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Emerging Trends and Adoption of Standards for Stoppings and Seals in Australian Coal Mines

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ABSTRACT

Strong regulatory changes have been imposed recently on some parts of the Australian coal industry pertaining to the construction of mine stoppings and seals. A study has been undertaken that examines these regulations and compares them with the changing situation in some foreign countries with similar mine layouts and practices. It examines the emerging responses to the regulatory and other changes through an analysis of the results of a comprehensive survey of the operational context of the placement of stopping seals in mines.

These reviews establish the present views of mines and stopping and seal manufacturers as to the current practices, appropriateness of these approaches and future direction. Intrinsic to the successful operation of stoppings and seals is their adequacy as a tool in ventilation engineering. Questions as to the functionality in preventing oxygen ingress, toxic/combustible gas egress and pressure rating of the device or nearby strata are important and need to be examined over the stopping or seal lifetime. An expanded understanding is given of the device as a structural component within the mine system.

INTRODUCTION

There are a number of challenges arising from changes to the regulations covering ventilation control devices in Queensland, Australia. A review of the safety of coal mining operations after the Moura Number 2 Mine explosion resulted in changes to mining regulations in Queensland. Under the new regulations, ventilation control devices (VCD) are required to be tested at "an internationally recognised mine testing explosion gallery" to achieve pressure ratings of 14, 35, 70, 140 or 345 kPa depending on the purpose of the unit.

The issue becomes more acute with the prospect of the state of New South Wales considering a similar approach. Both the Queensland and NSW coal-mining inspectorates have acknowledged that there is a paucity of information on the appropriate selection and use of stoppings and seals in mines. The aim of this study is to examine a number of important aspects of stopping and seal performance, usage, design and application for the practical coal mine environment.

The present views in the industry as to the current practices, appropriateness of these approaches and future directions needs to be established. Intrinsic to the successful operation of stoppings and seals is their adequacy as a tool in ventilation engineering. Questions as to the functionality in preventing oxygen ingress, toxic/combustible gas egress and pressure rating of the device or nearby strata are important and need to be examined over the lifetime of stoppings and seals.

An understanding of the device as a structural component within the mine system is important. What is confinement load on the stopping or seal over its lifetime? How can they be tied into the seam and surrounding strata to act in concert or interrelate with other structural or support components? Are there other materials for construction worthy of consideration?

A literature review on the stopping and seal practices and approaches used in mining industry was carried out. An overview on the currently available practices and acceptable approaches in the operation of stoppings and seals is described. A study has been undertaken that examines the regulations and compares them with the changing situation in some foreign countries with similar practices and mine layouts. It examines the emerging responses to the regulatory and other changes through an analysis of the results of a comprehensive survey of the operational context of the replace of stopping seals in mines.

OVERVIEW ON SEALS AND STOPPINGS

Background

Success in providing adequate ventilation to the active workings of a mine depends on adequate fan capacities, good primary ventilation air distribution and, when the air reaches the working section, good control and distribution of the face ventilation air. General acceptable practices use various ventilation control devices such as stoppings, seals, overcasts, airlocks and regulators arranged so that air flows in the desired manner at appropriate quantities.

In developing a mine, connections are necessarily made between intakes and returns. When these are no longer required for access or ventilation purposes, they should be blocked by stoppings. Stoppings, as defined by Hartman et al (1997), are physical barriers erected between intake and return airways to prevent the air flowing from mixing. Stoppings are classified according to construction, length of service, and purpose as temporary or permanent.

Temporary stoppings are extensively used in areas where frequent adjustment to air directions are necessary. They are moderately airtight and are normally hung in active workings where changes occur rapidly in the mining and ventilation methods. They must be readily movable and are generally reusable.

Permanent stoppings, also called bulkheads, are installed in places where a permanent or a long-term control of flow is needed, such as between the main intakes and returns or belt entries. In the past these have been constructed of frame, sheet metal (prefabricated sections), masonry (stone, brick, or concrete block), or gunite sprayed on wire mesh. Because their purpose is stop airflow for an indefinite period, they must be made airtight by tapping, plastering or caulking and resistant to cracking from blasting concussion or ground movement. Permanent stoppings are also used as fire bulkheads to seal off abandoned workings. Abandoned workings may in time hold toxic or explosive gas mixtures and so these bulkheads must both stop atmospheric mixing and be able to withstand a pressure event.

