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Lessons from 2 reticulation-induced shotcrete barricade failures in drift and fill mining

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Abstract

This case study investigates 2 paste wall failures that occurred during the tight filling stage in drift and fill mining, triggered by elevated reticulation pressures resulting from water and air flushing used to clear the distribution line. The sudden pressure spike caused by hydraulic surges exceeded the barricade's structural capacity, leading to containment loss. Field data, paste rheology, and reticulation system dynamics were analysed to determine the root cause of the failures. Contributing factors included insufficient shotcrete on the barricade and lack of pressure relief during line flushing. The findings highlight the importance of managing transient pressures in paste delivery systems and provide recommendations for barricade design, reticulation and fill placement control, and operational procedures to reduce failure risk in similar applications.

Keywords: *drift and fill, cemented paste fill, fill wall failure, shotcrete barricade failure, shotcrete bulkhead failure*

1 Introduction

Engineered shotcrete walls are essential structural containment plugs in drift and fill mining, designed to confine the freshly poured backfill material, until it cures and develops sufficient unconfined compressive strength to be self-supporting. The shotcrete barricades need to have adequate capacity to withstand the pressures generated during filling, while at the same time being designed and constructed in a cost-effective and efficient manner to support safety, productivity and cost efficiency.

In drift and fill mining, often under adverse geotechnical conditions, the cemented paste backfill process becomes particularly demanding. Tight filling is required to minimise rock mass displacements and maintain drift stability, reducing the need for additional costly and time-consuming ground support. The complexity increases with the integration of reticulation systems such as pumps, pipelines, water and compressed air flushing systems, high density polyethylene (HDPE), fill and breather pipes and flush valves, which must all operate reliably to maintain the system's integrity. To achieve safe, efficient and high-quality paste filling, each component of the system – starting from the materials used to produce paste (tailings, binder and water), to the paste plant, reticulation pipeline, HDPE pipes, flush valves and the shotcrete barricade – must remain well maintained, balanced, and compliant with quality procedures.

This paper focuses on 2 real-world paste fill barricade failure incidents that occurred at Olympias mine, less than a month apart from each other. This case study aims to analyse the technical, operational and procedural factors that contributed to these failures, and to extract key lessons, which can be useful in improving future design, installation and coordination of paste fill pumping in the tight fill stage.

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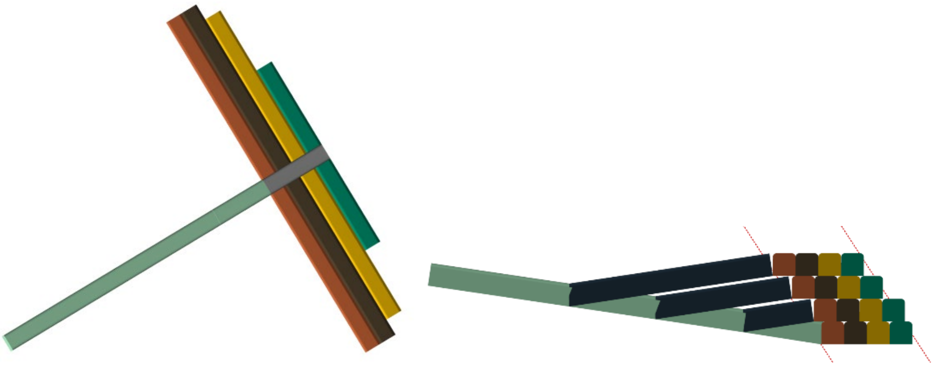
2 Technical background

2.1 Drift and fill mining with paste and fill wall function

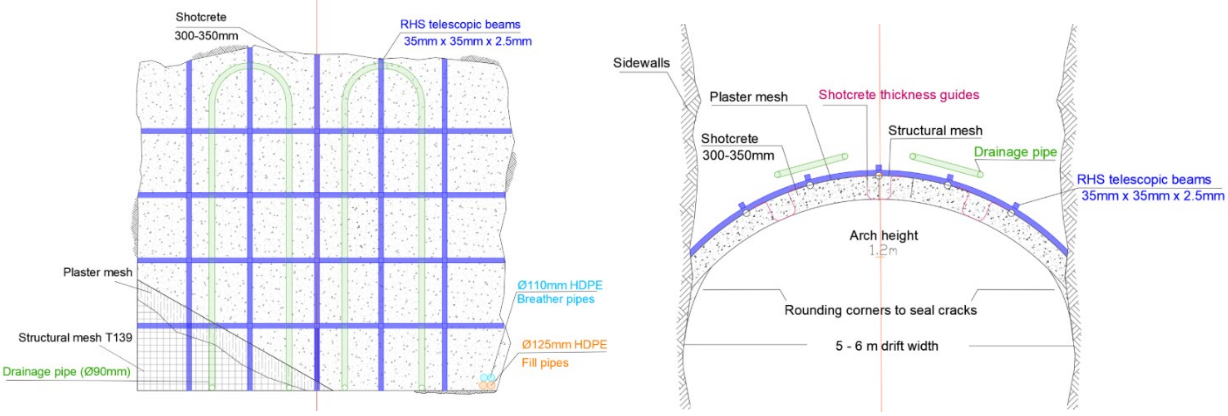
In the drift and fill mining method, a level access is driven into a footwall (FW) to reach the orebody. From this FW access, longitudinal drifts are excavated in pillarless retreat sequence to extract ore along the strike. After each drift is completed, HDPE fill and breather pipes are installed at the backs, and a shotcrete fill wall is built at the drifts' intersection. The drifts are then tightly backfilled with paste, allowed to cure to the required strength, and mining proceeds to adjacent drifts. This sequence is repeated until the entire sublevel is mined and filled. A new lift is then developed above the initial stope access in overhand sequence for mining the next sublevel, following the same cycle of drifting, extraction, filling, and curing until the orebody is fully mined. The typical drift dimensions are 5–6 (h) × 5 (w) × 50–80 m (l). Figure 1 illustrates a typical schematic of drift and fill mining method.



