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# TESTING AND USAGE OF VENTILATION CONTROL DEVICES WITHIN THE AUSTRALIAN COAL MINING INDUSTRY

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## ABSTRACT

This paper summarises an evaluation of an existing Australian explosion research facility in order to examine its suitability for determining the explosion resistance of ventilation control devices (VCDs). A combination of computational fluid dynamics (to model the methane/air explosion through time and space), finite element analysis (to model the structure's response to the pressure impulse) and measurements from full-scale tests were used in this study. Comparisons were made between the theoretically predicted, practically measured results and those found for the same designs tested at an established experimental mine, namely the Lake Lynn Experimental Mine (LLEM).

This paper also summarises the results of a survey of current Australian coalmine ventilation practices. Information was obtained of practices both before and after the introduction of new QLD coalmine ventilation regulations.

The research has shown that the TestSafe Australia Explosions Gallery is acceptable for testing of VCDs up to 70 kPa. This facility proved unsatisfactory for high-pressure tests on seals. Options for the verification of the explosion resistances of high-pressure seals are given.

## KEYWORDS

seal, stopping, bulkhead, ventilation, explosion testing, explosion modelling, structural modelling, mining, coal.

## INTRODUCTION

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. Generally acceptable practices use various VCDs such as stoppings, seals, overcasts, airlocks and regulators arranged so that air flows in the desired manner at appropriate quantities. A stopping, as defined by Hartman et al (1997), is a physical barrier erected between intakes, returns or abandoned mine voids to prevent air from mixing. 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.

A review of the safety of coal mining operations after the 1994 Moura Number 2 Mine explosion resulted in changes to mining regulations in Queensland, Australia. All ventilation control devices were now 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. These changes highlighted the lack of information on the appropriate selection and use of stopping seals and the strategic need for the development of a full-scale explosion test facility within Australia.

The main aim of the project was to examine if an existing Australian explosion research facility could be used for full-scale explosion resistance type testing of VCDs at high and low pressures. Computer modelling was conducted of the explosion impulses and their effects upon VCDs. Comparisons were made between the theoretically predicted and practically measured results. These results were compared to those found for the same designs tested at LLEM.

It should be noted that the LLEM test appears to be designed around the scenario of an explosion developing in a roadway passing and passing across the face of seals. The recent Moura explosion originated behind a sealed goaf area. The nature of these explosions may be different; both in terms of the pressures reached and their rates of pressure rise.

The second aim was to examine the operational context of the placement of stopping seals in mines and examine the application of engineering principles to design. The study endeavours to give a better understanding of the performance of stoppings and seals in mines and enhances the ability to select the most appropriate seal for a particular application and hence maximise safety and economy outcomes over the VCD lifetime. The study examined these QLD regulations and compared them with the changing situation in some foreign countries with similar practices and mine layouts. A full account of this work is given by R. Pearson *et al* (2000).

## SEALS AND STOPPINGS USAGE PATTERNS

### Queensland Standards

The current Queensland regulations for VCDs are summarised in Table 1.

Table 1. Queensland approved standards for VCDs.

| **Design Criteria** | **Location** | **Purpose or Intent** |
|---|---|---|
| **Type A :**<br>**14 kPa (2 psi) (Recommended)** | Limited Life Production Panel | All VCDs “fit for purpose” for the life of the panel and be capable of withstanding an overpressure of 14 kPa. |
| **Type B :**<br>**35 kPa (5 psi) (Recommended)** | Main Roadways | All VCDs “fit for purpose” and capable of withstanding an overpressure of 35 kPa. |
| | Sealed Areas | When flammable gas will always be less then the lower flammability limit. |
| **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 an 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 and main fan housing. |

### US Stopping and Seal Practices and Approaches

Since 1991 MSHA requirements have been that seal design must meet an explosion rating of 140 kPa (20 psi). A particular solid concrete block design is recommended and is described by N. Greninger *et al* (1991). Alternative methods or materials may be used to create a seal if they can withstand a static horizontal pressure of 140 kPa provided the method of installation and the material used are approved in the ventilation plan.

From discussions with a number of US longwall 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. However some mines in the western states with a propensity for spontaneous combustion, do or are planning to isolate individual goafs by sealing all cut-throughs. One other company with highly gassy seams isolates individual goafs in order to recover gas for commercial sale.

