to locate the operators cabins on the platforms of the ACBM.

6.6 Process Interactions

6.6.1 Process Control Interaction for the ACBM

The headings and activities given in the Table 6-8 and Table 6-9 on the “Interaction of Processes Involved under Normal Mining Conditions” were used to match the processes that interact with one another. This was completed in an Excel spreadsheet that was formatted with the identical headings down the left hand side and across the top of the page (Table 6-10 and Table 6-11). The interaction of processes was indicated with a marked box of one of three colours, based on its dependency on other activities. The three classifications used were "Independent", "Maybe Dependent" and "Dependent". The table was prepared to assist in the proceedings of technical meetings and for preparation of control system software. A similar table was formatted on the interaction processes between the “ACBM and the Mining System”. Schematic of the ACBM is shown in Figure 6.26.

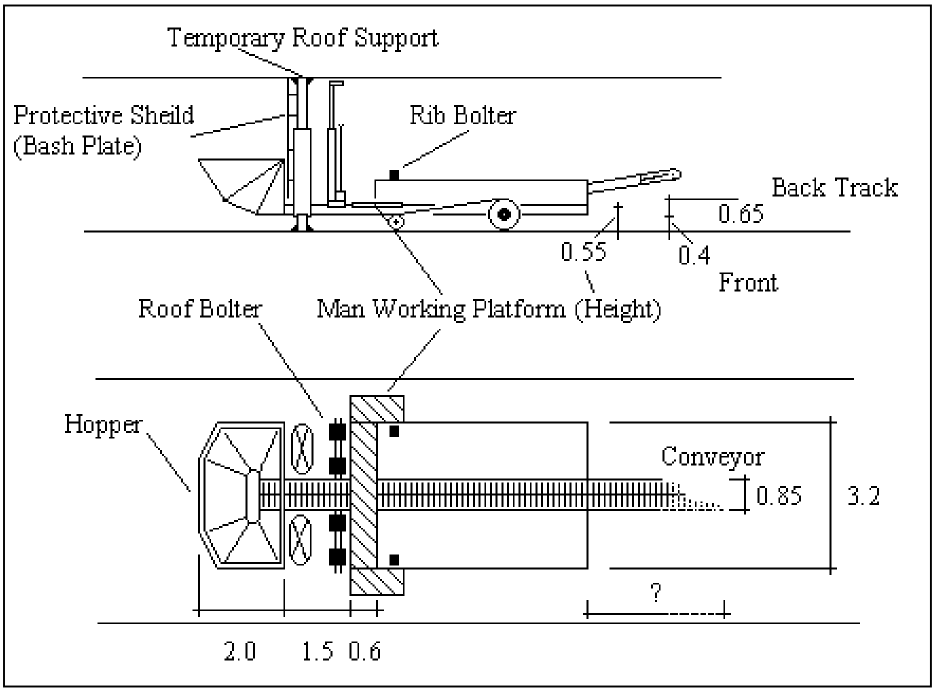


Figure 6.26. Schematic of ACBM used during preparation of process interaction tables

Table 6-8. Headings for ACBM process interaction

Support of Roadway – Roof
Installation of Self Drilling Roof Bolt - with plate
Set Temporary Roof Support to roof
Load roof bolt into Automatic Bolting unit with roof plate
Drill hole - auto feed/rotation/water flushing
Inject chemical resin - auto inject
Spin bolt to mix chemical - encapsulation of bolt
Chemical setting time
Pre-tension spinning of bolt
Retract drill head form roof line
Position location of bolt - bolter in retracted position (primary)
Roof Plate positioning in path of roof bolt to be loaded
Support of Roadway - Ribline
Installation of Self Drilling Rib Bolt - with plate
Load rib bolt into Automatic Bolting unit with plate or ?
Drill hole - auto feed/rotation/water flushing
Inject chemical resin - auto inject
Spin bolt to mix chemical - encapsulation of bolt
Chemical setting time
Pre-tension spinning of bolt
Retract drill head form ribline
Position location of bolt
Rib Plate positioning in path of rib bolt to be loaded
Advance of Bolting Module
Retract Temporary Roof Support from roof
Ensure all (roof & rib) bolting units are in retracted position
Ensure Bolting Module is not closer than 1.0 metres to Continuous Miner
Tram Bolting Module required distance for support pattern requirements
Set Temporary Roof Support to roof
Restock consumables to bolting units
Cutting Coal - Continuous Miner Advance
Direction of Continuous Miner on line
Ensure Continuous Miner is not more than 2.0 metres from Bolting Module hopper
Ensure conveyor tail on Continuous Miner is located over hopper on Bolting Module
Ensure Hopper has capacity to receive cut coal
Start flight conveyor on Continuous Miner
Start cutting head
Tram Continuous Miner forward - sump in

Cut pre set advancement of roadway
Monitor capacity of hopper on Bolting Module
Stop flight conveyor, forward advance of Continuous Miner, cutting head position
Coal Clearance from Bolting Module
Ensure tail of Bolting Module is over shuttle car
Ensure shuttle car has capacity to receive coal
Start flight conveyor on Bolting Module
Monitor capacity of shuttle car - operator
Monitor capacity of hopper on Bolting Module
Stop Flight conveyor on Bolting Module
Service Extensions
Ventilation - through/over/under Bolting Module
Ventilation up to Bolting Module
Power - Bolting module Advance
Water - Bolting Module advance
Communication - Bolting module advance

Table 6-9. ACBM and Interaction with the Mining System

(a) ACBM – Operational characteristics

Support of Roadway
Support Bolting Pattern - Roof and Ribline
Roof Bolt Placement
Rib Bolt Placement
Automatic Feed System - Roof/Rib Bolts
Roof / Rib Plate placement on bolts
Ribline Support - mesh/straps
Roof/Rib Bolt Chemical Injection System
Materials Location on Bolting Module
Temporary Roof Support - Canopy/Props - 2K tonne
Coal Clearance
Hopper - Dimension/Shape
Flight Conveyor dimension/location/length
Path of conveyor under/over/through
Guarding of conveyor
Conveyor Tail Configuration
Articulated Hopper Head?
Mobility
Propelling System -Dimension/Shape/Type

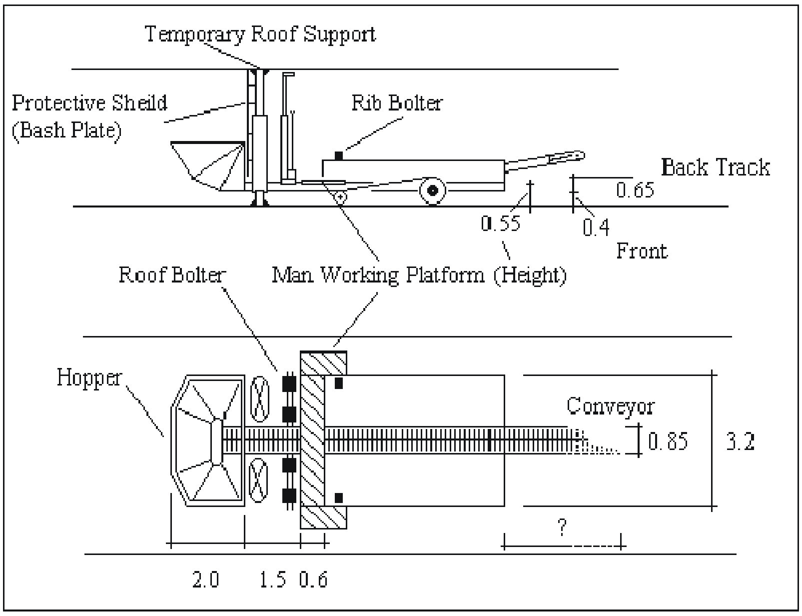
Manoeuvrability - Turning Circle
Motor size/capacity required
Track dimension
Fold up Working
Ventilation Requirement
Ventilation Path through Bolting Module
Ventilation extension during mining
Auxiliary Fan Located on Bolting Module/Continuous Miner?
Dust Suppression System - Bolting Module/Continuous Miner
Scrubber System - location, path, exhaust
Services Connection
Power - 1000 Volts
Water - minimum 5 lt./sec @ pressure 480 kPa
Air Line
Hydraulic Oil Line - ?
Communications - remote control, cable
Services Extension during Bolting Module/Continuous Miner advance

(b) Mining system

Mine Panel Design Layout
Cutting Sequence
Support Cycle
Location of Services (Power, Water, Air, Communication, other?)
Location of Materials (Consumables, service extension supplies)
Belt Location - dist. From working face
Conveyor Belt Extensions
Conveyor Belt Structure layout
Extra Conveyor Belt - length
Conveyor Belt attachment point - boot end or loop take
Move Boot End
Ventilation of developing roadway
Auxiliary Fan - capacity/location
Extension of Auxiliary Ventilation ducting outbye Bolting Module/Continuous Miner
Service Extensions
Power cable
Water line

Air line
Hydraulic line
Communication
Consumables
Transportation to Bolting Module
Form of Delivery to Bolting Module
Quantity of Materials Required in Load
Type of Materials in Load

