The Evolution of Sealing Practice under the Principles of Risk Assessment Criteria Appropriate to Individual Mines

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ABSTRACT

The US Sago mine disaster in 2006 caused mine seals to be destroyed by an atmospheric explosion. Investigations into the appropriateness of seal strength requirements to withstand a pressure event followed. New designs have been developed and various changes in US regulations implemented. Australian reviews of coal mine safety in the mid 1990s after the Moura Number 2 explosion in a similar way directly resulted in changes to management of hazards in Queensland.

An Australian industry funded research project has been undertaken with one of the main objectives being to examine views of Australian operating mines on the industry's approach to the use of seals; also the new US approaches to sealing and their possible application to Australian conditions. The research is current and results interim. While in many ways approaches to underground coal mining in Australia and the US are similar, Australian approaches to the management of hazardous mine atmospheres differ significantly. Australian risk management approach to handling hazardous situations implies adoption of international industry best practices. There has been a move for Australia to consider and possibly adopt new US standards for seal pressure rating codes. The Australian industry has gone through a debate on how the new US information on seal behavior and new regulations should be incorporated, if at all, into Australian practice. However the industry as a whole, including mines' management, state inspectorates and mining unions have decided not to adopt the principal dictates of the 2008 US seal regulations.

The second part of the project is undertaking further study of the risk of explosions in sealed areas. This propagation tube study of the consequences of explosions is being conducted to both determine the nature of the explosion overpressures that a structure can be subjected to and also the nature of the pressure pulses that will impact on the structure. During the tube studies an analysis of nine possible mine scenarios where a methane explosion could occur has been made.

KEYWORDS: Ventilations control devices, Seals, Gob, Explosion

INTRODUCTION

The US Sago mine disaster in 2006 caused seals to be destroyed by an explosion. Following the disaster investigations were launched into the appropriateness of seal strength requirements. Various studies have subsequently been undertaken, new seal designs have been developed and various changes in US regulations implemented. It is recognized that the US studies have advanced understanding of issues. The key US changes to US Mine Safety and Health Administration (MSHA) federal regulations has been to increase the pressure rating of seals installed in coal mines from 140 kPa to 840 kPa (or to 350 kPa if the gob being sealed is being monitored under real time gas analysis and inertization facilities are available to control a hazardous event).

Similar Australian reviews of the safety of coal mining operations in the mid 1990s after the Moura Number 2 mine explosion resulted in changes to hazard management in Queensland. Australian approaches are formulated on a risk assessment basis under which hazards must be identified and appropriate "world's best practice" systems adopted. The principal approach in Australia to gob management is early prevention of hazardous situations through use of real time gas monitoring from the gob periphery to ensure the maintenance of gob inert atmospheric conditions. Another line of defense is having inert gas systems on hand (most commonly jet or diesel engine exhaust, nitrogen or CO_2) to proactively ensure potentially explosible gas concentrations cannot form or are handled appropriately. The final approach is through use of well engineered seal structures constructed to segregate all worked out areas where there is any likelihood of explosible gas concentrations occurring. Seals on gassy gobs most commonly are designed to meet a 140kPa rating.

INDUSTRY QUESTIONARIOUS SURVEYS

A comprehensive and representative survey of a large number of Australian mines has been undertaken to establish how mine managers are handling seal design and implementation. Fourteen mines were included in the survey, seven from each of Queensland and New South Wales and the basis of the survey was an interview questionnaire completed at site. In brief the following information was sought.

1. Ventilation network details such as main fans, underground monitoring systems, types and numbers of sensors installed, seam gas type and quantity, gas drainage system, gas concentration in air and possibility of spontaneous combustion.
2. Specific questions asked on whether sealed areas pass through the explosive range, final gob atmospheric conditions in sealed area, records on behavior after

sealing, permeability and pressure issues, consideration of induced inertisation, and use of panel bleeders and their arrangements.