(a) (b)

Figure 1 Schematic of drift and fill mining method. (a) Plan view; (b) Section

Shotcrete fill walls play a critical role in ensuring effective containment of backfill during mining with paste fill. An unexpected barricade failure can result in severe consequences, including serious risks to underground personnel, fill inrush, damage to the mining equipment, and at the very least, disruption to underground production. Typical fill wall design parameters include shotcrete unconfined compressive strength (UCS) under a certain curing time, shotcrete thickness, drift and barricade geometry, and reinforcement. Quality control of shotcrete barricades is crucial, encompassing not only the shotcrete strength but also parameters such as arch rise and shotcrete thickness. Prefabricated steel wall kits are used to maintain geometric control and dedicated guides, such as bent mine mesh, are used to help operators verify the applied thickness and ensure that the shotcrete is evenly distributed across the entire surface of the barricade. The design of a standard shotcrete barricade at Olympias mine, is shown in Figure 2.



(a) (b)

Figure 2 Standard design of Olympias fill wall. (a) Front view; (b) Plan view

Olympias applies a C28/35 fibre-reinforced shotcrete mix design. Shotcrete quality is controlled through UCS tests at specific curing times, on representative drilled cores obtained from panels sprayed underground. The diameters of the cores are 100 mm and their length-diameter ratio (L:D) is 1. The results are converted to equivalent cylinder (L:D=2) strengths by multiplying them with 0.87 according to EFNARC European specification for sprayed concrete EFNARC (1996). A summary of shotcrete sample strength test results is presented in Figure 3. For Olympias paste fill barricades, the most important UCS value is the 24-hour test, since this value is used for the barricade design. As illustrated in Figure 3, the median 24-hour UCS of shotcrete is 16 MPa.

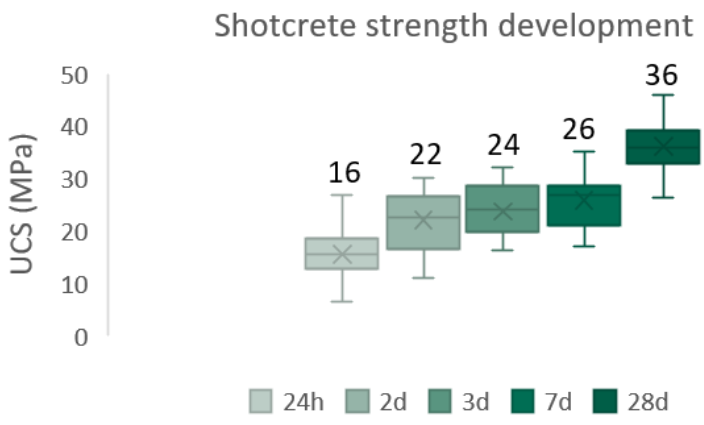


Figure 3 Fibre-reinforced shotcrete unconfined compressive strength (UCS) at 24-hours, 2-days, 3-days, 7-days and at 28-days, including their median values

2.2 Barricade pressure monitoring results

The drift and fill mining method requires rapid and efficient construction of several backfill barricades, as each drift volume typically has a limited capacity of 1,000–2,000 m^3. At Olympias mine, the production plan requires for an average of 10 drifts to be paste filled each month, thus a minimum of 11 fill walls to be constructed monthly. Consequently, pressure monitoring for each barricade is not practical for drift and fill mining. However, selected walls at Olympias mine have been monitored to validate pressure development behind the fill barricades. Figure 4 presents an example of lateral pressure readings from earth pressure cells installed 1.5 m above the floor.

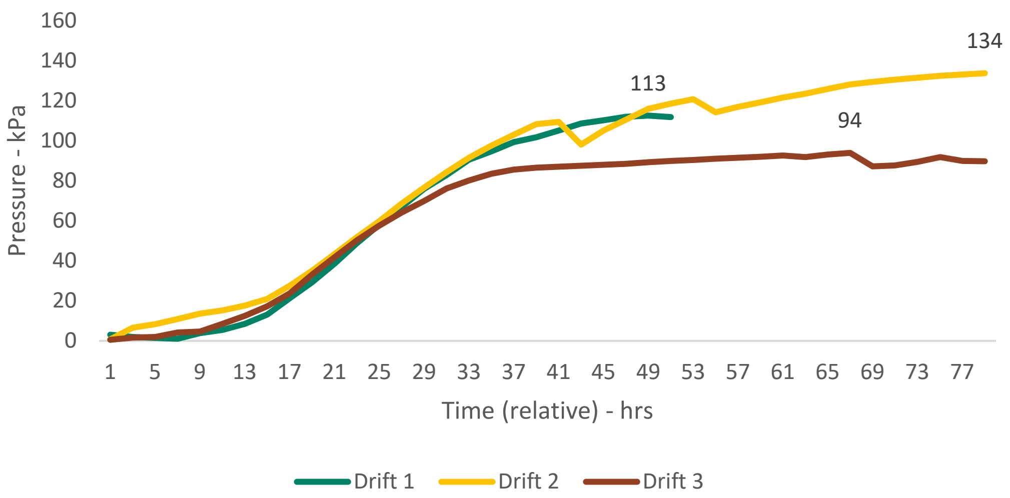


Figure 4 Barricade pressure monitoring using Earth Pressure Cells

The recorded pressure starts at 0 kPa until paste reaches the cell, then rises to a maximum of 94–134 kPa, depending on paste and drift conditions. After filling, pressure drops as the paste cures, with minor fluctuations during flushing or resting periods, e.g. shift changes. The graph reflects a typical tight-filling procedure, during which all breather pipes discharged paste as intended. However, if a breather pipe becomes blocked, pressures behind the barricade can rise sharply. Without halting paste pumping this situation may result in barricade failure due to overfilling. It should be noted that the barricade failures described on this case study were not equipped with pressure cells installed, so this data was not available to support the failure investigation.

2.3 Paste reticulation system

Olympias employs a pump-assisted delivery system. The backbone of the paste backfill infrastructure consists of the paste delivery pump, pipelines and cased boreholes, flushing valves, and pressure and flow instrumentation. The paste plant pump has a delivery capacity of 42 m^3/hr and can operate at a maximum pressure of 140 bar. The paste reticulation consists of a steel delivery line, with an internal diameter of 125.5 mm, an external diameter of 139.7 mm and a pressure rating of 130 bar, with pipe spools connected using two-bolt couplings. Pressure-indicating transmitters are installed along the paste reticulation in critical locations, such as immediately downstream of the paste plant pump, at the base of interlevel boreholes and within long lateral sections. In areas with extended lateral runs, 2 transmitters are placed to enable friction loss calculations. This instrumentation provides real-time pressure readings and friction loss trends, which are continuously monitored by operators in the paste plant control room.