Table 6-10. Interaction of process on ACBM



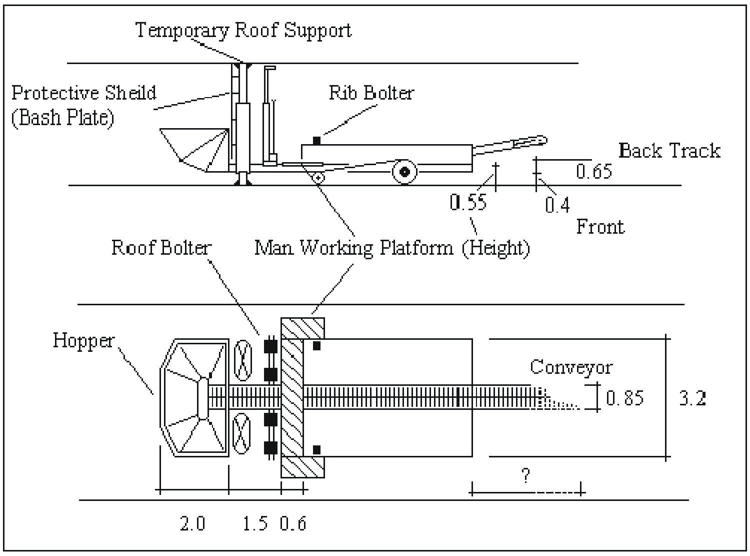
🟥 Dependent

🟦 Maybe Dependant

🟩 Independant

	Support of Roadway - Roof	*Support of Roadway - Ribline*	*Advance of Bolting Module*	*Cutting Coal - Continuous Miner Advance*	*Coal Clearance from Bolting Module*	*Service Extensions*	*Consumable Restocking*
Support of Roadway - Roof	🟥	🟦	🟥	🟦	🟦	🟩	🟥
Support of Roadway - Ribline	🟦	🟥	🟥	🟦	🟦	🟩	🟥
Advance of Bolting Module	🟥	🟥	🟥	🟦	🟥	🟩	🟩
Cutting Coal - Continuous Miner Advance	🟦	🟦	🟦	🟥	🟩	🟩	🟦
Coal Clearance from Bolting Module	🟦	🟦	🟥	🟩	🟥	🟩	🟦
Service Extensions	🟩	🟩	🟩	🟩	🟩	🟥	🟦
Consumable Restocking	🟥	🟥	🟩	🟦	🟦	🟦	🟥

Table 6-11. Interaction of ACBM and mining system



🟥 Dependent

🟦 Maybe Dependant

🟩 Independant

	Support of Roadway	Coal Clearance	Mobility	Ventilation Requirement	Services Connection	**Mining System**	Mine Panel Design Layout	Conveyor Belt Extensions	Ventilation of developing roadway	Service Extensions	Consumables
Bolting Module											
Operational Characteristics											
Support of Roadway	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟥
Coal Clearance	🟩	🟥	🟩	🟩	🟩	🟦	🟩	🟩	🟩	🟩	🟩
Mobility	🟩	🟩	🟥	🟩	🟦	🟦	🟩	🟩	🟩	🟩	🟩
Ventilation Requirement	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟦	🟩	🟩
Services Connection	🟩	🟩	🟦	🟩	🟥	🟦	🟩	🟩	🟦	🟩	🟩
Mining System	🟥	🟦	🟦	🟥	🟦	🟥	🟥	🟥	🟥	🟩	🟩
Mine Panel Design Layout	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟦	🟩	🟩
Conveyor Belt Extensions	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩
Ventilation of developing roadway	🟩	🟩	🟩	🟦	🟦	🟥	🟦	🟥	🟥	🟩	🟩
Service Extensions	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩
Consumables	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥

6.6.2 Cut-out Sequence Control Specification

The following list of items concerning the operational controls that needs to be performed by the RRD mining system to complete a 1.0-1.2 m development cycle (4 roof bolts and 2 rib bolts) was developed to assist in the technical committee meeting agendas.

1. Tram ACBM forward predetermined distance – Automatic/manual
    - Input received from heading control system and Forced Potato as position in mine heading, back to operator screen.
    - Adjust tilt of hopper if required to overcome dips in heading – manual control
2. Level and stabilise ACBM
    - Deploy stabilising rams and set Temporary roof support to roof line – Auto/manual
3. Commence supporting heading roof and ribs
    - Loaded roof bolters will begin installation from heading centre line out towards the ribline. Position drill head, drill the bolt, resin injection process, waiting period for anchor setting and then apply torque to roof bolt for tensioning. Roof bolter is returned to the bolt loading position
    - Rib bolters install rib bolts simultaneously
    - 2nd Bolt installation pick up new bolt, position drill head, drill the bolt, resin injection process, waiting period for anchor setting and then apply torque to roof bolt for tensioning. Roof bolter is returned to the bolt loading position
    - Roof and Rib bolters are restocked with new bolts ready for next support pattern
    - restocking the 3 x roof bolt rotational magazine can be completed at any time other than when a bolt is being selected by the bolt head for installation
    - Return bolters to park position, roof and rib
4. Coal conveying cycle
    - Is shuttle car in position to receive coal
    - Is ACBM in position to convey coal in shuttle car
    - Is the Continuous Miner in position to cut coal
    - Visual/systems check to see if ACBM conveyor is running
    - Visual/systems check to see if Continuous Miner conveyor is running
    - Proceed to cut coal using Forced Potato system and manual control
    - Monitor hopper level on ACBM and position of Continuous Miner tail
    - Monitor shuttle car level and position of ACBM tail
5. Stop coal clearance system, Continuous Miner/ACBM conveyors
6. Check to see if ACBM can advance
7. Retract stabilisers and Temporary roof support

8. Locality check of cables and other hazards around ACBM
9. Tram forward

6.6.3 Roles and Responsibilities of Mining Operators

Number of operators:

Continuous miner	1
ACBM	2
Shuttle car	1

1. Continuous Miner operator – Advancement of Continuous Miner
    - Operator controlled - direction control assisted Big Brain
    - Continuous Miner cutting head inclination and rotational control
    - Continuous Miner conveyor direction and status – assisted by camera display and system feedback
    - Monitor ACBM hopper capacity - assisted by camera display
    - Monitor ACBM conveyor direction and status - assisted by camera display and system feedback
    - Shuttle car position - visual

2. Continuous Miner operator – Forward Roof bolt installation off Continuous Miner
    - Stop coal cutting sequence on Continuous Miner
    - Extend stabilising jacks
    - Position roof bolter for roof bolt installation
        - Extend roof bolter head plate to roof line (MAY BE AUTOMATIC)
        - Drill roof bolt hole
        - Drill performance monitored – alarms activate anomalies
        - Inject resin into bolt
        - Wait for chemical resin to set
        - Apply torque to bolt
        - Retract drill head plate from roof
        - Return bolter to loading position

3. ACBM operator 1 or 2 – Tramming ACBM
    - Check ACBM conveyor is stopped – visual and systematic
    - Check roof and rib bolting rigs are in the parked position - visual and systematic
    - Check roof and rib bolt auto feed system is in the parked position - visual and systematic
    - Retract Temporary roof support and position for tramming - visual and systematic
    - Monitor angle of ACBM hopper, adjust tilt if required - visual and systematic

- Check status and position of cables to ACBM and Continuous Miner - visual and systematic
- Check proximity of ACBM for operators – ACBM operator visual inspection
- Tram ACBM to desired position – manual control assisted by Big Brain heading directional control
- Level and stabilise ACBM – rams and Temporary roof support – ACBM manual control

4. ACBM operator 1. – Heading support of roof and ribs
    - Check ACBM stabilising rams and Temporary roof support are in set position
    - Engage the automatic bolting systems – roof and rib
    - Monitor drilling performance – alarms to activate anomalies in drilling feed and rotation
    - Monitor grout injection system and torque application
    - Check bolt pick up interaction
    - Alarms to alert operator of process failures in the system
    - Check parking position of bolting rigs before tramming mode
    - Retract stabilising rams and temporary roof support

5. ACBM operator 2. – service support and cable man
    - Ensure ventilation extension tube is in close proximity to working area
    - Monitor position of cables in travelling area, shuttle car-ACBM and ACBM-Continuous Miner interaction
    - Assist Continuous Miner operator when forward bolting, ACBM operator when bolting and tramming

6.7 Summary

The Rapid Roadway Development project systems engineering component presented work in many areas of the overall mining system. This includes configuration details and specifications of the ACBM and the mining development system.

The ACBM conceptual model development section of the report presents the results of the mine survey, specification criteria developed based on this survey and details the current specifications of the ACBM and the mining system as they were agreed on through technical committee meetings. Lists of additional items that required to be clarified in the technical meeting discussions have also been included in the report.

The objective of the mine survey was to list design criteria that reflected the Australian environmental conditions, which the ACBM and mining system would be best suited to. A criterion for selection was to meet approximately 80% of the market. Specifications for the ACBM include, machine total length 11.0 metres, one metre advance support pattern of 4 roof bolts and one rib bolt per side installed in 4 minutes and the tail configuration of the ACBM should be similar in conceptual design to that on a continuous miner. The process of materials supply was highlighted under mining system criteria.