3. Specific questions on possible dimensions for explosion propagation, propensity for propagating explosion and probability of explosion.
4. Information on current approach to installing Ventilation Control Devices (VCDs) and seals such as Mains separating intake from belt air, Mains separating intake or belt air from return, panel gate roads separating intake from return, final panel seals providing separation from adjacent panel air, final panel seals providing separation from Mains air and other seals separating air.
5. Information on ground stress relationships and seal integrity, structural properties of seals and stress time dependent relationship through life of seals,.
6. Views were sought in the final section on the following issues:
   i) Sources of explosion, pressure disturbance or air blast,
   ii) Should a seal be designed to as an impervious membrane or as an explosion barrier or both?
   iii) How seals, stopping and VCDs should be designed and tested and opinions on Queensland 14/35/70/140/350 kPa rating codes.
   iv) Should design be by structural analysis or physical destruction testing?
   v) Pressure balancing of a sealed area and how to achieve, barometric pressure influence and intake air passing a sealed area.
   vi) Contractors vs company labour installing VCDs.

RELEVANT US DIFFERENCES WITH AUSTRALIAN MINES

Some of relevant differences of US underground coal mines compared with Australian mines are as follows. In the US:

- Most US Longwall Gate roads have three Headings. The middle Heading when within the Gob can be expected with a gas initiation to lead to an explosion disturbance characterized by a long run-up distance. This compares with Australian practice of normal use of two Headings.
- Significantly lower take up of electronic monitoring
- Only one mine makes use of “Tube bundle” gas monitoring
- Little proactive use of inertisation
- Limited use of ventilation network programs
- Limited usage of trained Ventilation Officers
- Extraction in US of thinner seams common; these mines leave less coal in gob
- Seals placed along Mains but generally not along chain pillars separating panels

Figure 1 shows a typical longwall district (series of longwalls) and panel sealing practices in US longwall mines. Multiple seals may be constructed against the Mains or SubMains at the mouth and bleeder ends of the panel after a longwall is mined out and the tailgate is no longer needed. A mined-out longwall panel district may then be closed off by constructing seals across Mains, SubMains, and bleeders at the proper location. This type of sealing is referred to as “delayed panel sealing” and is common where there is low risk of spontaneous combustion as shown in Figure 1.

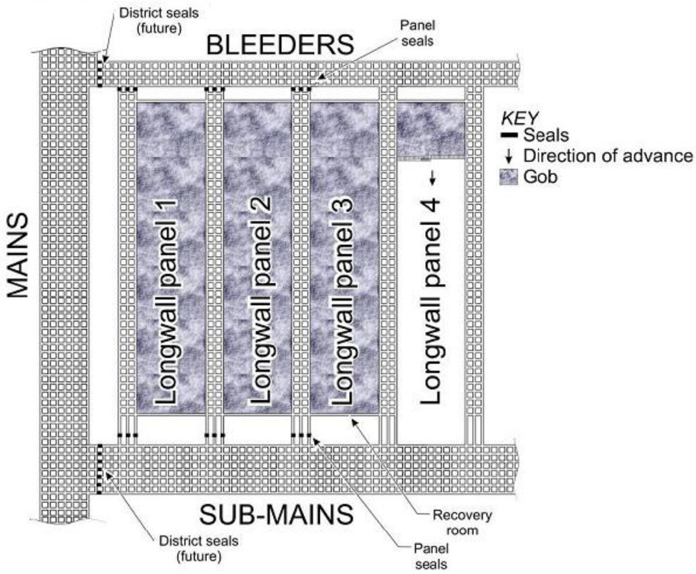

Figure 1 Typical district (series) and panel sealing practices in US longwall mines (after Zipf, Sapco and Brune, 2007)[1].

Where spontaneous combustion is a potential problem as occurs in some Western US states, longwalls may undertake “immediate panel sealing” with seals constructed in every crosscut nearest the gob down the Headgate entries immediately behind the longwall face. The newly formed mined-out area is substantially isolated from oxygen soon after mining, thereby decreasing the risk of spontaneous combustion problems. Depending on the length of the longwall panel, 50 to 100 seals might be constructed as the panel is mined.

In Australia, “immediate panel sealing” is used in the majority of mines especially in Queensland. Use of bleeder roads is not as prevalent as in the US. Figure 2 shows typical district (series) and panel sealing practices in Australian longwall mines.

1 Zipf, Jr. RK, Sapko, MJ. and Brune, JF. 2007 Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines, IC 9500, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Pittsburgh, PA.