A seal is a special stopping used to isolate abandoned workings and goafs or as fire bulkheads. Seals eliminate the need to ventilate those areas; they may also be used to isolate fire zones or areas susceptible to spontaneous combustion.

US Stopping and Seal and Stopping Practices and Approaches

In the US prior to the 1990s the normal practice was for stoppings seals to be built according to the specifications of the Coal Mine Health and Safety Acts of 1969 as given in Title 30, Code of Federal Regulations (CFR). Ordinary seal construction practice was to construct two solid block stoppings about 0.3-0.6 m apart and to fill this void with concrete, earth or sand. The stopping should be substantially built so that they are airtight and resist the disruptive forces of explosions. All contraction materials for permanent stoppings and seals being used in the US underground coal mines must meet the standards in terms of non-combustibility, and have the average flexural strength of at least "39 pound per square foot" for three walls. The sealants used must meet the flame-spread index under ASTM E162-87 (Tien, 1996).

An important factor to be considered for any seal design is its impermeability, or its ability to prevent or reduce he exchange of gases from one side of the seal to the other. Measurements of the air leakages across the seals were conducted before and after the explosion tests and compared to Mine Safety and Health Administration (MSHA) established guidelines. These guidelines are as follows: for pressure differentials up to 0.25 kPa, air-leakage through the seal should not exceed 2.8 m^3/min; for pressure differentials over 0.75 kPa, air leakage should be less than 7.1 m^3/min.

Since 1991 MSHA requirements have been that seal design must meet an explosion rating of 140 kPa (20 psi) and in summary are;

- Constructed of solid concrete blocks at least 150 by 200 by 400 mm laid in a transverse pattern with mortar between all joints,
- Hitched into solid ribs to a depth of at least 100 mm and hitched at least 100 mm into the floor,
- At least 400 mm thick. When the thickness of the seal is less than 600 mm and the width is greater than approximately 5 m or the

height is greater than approximately 3 m, a pilaster shall be interlocked near the center of the seal. The pilaster shall be at least 400 mm by 800 mm,

- Coated on all accessible surfaces with flame-retardant material that will minimise leakage.

This standard seal design is illustrated in figure 1. Alternative methods or materials may be used to create a seal if they can withstand a static horizontal pressure of 140kPa provided the method of installation and the material used are approved in the ventilation plan.

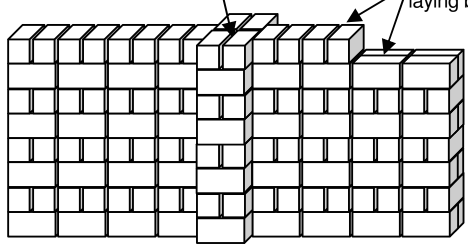

Figure 1. Standard Type, Solid-Concrete-Block Seal (after Greninger et al, 1991).

From discussions with a number of long-wall mine engineers it appears that in most mines the practice is to construct these seals to isolate old goafs in blocks. A number of adjacent longwall panels within a block are extracted in sequence up to a natural barrier or planned long barrier pillar. All longwalls within the block are isolated by sealing where gateroad entries meet the Mains heading. It is not normal practice to seal individual longwall goafs from adjacent panels ie cut-throughs along the chain pillars length are not sealed to isolate one goaf from the next. However some Western states mines with a consideration for spontaneous combustion propensity such as Twenty Mile, San Juan and a new mine in the Fruitland seam in New Mexico, do or are planning to isolate individual goafs by sealing all cut-throughs along the length of the chain pillar. One other company, Jim Walters Resources in Alabama with highly gassy seams also isolates individual goafs for gas management. These are connected with vertical boreholes to the surface with goafs acting as reservoirs for marketing of gas.

In Australia, within Queensland according to Standards for Seals and Airlocks 1996 issued by Coal Operations Branch, Safety and Health Division, Queensland Department of Mines and Energy (QDME), four specific elements must be addressed when installing seals. These are

- design and specification,
- location,

- construction, and
- maintenance and monitoring.

Depending on the purpose or intent of the seal and its location, different design criteria are recommended by QDME. These recommended design criteria are listed in Table 1.