### Mines’ Survey Responses

Fourteen QLD and NSW mines were asked about their usage 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 cementatious 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 cementatious material. For final panel seals providing separation form Mains, four mines used mortared block, two plasterboard, two block, one reinforced cementatious and one composite polymer material. For overcasts applications, nine mines used pre-fabricated steel, two block, one sprayed brattice, and two reinforced cementatious material.

Currently for belt road segregation, two mines use brattice, two reinforced cementatious 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 cementatious 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 cementatious 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 from Mains, seven mines use reinforced cementatious 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.

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. Six mines indicated that 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.

Manufacturers' Survey Responses

A seven-page questionnaire was mailed to selected stopping and seals manufacturing companies, seven companies responded.

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. All except one have own (proprietary) approaches to designing for varying height and/or width dimensions of stopping and seal.

Four manufacturers have had their seal and stopping products tested at the LLEM facility. Three have had their products tested at the TestSafe facility, Londonderry, 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 responding claim that their seals or stoppings are designed to meet at least part of the VCD rating codes.

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. About half of the manufacturers prefer products installed by own labour to maintain quality.

## TESTING PROGRAM AT THE TESTSAFE EXPLOSIONS GALLERY

The research program was limited to explosion tests one each of a steel a reinforced shotcrete stopping of 40 mm thickness and a 325 mm thick seal. These were proprietary design manufactured by an Australian company, Tecrete/Fosroc, located in Nowra NSW. These were constructed to the same design and thickness, and using the same materials and construction methods as tested previously at LLEM and reported by E. Weiss *et al* (1999). Thus the major remaining differences were the dimensions of the test apertures and any intrinsic differences between the two test stations.

There are some important differences between the two test configurations. The LLEM was once a limestone mine. It was modified to closely simulate the three dimensional configuration of a coalmine. The design, testing methods and layout are described by E. Weiss *et al* (1999).

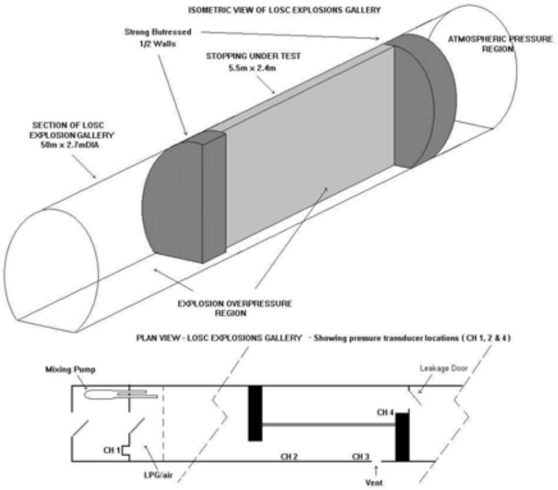

*Figure 1. Plan and isometric view of the TestSafe Explosions Gallery.*

The TestSafe Explosion Gallery test configuration is illustrated in Figure 1. The TestSafe Explosions Gallery is 50m long a concrete pipe. The internal diameter is 2.7 m and there is a cast in floor reducing the effective maximum height to 2.4 m. It is buried about 1m below ground and has a shell thickness of 150 mm. The explosion overpressure is allowed to vent through a 300 mm diameter hole on the side of the gallery. The test aperture was produced between two 500mm thick reinforced semicircular concrete walls placed 5.5 m apart as shown in Figure 3.

Explosion tests on the 40 mm thick stopping involved inflating a thin plastic bag with a known volume of a 10% methane/air mixture. Explosion tests on the 325 mm thick seal involved fitting a plastic sheet across the closed end of the gallery enclosing a known volume of air. A weighed quantity of propane was then injected into a recirculation fan over a period of several minutes. These gas mixtures were ignited and signals from the pressure and movement sensors were collected at a rate of 1000 measurements per second for each channel.

Results of Testing

The 40 mm stopping was tested to destruction. However, a decision was made not to test the 325 mm seal to destruction as it was considered that this might cause damage to the gallery's shell.