In the stope access and relatively close to the drift, the permanent steel reticulation transitions to the HDPE fill pipe with a 125 mm outer diameter, 11.4 mm wall thickness and 16 bar pressure capacity. Each fill pipe entering the drift is accompanied by a PN 10 breather pipe, which allows air to escape from the drift while filling is in progress.

Immediately downstream of the steel pipe and before the HDPE fill pipe enters the drift through the barricade, a DN125 PN16 manually operated knife-gate valve (handwheel type), is installed for flushing. This valve prevents water and compressed air from entering the drift during flushing of the underground line. Its proper maintenance and cleaning are essential, as paste buildup can compromise functionality. A malfunctioning flushing valve may result in barricade failure if water or compressed air is pumped into the drift, or it may contribute to a paste line blockage, if proper flushing cannot be executed.

Within the overall paste backfill system, the shotcrete fill barricade is the weakest link, since the HDPE pipes can withstand 1,600 kPa and steel pipes up to 13,000 kPa, whereas the barricade's capacity is significantly lower. Depending on the design, construction quality, shotcrete application and curing time, a barricade with an approximate thickness of 200–250 mm and a 20 MPa shotcrete strength in a 5 m drive section, typically has an ultimate capacity of about 800–900 kPa, with similar values having been reported by Veenstra et al. (2024) and Chatziefstratiou et al. (2025).

3 Case study 1: fill wall failure induced by paste line pressure surge

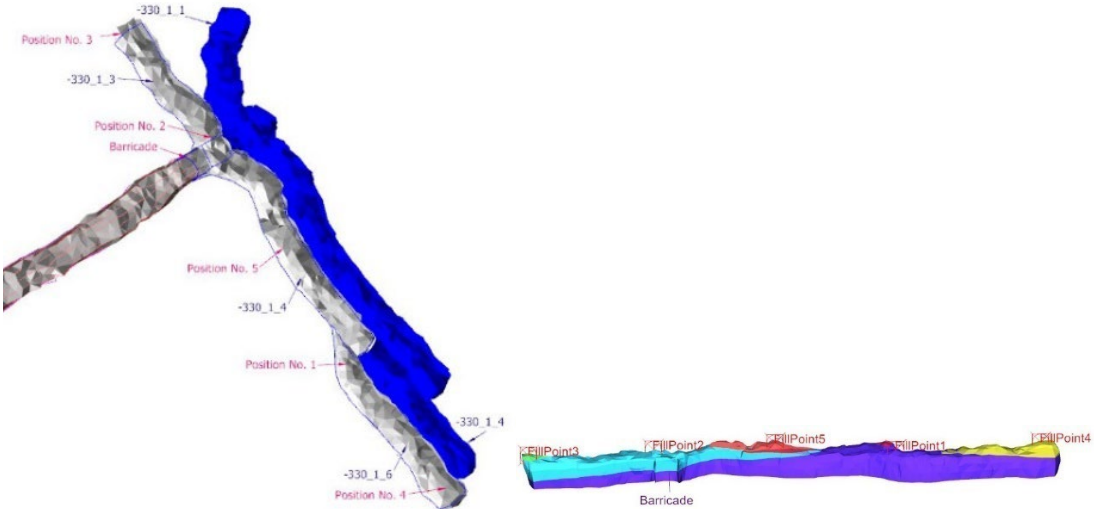
3.1 Site description and placement details

The first barricade failure occurred at OLW_−330_−330_1_3 & −330_1_6 drift. The drift had a length of 111 m, a volume of 3,049 m^3 and an area of 581 m^2 with an average height of 5 m and no water inflow. The barricade was constructed following the normal procedure, using prefabricated vertical and transverse rectangular hollow section beams, structural mesh and plaster mesh. The design of the fill wall specified a 300 mm thick layer of shotcrete. A total of 15 m^3 fibre-reinforced shotcrete was applied on the barricade surface, covering a surveyed area of 19.7 m^2. Allowing for a 30% rebound loss during application, along with the additional shotcrete applied to round the barricade corners and seal the perimeter of the 10 HDPE pipes (5 fill and 5 breather), the effective shotcrete volume is estimated at approximately 10.5 m^3, corresponding to an average thickness of 533 mm. The paste reticulation length was 1,760 m with a volume of 22 m^3 and was equipped with 7 pressure-indicating transmitters located along the route, allowing real-time monitoring in the paste plant control room. To reach this specific underground drift, the paste material required approximately 40–45 minutes from the paste plant, depending on the pump rate.

Within the drift, there were 5 filling points, each with its corresponding breather pipe. The average paste fill pump rate was 34 m^3/hour, over a paste fill process lasting 17 shifts, including 6 flushing cycles and some operational delays, totalling 50 hours. The maximum recorded pump rate was 35.4 m^3/hour, while at the time of the barricade failure – during the tight fill stage – the pump rate was 30.9 m^3/hour. The paste rise rate behind the barricade was approximately 6 cm per operating hour.

The paste mix design was 75% solids mass concentration and 12.5% CEMII/B-M (P-W-L) 42.5 N cement by weight of solids, allowing paste to achieve a compressive strength of 0.5 MPa after 3 days of curing and approximately 1 MPa after 7 days. Superplasticiser, dosed at 3–4.2% of cement by weight, was added to the paste mixture to improve rheology by reducing yield stress. Paste yield stress, measured once per operating shift, ranged from 113–470 Pa, with an average of 231 Pa. Under normal operating conditions, the maximum pressures recorded were 26 bar on surface, 65 bar at −150 level and 12 bar at the pressure transmitter on the level closest to the barricade.

The drift layout and backfill plan, are illustrated in Figure 5a and b. Table 1 indicates the expected cumulative fill volume as specified in the dedicated drift fill note, alongside the actual cumulative fill volume recorded each time a breather pipe discharged paste during tight fill. Figure 6 illustrates the measured paste UCS values after 3 and 7 days of curing for the OLW_−330_−330_1_3 and −330_1_6 drifts.



