Investigation Into The Structural Behaviour of Mine Brick Barricade

Authors: Colin F. Duffield, Emad F. Gad and William E. Bamford

Abstract

This paper reports on a study into the structural behaviour of brick barricades when used to support backfill in underground mines. In recent years, there have been a number of failures of such barricades and subsequent investigations have clearly demonstrated the need for research into the behaviour and properties of the backfill material, the backfilling process and the relationship between the loads induced by the backfill and the structural capacity of the barricade to satisfy and withstand these loads.

Brick barricade material properties have been established through a range of laboratory tests undertaken to replicate field conditions. These material properties have been used in an analytical study of the capacity of barricades. The analytical study has utilised a finite element model to establish the relationships between the boundary conditions between barricade and mine wall, and the influence of an irregular mine cross-section on the likely cracking pattern of a brick barricade when loaded. This information has been used as input to arch action techniques to forecast an ultimate capacity of various sized barricade walls.

The predicted results have been compared with previous 'field testing' of barricades at Mt Isa in Australia. The predictive techniques have produced a range of useful outcomes but it is evident that additional 'field testing' and research is required.

Introduction

Brick barricades (also known as bulkheads) are used extensively in underground mine operations to retain hydraulic backfill that is used to fill the cavities created by mining. The hydraulic backfill material is de-slimed and de-watered mill tailings. Additives such as cement and slag are frequently added to the backfill to assist with consolidation and cohesion. Hydraulic backfill slurries are transported by gravity through boreholes and pipelines to the mine stope being filled.

The brick barricades are designed to facilitate free drainage from the backfill. The rate and volume of water that drains is dependent on the initial density of the slurry and the residual water content of the backfill (Grice 1998). Hence, the initial slurry placement subjects the barricade to hydrostatic pressure. As consolidation takes place, the hardened developing mass becomes self-supporting.

In current practice, brick barricades are typically constructed from autoclaved cured bricks with dimensions of 400x200x100mm. In the past, larger bricks used to be used (typically 460x200x115mm). The characteristic compressive strength of the bricks is typically between 10-15MPa. The mortar used is designed to be permeable and to have comparable compressive strength to the brick units. A typical barricade layout and configuration is shown in Figure 1. Steel reinforcing bars (pins) are also used to anchor the barricade into the surrounding rock. These pins are typically 1.2m long with half the length anchored into the rock and the other half embedded into the brickwork. Sometimes, an agroflex drain pipe is installed on the fill

side of the barricade with the two ends fed through the barricade to improve the drainage. The design and construction objectives for brick barricades are:

(a) the barricade must have adequate strength to resist the pressure from the backfill (including initial hydrostatic pressure)
(b) the barricade must have adequate drainage/permeability (more than the backfill) to ensure minimal pore water pressure

Brick barricades are used widely in underground mines in Australia and overseas. Unfortunately, there have been many failures. As an example of recent failures, in mid 2000, a large brick barricade failed only three weeks after the start of the filling operation killing three workers at the Normandy Bronzewing Mine in Western Australia. In the same year, two more barricades failed at the Osborne Mine in Queensland. In both locations hydraulic back filling was stopped for an extended period of time pending the outcomes of exhaustive investigations. In case of the Osborne Mine, fill activities were terminated for the reminder of 2000 and all of 2001.

Investigations of failed brick barricades tend to be large and do not only concentrate on the strength of the barricades, but also the properties of the hydraulic backfill and the backfill operation itself. In addition, investigations are carried out in relation to seismic activities, soundness and suitability of surrounding rock, construction practices and monitoring procedures.

