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GEOLOGY CONSOLIDATION AND VENTILATION CONTROL DEVICES IN UNDERGROUND MINES: DETERMINATION OF DESIGN, MONITORING AND SAFETY STANDARDS

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ABSTRACT

While hazards resulting from spontaneous heating, gas migration, explosions and flooding remain a major threat to the safety and productivity of underground mines, specific research into overpressure ratings and integrity testing of ventilation control devices (VCDs), bulkheads and dams remains relatively limited.

Given the difficulty to conduct field tests in operational environments, as well as the high variability of mine ventilation and geology conditions, the performance of ventilation control devices poses a significant challenge for underground mines.

In Australian studies, a computational engineering model has been developed to determine overpressure-rating standards for ventilation control and geology consolidation devices.

With data obtained from live blast testing in an underground mine in Western Australia, explosion dynamics and structural responses of full size ventilation control devices (VCDs) were analysed and used to calibrate a 3-dimensional finite-element computer model of a VCD subjected to blast loading. This calibration began by transferring actual pressure distribution contours from the testing and then compared axial, bending and shear stresses as well as total loading and deflection between various configurations. The results were then used to develop a design tool that can assess installation requirements for a combination of height, width, over pressure, head of water and a factor of safety for individual sites.

As the mining industry strives to develop a national standard for conformance of ventilation control and geology consolidation devices, the development of new methods of determining specifications not only aids the design of innovative ventilation management strategies, but also provides the industry with the assurance of knowing that their ventilation control devices increase the safety factor in underground mine environments.

INTRODUCTION

While many underground mining fatalities in Australian mines have been directly attributable to ventilation control failure, the variability of underground mine ventilation and geology conditions continues to challenge the implementation of widespread industry performance standards.

Affected by three significant disasters since 1975, the Moura district in central Queensland has presented a substantive case for ventilation and geology control standards in underground mining.

The first of these disasters occurred at Kianga Mine on 20 September 1975, where thirteen miners died from an explosion found to have been initiated by spontaneous combustion. The second occurred on 16 July 1986 at Moura No 4 Mine when twelve miners died from an explosion thought to have been initiated by one of two possible sources: frictional ignition or a safety lamp.

The third of the disasters occurred on 7 August 1994 at Moura No 2 Mine. On this occasion eleven miners died following an explosion.

As a result of these disasters, and more specifically the loss of 36 lives, a series of task groups was formed by the Mines Inspectorate to report on various aspects of mine operations and the disasters themselves.
In 1998, Task Group no. 5 reported on the development of appropriate standards for construction of underground mine seals and stoppings. New mining regulations, that specified the strength requirements for Ventilation Control Devices (VCDs) became effective in Queensland coal mines in March 2001.

The Queensland Department of Mines and Energy Safety and Health Division subsequently established a recognised standard for the evaluation of performance of VCDs. This standard provides for either physical testing of VCDs or certification of a design including material strength and appropriate safety factors by a certified professional engineer.

ENGINEERED COMPUTATIONAL VCD MODELLING

With a large number of variables involved in determining the actual strength of a VCD and limited guidelines provided on appropriate material strength or safety factors, in 1998, Australian company, Aquacrete, in co-operation with independent engineering consultants, PB, decided that full-scale explosion testing was needed to determine if VCDs designed to a theoretical model would withstand an overpressure event.

While similar testing had been conducted at purpose-built facilities such as Londonderry testing facility in New South Wales, the use of an underground mine in Western Australia provided full underground confinement of the explosive testing and enabled a wider range of tests to be completed.

Testing was carried out on a range of VCD thicknesses, ranging from 100mm to 500mm. Typical VCD size was 4.2m x 4.2m, determined by the dimensions of the mine roadways where the testing was carried out. Various full-scale blast forces were simulated using high explosives. Each VCD was monitored with five pressure sensors distributed on the face, so that actual blast pressures could be measured. Peak blast pressures up to 75 psi (525kPa) were recorded.