To assist in technical discussions and development of the design specification for the RRD system a number of 3D visualisation models of the ACBM were developed. The techniques used in the creation of 3D block models and some typical images from the visualisation are presented in this report. Flythrough movies of the RRD system are being presented at all the technical committee meetings. The models were used to demonstrate the size, configuration and interaction of moving components on the ACBM components.

The 3D visualisation is built in a three-stage process that starts in a CAD environment. The block diagram is currently held as a Solidworks model, and any design changes are made in this environment. The various components of the model are then exported as separate VRML files to go into the second stage of the modelling. After the animations have been added to the model, the VRML models are transferred into the JAVA control applet in the final stage. The applet used in this case is a small program that can run inside the web browser environment, and presents the user with a series of buttons which turn components ON/OFF and also control animations.

It is envisaged that the block components will gradually be replaced with fully detailed components as the project proceeds, with a fully detailed working 3D model being a deliverable out of the 3D visualisation work at the end of the project. It is also proposed to procure/develop equipment simulation capability in the next stage of the project.

The panel layout section details the theoretical development rates, panel cycle times, and results of sensitivity analysis. The mining cycle time calculations were developed utilizing the critical variables in the cycle time critical path. The two scenarios investigated were two heading development with 2 x 50 metre and 100 metre pillar panel configurations. The results showed that 100 m pillar layout is a better configuration for this Rapid Roadway Development system.

A review of the Australian coal mining regulations to identify the critical issues to be addressed pertaining to the application of proposed rapid roadway development system has been completed. Regulations and issues concerning the introduction of new remote/automatic equipment have also been identified.

Ventilation alternatives for the ACBM and mining system were developed and presented to the technical committee. Different configurations of conventional gateroad ventilation techniques utilizing exhaust and forcing systems were discussed. The most effective design has ventilation ducting over the top of the conveyor, through the temporary roof support and beside the hopper arrangement. Cables handling and operator's location issues were also discussed, as they need to be considered during design stage.

The interaction of the ACBM and the components of the RRD mining system had been itemized in the process interaction section. This study was conducted to detail the processes that could not happen simultaneously, and those that could operate independently on the ACBM. The ACBM cut out sequence control was also specified. An aim of this exercise was also to assist in the development of process controls that need to be employed in the programming of the ACBM functions and design of the mining system. The roles and responsibility of the mining operators was also itemized to highlight the processes that needed to be conducted.

7 PROJECT MANAGEMENT

7.1 Structure

Project leadership for the project has been a complex issue, both because of the size of the project, the interaction between the ACARP component and the larger JCOAL-CSIRO project, the large number of parties concerned and the differing financial years and reporting requirements.

Some practical measures have been carried out to ease these issues:

- ACARP project monitors are also on the technical committee for the JCOAL project
- The ACARP project yearly timetable is aligned to the Japanese fiscal years
- Annual reports for ACARP and JCOAL requirements from CSIRO will be similar
- Component responsibility is similar for both areas from CSIRO.

The component responsibility for the JCOAL-CSIRO project is shown below:

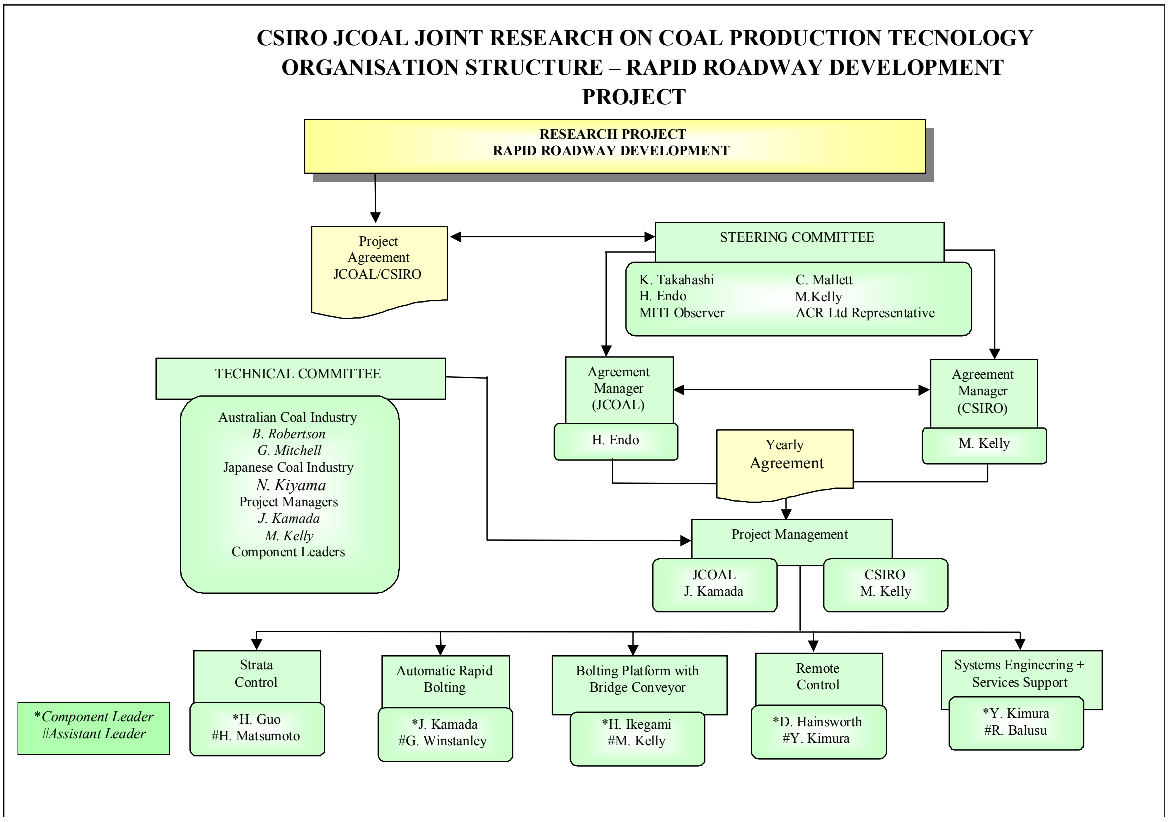


Figure 7.1. Rapid Roadway Development Organisational Chart

7.2 Technical meetings

Since the commencement of the project, there have been four extended technical meetings in Brisbane (2), Nagoya and Newcastle. The technical meetings have served to provide a detailed scope for the project, develop the design of the ACBM, report on geotechnical and systems programs and to demonstrate prototype autonomous feed and bolting systems.

7.3 IP agreement

An IP agreement has been prepared and is waiting on approval from all parties. The draft was prepared after a detailed discussion on all groups' requirements after the third technical meeting in Nagoya.

7.4 Risk assessment

A conceptional risk assessment prior to engineering drawings has been carried out with Prof. Jim Joy as facilitator. The outcomes of this risk assessment is attached (Appendix 1) The requirements highlighted in the risk assessment have been incorporated into the project work program. There are three more risk assessments planned during the remainder of the project:

- A engineering risk assessment prior to construction
- A systems risk assessment for mines department approval, and
- A site risk assessment prior to working underground

7.5 Technology Transfer

Michael Kelly delivered a paper titled 'Improving Roadway Development Systems through Automated Roof Bolting Technology' at the JCOAL Technology Exchange Workshop in Brisbane on 8th and 9th November, 1999. This led to an article being published in the December 1999/January 2000 issue of Australian Journal of Mining (p64 to p67). The article titled '2001 – A Coal Mining Odyssey', was featured as a special report in the publication.

7.6 Project outcomes

Substantial progress has been made in all areas of the RRD project over the last twelve month period. The major milestone for the year, the trial of a combined autonomous feed and bolting prototype has been achieved. Other substantial milestones in strata control, control systems, systems development and machine layout have also been accomplished. Challenges remain, as highlighted in the next section, but progress to date can be accrued to the depth of talent and motivation of the RRD team, including the monitors and support groups.

Up to the end of March 2000, the following outcomes have been completed for the RRD project.

7.6.1 Auto roof bolting system.

A prototype autonomous feed and bolting system has been constructed and successfully trialled. A feed system was designed and constructed by IHI in Japan and demonstrated during the October technical meeting in Nagoya. It was then modified and a second prototype was constructed and transported to Australia. The feed system is a mechanical underfeed system that does not depend upon robotics for bolt selection.

The bolting system has been developed to a remote controlled version by Hydramatic Engineering and BHP in a parallel, collaborative project outside the RRD project. During this development the new consumable, the BHP self-drilling bolt, and a new bulk chemical system have been combined to result in a completely hands off bolt installation process.

The two systems have been combined in a prototype trial to produce a fully autonomous feed and bolting unit. Bolt transfer via three-bolt carousel on either side of the ACBM allows for either a 4 or 6 bolt pattern to be installed with some independence from the feed unit. The production unit will have bolt boxes with a capacity of two hundred bolts on either side of the machine, a total live feed capacity of four hundred bolts. Cycle times of 75 seconds per installed bolt per side will result in advance rates of up to 15metres per hour with a four bolt pattern.