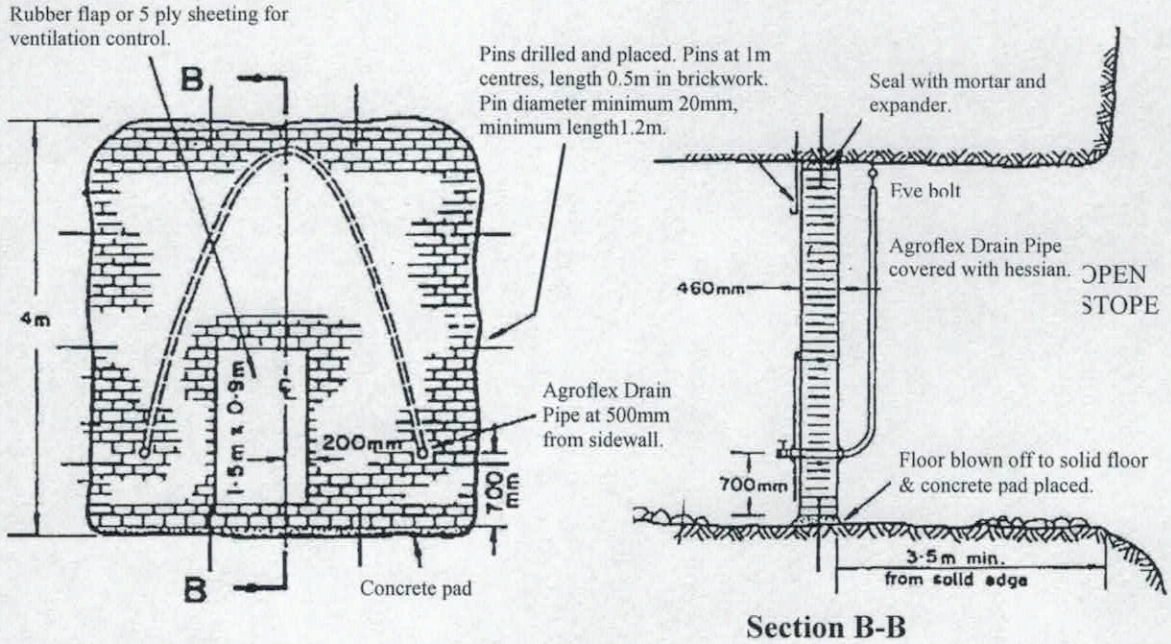


Figure 1: A typical barricade configuration (after, Beer 1986).

The findings presented in this paper are based on an investigation that took place after a barricade collapse. The paper only reports on the parameters related to the strength of brick barricades and not the fill properties or operation. The paper examines the material properties used for design and also investigates possible design models which can be used for analysing such structures.

The failed barricade measured approximately 6m wide by 5.3m high and was 400mm thick. It was constructed from 400x200x100mm bricks in similar manner to that shown in Figure 1. A

pressure transducer was placed on the barricade to monitor the load on the barricade and to regulate the filling process. When the barricade failed, the pressure reading was 200kPa. The accuracy of the pressure transducer was subsequently verified.

Material Properties and Testing

A limited number of tests were conduced on samples of barricade material salvaged from the failed barricade to evaluate the relevant material properties of the masonry units and mortar. The aim of these tests was to determine the appropriate material properties for subsequent analysis of the barricade. Further, the evaluated properties were compared with the material specifications that were requested for the construction of the barricade. One important feature of this testing program was that all tests were performed on dry samples as well as wet samples that had been saturated in mine water. The dry tests reveal properties comparable with those typically used to specification and design a barricade, however, the wet tests show the behaviour and properties in the working environment where the barricades are usually saturated due to high permeability. The tests performed were based on standard testing procedures with appropriate adaptation to accommodate large specimens. Specific tests conducted are listed below and the results are presented in Table 1:

(a) Shear tests – to determine the shear strength of the bond between the mortar and masonry units (refer to Figure 2).
(b) Bond wrench tests – to determine the flexural tensile strength of masonry perpendicular to the bed joints (refer to Figure 3). These tests were based on AS3700 (refer to Figure 3).
(c) Mortar compression tests – to determine the compressive strength of mortar only. These tests were based on AS2701.4 (refer to Figure 4).
(d) Masonry units compression tests – to determine the compressive strength of masonry units. These tests were based on AS/NZS4456.4 (refer to Figure 5).