Table 1 Queensland Approved Standard for Ventilation Control Devices.

Design Criteria	Location	Purpose or Intent
Type A (2 psi) 14 kPa (Recommended)	Limited Life Production Panel	All VCDs installed are to remain "fit for purpose" for the life of the panel and be capable of withstanding an overpressure of 14 kPa.
Type B (5 psi) 35 kPa (Recommended)	Main Roadways	All VCDs constructed as part of the main ventilation system are to remain "fit for purpose" for the life of that area of the mine and always capable of withstanding an overpressure of 35 kPa.
	Sealed Areas	For use in mines where the level of naturally occurring of flammable gas is insufficient to reach the lower explosive limit under any circumstances.
Type C (20 psi) 140 kPa	Sealed Areas	For use in all circumstances not covered by Type B and D seals.
Type D (50 psi) 345 kPa	Sealed Areas	When persons are to remain underground whilst an explosive atmosphere exists in a sealed area and the possibility of spontaneous combustion, incendive spark or some other ignition source could exist.
Type E (10 psi) 70 kPa	Surface Infrastructure	Surface entry stoppings for temporary emergency use and may include - Surface air locks - Main fan housing

Many countries have pursued research in explosion-resistant structures for underground mining. These include the US, Australia, South Africa, France, Germany, Poland and China. In the US extensive research in the last decade explosion testing of mine seals has been underway. The Pittsburgh Research Laboratory's (PRL) of the National Institute for Occupational Safety and Health (NIOSH) and MSHA have been jointly investigating the ability of various existing and new seal designs to meet or exceed the requirements of the CFR. Extensive explosion and air leakage tests on alternative seal designs have been conducted at the Lake Lynn Experimental Mine (LLEM), PA (Triebsch and Sapko, 1990).

Alternative seal designs and types that have been evaluated included (Sapko et al, 1999):

- Solid concrete block seals (Greninger et al, 1991);
- Modified solid concrete block seals (Weiss et al, 1993);
- Bulk cementitious (expanding) seals with various compressive strengths (Weiss et al, 1993 & Greninger et al, 1991);
- Low density block seals (Stephan 1990);
- Composite Polymer seals made from block walls that enclose

gravel and polyurethane foam (Weiss et al, 1996);

- Reinforced cementitious seals (using steel mesh) that are anchored to the ribs, roof, and floor with bolts and made with high strength cement with varying curing times (Weiss et al, 1999).

MSHA over the years has approved various materials and type of construction methods such as solid concrete blocks, Omega 384 foam blocks, cementitious foams and polymer foams. These seal designs are classified into several categories depending on the similarity of the construction materials used.

QUESTIONNAIRE SURVEY OF SEALS AND STOPPINGS

In order to achieve a better understanding of the type and properties of seals and stoppings currently being marketed and approaches to engineering design of these structures, separate surveys of Australian manufacturers and underground mine seal/stopping usage was undertaken. Fourteen mines and seven manufacturers responded to these surveys.

Mine Survey Questionnaire

A seven page questionnaire was mailed to select Australian coal mines. In brief the following information was sought.

1. Mine operation and production details including extraction methods used, annual production, extraction depth, working seam thickness, development and panel extraction heights.
2. Ventilation network details such as main fans, underground ventilation monitoring systems, types and numbers of sensors installed, seam gas type and quantity, gas drainage system, gas concentration in ventilation air and possibility of spontaneous combustion.
3. Specific questions are asked on whether extracted areas on sealing pass through the explosive range, final atmospheric condition in sealed area, records on behaviour after sealing, consideration of induced inertisation, ventilation simulation software used and panel bleeders and their arrangements.
4. Information was sought on approaches prior to 1997 to installing VCDs.
5. Information was sought on current approach to installing VCDs.
6. Additional information was sought on geomechanics properties such as Uniaxial Compressive Strength of roof, floor or coal seam, vertical/horizontal stress relationship and cleat direction on stopping integrity; structural properties of seals or stopping; stress time dependent relationship through life of seals, stopping or VCDs.
7. Views were sought in the final section on issues such as sources of

explosion, pressure disturbance or air blast, should a seal be designed as an impervious membrane or as an explosion barrier or both, design and testing of seals, stopping and VCDs, opinions on Queensland explosion rating codes, structural analysis or physical destruction testing, pressure balancing of a sealed area, barometric pressure influence, intake air passing a sealed area and contractors vs company labour installing VCDs.