(a) (b)

Figure 5 Drift (a) and backfill planning (b) layout

Table 1 Comparison of expected versus actual cumulative fill volumes during tight fill in OLW_−330_−330_1_3 & −330_1_6 drifts

Fill point number	Expected cumulative fill volume (m^3)	Actual cumulative fill volume (m^3)	% difference
1	2,220	2,453	+10.5%
2	2,900	2,887	−0.45%
3	2,910	2,887	−0.79%
4	3,000	2,946	−1.80%
5	3,049	N/A	N/A

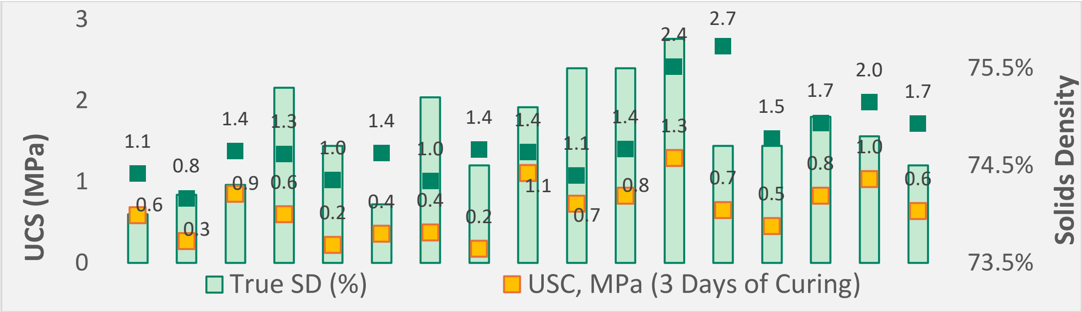
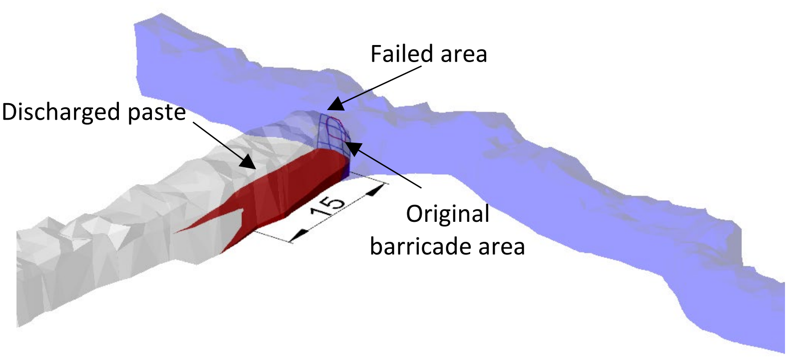


Figure 6 OLW_−330_−330_1_3 and −330_1_6 paste unconfined compressive strength (UCS) after 3- and 7-days curing time

3.2 Failure event summary

After ore depletion in the drifts, the HDPE pipes were installed, and the barricade construction was completed. Fill point 1 was positioned at the lowest surveyed point on the drift backs, with subsequent points set progressively higher, ending with Fill point 5 at the highest point. Shotcrete spraying was finished in 2 shifts and paste fill pumping began after 24 hours. Pumping continued for 5 consecutive shifts until a paste plant malfunction forced the first flush. Pumping resumed for another 5 shifts before a flushing cycle was initiated, as the cumulative volume neared the expected tight fill of Fill Point 1. Pumping then continued until breather pipes 1, 2, 3 and 4 discharged paste, with flushing cycles performed only when volumes approached the expected breather discharges. When a breather pipe released paste, flushing was not done; instead, pumping was paused to let residual material drain by gravity through the flush valve. The system was then switched to the next fill pipe, and pumping resumed once the service crew confirmed readiness.

During the shift of the barricade failure, all breather pipes except Fill Point 5 had discharged paste. Near the end of the shift, the service crew requested line flushing. Since Breather Point 5 had not discharged and 45 m^3 remained to reach the planned volume, the crew left the flushing valve closed, allowing the remaining paste in the reticulation to be pumped into the drift. Surveyed volumes indicated the drift was 99% full. Line flushing began at 03:55, by which time a total of 117 m^3 of paste had been pumped during the shift. After 25 minutes, the underground service crew observed water leaking through the rock mass joints and the shotcrete above the barricade, followed by minor cracking. Within a minute, partial failure occurred in the upper central part of the barricade, affecting 4.6 m^2, or 23% of the total barricade area. An estimated 60 m^3 of paste and water escaped, spreading 15 m from the breach. The service crew was safely away from the incident. Nonetheless, the event caused operational disruption and delays, resulting in financial impact, as the drift remained inactive until the investigation concluded and the escaped paste cured sufficiently to be removed. Figure 7a illustrates the original barricade perimeter, failure area, and discharged paste, while Figure 7b depicts the barricade failure and Breather Pipe 5, which never discharged.



(a)

(b)

Figure 7 (a) Original barricade perimeter, failure area and paste discharged; (b) OLW_−330_−330_1_3 and −330_1_6 barricade failure and blocked Breather Pipe 5

3.3 Root cause analysis

To investigate the barricade failure, several data were analysed, including the paste reticulation system dynamics, paste rheology and the quality of the constructed barricade.

Figure 8 shows the paste reticulation pressure trends from 03:35 when water flushing began, until the barricade failure at 04:22. The active pressure indicating transmitters (PITs) on the paste line plotted in the graph are:

- PIT-F50001, located at −150 level
- PIT-F50011 and PIT-F50012, located at −173 level
- PIT-F50002 and PIT-F50003, located at −240 level
- PIT-F50006, located at −280 level
- PIT-F50020, located at −320 level.