It was obvious from inspection of the supplied salvaged blocks that the mortar was sound, of consistent quality, and reflected a good standard of workmanship. This was verified by the test results as shown in Table 1. These results demonstrate that the mortar strength and the bond between the mortar and bricks are high.

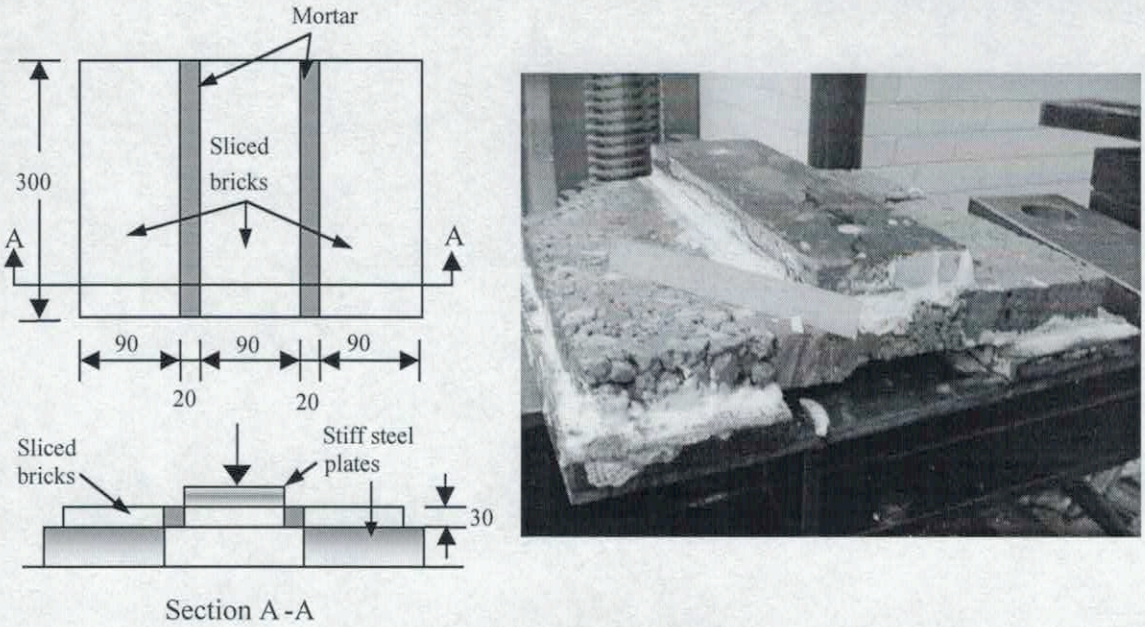


Figure 2: Typical layout of the shear tests to determine the shear strength of the bond between the mortar and brick units (dimensions are in mm).

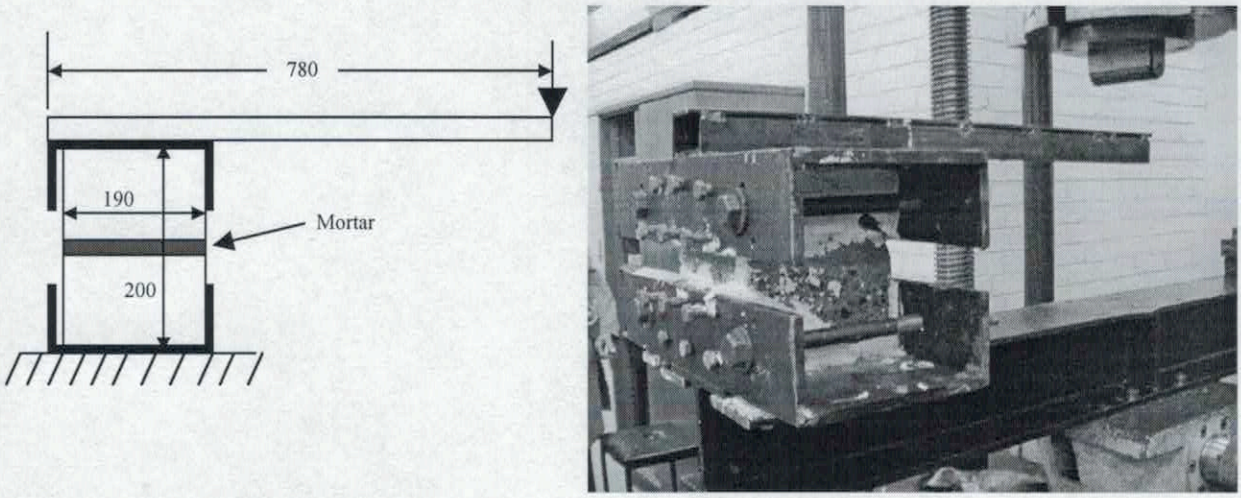
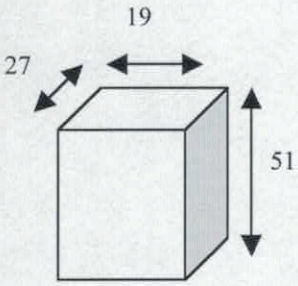


