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Evaluation of structural component design in life-of-mine planning

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EVALUATION OF STRUCTURAL COMPONENT DESIGN IN LIFE-OF-MINE PLANNING

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ABSTRACT: Industry practice around structural component design has progressed significantly in recent years with a key result being the application of known engineering principles to the design of ventilation control devices and bulkheads. The properties of shot blast products are now well understood with computer modelling and full-scale live blast test analysis having aided the selection of the most effective type of device for specific site conditions. However, as underground mines increasingly focus on life-of-mine planning, understanding the long-term behaviour of installations plays an increasingly important role in structural system design. As many structural components found in underground mines have been designed and certified at time of installation, the review of these installations, specifically the impact of environmental and other factors, provides the opportunity for continued learning and development in this area. Studies conducted at underground mines where structural components have undergone long term testing and monitoring are discussed. The impact of key environmental conditions on the behaviour of structural components in underground mines is described. The limitations of current testing and monitoring processes as well as opportunities for long term mine planning are assessed.

INTRODUCTION

While rigorous assessment is conducted at the time of mine planning to minimise safety risk and maximise production capabilities, the impact of unpredictable natural events such as severe weather, geological changes and seismic activity, can impact on the long term effectiveness of mine planning. Structural devices are used extensively in underground coal mines to segregate and stabilise mined-out areas as well as to isolate underground areas that are susceptible to fire, gas, water or unstable geological conditions. Stoppings are typically designed for differential air pressures up to 35 kPa (5 psi) while seals are typically designed to resist blast pressures of 140 to 345 kPa (20-50 psi). Other structural devices, including water-retaining bulkheads and dam walls play a critical role in storing and retaining water, often in areas where high heads and volumes of water are prevalent. In designing bulkheads and dam walls, the erosion capacity of water, combined with an analysis of the surrounding strata conditions, play a significant role in determining the factor of safety. Structural components have traditionally been constructed using a variety of materials and methods to address specific mine site conditions. However, as many installations have been temporary in nature, specific research into the construction requirements and performance measurement of devices has been limited.

As coal mines age and become more developed, greater attention needs to be placed on the long term integrity of structural devices. The risk of a device failure has the potential to be catastrophic and while sound engineering principles can be applied in the design stages, substantive measurement and monitoring of installed structural components is of critical importance.

In addition to reviewing the various factors influencing long term structural integrity, this paper highlights structural components installed at Australian mine sites as an assessment model. With the benefit of having engineered and constructed a range of structural devices at the site more than five years ago, as well as having implemented an ongoing site audit and assessment regime over a number of years, this paper assesses the design and construction of structural devices and reviews key environmental factors that have impacted on the devices' long term integrity.

STRUCTURAL COMPONENT DESIGN BACKGROUND

The long-term effectiveness of a structural device relies on many factors including geology, sitting, design, materials, construction and maintenance. While mine planning relies on comprehensive models to simulate the various scenarios of flow distributions, gas capture designs, inertisation strategies, head of water and geological and seismic activity, predicting the performance of underground structures has

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posed a significant challenge for underground mines. In 1998, Aquacrete worked with Parsons Brinckerhoff (PB) to develop an engineering basis for the design of shotblasted seals, stoppings and other structural components for underground mines.

With data obtained from live underground testing of structural devices, explosion dynamics and structural responses of full-size stoppings were analysed to establish precise device specifications. While limited testing had been conducted at purpose-built facilities such as the Londonderry testing facility in New South Wales, Aquacrete selected an underground mine in Western Australia which allowed the use of higher blast pressures due to full underground confinement of explosive testing. This enabled a wider range of tests to be completed and the results could be confidently extrapolated to ensure closer relevance to operational mines.

The blast test results were analysed and used to calibrate a 3-dimensional finite-element computer model of a seal 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 is now widely used to assess the required thickness of a structure for any combination of height, width, over pressure, head of water and factor of safety for individual site location. Following the successful application of this model over a number of years, Aquacrete again worked with PB to conduct trials on its water-resistant product to determine an engineering model for the construction of water-retaining bulkheads and dam walls. Compressive strength and water permeability were tested on full-size structural devices at varying time intervals from two days up to three months to gain a full understanding of material behaviour, which would be vital to accurately predict structural performance.

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

- Water pressure is not constant, with maximum pressure exhibited at the base of the bulkhead or dam and varying pressure elsewhere;
- Sustained water pressure over a significant period of time can lead to softening;
- Sustained water pressure poses the risk of leakage through fractures and strata surrounding the bulkhead;
- Unlike Ventilation Control Devices (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;
- Unpredictable roof falls can generate a pressure wave to a bulkhead or create a surface wave to over-top a dam.