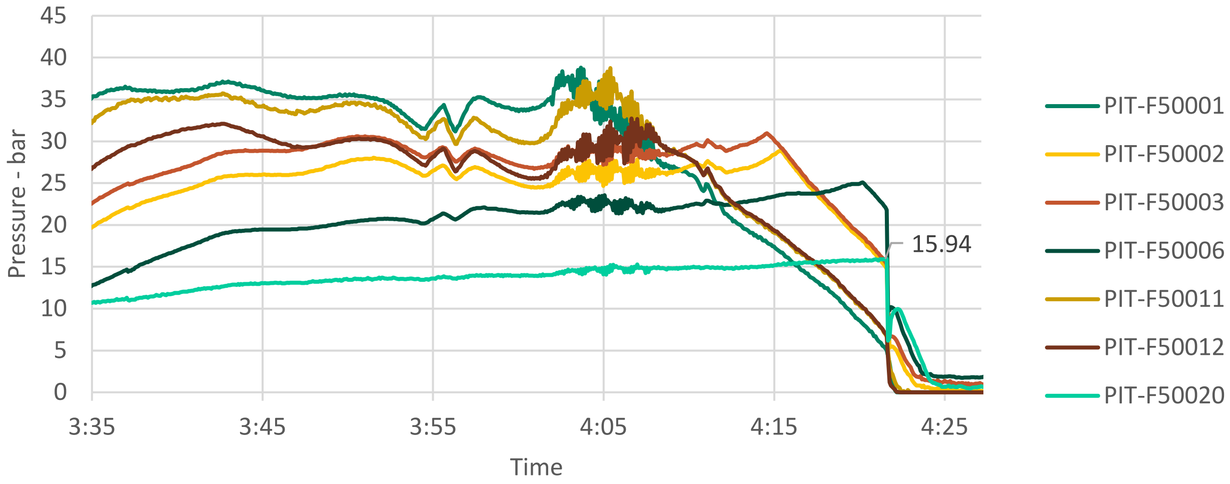


Figure 8 Pressure trends recorded by the paste reticulation pressure-indicating transmitters from 03:45 to 04:22, when the barricade failed

Water from the paste plant takes approximately 10 minutes to reach −150 and −173 levels. This is reflected in the graph, where pressure fluctuations occur between 04:00 and 04:05 as water pushes paste through the line. Soon after, fluctuations stabilise pipeline pressures begin to drop as water flushing reaches a steady state. Similar patterns are observed at −240 level, with a small pressure increase followed by a gradual drop as the line is cleared. The only instruments that do not show a gradual pressure drop, but instead a gradual pressure increase, are the instruments at −280 and −320 level – the 2 last instruments before the barricade. Specifically, between 03:35 when the flushing started and 04:22 when the barricade failed, the transmitter closest to the barricade (PIT-F50020), shows a gradual increase, since the pressure rises from 10.9 bar to 15.94 bar, corresponding to an increase of 500 kPa. PIT-F50020 was located 142 m (L) upstream of the barricade, with the barricade positioned 7 m lower in elevation. In addition, at 04:05, the recorded friction loss (F_L) between PIT-F50011 and PIT-F50012, located at −173 level, was 6.5 kPa/m. It is estimated that this paste material reached the barricade approximately 15 minutes later, coinciding with the failure event. At 04:22, all transmitters show rapid, almost simultaneous pressure drop to zero, indicating the sudden loss of containment caused by the barricade rupture. This pressure release affects the entire length of the pipeline.

Based on the pipeline pressure analysis, particularly from the pressure transmitter closest to the barricade, a back-analysis calculation was performed, to estimate the downstream pressure at the barricade, hence the barricade capacity. This calculation accounted for friction losses along the pipeline between the PIT and the barricade ($\Delta P_{friction}$) and the hydrostatic pressure due to elevation difference between the PIT and the barricade ($\Delta P_{hydrostatic}$):

$$P_{barricade} = P_{PIT-F50020} - \Delta P_{friction} + \Delta P_{hydrostatic}$$

$$P_{barricade} = 1594 - (6.5\ x\ 142) + 133 = 804\ kPa \quad (1)$$

where:

$$P_{PIT-F50020} = 1594\ kPa$$

$$\Delta P_{friction} = F_L\ x\ L \quad (2)$$

$$\Delta P_{hydrostatic} = \rho g \Delta h \quad (3)$$

where:

P = paste pulp density = 1,950 kg/m^3

g = gravity factor = 9.81 m/s^2

Δh = elevation difference between the PIT and the barricade = +7 m.

Under normal tight filling conditions, as shown by earth pressure cell monitoring at the Olympias mine, barricade pressure typically reaches a maximum of 140 kPa. However, since Breather Pipe 5 did not discharge paste while pumping continued, it is believed that the pipe became blocked, likely because it was installed too close to the fill pipe. During pumping, paste may have entered, cured and blocked the breather pipe, preventing pressure release. With no outlet, pressure accumulated behind the barricade. The paste first filled any available voids, such as cracks in the shotcrete and surrounding rock mass, before eventually exerting force strong enough to cause barricade failure in the weakest area. A gradual increase in paste line pressure, consistent with HDPE breather pipe blockage, further supports this explanation. Because the fill wall was not designed to withstand such transient loads, the barricade could not resist the surge.

After conducting in situ measurements of shotcrete thickness on the barricade perimeter within the failure zone, it was found to range between 200–300 mm. Despite the large volume of shotcrete applied, the spraying was uneven, leaving sections thinner than the required standard. When an estimated pressure of 804 kPa was exerted on the barricade during tight filling, the weaker area failed. Additionally, inadequate communication between the underground service crew and the paste plant control room contributed to the event. Although cracking of fill wall was observed, paste pumping was not halted quickly enough to prevent the failure.

The failure mechanism indicates overloading of the barricade, causing tensile failure of the shotcrete, induced by paste line pressure surge.

3.4 Response and mitigation

The response and mitigation measures implemented following the failure included a redesign of the breather pipe layout to ensure adequate separation from the fill pipe, preventing paste backflow and blockages by standardising a minimum distance in the design drawings. The updated design also incorporated additional redundant breather pipes to provide backup pressure relief in case one becomes blocked.

For the fill wall, the barricade design was revised to accommodate more shotcrete thickness guides, helping operators apply shotcrete evenly and maintain the required thickness. Additionally, the barricades were considered for redesign to account for transient pressure allowances.

In terms of operational procedures and communication, a remotely operated flushing valve was introduced to minimise the need for service crew presence at the barricade. A refresher training campaign was also conducted for both underground and paste plant crews to reinforce their ability to identify potential barricade over-pressurisation and ensure barricade integrity.