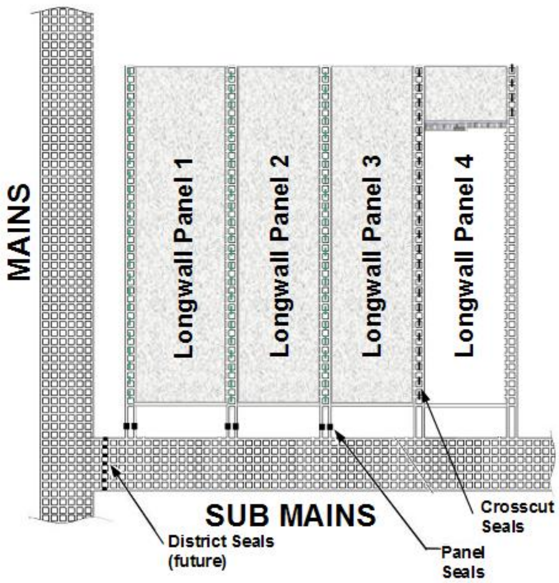

Figure 2 Typical district (series) and panel sealing practices on Australian longwalls

In comparing US and Australia some other issues of relevance are that in the US:

- Currently many changes are occurring in the handling of mine atmospheres and potential flammability conditions as a result of the Sago Mine disaster.
- There are a large number of small mines.
- MSHA adopts a system of "prescriptive regulations" and in general there is lower acceptance of risk assessment approaches.
- There is a perceived lack of trust between managers and inspectors and less working together of the two groups; the role of unions is less.
- US underground industry is diverse and larger; as a result the industry is less cohesive and there is less availability of data, less sharing of information and less frequent industry forums.

SURVEY RESULTS ANALYSIS

Of the 14 mines surveyed 13 used longwall extraction while one uses room and pillar method only. Of the longwall mines, five mines have Run of Mine coal production of more than 4 mtpa, three mines have 3 to 4 mtpa, two mines have 2 to 3 mtpa and the rest of mines have less than 2 mtpa. Production from these surveyed mines represents about 46% (43 mt) of total Australian longwall production of 92 mt in 2007. For the final Chain Pillar seals providing separation from adjacent panel air, it was found that

- The one Room and pillar mine uses no seals.

- Eight mines use 140kPa rating.
- One mine uses 70kPa rating.
- One mine uses 35kPa rating.
- Two mines use Nitrogen balance chambers with a cross-cut space formed with one seal rated at 35kPa and the other at 140kPa.
- Two mines use cementitious seals or plaster board stoppings with sealed joints meeting no rating standard.

For the final panel seals providing panel separation from Mains air, it was found that

- Five mines use 350kPa rating.
- Four mines use 140kPa rating.
- Two mines use 35kPa rating.
- One mine uses 140kPa but may move to 350kPa in the future.
- Two mines use Nitrogen balance chambers with seal ratings as above.

In summary all mines were receptive and positive to sharing information. Gob management is proactive with universal use of risk assessment methodologies. Gob atmospheres are complex and changing; gas concentrations vary across the gob and some move in and out of explosibility ranges. There is a good understanding of

- sealing purpose (stated as to separate the gob atmosphere from adjacent ventilation network air),
- diurnal atmospheric changes, pressure effects and seal limitations and leakage.
- geomechanics issues related to the key structural member – the roof, ribs and walls, floor and the seal itself.

Almost all mines mentioned that they have had seals that became defective over life. It is recognized that chain pillars crush out leading to atmosphere connectivity. All mines (including those with only two Heading Gate roads) have voids within sealed gobs of longer than 50m. More information is needed on gas concentration data across the extent of gobs; it cannot be assumed that gas composition is the same along the length and breadth of individual gobs. Many of the gobs record significant CO_2 that occurs in mines either as a seam gas or as a product of oxidation and it is considered that as CO_2 is an inerting gas and reduces the likelihood of an explosion its existence should be taken into account in determining risk of a gob ignition.