Figure 3: Typical layout of the bond wrench test to determine the tensile flexural strength of the bond between the mortar and brick units (dimensions are in mm).



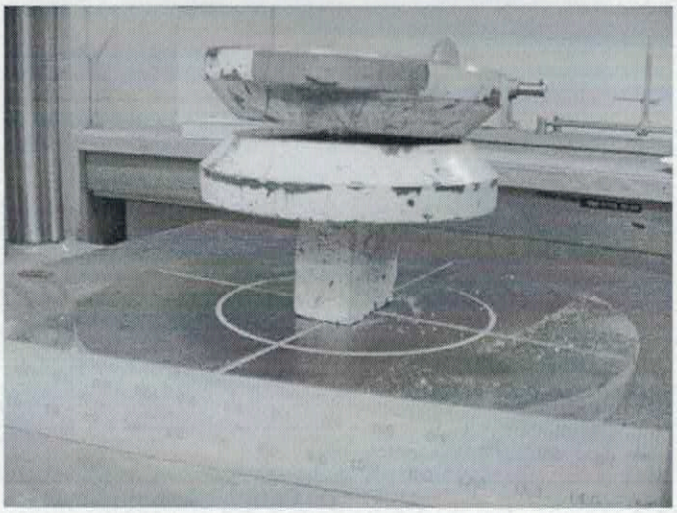


Figure 4: Typical mortar specimen used for compression test (dimensions are in mm).

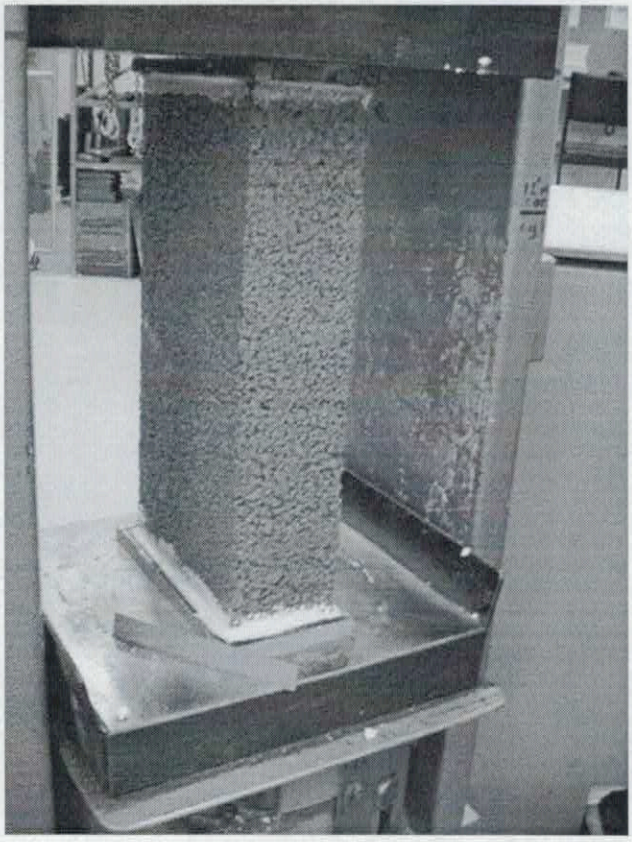


Figure 5: Typical brick specimen used for compression test (dimensions are in mm).