4 Case study 2: fill wall failure induced by valve blockage and flushing compressed air surge

4.1 Site and design description

After ore extraction in drift OLF_−340_−345_1_7, HDPE pipe installation and barricade construction were completed, with high water inflow reported from the drift floor. The drift, measuring 25 m in length, had a volume of 886 m³, area of 149 m², and an average height of 5.95 m, and included 3 filling points with breather pipes, each of the pairs of pipes having minimal difference in elevation. The paste reticulation system extended 1,175 m with a total volume of 14 m³, equipped with 5 pressure transmitters for real-time pressure monitoring. Paste delivery to the drift required 20–25 minutes, depending on the pump rate. Paste pumping began 15 shifts after the barricade shotcrete sealing, with an average pump rate of 31.3 m³/hour, resulting in a paste rise rate behind the barricade of 21 cm per operating hour over 5 shifts, with minor delays totalling 3.5 hours. The fill wall had a designed 300 mm shotcrete layer. A total of 15 m³ fibre-reinforced shotcrete was applied over a 48 m² barricade area, accounting for 20% loss, giving an effective thickness of 250 mm.

The paste mix contained 75% solids, 12.5% CEMII/B-M (P-W-L) 42.5 N cement by weight of solids, and 2.2% superplasticiser by cement weight, achieving yield stress ranged of 350 and 500 Pa. Under normal operating conditions, maximum pressures were 30 bar on surface, 60 bar at −150 level and 22 bar at the pressure transmitter closest to the barricade. The drift layout and backfill plan, are illustrated in Figure 9. Table 2 shows the expected cumulative fill volumes, compared to the actual cumulative volumes during tight fill. Figure 10 illustrates the measured paste UCS values after 3 and 7 days of curing for the OLF_−340_−345_7 drift.

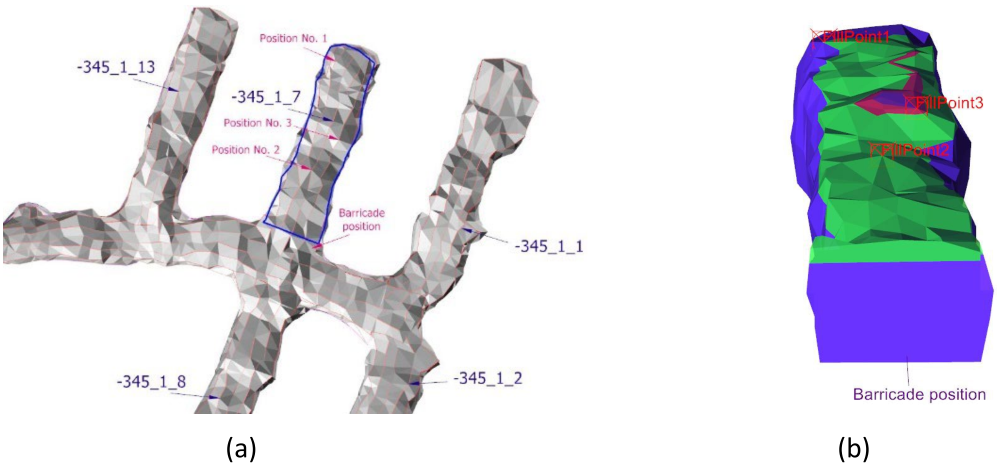


Figure 9 Drift (a) and backfill planning (b) layout

Table 2 Comparison of expected versus actual cumulative fill volumes during tight fill in OLF_−340_−345_1_7 drift

Fill point number	Expected cumulative fill volume (m³)	Actual cumulative fill volume (m³)	% difference
1	810	740	−8.64%
2	890	750	−15.73%
3	886	766	−13.55%

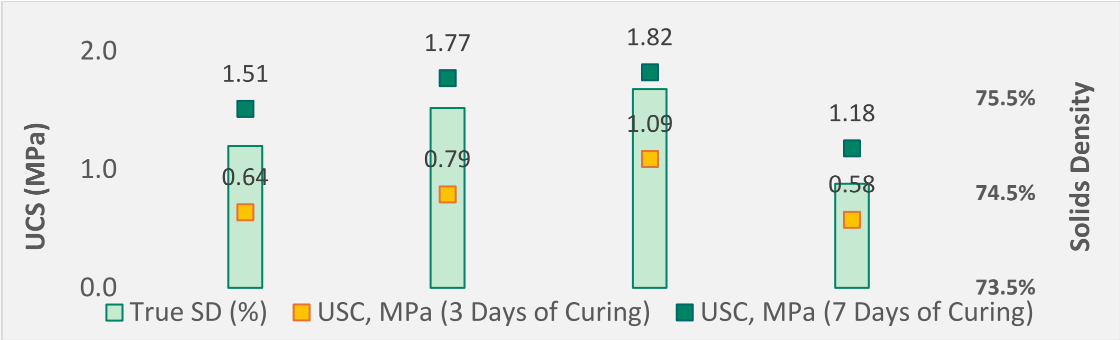


Figure 10 OLF_−340_−345_1_7 paste unconfined compressive strength (UCS) after 3- and 7-days curing time

4.2 Failure event summary

During the shift in which the barricade failure occurred, the underground service crew arrived at the barricade area for inspection at approximately 23:50. They observed Breather Pipe 2 discharging paste while pumping was active from Fill Pipe 1. The crew instructed the paste plant operator to halt pumping, after which the valve on Breather Pipe 2 was closed. Pumping was then resumed as directed by the service crew. A few minutes later, Fill Pipe 2 also began discharging paste, prompting the crew to repeat the procedure: pumping was paused, and the valve on Fill Pipe 2 was closed. Shortly thereafter, Breather Pipe 3 started discharging paste. Following another pause in pumping, the crew closed the valve on Breather Pipe 3, though minor leakage was still observed. At this point, the service crew decided to request paste line flushing, which was initiated by the paste plant at 23:54.

Meanwhile, Breather Pipe 1 began discharging paste. To relieve pressure, the crew opened the valve on Breather Pipe 3 and proceeded to the flush valve, which they attempted to open multiple times. The valve, however, was stuck due to paste buildup, and the crew retreated to a safe distance. At that stage, based on surveyed and expected fill volumes, the drift was estimated to be 86.6% full, although it had been tight-filled. During the water flushing, because the flush valve was malfunctioning, the remaining paste/diluted paste in the pipeline was pumped into the already tight-filled drift. Leakage of watery material was observed on the upper part of the barricade and recorded by the monitoring camera (Figure 11a).