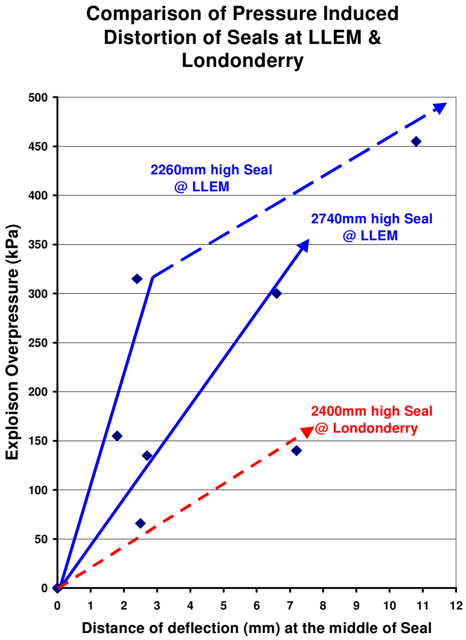

*Figure 2. Comparison of seal displacement at LLEM and TestSafe.*

The explosion pressures generated at TestSafe are present at the face of the stopping or seal for a much longer period of time than at LLEM. The initial rates of pressure rise are also less. The significance of this longer time of exposure and slower onset of the pressure impulse is discussed elsewhere. However, one difference that was immediately noted was that the seal deflected by an amount more than twice that found at LLEM for the same explosion overpressures see Fig 2. This plot shows linear displacements with respect to pressures, as long as the seal remains undamaged. A 2mm vertical expansion of the explosion gallery shell was also observed during the 135 kPa explosion test. The Tecrete steel re-enforced structures are designed to take advantage of a ridged boundary in order to achieve the desired explosion resistance. These results indicated that there might be insufficient rigidity in the TestSafe gallery shell to achieve explosion resistance ratings comparable to LLEM for these kinds of designs at high pressures.

## COMPUTER SIMULATIONS

The current TestSafe test configuration used for stoppings and proposed for seals may not be the best method of testing these structures. Consequently there was a requirement in this project to assess alternative test designs in an attempt to characterise an ideal test design. The only way of assessing these designs quickly is through a computational simulation of the explosion process within the test geometry. Requirements for a good design include decoupling the test from the environment and simple design to obtain repeatable and reproducible results. It is important that variations in loading of the VCD under explosion test conditions are predicted in order that a comparison between various alternative test facilities can be made.

Simulation of Alternative Test Geometries:

The simulations were based around five different base geometries as shown in Figure 3. Four variations of base geometry 4 and two variations of base geometry 5 of the TestSafe explosion gallery were simulated in two dimensions using the computational fluid dynamic code, EXPLODE II.

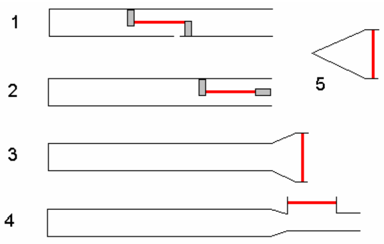

*Figure 3. Schematic illustration of the five geometries used for the simulations. Geometries 1 to 4 are variations of the current TestSafe Explosions Gallery.*

This was developed over the last decade between the

Universities of NSW and Wollongong and TestSafe. At least two simulations were carried out for each geometry. The first represented a 2 Bar or 4 Bar pressure pulse of length 10 m in base geometries 1-4 and half the length in base geometry 5. The second simulation was that of a 10 percent methane explosion contained within the first 5m of base geometries 1-4 and throughout base geometry 5.

### Simulation Results

Figure 4 shows the triangular prismatic structure, geometry 5, designed so that as the explosion developed, the pressure front would remain planar rather than curvilinear and so would be expected to give an even loading on the test structure. The diagram shows an even development of the explosion in this facility.

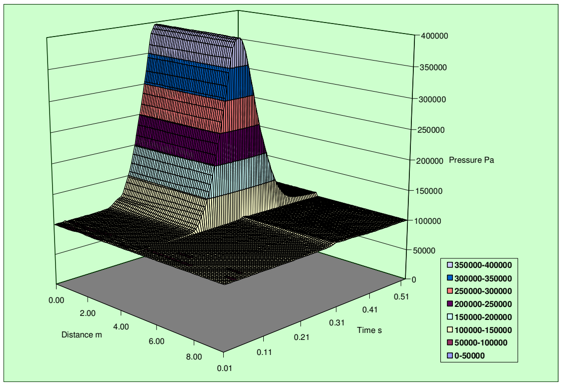

*Figure 4. Simulated 2D explosion pressure profile from Geometry 5.*

Generally, the geometries with test VCDs oriented normal to explosion front, eg geometies 3 and 5, had a much lower variation in pressure across the face of theVCDs. This variation was typically 2-9 percent as opposed to 25-40 percent when the test structure was side on to the explosion flow eg geometries 1,2 & 4.