Manufacturer Survey Questionnaire

A seven page questionnaire was mailed to select stopping and seals manufacturing companies. In brief the following information was sought.

1. Products details including under what extraction methods the products are used, and minimum and maximum mine opening height applicable.
2. Current stopping and seal products against locations of installation. Questions were also asked on other technical issues relevant to VCDs such as strength, stiffness and leakage characteristics.
3. Products applications, design and testing information, including testing and rating approaches, design approaches for varying dimensions, geomechanics considerations, and effects of door installation and additional supports.
4. Additional information was sought on stress time dependent relationships through life of products, mine life span of products before integrity is lost, historical data on gas concentration vs time trends, induced inertisation, and the ability of products after a significant mine pressure event.
5. Opinions were sought in the final section on issues such as sources of explosion/pressure disturbance/air blast, should a seal principally be designed as an impervious membrane or as an explosion barrier or both, rib seal behaviour as ground load imposed, in-mine leakage tests, views on the Queensland explosion rating code, design and installation approaches.

SURVEY RESULTS SUMMARY AND ANALYSIS

Mines' Survey

A total of 14 mines were visited and surveyed, seven from each of NSW and Queensland. Ten mines surveyed used longwall extraction method, two used room and pillar method only and two used both methods.

Seven mines have annual production rate of more than 3 mtpa. Average development height is 3.0 m with a range varying from 2.3 to 4.0 m. Penal height averaged 3.3 m with a range varying form 2.1 to 4.5 m.

Gas and ventilation information Five mines have very low seam gas present (<2 m^3/tonne), three are low (3-5 m^3/tonne), two moderate (5--10 m^3/tonne) and four are high (>10 m^3/tonne). Half of the mines surveyed have some forms of gas drainage systems such as pre-drainage, in-seam drainage and post drainage in place.

Of 14 mines surveyed, 9 mines indicated that their sealed goaf areas could be expected to pass through the explosive range. Eight mines have low and the rest moderate potential for spontaneous combustion. Seven mines surveyed have historical data on gas concentration vs time trend data. Three mines have considered use of induced inertisation. Four mines used “Full Panel Bleeder”, another four used “Peripheral Bleeder” and the rest did not incorporate panel bleeders in their ventilation systems.

Pre 1997 VCD approaches Mines were asked usage pattern of seals and stoppings before 1997 and currently. Prior to 1997 for belt road segregation, two mines used brattice, two plasterboard, one sheet metal or reinforced cementatious, one mortared block and the rest use nothing. To separate Mains intake or belt from return, four mines used reinforced cementatious, six mortared block and two plasterboard. To separate intake from belt air in panel gateroads, seven mines used plasterboard, two block, two reinforced cementitious and one sheet metal.

For final panel seals providing separation from adjacent panel air, four mines used block, three plasterboard, two low density block, and one reinforced cementitious material. For final panel seals providing separation form Mains, four mines used mortared block, two plasterboard, two block, one reinforced cementitious and one composite polymer material. For overcast applications, nine mines used pre-fabricated steel, two block, one sprayed brattice, and two reinforced cementitious material.

Current VCD approaches Currently for belt road segregation, two mines use brattice, two reinforced cementitious and two mortared block, one block and the rest of mines use nothing. To separate Mains intake or belt from return, five mines use reinforced cementatious, five mortared block, one composite polymer, one bulk cementitious and one low density block. To separate intake from belt air in panel gateroads, five mines use plasterboard, three block, three reinforced cementatious, one bulk cementitious and one sheet metal.

For final panel seals providing separation from adjacent penal air, four mine use reinforced cementatious, three bulk cementatious, two composite polymer, one block and one concrete plug. For final panel seals providing separation form Mains, seven mines use reinforced cementitious and three composite polymer, two bulk cementatious, one concrete plug and one block. For overcasts applications, nine mines use prefabricated steel, two block, one sprayed brattice and two reinforced cementatious.