Upon completion of the water flush and confirmation from the paste plant that the pipeline pressure had dropped to zero, indicating the line was clear, the crew requested an air/water line flush. Despite concerns expressed by the paste plant operator, the underground crew insisted that compressed air was necessary to fully flush the line. The operator complied. When the compressed air reached the barricade, the entire surface of the barricade failed, resulting in the release of an estimated 100 m³ of paste, which spread over approximately 12 m.

(a) (b)

Figure 11 (a) Barricade leakage recorded by the camera at OLF_−340_−345_1_7 drift before the failure and (b) OLF_−340_−345_1_7 drift after the failure

4.3 Root cause analysis

To investigate the barricade failure, the paste reticulation system pressure, as well as the quality of the constructed barricade were analysed.

Figure 12 shows the paste reticulation pressure trends from 23:15, until the barricade failure at 00:20. The active PITs on the paste line plotted in the graph are:

- PIT-F50001, located at −150 level
- PIT-F50011 and PIT-F50012, located at −173 level
- PIT-F50026, located at −340 level.

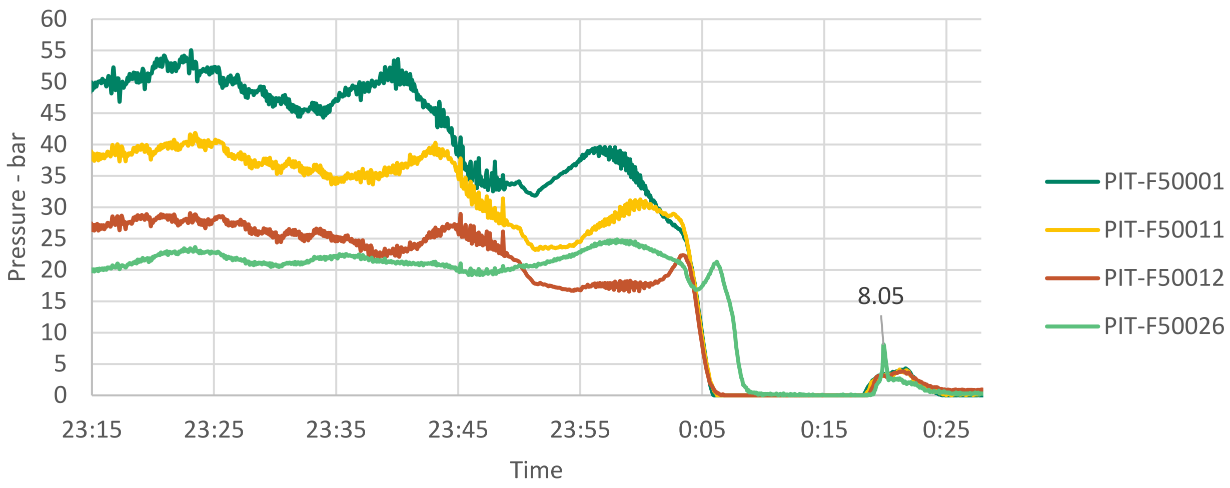


Figure 12 Pressure trends recorded by the paste reticulation pressure-indicating transmitters from 23:15 to 00.20, when the barricade failed

The analysis of the graph indicates that all pressure-indicating transmitters are stable, fluctuating in expected ranges under normal pumping, until 23:50. At 23:51 PIT-F50026 (closest to the barricade), starts to rise from 20.5 bar to 24.8 bar, which is aligned with the crew's observation of Breather Pipe 2 discharging paste. This is the time when the service crew requests line flushing, which is reflected at 23:58 when water pushes paste at −340 level, paste becomes diluted and the pressure starts dropping. By 00:10, pressures across the line drop to 0 bar, confirming that the pipeline is depressurised and clean. Between 00:10 and 00:20, the graph shows a zero-pressure trend, while the service crew and paste plant operator discuss flushing with compressed air. At 00:20 the compressed air reaches the barricade, and a sharp pressure spike is seen at PIT-F50026, rising to 8.05 bar, followed by an immediate collapse to zero. This is a transient overpressure followed by the immediate barricade collapse. As paste or water was not being pumped at the time, but only compressed air, the barricade capacity is expected to be nearly equal to the pressure indicated by the pressure transmitter PIT-F50026:

$$P_{barricade} \approx P_{PIT-F50026} = \ 805\ kPa$$

The barricade shotcrete thickness could not be directly measured; but the volume of sprayed material suggests it was below the design requirement. The barricade was 8.4 m wide and 5.8 m high (Figure 13). However, even if the shotcrete had met the required thickness, failure would still have occurred, as compressed air was introduced into the drift.

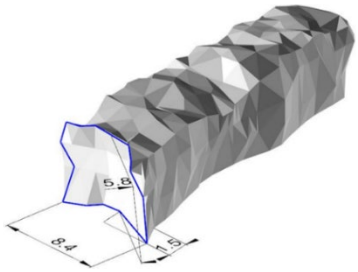


Figure 13 OLF_−340_−345_1_7 barricade geometry and dimensions

The flush valve, which was malfunctioning, is of utmost importance for safe backfilling. If inoperative, it can directly contribute to barricade failure during tight filling.

The operating procedure followed by the underground crew demonstrates strict compliance with standard protocols but lacked flexibility and failed to account for emergencies such as the leaking barricade. The underground crew requested compressed air flushing to address a suspected blockage in the pipeline. From their perspective, compressed air appeared to be a practical way to clear any residual paste quickly when water flushing had been completed. Their decision, made under pressure, aimed to restore safe operation. However, in the absence of clear procedural guidance, adequate equipment safeguards, and full awareness of the risks, the crew underestimated the potential of over pressurisation at the barricade.

The failure analysis indicates overloading of the tight-filled barricade induced by an air transient surge during flushing, compounded by flush valve malfunction, poor decision-making and procedural gaps.

4.4 Response and mitigation

The response and mitigation measures focused on procedural improvements, including the development and enforcement of clear flushing procedures that outlined approved methods, limitations, and prohibitions on the use of compressed air for clearing paste lines. Targeted training was delivered to service crews, operators, and supervisors to improve understanding of air-induced pressure surges. The incident analysis was shared with both surface and underground teams to promote collective learning. Communication protocols were strengthened to require supervisory approval before any non-standard flushing methods could be initiated. In addition, inspection protocols were enhanced to cover reticulation, flushing, and barricade integrity.