DEWATERING SUMP DAM WALLS AND BULKHEAD DESIGN

Largely as a result of the high level of risk associated with the design and construction of dam walls and bulkheads, many underground mines specify large factors of safety that take into account uncertainties in construction, nature of the surrounding strata and potential for roof falls or explosions in the goaf. A significant factor in the design of dam walls is that, 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 an appropriate factor of safety. Unpredictable roof falls that can generate a surface wave to over-top a dam need to be considered in addition to the static water pressure.

In developing the design parameters for dam walls and bulkheads at a dewatering sump installation in New South Wales (Figure 1), PB considered the mine plan that had been developed to address the faults and geological nature of the mine. These factors necessitated each device to be independently designed to address the potential life of device, based on the water head, the geological factors affecting each site as well as consideration for the duration of potential exposure of the seal to the mine workings before becoming part of the goaf.

The engineering solution encompassed the design and installation of a combination of bulkheads and dam walls (Figure 1). Due to the extensive approach, combining the use of bulkheads and dam walls to mitigate potential risks and unforeseen events, the mine requested a factor of safety of two.

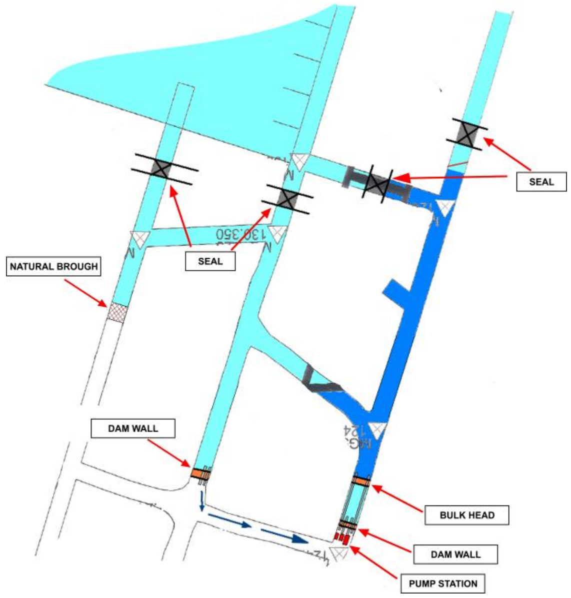

Figure 1 - Dewatering sump dam wall and bulkhead design

Dam wall 1 (Figure 2) was designed to accommodate a 5.6 m wide x 2.4 m high cavity while Dam wall 2 was designed to be 5.61 m wide x 2.0 m high. The dam walls were installed using accepted shotblast techniques, achieving a thickness of 400 mm and 350 mm respectively, and included a 200 mm key all around into the ribs and floor.

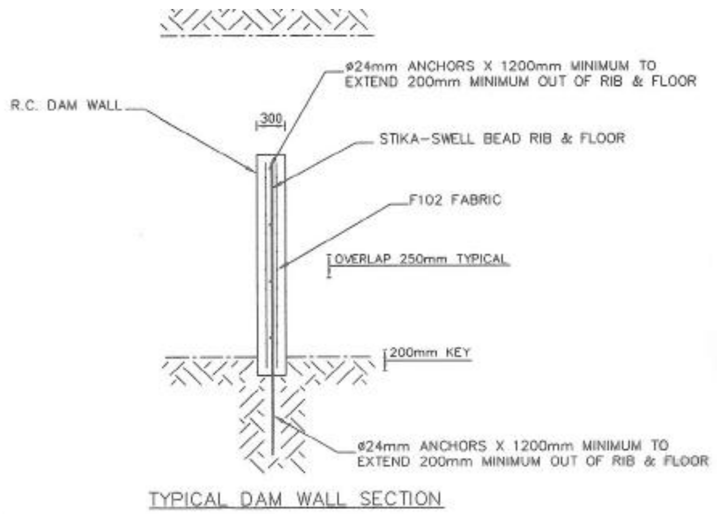

Figure 2 - Dam wall design, side view shown

INSPECTION AND MONITORING OF BULKHEADS AND DAM WALLS

Regular inspection of structural devices not only contributes significantly to their successful long-term performance, but also impacts on the safety of operational environments. Having identified the potential stress of the dam walls at the New South Wales site, PB worked with Aquacrete to establish a site audit procedure that has been implemented consistently over a period of two years.