Table 1: Results from experiments on dry and saturated samples.

Shear tests			
	Saturated sample (from failed barricade)	Shear strength	0.55 MPa
	Dry sample (from failed barricade)	Shear strength	0.95 MPa
Bond wrench tests			
	Saturated sample (from failed barricade)	Flexural tensile strength	1.04 MPa
	Dry sample (from failed barricade)	Flexural tensile strength	1.80 MPa
Mortar compression tests			
	Saturated mortar (from failed barricade)	Compressive strength	14.0 MPa 11.0 MPa 10.45 MPa 9.5 MPa Average = 11.2MPa
	Dry mortar (from failed barricade)	Compressive strength	17.8 MPa 14.9 MPa Average = 16.4MPa
Masonry units compression tests			
	Saturated block (new block)	Compressive strength	14.7 MPa
	Dry block (from failed barricade)	Compressive strength	26.3 MPa

It should be noted that number of specimens was small due to the limited availability of the usable salvaged parts of the failed barricade. Complementary tests, undertaken by others, have confirmed the results for dry samples. While the number of samples tested is not statistically sufficient to draw definite conclusions, some trends can be noted.

- In all four types of tests, the saturated samples produced significantly lower strength than dry samples.
- The characteristic strength of the masonry units specified by the manufacturer (13MPa) is approximately half the tested dry compressive strength (26.3MPa), but much closer to the saturated compressive strength (14.7MPa).
- The mortar compressive strength (dry and saturated) is comparable to the specified characteristic strength of the masonry units.
- The maximum characteristic flexural strength permitted in AS3700 (2001) is 1.0MPa. The bond wrench test on the one dry specimen from the failed barricade would suggest that the characteristic flexural strength of the failed barricade may be close or exceed that maximum.

Finite Element Modelling

Linear elastic Finite Element (FE) modelling was performed to:

1. Identify possible stress concentration locations arising from the sharp corners around the perimeter of the barricade.
2. Identify the overall stress distribution across the barricade and compare with other analytical models.
3. Conduct sensitivity analysis on various degrees of fixity of the barricade along the rock interface.

The findings of this FE model have assisted in the consideration of cracking patterns of brick barricades.

The FE model created was based on elastic behaviour with assumed Young's modulus (E) of 1 GPa which is consistent with AS3700 (2001) and Possion's ratio of 0.2. It should be noted that the Young's modulus for masonry may vary greatly and it could range between 0.2GPa and 4GPa. A display of the model is shown in Figure 6. The FE model comprised some 6000 3D 8-node elements to facilitate detailed consideration of deformation and stress patterns for the barricade. Each element represented approximately 80x140x140mm of barricade wall.

Based on the results from the FE work, it was found that the geometry of the barricade did not result in areas of high stress concentration where damage could initiate premature failure. In addition, from the form of the stress distribution, the barricade could be simplified for other analytical analysis as a rectangle.