5 Lessons learned

Although unfortunate, the 2 barricade failures provided critical experience with tight-filling procedures and yielded valuable lessons that have contributed to safer paste-filling operations. These lessons are considered important to share with the wider mining industry to help prevent similar failures during tight filling.

A key finding was the importance of strict adherence to flushing protocols. Flushing must occur at prescribed intervals, independent of breather pipe discharge status, as delaying flushing until breather pipes discharge paste increases the risk of overfilling. Surveyed volumes should not be taken at face value; instead, calculations must be supported by real-time monitoring and conservative safety margins.

One incident involved leaving a flushing valve closed and attempting to flush inside a barricade despite nearing fill capacity. This underscores the need for structured decision-making protocols and supervisory approval before deviating from standard operating procedures. With respect to barricade management, conservative fill limits were implemented to safeguard structural integrity, while the reticulation system must be recognised as a dynamic, load-inducing system rather than static infrastructure.

Equally important are communication, inspections, monitoring systems, and remotely operated flushing valves, which were identified as critical elements of safe operation. Emergency response protocols and contingency planning must address both safety and operational continuity. Valve maintenance and reliability also proved to be crucial, as one flush valve became inoperable due to paste buildup, delaying pressure relief and forcing unplanned decisions. Regular inspection, maintenance, and redundancy, such as secondary relief mechanisms can be considered to ensure flushing valves function when required.

The risk of pumping into a tight-filled drift was highlighted when survey data indicated 87% fill, yet the drift was already fully tight-filled due to water inflow from the rock mass. Continuing to pump into an already full drift significantly increased barricade loading. Surveyed volumes must therefore be treated conservatively and validated against real-time indicators of tight fill.

Clarification of decision-making authority and escalation procedures was also identified as necessary. In one case, the underground crew overrode the paste plant operator’s concerns regarding compressed air use. Clear authority boundaries, escalation requirements, and supervisory approvals must be in place to avoid unsafe decisions made under operational pressure.

Finally, warning signs were not consistently treated as critical triggers. Leakage at the barricade and minor valve malfunctions were observed but regarded as manageable, rather than as immediate stop-work conditions. Such indicators must be formalised as ‘red flag’ conditions that require immediate cessation of operations and escalation.

6 Recommendations

The 2 barricade failures, highlighted opportunities for improving operational safety and reliability. The following recommendations have been derived from these events and are intended to guide safer paste-filling operations across the underground mining industry.

- Operational procedures
    - Flushing protocols: flushing must occur at prescribed intervals, independent of breather pipe discharge status. Delaying flushing until paste discharge is observed at breather pipes significantly increases the risk of overfilling and should be strictly prohibited.
    - Survey and monitoring integration: surveyed volumes must be verified through real-time monitoring and supported with conservative safety margins to account for water inflow.
    - Decision-making and authority: clear authority boundaries must be defined between underground crews and paste plant operators. Supervisory approval and structured escalation processes are required before any deviation from established procedures.
- Engineering and system design
    - Dynamic system recognition: the reticulation system must be treated as a dynamic, load-inducing network rather than static infrastructure. Conservative barricade fill limits should be maintained to protect structural integrity.
    - Breather pipes and valve maintenance and reliability: regular inspection, preventative maintenance, and timely servicing of flushing valves are essential. Redundancy, such as secondary relief options, should be incorporated to ensure reliable performance during critical operations.
    - Monitoring and technology: remotely operated flushing valves and enhanced monitoring systems should be implemented. Automated alarms must be established to highlight ‘red flag’ conditions for immediate response.
- Risk management and training
    - Red flag conditions: indicators such as barricade leakage, valve malfunctions, or abnormal pressure readings must be formally designated as critical triggers, requiring an immediate stop to operations and escalation to supervisory personnel.

- Emergency preparedness: emergency response protocols must be in place and regularly tested through drills. Contingency plans should balance both personnel safety and operational continuity in the event of barricade instability or tight-fill incidents.
- Protocol discipline: operators and crews must be trained and regularly reminded of the necessity of strict adherence to standard procedures, even under production pressures. Safety protocols must take precedence over operational expediency.
- Cross-functional communication: effective communication between supervisors, paste plant operators and underground crews is critical. Structured handover processes, clear reporting requirements, and formal escalation channels must be reinforced.

7 Conclusion

The barricade failures served as a powerful reminder of the complex risks associated with paste-filling operations and the consequences of deviations from established protocols. While the events highlighted vulnerabilities in flushing practices, monitoring systems, decision-making structures, and equipment reliability, they also provided valuable opportunities to strengthen operational standards. Emphasis must be given on proactive, integrated design and construction and fill placement, as well as flushing planning and management. By implementing the recommended measures – ranging from stricter flushing discipline and enhanced monitoring to clearer authority boundaries, robust maintenance, and improved communication – the mining industry can significantly reduce the likelihood of recurrence. Ultimately, these lessons underscore the need for a proactive safety culture where technical rigour, operational discipline, and effective risk management are prioritised to ensure both the protection of personnel and the long-term integrity of underground operations.

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References

Chatziefstratiou, V, Carmichael, P & Thomson, BD 2025, 'Analysis of an instrumented tight-filling-induced paste containment wall failure and lessons learned for safe backfilling', in AB Fourie, A Copeland, V Daigle & C MacRobert (eds), *Paste 2025: Proceedings of the 27th International Conference on Paste, Thickened and Filtered Tailings,* Australian Centre for Geomechanics, Perth, pp. 49–64, https://doi.org/10.36487/ACG_repo/2555_02

EFNARC 1996, *European Specification for Sprayed Concrete*, European Federation of Producers and Applicators of Specialist Products for Structures, Farnham.

Veenstra, RL, Grabinsky, MW, & Thomson BD 2024, 'Tight filling Challenges - comparing uncoupled and coupled backfilling of underground stopes with cemented paste backfill', *Proceedings of the 58th US Rock Mechanics/Geomechanics Symposium,* American Rock Mechanics Association*,* Eaton.