VIEWS ON US CHANGING APPROACHES

When asked about the US changing approaches on seals and adoption of new MSHA regulations it was found that majority of mines agreed that the Australian industry should stick with what appears to work best for the conditions for Australian industry. Industry should use appropriate risk levels for seal design. The proposed new 840kPa seals design in the US are considered excessive and the US move to this rating an overreaction. Regardless of application of seal pressure rating requirements it is impossible to contain some explosions in the highly variable mine environment. The introduction of prescriptive US seal pressure ratings does not appear to have been formulated on any risk assessment basis. There are impressions that US (in almost all cases without realtime monitoring systems in place and relying on periodic "bag" sampling) is coming from a lower standard to current Australian practices. There is a perception that the US appears to have a different approach to the way Australian mines manage gobs. It is considered that US should move to use of gas monitoring and prevention of situations in which a gob atmosphere can ignite.

Australian approaches to health and safety management are formulated on a risk assessment basis under which hazards must be identified and appropriate "world's best practice" systems adopted. The principal approach in Australia to gob management is early prevention of hazardous situations through use of real time gas monitoring from the gob periphery to ensure the maintenance of gob inert atmospheric conditions. Another line of defense is having inert gas systems on hand (most commonly jet or diesel engine exhaust, nitrogen, CO_2 or CH_4) to proactively ensure potentially explosible gas concentrations cannot form or are handled appropriately. The final approach is through use of well engineered seal structures constructed to segregate all worked out areas where there is any likelihood explosible gas concentrations occurring.

In undertaking risk assessments a number of Australian companies have expressed that they do not consider US new approaches are "world's best practice". The comment has been made that the US approach of principally and almost exclusively considering "seal rating" is one of "guarding against failure rather than adopting an approach of prevention". There appears to be a consensus among mine operators, inspectorates and union leaders that Australia should not blindly go down the path of copying US current and post Sago sealing practices.

CONCLUSIONS FROM INPUT TO SURVEY

From survey results analysis and recent Australian debate on the topic it is concluded that seal design should start from premise that it is impossible to build a perfect seal.

- Seal designs must be determined using priorities from risk assessment of particular situations. Risk levels should meet ALARA (as low as reasonably achievable) with health and safety conditions expectations of less than
    - 1 death per million miner days of work

    - Less than 10 deaths per 10 million miner days of work
    - Never more than 10 miner deaths
- There is no known evidence of a mine atmosphere explosion detonations; every mine explosion has remained within the limits of a deflagrations.
- Seal should be rated to "seal" and not on structural applied pressure loading (to keep gob gases out of ventilation air and oxygen out of gobs).
- Monitoring of gob atmosphere and requirements for inert gases is critical.
- Mines with low gas levels should not face onerous conditions. Mines with potentially explosible gases need to monitor, respond and control. It is believed that "one rule is not appropriate for all situations".
- Seals must be competent engineered structures that normally meet 140kPA pressure rating.
- More understanding of mine strata geomechanics is needed; structural analysis should take account of the properties and behavior of the strata surrounding the seal and maintain a low leak interface with coal seam and surrounding strata.
- More understanding of gob gases ignition potential is needed. More information is needed on the variability of gas concentration data across the extent of a gob; it cannot be assumed that gas composition is the same along the length and breadth of individual gobs.

SIMTARS TEST WORK

The Queensland group SIMTARS is part of the study and work on the consequences of such explosions is being conducted in a propagation tube as part of the effort to determine the risk of explosions in sealed off areas. This is being investigated not only to determine the nature of the explosion overpressures that a structure can be subjected to but also the nature of the pressure pulses impacting on the structure.

An analysis of possible scenarios in a mine was made and indicated that there were nine different situations where a methane explosion could occur in a mine. The most probable of these scenarios was a high length to diameter ratio roadway that would be full or partially filled with an explosive mixture. If an explosion occurred in the workings of the mine the roadway would not be enclosed and in the case of an explosion occurring behind a seal the roadway would be enclosed. Tests in the propagation tube (as shown in Figure 3) were designed so that varying parts of the tube were filled with an explosive mixture and the tube was left open or closed off with structure that withstood or failed under the pressure.