The rib bolt system will be similar in concept to the bolt feed system, except that the bolt will be fed directly into the bolter and not via a carousel. Only conceptional drawings have been completed at this stage.

7.6.2 ACBM platform.

A specification for the platform detailing its functionality, environmental constraints including manoeuvrability has been completed. An industry survey was used to assist in this process. Mitsui Miike has prime responsibility for the design and construction of the platform. They have completed a series of drawings for a conceptional design (Appendix 2). Discussions at this time (April 2000) are being carried out to fine tune the design and reduce overall dimensions as much as possible. Detailed discussions are also ongoing on the subsystems component design and integration (autonomous feed and bolting, hydraulic, electrical, tramming, conveying, control etc). The CSIRO has completed concept drawings and incorporated this into 3D visualisation that has proven useful in the design development.

7.6.3 Strata Control

One of the key components of the RRD project is to determine suitable geological and geotechnical conditions and roadway support design methods for the new RRD system. To date, preliminary field monitoring and numerical modelling work has been carried out to determine effects of the unsupported span length and time.

A 2D Cosserat Finite Element code has been incorporated into a finite element package called AFENA, to predict the stability of the roadway involved, and study effects of the unsupported span length in strata with highly anisotropic deformation characteristics. The modified code is now capable of modelling elastic-plastic behaviour of both the lamination or bedding planes and rock layers involved more realistically than widely used conventional elasto-plastic models. The code is being calibrated against actual field monitoring data.

To provide a simple and easy-to-use predictive tool for the initial evaluation of the unsupported roadway span stability, an analytical model, the Bedded Span Stability Model, has been developed. The model is based on the previous CSIRO model for highwall mining span stability (Shen and Duncan Fama, 1996), and it takes into account the delamination and breakage of roof strata.

As a first attempt to monitor unsupported roof behaviour, a joint monitoring program has been completed at Moura Mine between CSIRO Highwall Mining Project and RRD Project Teams. Extensometer results have been analysed using UDEC and the new Cosserat model. Microseismic analyses have been completed.

A second underground site at Central Colliery has been completed. The study focused on the influence of roof beams, structure and stress direction on cutout distances achieved and stand up times.

7.6.4 Remote/Automatic Control Systems

The specification and acquisition of Miner Remote Control System has been completed. The conceptual design and preliminary specification of supervisory and bolting platform control system and detailed definition of the functionality of system components has also been completed. Work on sensor acquisition and definition of sensor development requirements and specifications is underway. A result has been the successful trial of a laser sensor through Perspex for roof and rib profiling. This will enable the sensor to be housed in a flameproof enclosure. Further evaluation of the laser distance measurement system for rib and roof profiling has also been undertaken with good results.

The data communications system between the miner and the ACBM, including a two-channel video link has been specified and ordered. Design work has progressed on the flameproof instrumentation enclosures to be mounted on the ACBM.

There has been some issues regarding electrical installation and a quotation from AT Flameproofing has been sourced to help resolve these requirements.

7.6.5 Systems Engineering

The Rapid Roadway Development project systems engineering component presented work in many areas of the overall mining system. This includes configuration details and specifications of the ACBM and the mining development system.

The ACBM conceptual model development section of the report presents the results of the mine survey, specification criteria developed based on this survey and details the current specifications of the ACBM and the mining system as they were agreed on through technical committee meetings. List of additional items that required to be clarified in the technical meeting discussions have also been included in the report.

The objective of the mine survey was to list design criteria that reflected the Australian environmental conditions, which the ACBM and mining system would be best suited to. A criterion for selection was to meet approximately 80% of the market. Specifications for the ACBM include, machine total length 11.0 metres, one metre advance support pattern of 4 roof bolts and one rib bolt per side installed in 4 minutes and the tail configuration of the ACBM should be similar in conceptual design to that on a continuous miner. The process of materials supply was highlighted under mining system criteria.

To assist in technical discussions and development of the design specification for the RRD system a number of 3D visualisation models of the ACBM were developed. The techniques used in the creation of 3D block models and some typical images from the visualisation are presented in this report. Flythrough movies of the RRD system are being presented at all the technical committee meetings. The models were used to demonstrate the size, configuration and interaction of moving components on the ACBM components.

The 3D visualisation is built in a three-stage process that starts in a CAD environment. The block diagram is currently held as a Solidworks model, and any design changes are made in this environment. The various components of the model are then exported as separate VRML files to go into the second stage of the modelling. After the animations have been added to the model, the VRML models are transferred into the JAVA control applet in the final stage. The applet used in this case is a small program that can run inside the web browser environment, and presents the user with a series of buttons which turn components ON/OFF and also control animations.

It is envisaged that the block components will gradually be replaced with fully detailed components as the project proceeds, with a fully detailed working 3D model being a deliverable out of the 3D visualisation work at the end of the project. It is also proposed to procure/develop equipment simulation capability in the next stage of the project.

The panel layout section details the theoretical development rates, panel cycle times, and results of sensitivity analysis. The mining cycle time calculations were developed utilizing the critical variables in the cycle time critical path. The two scenarios investigated were two heading development with 2 x 50 metre and 100 metre pillar panel configurations. The results showed that 100 m pillar layout is a better configuration for this Rapid Roadway Development system. A review of the Australian coal mining regulations to identify the critical issues to be addressed pertaining to the application of proposed rapid roadway development system has been completed. Regulations and issues concerning the introduction of new remote/automatic equipment have also been identified.

Ventilation alternatives for the ACBM and mining system were developed and presented to the technical committee. Different configurations of conventional gateroad ventilation techniques utilizing exhaust and forcing systems were discussed. The most effective design has ventilation ducting over the top of the conveyor, through the temporary roof support and beside the hopper arrangement. Cables handling and operator's location issues were also discussed, as they need to be considered during design stage.

The interaction of the ACBM and the components of the RRD mining system had been itemized in the process interaction section. This study was conducted to detail the processes that could not happen simultaneously, and those that could operate independently on the ACBM. The ACBM cut out sequence control was also specified. An aim of this exercise was also to assist in the development of process controls that need to be employed in the programming of the ACBM functions and design of the mining system. The roles and responsibility of the mining operators was also itemized to highlight the processes that needed to be conducted.

7.7 Project issues

Although one could enunciate several pages of challenges that lay ahead for project team, only a few require a special mention as being critical to continuance of the project. These include:

- Confirmed test site. Japanese interests are asking for a confirmed test site for the project to proceed. Australian interests will agree to a test site in principle, but won't commit to a site without something more tangible to consider. We are progressing this issue, but it is still a critical one to the project.

- Machine size. Although much progress has been made on machine functionality, there remains substantial work to integrate the systems into a practically sized machine. This is the main area of focus over the next months before engineering drawings are to be finalised.

- IP agreement. A draft agreement that was formulated by the technical group is currently under consideration by the company partners to the project. This has to be finalised before manufacturing progresses.

7.8 Program for 2000-2002

During the next two years, the ACBM will undergo final design, manufacture and initial field trials. The CSIRO responsibility includes support of this process in design and design approvals, manufacturing process, and arranging field trials and project management. In addition CSIRO has major responsibilities in automation control, systems engineering and strata control. Some unresolved issues remain regarding the process for design, approval and installation of power electrics and it is the requirement for front bolters, although firmly confirmed as a necessity, have not been fully scoped. The current detailed program for the ACARP/CSIRO components is shown below.

7.8.1 Automation and Control Component

1. Miner Remote Control
    - Acquire and commission laser-based miner heading control system
    - Develop miner control station on ACBM platform
- Commission Forced Potato "Simpson" radio remote control system including interfaces to miner-mounted horizon control and orientation sensors
    - Develop video monitoring system for coal cutting and forward bolting operations

Milestones:

  - Heading control system operational (6 months)
  - Simpson control system operational (12 months)
  - Video monitoring system operational (12 months)

2. ACBM control system

- Design and acquire flameproof enclosures compatible with ACBM layout to house computer and sensor equipment
  - Design, implement and trial sensor systems to provide:
    Distance measurement to ribs, roof and miner
    Odometry on ACBM platform drive
  - Develop video monitoring system for hopper and ACBM belt
- Acquire computer hardware, install in flameproof enclosures and interface to external sensors
- Develop software to control overall system and interface to operators
  Milestones
  - Flameproof enclosures fitted out with computer equipment and operator interfaces (12 months)
  - Sensor systems for distance measurement and odometry operational (12 months)
  - Video monitoring system tested (18 months)
  - Control system software complete (24 months)

3. Forward bolting system
  - Provide interface in ACBM hardware and software for bolter data transmission
  - Design miner lighting and camera system to allow monitoring of forward bolting operation.