There are several important points to note regarding the VCD tests conducted by Aquacrete, which clearly demonstrate the advantages of full-scale explosion testing over theoretical calculation methods. (Figure 1)

Figure 1
Test chamber design for full-scale blast testing

The VCDs were sprayed using normal construction methods, however, they were not keyed into the ribs, roof and floor. There were no anchor bolts fixing the perimeter of the VCDs. Theoretically, this should not provide a sufficient tie-in between the VCD and the geology. However, in the test application, it was more than sufficient.

No reinforcement was provided in the Aquacrete VCDs. Again, the flexural strength based on theoretical considerations did not accurately reflect the actual performance of the VCDs.

The VCDs were tested just 24 hours after completion of spraying. This short timeframe is critical for the effectiveness of a VCD in a commercial environment, where a time delay of three to seven days is typically required for cementitious VCDs to gain sufficient strength to be certified by an engineer.

The blast test results from six explosion tests were analysed and used to calibrate a 3-dimensional Finite Element (FE) computer model of a VCD subjected to blast loading (Figure 2). This calibration began by transferring actual pressure distribution contours from the testing and then compared axial, bending and shear stresses as well as total loading and deflection between various configurations. Once all the test data had been incorporated into the computer model, a series of simulations were run and the results calibrated against the

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actual test results to validate the computer modelling.

Firstly, with the computer model calibrated, PB expanded the work to determine the equivalent uniform pressures that corresponded to the highly variable pressures recorded by the instrumentation during the live testing (Figure 3 & 4). Secondly, the test results were extrapolated from 4.2m x 4.2m size VCDs to sizes more commonly encountered in coal mines; eg 3m high x 5.5m wide and through to unusual shaped roadways; eg. 7m high x 6m wide.

The results were then used to develop a calibrated engineering design tool that could assess the required thickness of a VCD for any combination of height, width, overpressure, head of water and factor of safety for an individual site.

The original research conducted by Aquacrete has been supplemented in recent years by an ongoing research and development program that has encompassed several different strands.

The project has been further extended to determine the equivalent uniform pressures that corresponded to the highly variable pressures recorded by the instrumentation during the live testing (Figure 3 & 4). Secondly, the test results were extrapolated from 4.2m x 4.2m size VCDs to sizes more commonly encountered in coal mines; eg 3m high x 5.5m wide and through to unusual shaped roadways; eg. 7m high x 6m wide.

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**Figure 2: Blast pressures were recorded at five locations on each VCD test.**

**WATER RESISTANCE IN STRUCTURAL DESIGN**

While the incidence of underground mining accidents directly attributable to inundations is limited, observations in operational environments have underscored the need for supplementary research into the design and maintenance of structures for wet conditions.

Following the development of a water-resistant mining gypsum-based product (WetRepel™) that has been shown to exhibit enhanced structural properties, research has again been conducted on full-size VCDs; this time constructed above ground for ease of access and sampling of cores for material testing. Compressive strength and water permeability have been tested at varying time intervals from two days up to three months to gain a full understanding of material behaviour, which is vital to accurately predicting structural performance.

Having exhibited high early strength and low water permeability results in varied operational applications to combat water ingress, Aquacrete further extended its research to determine the engineering design requirements for bulkheads and dams.
Successfully applied in several underground coal mines in Australia, the structures are designed to hold a specific head of water, rather than just a blast pressure (Figure 5 & 6).

General design guidelines and procedures for constructing and maintaining bulkheads have been developed to ensure long-term structural integrity of Aquacrete installations while significantly reducing inundation risks for miners.

In developing the engineering parameters for the design of bulkheads and dam walls to withstand sustained water pressure, certain key differences to blast pressure are relevant:

- Water pressure is not constant, with maximum pressure exhibited at the base of the bulkhead or dam and varying pressure elsewhere (Figure 7 & 8)
- Sustained water pressure over a significant period of time on the wall structure, surrounding ribs, roof and floor can lead to softening
- Sustained water pressure poses the risk of leakage through fractures and strata surrounding the bulkhead, so keying of the walls into the surrounding geology is of critical importance
- Long-term monitoring and maintenance is required for VCDs, so that any minor leak that occurs can be addressed quickly before it becomes potentially serious

Unlike VCDs and bulkheads that are supported on four sides, dam walls are supported on three. This results in a reduction in robustness, which is addressed by use of appropriate factors of safety.