It needs to be emphasised that the computer simulation explosion modelling was undertaken in two dimensions using highly intense computer generated explosion impulses. This may produce pressure irregularities that are not observed during practical low-pressure tests, but is very useful for design purposes.

## STRUCTURAL BEHAVIOUR OF MINE STOPPINGS AND SEALS

### Introduction

The principal aim of this research was to investigate the structural behaviour of stoppings and seals subject to explosion loads. The investigation was achieved via the use of non-linear finite element analysis. The analyses of the 325 mm seal and a 40 mm stopping have revealed the way these structures carry load and the particular stress conditions leading to failure. Two and three-dimensional non-linear finite element analysis was performed. The concrete was modelled as a Mohr Coulomb material with a tension cutoff. Static analysis was performed on 325mm thick reinforced-sprayed concrete seal and a 40mm thick reinforced sprayed concrete stopping. The applied pressure was distributed uniformly on the whole face of the wall. These two walls were tested at LLEM and the TestSafe explosion gallery. The analysis allows a study of the wall behavior in the test facilities. The test results are compared with the numerical analyses.

### Structural Response of 325 mm Seals

There are two mechanisms in which the seal is able to resist the applied load - arching and bending. In the arching mechanism a compression arch forms within the thickness of the wall (Figure. 5). This mechanism is very stiff, very little deflection needs to occur for it to develop. If the seal is wider than it is high, as is the usual case, arching between floor and roof is the principal load transfer mechanism. The strength of the wall in this mechanism is limited by the crushing of the concrete (or the support material) in the high stress regions at the roof and floor. The load / deflection behaviour is linear and failure is expected to be sudden or brittle. The behaviour and response is essentially independent of steel reinforcement in the wall. The stiffness of the roof and floor supports has a large influence on the ultimate failure strength of the seal.

In the bending mechanism the applied force is resisted by flexural tension and compression stresses in opposite faces of the wall accompanied by shear as the load is carried to the supports. This mechanism is considerably less stiff than arching. Provided sufficient shear support (or keying) is available at the roof and floor then the strength of the seal is limited by the amount of tensile reinforcement ie-steel bars, mesh etc.

If the roof and floor are rigid the arching mechanism develops in preference to the bending mechanism because it is considerably stiffer. If the arching mechanism is lost or cannot develop because of roof and floor deflection or crushing of the material, then the bending mechanism will become dominant.

A comparison of the calculated seal strengths for both mechanisms, to the actual strengths exhibited in testing at LLEM, indicates that arching as the mechanism by which these seals resisted the explosion overpressures. The magnitude of the deflections also confirms arching as the principal method of load transfer to supports.

The explosion chamber at TestSafe is a 2.7 m internal diameter concrete tube with a wall thickness of 150mm and as such the maximum height of the wall that can be constructed is 2.4m. Numerical analysis indicates that the distortion of the TestSafe Gallery will prevent significant arching from occurring in the seal in the test safe explosion chamber. Therefore the capacity of a seal is likely to be closer to its bending capacity. The development of some thrust in a seal would lead a combined failure mode. The finite element method was not used to predict the ultimate capacity of the seal in the TestSafe apparatus because of uncertainty about the actual physical condition and stiffness of the tubular shaped Gallery that provides the essential restraint to the seal.

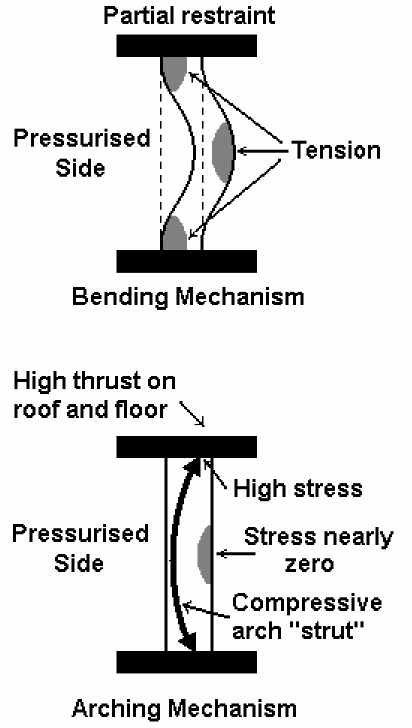

*Figure 5. Structural mechanisms for the 325 mm seal.*

In an underground situation, floor, roof and wall convergence after construction may add significant compression stress to the seal. The capacity of the seal may therefore be reduced since less pressure will be required to increase the concrete stress to its failure level. Creep of the concrete affects convergence-induced stresses in the seal. It is possible that convergence of the roof and floor induce a curvature in the seal. If the convex side of the seal is towards the explosion the ultimate capacity of the seal could be increased. Alternatively, if the concave side is towards the explosion the ultimate capacity will be further reduced. The effects of floor and roof convergence, changes in geometry and material creep can by analysed using finite element methods.