  Milestone
  - ACBM control system interface to forward bolting complete (24 months)

7.8.2 Systems Engineering Component

1. Systems – Sequences, Designs and Hardware requirements.
  - Plans of alternative mining sequences and auxiliary services' arrangements such as power, water, monitoring and communication systems through bolter will be developed. (6 months)
  - After analysis of the conceptual models and system components final designs and logistics of consumable supply, services extension and maintenance schedules will be developed (12 months)
  - Design and manufacture of supply cassettes, cable hangers, vent-tube/adapters and other required hardware for services. (18 months)

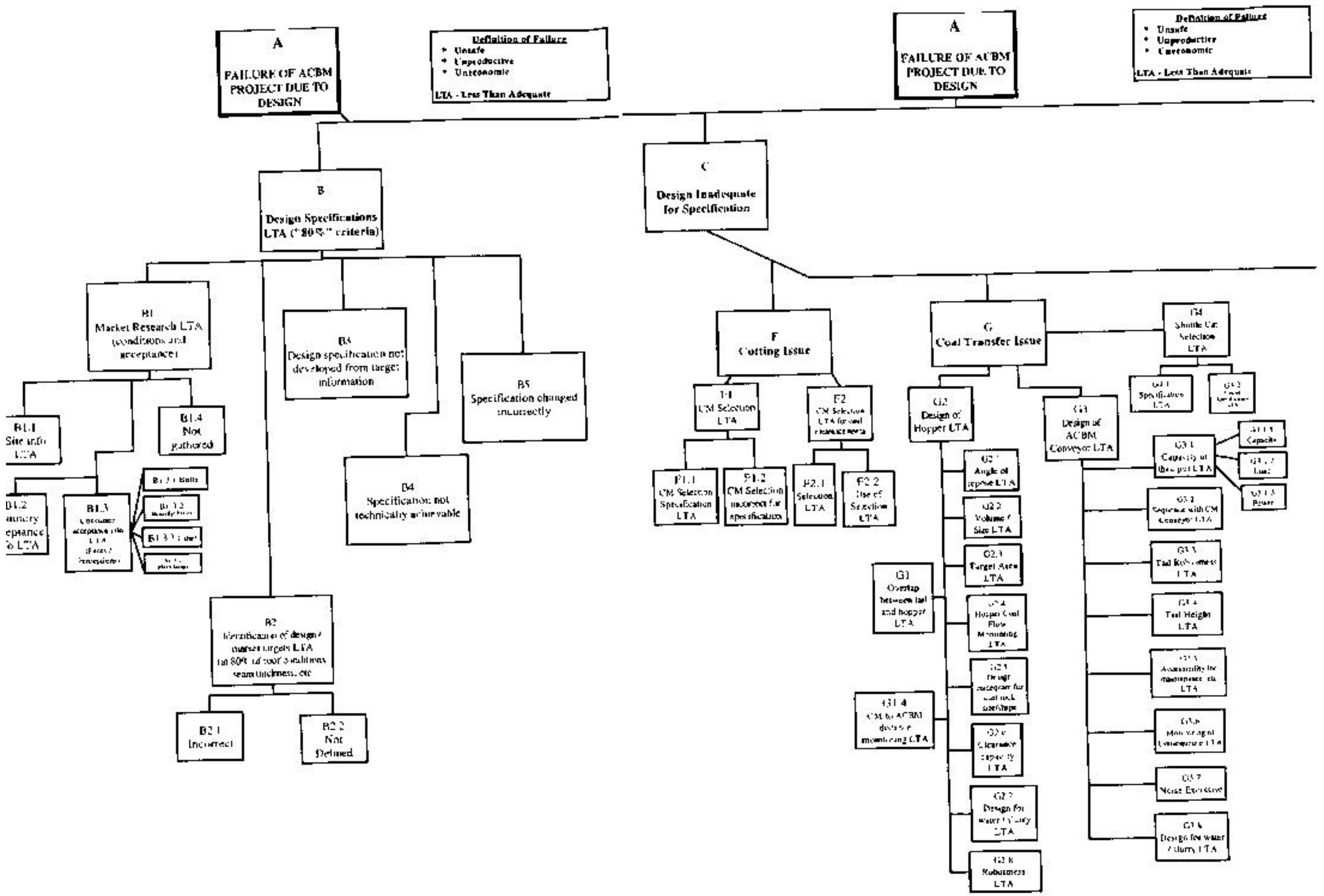
2. Gas and Ventilation Studies.
    - Field studies at selected mines to obtain gas emission data versus development rate. (12 months)
    - Setting-up and calibration of the gas emission model to estimate of gas emissions for different development rates and gas contents and seam permeability. (18 months)
    - Computational fluid dynamics model of the roadway constructed using actual machine configurations. This model will be used for simulating the effect of various parameters and design optimisation of the ventilation system for this remote miner and bolter combination. (18 months)
3. 3D Visualisation Studies.
    - Existing models will be updated when detailed plans are available. These will be used to simulate interactions between the components at various cutting stages. (6- months - ongoing)
    - A full sequence simulation will also be developed to address interfaces between the machine components and logistics of services extension. (12 months – ongoing)