Views on seals and stoppings Only four mines had information about structural properties of their seal products. Half (seven) of the mines have information about stress vs time dependent relationship through the life of their seal or stopping products. Eleven mines indicated face ignition to be the anticipated main source of major pressure disturbance and two mines indicated air blast. seven mines indicated that seals should be designed as both impervious (leakproof) and explosion-proof and six mines indicated design for sealing (leakproof) is most important.

Nine mines consider design should be mainly through structural analysis, Two support physical testing and two indicated both should be considered. When asking views on the Queensland rating code, two mines support this code, three mines consider focus should be on sealing ability, four mines were concerned with the validity of tests required for the rating code and one was concerned with how old stopping should be handled.

Only five mines utilised the concept of pressure balancing sealed areas. Half of the mines have taken account of barometric pressure influences on sealed areas and most of them also monitored sealed areas. In term of views on prohibition on "intake air passing a sealed goaf", half of mines agreed and the other half disagreed. Nine mines indicate preference to use contractors and only three prefer mine labours for installing VCDs as they have concerns with quality and time vs cost issues.

Manufacturers' Survey

All seven stopping and seals manufacturers responded were located in NSW. The majority of the manufacturers are relatively new in business. All manufacturers except one supply products for longwall, room and pillar, gateroad, mains development and other applications. Average minimum mine opening height to install their seal and stopping products is about 2.0 m with a range varying from 1.2 to 2.7 m and average maximum height is about 4.6 m with variation ranging from 3.0 to 6.0 m.

Design and testing information Four manufacturers have had their seal and stopping products tested at the LLEM facility. Three have had their products tested at the Londonderry TestSafe testing facility, NSW. Two manufacturers also use scaled model testing or engineering model rating for their products. All surveyed can have doors installed in their stopping and claimed no effect on integrity but no test data published. All except one have own (proprietary) approaches to designing for varying height and/or width dimensions of stopping and seal. All manufacturers have products that can be installed alone. Some manufacturers have products can be both stand alone or adjacent to supports. All responding claim that their seals or stoppings are designed to meet at least part of the VCD rating codes.

Five manufacturers claim to use some knowledge of geomechanics considerations in their product design processes. Six respondents claim that products are designed to have the same ability to withstand a force from front and back. Most of the manufacturers except one have information on mine life span of their products before integrity is lost. Most of manufacturers have been involved in sealed area induced inertisation. Five have information on product ability to function adequately after a significant mine pressure event.

All except one believe that a seal principally should be designed as both as an impervious membrane and as an explosion barrier. All manufacturers surveyed believe that their products would maintain rib seal as ground load is imposed. Five are aware of some in-mine leakage tests undertaken on seals/stopping by manufactures or others. Most of the manufacturers are aware of some literature or guides on how to undertake accurate in-mine leakage tests and referred to test procedures used by LLEM or TestSafe.

Views on design and testing In general most accept that some industry regulations or standards would benefit in terms of safety. One suggested that rating codes should be standardised across Australia. There are some doubts concerning the 14 and 35 kPa stopping standards and how these were determined.

A divided view exists on whether design should be principally through design structural analysis or physical destruction testing. One suggested that design should be based on physical destruction tests alone. Another suggested both physical testing and structural analysis for seals but for stoppings structural analysis is sufficient. Two suggested that Australia needs a rating test facility meeting agreed guidelines as LLEM test procedure is considered flawed. About half of the manufacturers prefer products installed by own labour to maintain quality.

GEOMECHANICS CONSIDERATIONS

The load placed on a cut-through stopping or seal can be examined through chain pillar and intersection loading cycle stress analysis. A recently completed ACARP study (Colwell, 1998) examined conditions in this regard, compared US and Australian conditions and undertook site measurements at Central, Crinum, Kenmare, Newstan, West Wallsend and West Cliff collieries. These findings have relevance to the stress placed on a newly formed Longwall panel seal and the subsequent loading history. The in-situ coal strength is taken to be a constant of 6.2 MPa. Mark and Barton (1996) discussed the role, if any, of the laboratory compressive strength of coal specimens in pillar design. They indicated that the strength values obtained in this manner couldn't be used in a meaningful way in pillar design. This is not to say that the in-situ strength of all US coal is the same. Their study simply concluded that for pillar design purposes uniform coal strength is a better approximation of average pillar strength than one based on laboratory testing. Salamon et al (1996) suggested that the results of University of NSW study support the same conclusion.