Visual inspections

Ongoing fluctuations in water level behind the dam walls, combined with the three-sided construction of these devices provided an ideal monitoring environment where visual inspections could assess potential deterioration and stress of the dam walls and their surrounding strata.

Key areas of observation included:

- An inspection of the surrounding strata to identify water leakage;
- Potential softening of the structural device;
- Erosion and breakdown of structural integrity;
- Measurement of device thickness.

As outlined in Table 1 below, following inspections conducted over a period of two years, no visual deterioration or softening to the surface of the dam wall has been observed. An assessment of the dam walls' ability to cope with the variations in water pressures and geological activity have been monitored and reviewed by the mine staff and potential risks have been re-assessed to determine any changes in the site conditions.

Following one event on site, where an unplanned power outage prevented water from being pumped outbye, the site engineer reported that the water head reached a height of 2.5 m. The water pressure as a result of this incident was well in excess of the design specifications. While site engineers took all necessary precautions to maintain site safety during the event, inspection of the dam walls after the event confirmed that no water leakage occurred and the dam wall maintained full integrity.

Table 1 - Site inspection summary table

Site Inspection Date	Site Observations
August 2010	Inspection of 2 completed bulkheads and 1 dam wall. Inspect preparation for 2nd dam wall. Bulkheads and dam wall installed to specification. Strata bond appears good ; effective overspray carried out
December 2010	Inspection of completed works. Dam walls sprayed to 500mm thickness
October 2011	Inspection of dam walls. No deterioration or erosion of device. Wall thickness measured and still 500mm
November 2012	Inspection of dam walls. No deterioration or erosion of device. Wall thickness and velocity testing confirm structural integrity of devices

Non-destructive testing

While visual inspections of structural devices provide significant reassurance of a structure's integrity, the 'health' of a device can be verified with the use of echo impact testing. This method of testing uses sound waves to test a material for integrity and strength properties. It works by striking a surface with a hammer and then measuring the elapsed time for the sound waves to reflect off the far surface. If there are any defects within the material such as voids, the sound waves will not transmit through and the instrument will record the sound waves bouncing off an apparently thinner section.

If the thickness of a section is known, as is the case with the installed dam walls at the New South Wales mine site, then the speed of sound in the material can be measured. Following extensive trials with an echo impact tester on VCDs, PB has worked with Aquacrete to confirm the performance and suitability of this testing method as it applies to the density and material structure of Aquacrete products.

Levels of testing have included testing of cored samples (Table 2) as well as verification of installed seals both in a controlled environment (Table 3) and a live underground site (Table 4). These results have verified the effectiveness of long term monitoring of structural devices using non-destructive testing methods.

Testing of dam wall integrity at the New South Wales site has confirmed that structural integrity of the devices has been maintained, with the measured thickness being verified by the measurements shown in the echo impact testing.

Table 2 - Results from testing cored samples

Material	Average Cylinder Height (mm)	Average Velocity (m/s)
Aquacrete OPR2	199	2250
Aquacrete Wet-Repel	203	2550

Table 3 - Results from mines rescue station

Location	Material	Tested thickness	Actual thickness	Average velocity (m/s)
Stopping 1	OPR2	218	200	2200
Stopping 2	OPR2	150	155	2150
Stopping 3	Wet-Repel	216	209	2420

Table 4 - Results from underground mine testing

Location	Stopping/Rating	Tested thickness	Minimum thickness	Pass/Fail
Site 1 c/t	OPR2/2psi	86	75	Pass
Site 2 c/t	OPR2/2psi	93	75	Pass
Site 3 c/t	OPR2/5psi	162	100	Pass
Site 4 c/t	OPR2/5psi	138	100	Pass

SUMMARY AND CONCLUSIONS

Live testing and the subsequent development of engineering models have been used for many years to provide mines with the assurance that their structural devices are constructed to withstand the geological and operational conditions relevant to individual mine sites.

As the focus in underground mining continues to shift to life-of-mine planning, mines are increasingly looking for reliable tools and methods to measure and monitor the structural integrity of devices, particularly in environments where unpredictable events have the potential of affecting underground safety.

Using structural design specifications as a benchmark, and applying an audit process encompassing a combination of visual inspection and non-destructive testing processes has proved to be an effective monitoring approach for a New South Wales mine.

There is significant opportunity for the mining industry to develop new methods that will further assist in life-of-mine planning for structural devices, which in turn will provide greater assurance of underground safety and productivity.

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