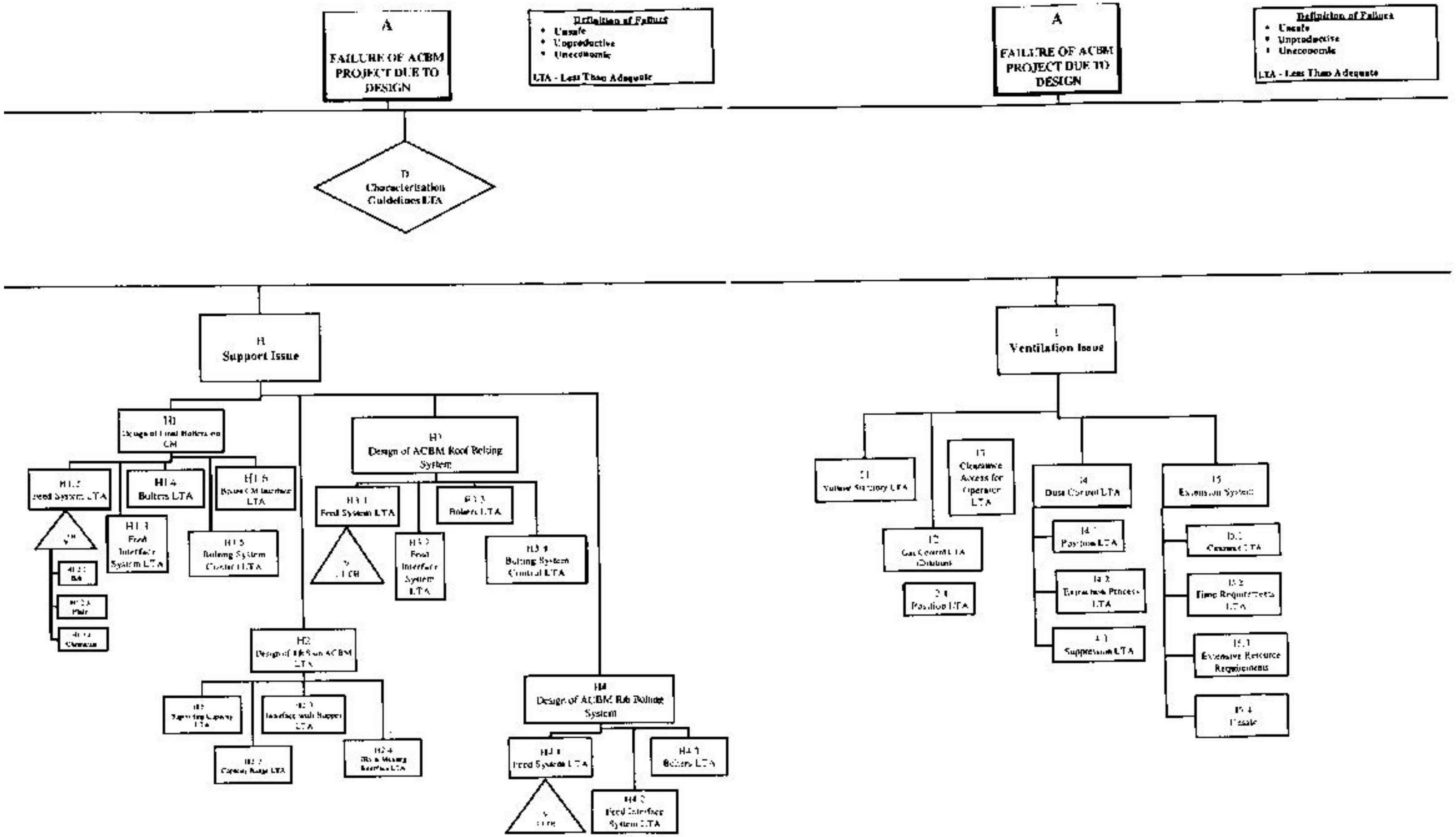
7.8.3 Strata Control Component

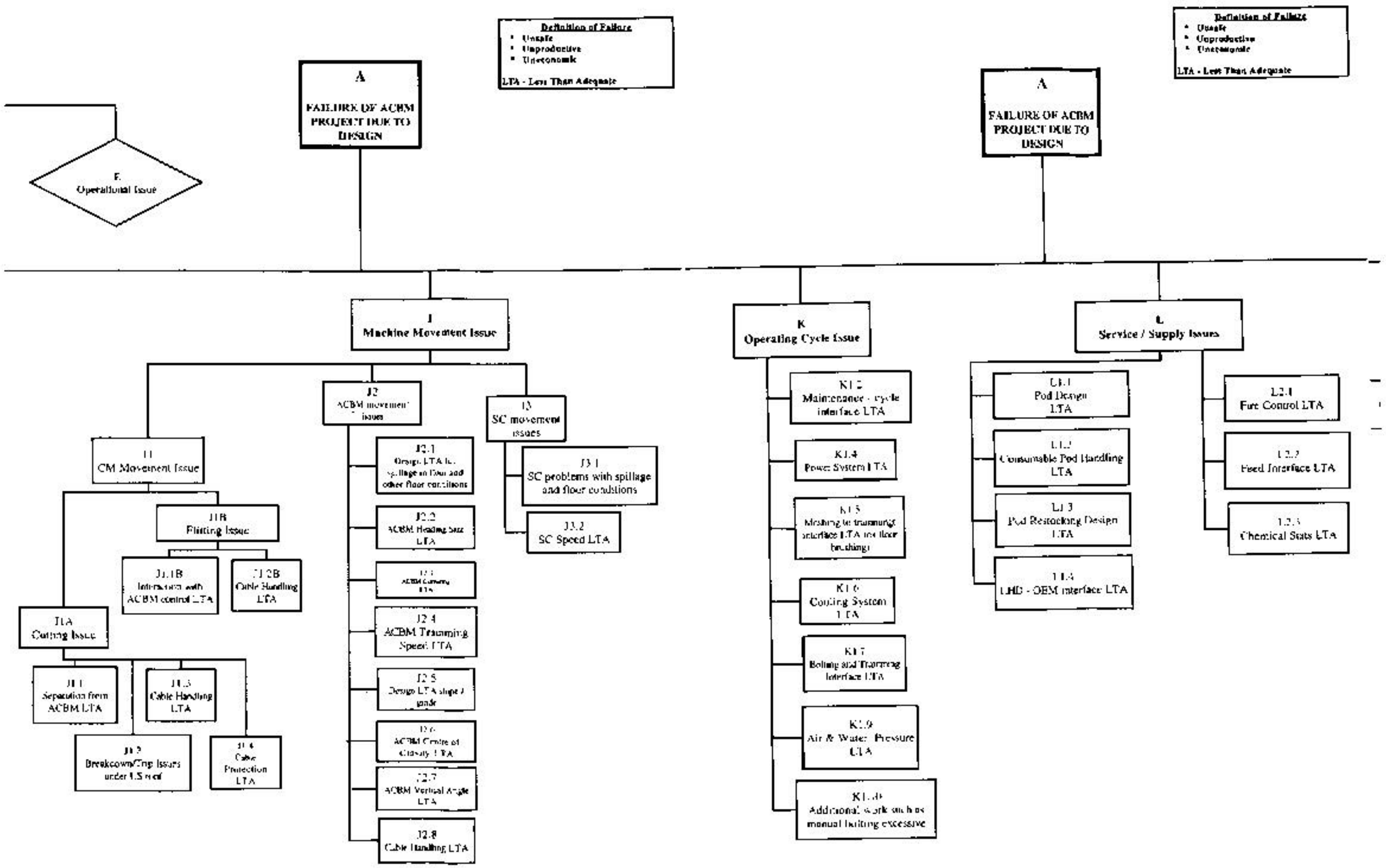
- Complete evaluation of the first two field sites for the effects of unsupported span length, time and bolting away from the face. (4 months)
- Complete development of numerical modelling tools to predict unsupported roadway roof and rib stability to determine appropriate support in given geological conditions (8 months)
- Carry out additional field geotechnical studies at other selected mines (12 months)
- Identify potential geotechnical hazards and risks involved in the new RRD system (18 months)
- Develop support design methods for the new system, including forward support from the miner (20 months)
- Coordinate underground field trials and calibration for the Japanese on-line rock monitoring system.(16 months)
- Undertake site specific geotechnical assessment and support design for the selected potential trials site for the new RRD system (18 months)
- Monitor first field site (24 months)