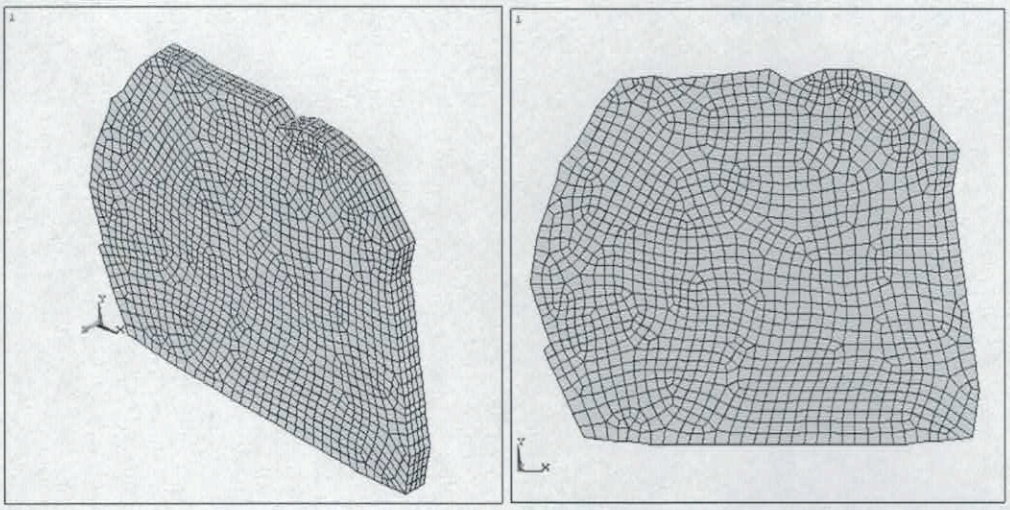


Figure 6: Isometric and front view of the FE model of failed barricade (it is approximately 6m wide, 5.3m high and 400mm thick).

The FE analysis also showed that for the case of the barricade fully fixed at the interface with the rock face (i.e., barricade fully keyed to the mine wall) the initial cracking in the barricade would occur close to this interface. This would happen at a pressure of about 20kPa. For Young's modulus (E) of 1.0GPa, the corresponding maximum displacement would be 5.5mm (if E=4 GPa, the displacement would be 5.5/4=1.4mm, etc.). If all sides of the barricade are assumed to be simply supported, the initial cracking would take place at a displacement of approximately 18mm for E equal to 1.0GPa. The cracking stress criterion used in the model was based on the experimental results obtained from the bond wrench test which yielded the flexural tensile strength (refer Table 1).

It is not considered appropriate to use a linear elastic FE model to predict the ultimate load capacity of the barricade as the mechanism of failure involves crack formation, shear flow and arching action, all of which require complex consideration of non-linear behaviour. However, the model did confirm that the irregular shape of the barricade modelled did not induce stress concentrations. Hence, it is reasonable to adopt a regular shaped wall to analyse the likely capacity of a barricade when non-linearities, e.g. the formation of cracks or arching action are considered.

Structural capacity of brick barricade

No single recognised technique for the design of brick barricades is available due to their unique construction and loading. Hence, it was necessary to investigate various possible representative models and theoretical techniques to establish the most appropriate approach for this situation. In all the models the barricade was assumed to be subjected to a uniform pressure across the entire face. It should be noted that the design models considered in this paper relate to the overall structural failure of the barricade and not piping failure. It has been found in previous studies that piping failure can occur where a very high pressure forms on a discrete part of the wall. The piping failure mechanism was described by Harr (1977) and investigated further by Bloss and Chen (1998).

The models considered in this study to predict the ultimate load capacity of a brick barricade were:

a) Bending action only according to Australian Standard AS3700: 2001 Masonry Structures
b) One way arch action according to BS5628:1992
c) Fully restrained slab according to Park and Gamble, 2000

Each of these techniques is discussed below.

a) Bending action only according to Australian Standard AS3700:2001 Masonry Structures

The Australian masonry code provides design rules for unreinforced masonry walls under short-term transient out-of-plane loading (eg. wind and earthquake loading). In this model the wall is designed to resist the loading through two-way bending. For AAC (Autoclaved Aerated Concrete) masonry, the lateral load capacity is calculated in accordance with Section 7.4.4 of AS3700 (2001) as follows:

$$w_d \leq 12\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2} + \frac{b_h M_{ch}}{L^2}\right)$$

where

w_d = total design pressure acting on the all
H = clear height of the member between horizontal supports
L = clear length of wall between vertical lateral supports
b_v = vertical bending coefficient
b_h = horizontal bending coefficient
M_{ch} = horizontal bending moment capacity of a unit width strip
= $\phi(0.22f'_{ut} + 0.33k_{mt}f'_{mt})Z_d$
M_{cv} = vertical bending moment capacity of a unit width strip
= $f_d Z_d$
ϕ = capacity reduction factor
f'_{ut} = characteristic lateral modulus of rupture of masonry units
K_{mt} = a bending moment capacity factor (= 1.3 for AAC in thin-bed mortar)
f'_{mt} = characteristic flexural tensile strength of masonry
Z_d = section modulus of the bedded area
f_d = minimum design compressive stress on the bed joint at the cross-section under consideration

This design model only considers the bending strength of masonry walls and does not include any contribution from possible arching action when rigid supports are present.