From observations in the design and manufacture of bulkheads and dam walls, some of the key aspects of the design and construction process include:

Close collaboration between all parties involved in its development. The mine layout determines the location for the bulkhead. Therefore, geotechnical information on
the site-specific conditions is required, particularly as most known bulkhead failures have been through the surrounding strata or along the strata/bulkhead interface.

The characteristics and conditions for the bulkhead or dam site need to be identified and evaluated. The strata in the immediate roof, floor and ribs needs to be assessed in detail and should include all strata that can be affected by a change in hydrologic conditions. The structural design of the dam or bulkhead must take into account the maximum possible head, long-term deterioration and life of the structure as well as extreme cases such as explosions or roof falls into the stored water.

FUTURE CONSIDERATIONS
Legislative environment and Industry Standards
The legislation in regard to seals in underground coal mines varies between Queensland and New South Wales. In both states, the coal mining legislation holds specific requirements with the onus for compliance primarily resting with the operators.

Legislation introduced for Queensland and New South Wales coal mines provides different levels of prescription regarding specifications for geology control and ventilation control devices.

The “fit for purpose” New South Wales requirements contrast with specified uniform design pressures from 2psi (14kPa) up to 50 psi (345kPa) for different underground applications in Queensland. Underground hard rock and metal mines have different regulations again.

As Australian underground mines gradually become deeper and potentially encounter more gas, greater consideration needs to be given to the integration with management plans that cover spontaneous heating, gas monitoring, ventilation, gas drainage, strata management and flooding. Australian standards for ventilation control and geology consolidation design are needed to ensure long-term performance and ultimately the safety of mine employees.

In determining industry standards for existing and proposed ventilation control and geology consolidation devices, testing and monitoring of structural integrity is critical. In this respect, a key issue for the underground mining industry is the accessibility of a suitable purpose-built test facility, capable of blast testing various types of VCD construction at pressures up to and beyond 50 psi. While the Londonderry test facility in New South Wales is a good facility, it is too small (maximum height 2.4m) and not strong enough (maximum blast pressure 10 psi (70 kPa)) to test realistically-sized VCDs at pressures specified in the Queensland regulations.

An ACARP report published in 2004 (Report no. C12009) investigated test facilities and recommended construction in Australia of a purpose-built full-scale blast testing facility. Despite this recommendation and the assertion that “it would generate considerable safety and economy benefits to the Australian mining industry”, nothing has progressed on this issue and to date, the Londonderry test facility remains the only one in Australia and larger scale testing faces the significant cost of testing at overseas facilities.

AUTHOR BIOGRAPHY
Michael Salu is a Principal Structural Engineer with PB in Brisbane. He has over 25 year’s experience in the structural design and construction of heavy civil infrastructure for mining, water, power, road and rail projects.

Recently promoted to Technical Executive within the PB Structures group, he leads the team that has developed a sound engineering basis for the design of Aquacrete VCDs, based on full-scale explosive testing and structural engineering principles.

AQUACRETE COMPANY INFORMATION
Since its inception in 1993, Aquacrete has established itself as a leading manufacturer of earth-conscious solutions for addressing dust, gas and unstable geology conditions in mining, quarry and construction environments.

A wholly Australian-owned company, Aquacrete manufactures and supplies a range of shotblast products to more than 90% of Australia’s underground coal mines and a growing base of underground gold, nickel, copper and lead...
mines throughout Australia. The company’s products are also specified for environmental and engineering applications to overcome dust, erosion and unstable geology conditions.

Aquacrete can attribute much of its success to a company-wide commitment to delivering products that increase productivity whilst enhancing safety.

With a client base that includes some of the largest resource companies in Australia, Aquacrete’s client partnership approach has seen the company invest significantly in the development of new technologies.