Appendix 1

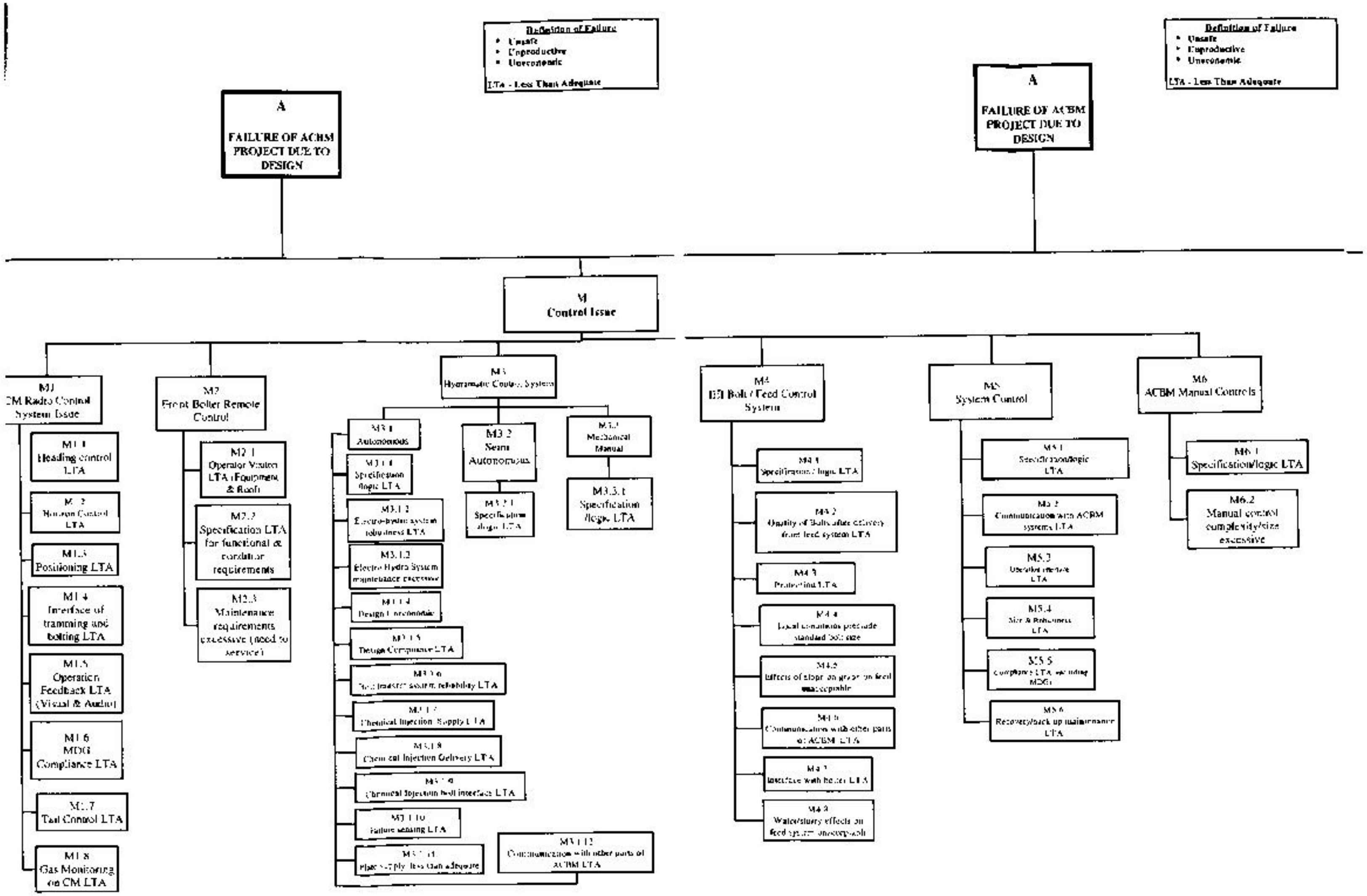
RRD Risk Assessment Fault Tree

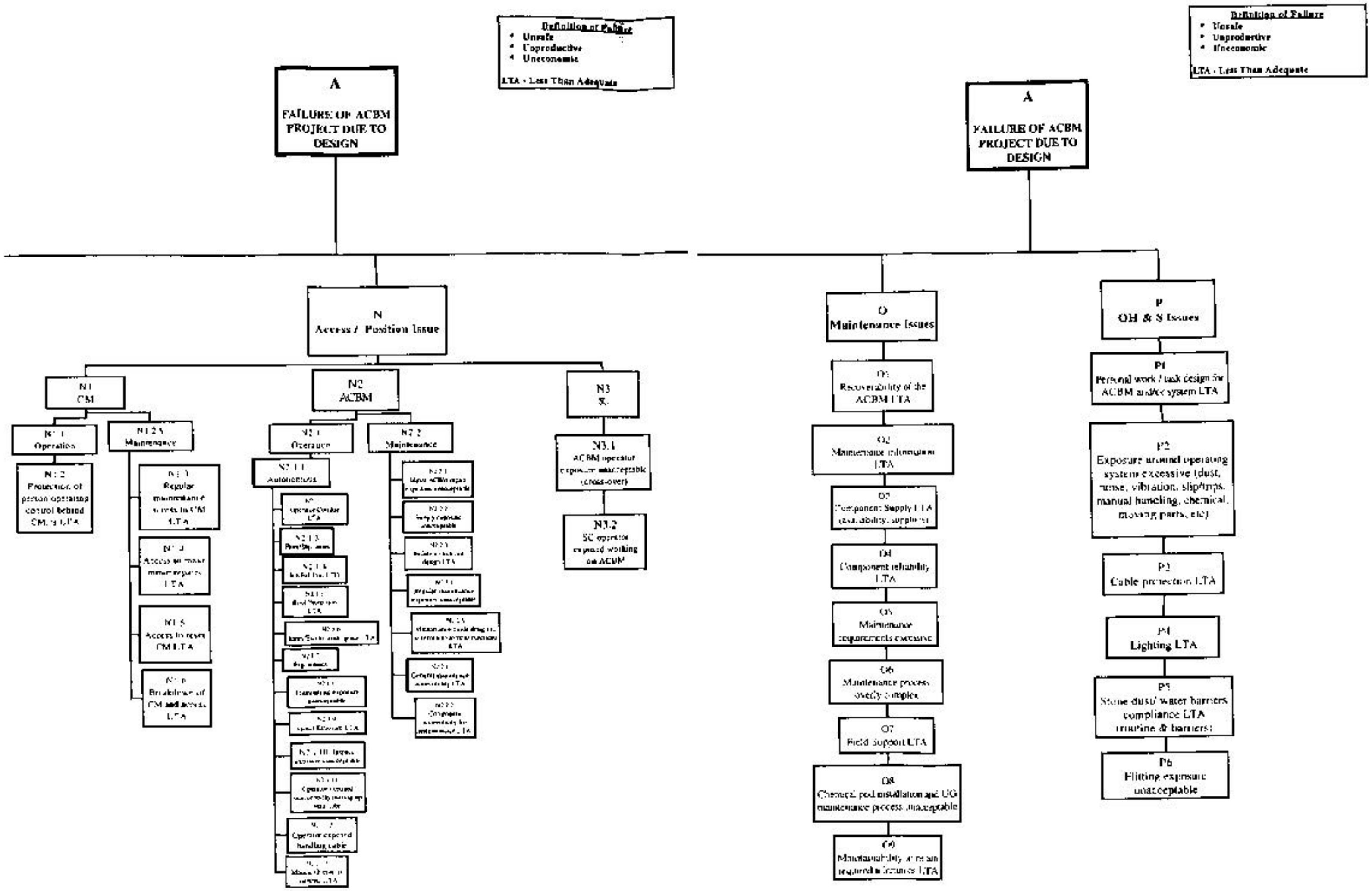

A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
B
Design Specifications LTA ("80%" criteria)
B1
Market Research LTA (conditions and acceptance)
B1.1
Site info LTA
B1.2
LTA
B1.3
LTA
B1.3.1 Bolts
B1.3.2
B1.3.3
B1.4
Not gathered
B2
Identification of design / market targets LTA
B2.1
Incorrect
B2.2
Not Defined
B3
Design specification not developed from target information
B4
Specification not technically achievable
B5
Specification changed incorrectly
A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
C
Design Inadequate for Specification
F
Cutting Issue
F1
CM Selection LTA
F1.1
CM Selection Specification LTA
F1.2
CM Selection incorrect for specification
F2
CM Selection LTA for coal
F2.1
Selection LTA
F2.2
Use of Selection LTA
G
Coal Transfer Issue
G1
Overlap between tail and hopper LTA
G2
Design of Hopper LTA
G2.1
Angle of repose LTA
G2.2
Volume / Size LTA
G2.3
Target Area LTA
G2.4
Hopper Coal Flow Monitoring LTA
G2.5
Design adequate for coal rock size/shape
G2.6
Clearance capacity LTA
G2.7
Design for water / slurry LTA
G2.8
Robustness LTA
G3
Design of ACBM Conveyor LTA
G3.1
Capacity of the pet LTA
G3.1.1
Capacity
G3.1.2
Load
G3.1.3
Power
G3.1.4
CM to ACBM distance monitoring LTA
G3.2
Sequence with CM Conveyor LTA
G3.3
Tail Robustness LTA
G3.4
Tail Height LTA
G3.5
Accessibility for maintenance etc LTA
G3.6
Consequence LTA
G3.7
Noise Excessive
G3.8
Design for water / slurry LTA
G4
Shuttle Car Selection LTA
G4.1
Specification LTA
G4.2


A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
D
Characterisation Guidelines LTA
H
Support Issue
H1
Design of Final Bolters on CM
H1.2
Feed System LTA
H1.4
Bolters LTA
H1.6
LTA
H1.3
Feed Interface System LTA
H1.5
Bolting System Control LTA
H1.2.2
Flair
H2
Design of Rib Span ACBM LTA
H2.3
Interface with Support LTA
H2.2
Capacity Range LTA
H2.4
H3
Design of ACBM Roof Bolting System
H3.1
Feed System LTA
H3.3
Bolters LTA
H3.2
Feed Interface System LTA
H3.4
Bolting System Control LTA
H4
Design of ACBM Rib Bolting System
H4.1
Feed System LTA
H4.3
Bolters LTA
H4.2
Feed Interface System LTA
A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
I
Ventilation Issue
I1
I3
Clearance Access for Operator LTA
I4
Dust Control LTA
I5
Extension System
I2
Gas Control LTA
Position LTA
Position LTA
Extraction Process LTA
Suppression LTA
Time Requirements LTA
I5.3
Extensive Resource Requirements
I5.4



E
Operational Issue
A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
J
Machine Movement Issue
J1
CM Movement Issue
J1B
Flitting Issue
J1.1B
Interaction with ACBM control LTA
J1.2B
Cable Handling LTA
J1A
Cutting Issue
J1.1
Separation from ACBM LTA
J1.2
Breakdown/Trip Issues under LS roof
J1.3
Cable Handling LTA
J1.4
Cable Protection LTA
J2
ACBM movement issues
J2.1
Design LTA for spillage on floor and other floor conditions
J2.2
ACBM Heading Size LTA
J2.3
ACBM Cornering LTA
J2.4
ACBM Tramming Speed LTA
J2.5
Design LTA slope / grade
J2.6
ACBM Centre of Gravity LTA
J2.7
ACBM Vertical Angle LTA
J2.8
Cable Handling LTA
J3
SC movement issues
J3.1
SC problems with spillage and floor conditions
J3.2
SC Speed LTA
K
Operating Cycle Issue
K1.2
Maintenance - cycle interface LTA
K1.4
Power System LTA
K1.5
Meshing to tramming interface LTA (or floor brushing)
K1.6
Cutting System LTA
K1.7
Bolting and Tramming Interface LTA
K1.9
Air & Water Pressure LTA
K1.10
Additional work such as manual bolting excessive
L
Service / Supply Issues
L1.1
Pod Design LTA
L1.2
Consumable Pod Handling LTA
L1.3
Pod Restocking Design LTA
L1.4
LHD - OEM interface LTA
L2.1
Fire Control LTA
L2.2
Feed Interface LTA
L2.3
Chemical Stats LTA