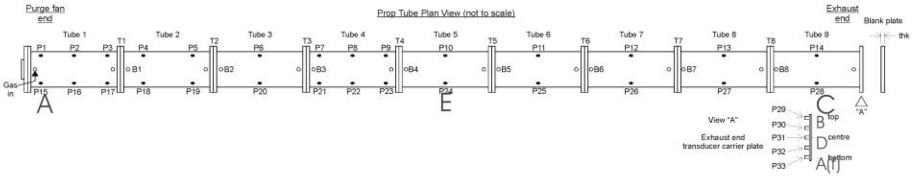

Figure 3 Layout of the explosion propagation tube at SIMTARS

Even though it could be argued that mine scale larger galleries with greater volume are more suitable for this type of study the propagation tube is nevertheless deemed appropriate for the following reasons. It has been proven that the maximum constant volume pressure is determined by the temperature of the burning gases in the container and not by its volume. The nature of the volume or space in the container might however influence the temperature that can be reached. The level of instrumentation on the tube allows significant information with regard to the pressures to be gathered. The tube allows a high rate and multiple daily firings to be conducted. The tube has design strength of 2 MPa and can be closed with a strong structure to allow a contained constant volume explosion with a stoichiometric mixture. The tube at 30m long and 0.5m diameter has high length to diameter ratio. This allows simulation of compression of unburnt gases before the explosion front. Due to availability of natural gas it is being used as fuel rather than pure methane.

The structures that were used consisted of plywood of varying thicknesses that was firmly bolted to the front of the end of the tube. Just inside of these structures there is a set of pressure and force transducers. The force transducer measures the dynamic pressure of the pressure wave and also gives a very good indication of when the air started moving after the structure failed. As the pressure transducer at the end of the tube was directed into the incoming pressure wave it would read the total pressure whereas the pressure transducers that was at right angles to the pressure wave and placed in the walls of the tube would read the static or omni-directional pressure. In the testing process no attempt was made to generate a detonation even though obstructions can be placed in the tube to cause increased turbulence. To date tests have been done with varying numbers of sections up to a maximum of six out of the nine sections being filled with an explosive mixture. For any filling of more than one tube the extent of the flame is beyond the end of the tube. It is proposed to conduct a full closed volume test in future. The strength of the structures was increased with each series of tests using a constant length of sections. by increasing the thickness of the plywood until the explosion was contained in the tube by the structure.

Characteristics considered to be of importance notwithstanding variance caused by changes in explosive energy and structure strength are as follows.

- The maximum pressure generated by constant volume explosions was less than the theoretical or calculated pressures for the test conditions. In the absence of any evidence of significant leakage the opinion was reached that the temperature has a significant effect on the pressure reached by the explosion. Efforts are presently directed to confirming the temperature effect.
- There is a very close correlation between the total pressure that is measured at the end of the tube and the sum of the dynamic pressure at the tube end and the omni-directional pressure in the last tube. This supports the theory that the total pressure is comprised of the dynamic and omni-directional pressures. It also indicates that there is no measurable reflected pressure generated by the explosive pulse It was also evident that the structures failed due to being subjected to an increasing pressure caused by compression of gas due to deflagration rather than being subjected to the impact of a blast wave.
- The pressures that were measured when structures were broken indicated that during the period of the explosion and directly after, there was a significant larger total pressures measured after the structure had broken than at the point in failure. The point of failure can be determined on the pressure traces as there is no flow of gases as measured on the dynamic sensor prior to the failure. This increased total pressure is caused by the increase in dynamic pressure at the tube end caused by a rapid increase in the outflow of gases. The work in the tube has indicated that the flow of gas through a breach in the structure and the original pressure is related but not necessarily proportional to each other.
- The omni-directional pressure measured when the tube is not closed off does not seem to be much influenced by the volume of gas used in the explosion. This pressure would be a function of the friction in the tube as well the inertia of the unburned gas column When the tube is closed off the pressure measured on the total and omni-directional pressure sensors for a specific volume of explosive gas is proportional to the strength of the installed structure. In the event that the structure does not fail the total pressure is proportional to the volume of flammable mixture in the constant volume formed by the enclosed tube.
- The increase of total pressure that occurs after the release of gas following the failure of the structure is caused by the unburnt portion of the gas mixture burning after being compressed by the reflection of the pressure wave back from the structure in the tube. The ignition of this “piling” effect occurs after the structure has failed and thus causes a significant increase of gas flow in the opening.

The initial findings have given a new understanding to the complex ways deflagrations act on structures. Sufficient evidence exists to warrant further in depth investigations. These fundamental characteristics will assist in drawing up measures that will assist in mitigating the effects of pressures of explosions on seals.