The stiffness and strength of the floor and roof supporting material is important. Finite element analysis can be extended to include the stiffness and strength characteristics of the support material. Analysis of this would indicate whether failure occurs in the supporting material or the concrete wall.

Structural Response of 40 mm Stoppings

There are two possible mechanisms in which the 40 mm stopping is able to resist the applied load - cable action and bending. The 40mm stopping has insufficient depth to develop the arching mechanism described above for the seal. The bending mechanism is the same as for the seal. Deflection occurs as shown in Figure 6. If the deflection is large the change in geometry requires the wall to stretch which results in tensile forces in the stopping. If the material is ductile, sufficient deflection can occur such that a tensile or cable mechanism is developed. The concrete with fine mesh reinforcement spans laterally between the anchored ties. In the cable mechanism the tensile forces in the wall rather than the bending mechanism are more significant in resisting the applied load.

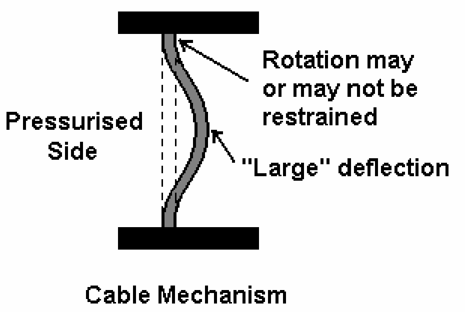

*Figure 6. Cable mechanism for the 40 mm stopping.*

The cable mechanism is stiffer than the bending mechanism. Its stiffness (load/deflection response) increases as the wall deflection increases. Therefore this mechanism is non-linear. This mechanism imposes very large tensile forces at the anchorage points in the roof and floor. It relies on the anchors having sufficient pullout strength. The strength of the wall in this mechanism is limited by the tensile strength of the wall (or the anchors) or the tensile strength at details such as at the overlaps in the internal steel reinforcement. Failure of the wall occurs when the tensile capacity is exceeded at some location. The capacity in the bending mechanism is typically much less that the capacity of the cable mechanism.

In an underground situation convergence of the roof and floor induce a curvature in the stopping. Because of the slenderness of the stopping it is unlikely that any significant compressive stress would be induced. The effect of floor convergence is likely to increase the capacity of the cable mechanism.

The design of the 40mm stopping consisted of 24mm reinforcing bars overlapped near the top and bottom of the wall. Accurate prediction of the ultimate capacity is not possible with current models. The principal reason for this is that the strength and deformation characteristics at the overlaps are unknown. These could be obtained by laboratory testing. Observations of test walls (both LLEM and TestSafe) indicate the capacity of this design is limited by the tensile strength in the region of the overlapped steel bars.

## SUMMARY OF FINDINGS

### Testing

The physical test program was able to produce data that characterised the nature and degree of differences between the TestSafe tests and the LLEM tests. However, it should be understood that this data represent a comparison based upon only one kind of seal/stopping design (steel re-enforced shotcrete). Caution should be exercised in extrapolating these differences to other seal/stopping designs. This basic data indicates that the TestSafe Gallery Shell is too flexible to allow a one to one correlation between TestSafe and LLEM on the basis of high-pressure explosion test on seals. The test data obtained from the low-pressure tests on the stopping indicated that the TestSafe test is probably more severe than LLEM, but the exact amount of difference may be much smaller than found for seals.

### Explosion Modeling

It would appear that the current test configuration is suitable for low-pressure tests on stoppings but high-pressure events should really be tested in a new facility. The modelling shows that simple test geometries produce simple pressure histories that are easy to interpret from a testing point of view.

### Structural Analysis

The numerical research has enabled a comparison to be made between likely test outcomes at LLEM and TestSafe facilities. Analytical results are directly compared with LLEM test results for the 325 mm seal were are shown to provide reliable predictions. As discussed, for the 325mm seal, the test capacity in the TestSafe chamber is expected to be less than that from testing at LLEM. A comparison has not been made for the 40mm stopping but test capacity at TestSafe could be expected to be similar to that at LLEM because the pressure required to cause failure is relatively low. However, unless the mine conditions match the test conditions (stiffness and strength of support) there is no guarantee that a test result will indicate the capacity of the wall in situ. This is particularly so for seals which rely on arching.