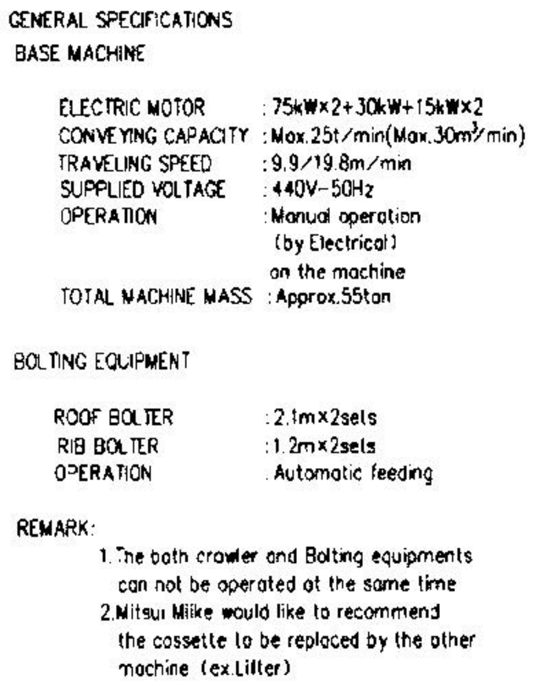

A
FAILURE OF ACBM PROJECT DUE TO DESIGN
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
M
Control Issue
M1
CM Radio Control System Issue
M1.1
Heading control LTA
M1.2
Rotation Control LTA
M1.3
Positioning LTA
M1.4
Interface of tramming and bolting LTA
M1.5
Operation Feedback LTA (Visual & Audio)
M1.6
MDG Compliance LTA
M1.7
Tail Control LTA
M1.8
Gas Monitoring on CM LTA
M2
Front Bolter Remote Control
M2.1
Operator Vision LTA (Equipment & Roof)
M2.2
Specification LTA for functional & condition requirements
M2.3
Maintenance requirements excessive (need to service)
M3
Hydramatic Control System
M3.1
Autonomous
M3.1.1
Specification /logic LTA
M3.1.2
Electro-hydraulic system robustness LTA
M3.1.3
Electro Hydro System maintenance excessive
M3.1.4
Design Uneconomic
M3.1.5
Design Compliance LTA
M3.1.6
Bolt transfer system reliability LTA
M3.1.7
Chemical Injection Supply LTA
M3.1.8
Chemical Injection Delivery LTA
M3.1.9
Chemical Injection bolt interface LTA
M3.1.10
Failure sensing LTA
M3.1.11
Plate supply less than adequate
M3.1.12
Communication with other parts of ACBM LTA
M3.2
Semi Autonomous
M3.2.1
Specification /logic LTA
M3.3
Mechanical Manual
M3.3.1
Specification /logic LTA
M4
EH Bolt / Feed Control System
M4.1
Specification / logic LTA
M4.2
Quality of Bolts after delivery from feed system LTA
M4.3
Protection LTA
M4.4
Local conditions preclude standard bolt size
M4.5
Effects of slope on gravity on feed unacceptable
M4.6
Communication with other parts of ACBM LTA
M4.7
Interface with bolter LTA
M4.8
Water/slurry effects on feed system unacceptable
M5
System Control
M5.1
Specification/logic LTA
M5.2
Communication with ACBM systems LTA
M5.3
Operator interface LTA
M5.4
Size & Robustness LTA
M5.5
Compliance LTA including MDG
M5.6
Recovery/back up maintenance LTA
M6
ACBM Manual Controls
M6.1
Specification/logic LTA
M6.2
Manual control complexity/size excessive


Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
A
FAILURE OF ACBM PROJECT DUE TO DESIGN
N
Access / Position Issue
N1
CM
N1.1
Operation
N1.2
Protection of person operating control behind CM is LTA
N1.2 S
Maintenance
N1.3
Regular maintenance access to CM LTA
N1.4
Access to make minor repairs LTA
N1.5
Access to reset CM LTA
N1.6
Breakdown of CM and access LTA
N2
ACBM
N2.1
Operation
N2.1.1
Autonomous
N2.1.3
N2.2
Maintenance
N2.2.2
N3
SC
N3.1
ACBM operator exposure unacceptable (cross-over)
N3.2
SC operator exposed working on ACBM
Definition of Failure
Unsafe
Unproductive
Uneconomic
LTA - Less Than Adequate
A
FAILURE OF ACBM PROJECT DUE TO DESIGN
O
Maintenance Issues
O1
Recoverability of the ACBM LTA
O2
Maintenance information LTA
O3
Component Supply LTA (availability, suppliers)
O4
Component reliability LTA
O5
Maintenance requirements excessive
O6
Maintenance process overly complex
O7
Field Support LTA
O8
Chemical pod installation and UG maintenance process unacceptable
O9
Maintainability of retain required features LTA
P
OH & S Issues
P1
Personal work / task design for ACBM and/or system LTA
P2
Exposure around operating system excessive (dust, noise, vibration, slip/trips, manual handling, chemical, moving parts, etc)
P3
Cable protection LTA
P4
Lighting LTA
P5
Stone dust/ water barriers compliance LTA (routine & barriers)
P6
Hitting exposure unacceptable

Appendix 2

RRD Conceptual Design Drawings

MMM – ACBM General Specifications



GENERAL SPECIFICATIONS

BASE MACHINE

ELECTRIC MOTOR : 75kW×2+30kW+15kW×2
CONVEYING CAPACITY : Max.25t/min(Max.$30m^3/min$)
TRAVELING SPEED : 9.9/19.8m/min
SUPPLIED VOLTAGE : 440V–50Hz
OPERATION : Manual operation (by Electrical) on the machine
TOTAL MACHINE MASS : Approx.55ton

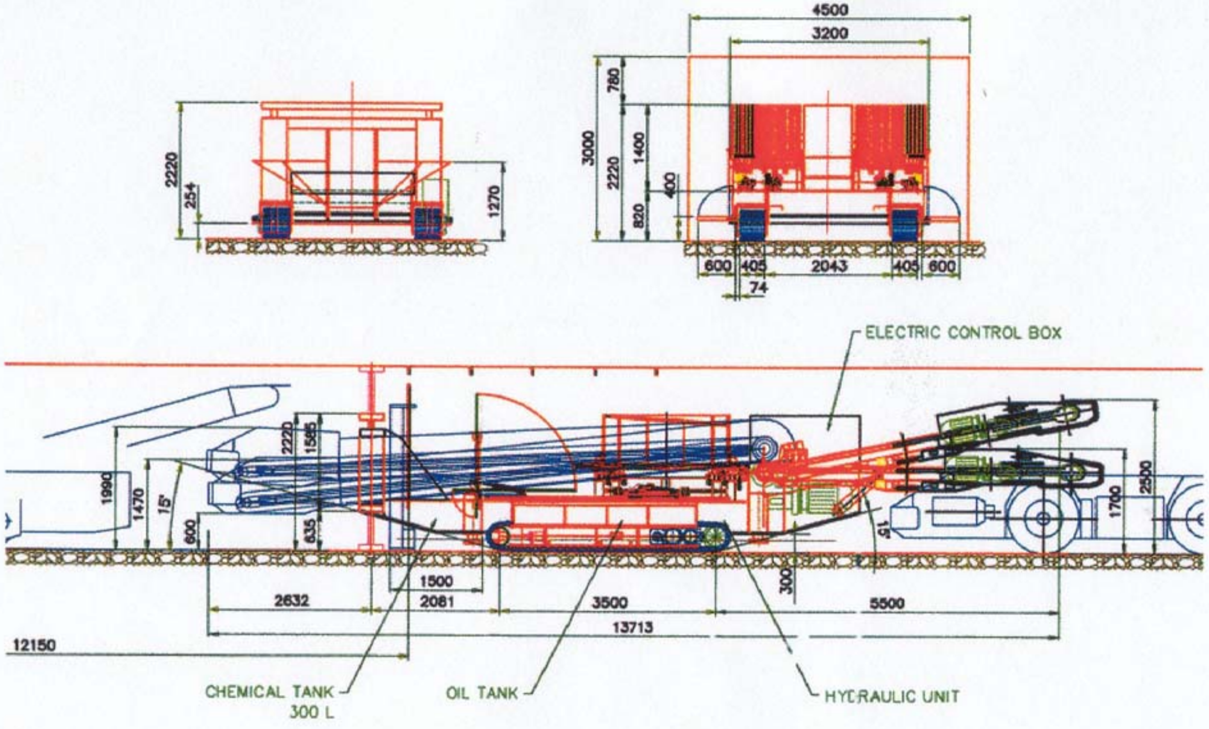
BOLTING EQUIPMENT

ROOF BOLTER : 2.1m×2sets
RIB BOLTER : 1.2m×2sets
OPERATION : Automatic feeding

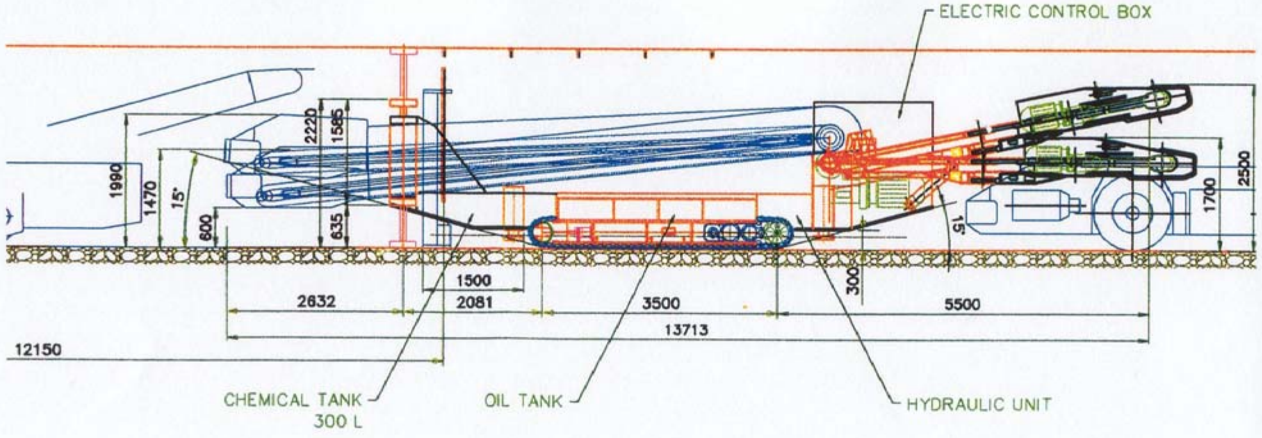
REMARK:

1. The both crawler and Bolting equipments can not be operated at the same time
2. Mitsui Miike would like to recommend the cossette to be replaced by the other machine (ex.Lilter)

MMM – ACBM design showing bolting layout - section



MMM – ACBM design layout – section



MMM – ACBM design layout – plan