The total vertical load transmitted to a chain pillar during the extraction process is a function of some measurable factors and some subjectively determined aspects. These include depth, overburden density, distribution of load between chain pillar, longwall face and adjacent unmined block, position of faceline relative to chain pillar, overburden caving characteristics, spanning characteristics of strata overlying goaf, and roof and floor strength/structure.

Pillars that lie between two longwall panels will experience greatest vertical loading and account for bulk of chain pillars in series of panels. As a longwall laterally approaches and retreats past a chain pillar a dynamic loading cycle is experienced. This incorporates the development load plus the onset of a front abutment load as face approaches pillar. The abutment load increases as face retreats outbye to become a side abutment load - this rises to static maximum.

As the adjacent longwall retreats these chain pillars in the tailgate go through a second dynamic loading cycle. This incorporates development load and first side abutment load plus the onset of a second front abutment load. Second load is estimated as 70 percent of first. Double goafing conditions apply once the second longwall face retreats to a distance sufficiently removed from the pillar. Figures 2 and 3 indicate instrument measuring points and loading pattern on a chain pillar. Stress profiles across the pillar are shown for the initial condition when the pillar forms part of the Main gate access to the Longwall panel and subsequently a panel cycle later when it carries additional load as part of the Tailgate heading.

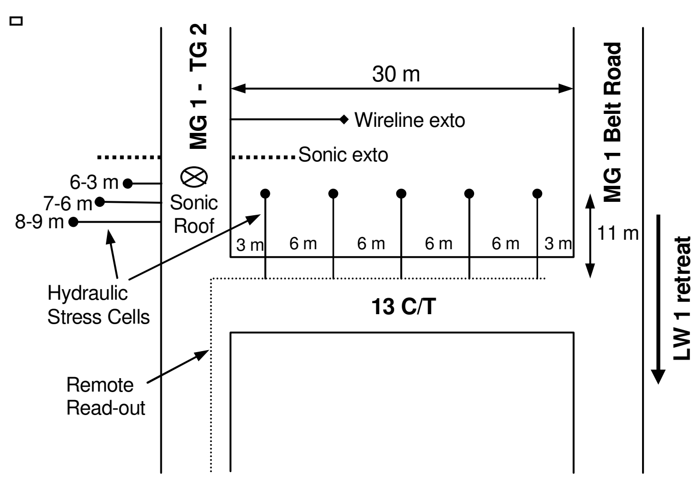

Figure 2. Typical instrumentation layout (after Colwell, 1998)

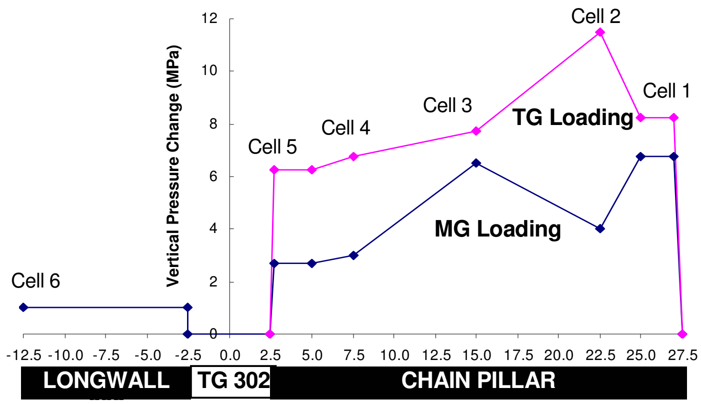

Figure 3. Maingate and tailgate stress profiles (after Colwell, 1998)

CONCLUSIONS

There is no doubt that the introduction of Queensland regulations has forced attention on the use design and installation of stoppings and seals. Based on the survey results, mines across Australia have improved the quality of stoppings and seals installations in recent years. Australian seal and stopping manufacturers operate in a competitive market and provide the range of products available in the US. US stopping and seal general practice is the same as that being implemented in Queensland in terms of provisions for sealing completed goaf blocks against Mains. However, other US approaches in use for stoppings and seals significantly differ to current Queensland practice. Questions on seal explosion and leakage ratings, geomechanics consideration and approaches to design need to be addressed to ensure that VCDs are sensibly designed, tested and installed.

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