The principal conclusion from the research is that predictive methods can be used in design of seals and stoppings. Blast testing as the sole criterion for acceptance of the structures is questioned. It is concluded that static testing is likely to be as reliable and that computer analysis is a practical way of including variable conditions of support likely to be found within and between mines.

### Mine Survey

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 operated 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 of stoppings and seals significantly differ to current Queensland practice.

## OPTIONS FOR THE VARIFICATION OF THE STRENGTH OF VCDs

Given the current regulatory requirements for VCDs and that the TestSafe Explosions Gallery is unsuitable for high-pressure tests, there needs to be a means of verification of the explosion resistance of these designs. There appear to be two basic ways to verify the strength of VCDs. These are by means of full-scale explosion resistance tests and by engineering calculation.

The analysis of the structural behavior of VCDs undertaken as part of this research has clearly highlighted the potential benefit in applying known engineering principals to the design of internally steel reinforced shotcrete seals and stoppings. The properties of reinforced concrete are well understood and choosing this type of seal greatly simplified the process of comparing TestSafe to LLEM. However, there are quite a range of designs of seals and stoppings currently in use. Some designs are a complex sandwich of composite materials, others are low density crushable non-reinforced foamed concrete. These designs respond to the pressure load in a more complex way than does the reinforced shotcrete designs. Faced with this level of complexity in both material properties and design, it is unlikely that most manufacturers of VCDs would have the expertise to develop new designs “in house”. Clearly if engineering calculation is to be used for verification of the strength of VCDs then this assessment needs to be conducted by independent experts in this field.

Full-scale explosion tests on VCDs provide a means by which an independent testing authority can apply a constant and agreed benchmark test for all designs. It is also a process by which a manufacturer's design, construction competency and choice of materials can be assessed in one test. Internationally, it is the current accepted means of verification of VCDs. However, this approach has limitations. Some of these are: -

1. that only one prototype at one height is usually tested,
2. there is currently no formal verification that "approved" VCDs are always constructed to the same standard and using the same materials as the prototype, and
3. engineering analysis has highlighted influence of the rigidity of the boundary between the VCDs and its supports on the ultimate explosion resistance. Full-scale tests on VCDs are currently conducted within the confines of concrete or limestone, but not coal. In real mining applications, the properties and quality of the coal surrounding the VCD would appear to play a large role in determining the actual ultimate explosion resistance of a VCD.

Clearly there is a need for a facility within Australia to test VCDs at high pressures and at full-scale. Current regulations and industry practices limit the role of engineering design and calculation in the verification of the strength of VCDs. However, there appears to be great benefit in the use of this approach to ensure that adequate strength is maintained for tested and approved VCDs when they are to be constructed with dimensions greatly different to that which were tested and/or enclosed by coal of variable compressive strengths.

## CONCLUSION

Overall there have been some significant achievements as a result of this research. This project has led to a greater understanding of the physical requirements for full-scale explosion testing of seals and stoppings.

The current usage of seals and stoppings in the NSW and Queensland coal mining industry, and the context of the current Queensland standards in relation to the US regulatory environment have been described.

The structural analysis has shown that internally steel reinforced shotcrete seals can be reliably designed to achieve levels of pressure resistance required for the mining environment. Extension of this approach to include other methods of construction and other aspects of compliance and safety within mines may prove advantageous.

It has been shown that the TestSafe Explosions Gallery can be used to conduct full-scale explosion type testing of low-pressure stoppings. The limitation of the current TestSafe Explosions Gallery for high-pressure tests on seals has been shown direct measurements and through structural analysis. The project has justified the decision by TestSafe not to undertake testing on high-pressure seals until a proper comparison was made between TestSafe and an internationally established research mine.

TestSafe has undertaken explosion tests on about ten low-pressure stoppings over the last 3 years. This testing was provided at a much lower cost that it would have been if conducted at foreign testing facilities. The availability of this limited test service has led to considerable innovation in stopping design and has improved levels of safety, economy and compliance throughout the whole industry.

TestSafe is currently examining possible sites for the establishment of a new test facility for explosion resistance type testing of high-pressure seals.

## ACKNOWLEDGEMENT

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