Based on various experimental programs on rectangular wall panels subjected to out-of-plane loading, common cracking patterns have been observed (Lawrence and Marshall, 1998). These are summarised as follows:

- For panels which are simply supported on four sides the first crack is always along a bed joint at mid-height of the panel. Following the formation of this crack the upper and lower halves of the panel behave independently as panels with half the original wall height (Figure 7a).
- Where adjacent sides are both supported, diagonal cracks initiate and radiate from the corner following the mortar joints. These diagonal cracks continue until they meet a free edge, a centre horizontal crack or another horizontal crack. When diagonal cracks intersect, a vertical crack develops and propagates to the top edge of the panels for walls supported on three sides Figure 7b).
- The angle of diagonal cracks is governed by the size of masonry units. The slope of the crack is equal to the unit height divided by half of the unit length.

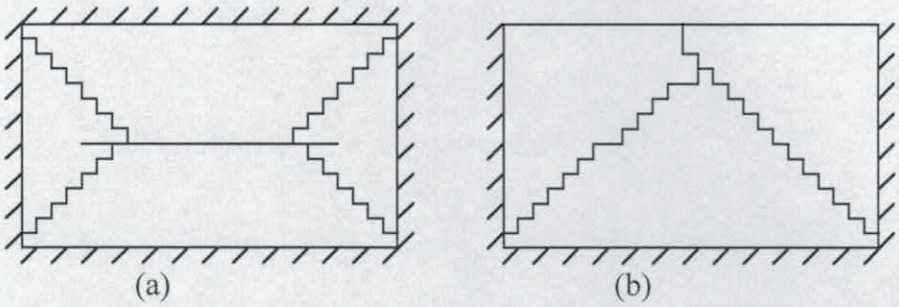


Figure 7: Typical cracking patterns: (a) wall simply supported on four sides; (b) wall simply supported on three sides.

In order to estimate the barricade capacity in bending according to AS3700 (2001), assumptions about the barricade boundary conditions had to be made. The upper-bound estimate is based on all four sides of the barricade are supported and rotationally restrained. Thus, the values of the bending coefficients b_v and b_h are maximum. The other parameters adopted were:

Length	= 6000mm	
Height	= 5300mm	
Thickness	= 400mm	
b_v	= 1.0	(AS3700 Table 7.5)
b_h	= 1.5	(AS3700 Table 7.5)
f'_{mt}	= characteristic flexural tensile strength of masonry	
	= 1.0MPa	(maximum possible value according to AS3700, 2001)
f'_{ut}	= 0.8MPa	(maximum possible value when test data not present according to AS3700, 2001)

Since the purpose of this exercise is to estimate the load capacity of the barricade, the capacity reduction factor (ϕ) is assumed to be unity. For design purposes ϕ would be taken as 0.65 according AS3700 (2001). Based on these parameters and assumptions, the capacity of the barricade was estimated to be 21kPa.

Adoption of higher values for the flexural tensile strength, as obtained from the dry bond wrench test, i.e., 1.8MPa, results in the capacity of the wall increasing to 31kPa. Such an increase is inconsistent with field observations where the barricade sustained loads up to 200kPa.

It is evident that this analytical model in the Australian Standard AS3700 (2001) is inadequate to represent the true behaviour of the brick barricade. This is primarily due to the fact that barricades develop an arching action with the thrust developing against the rock face of the mine stope. The Australian masonry standard AS3700 (2001) does not provide guidance on such arch action.

b) One way arch - British Standard BS 5628:1992 Code of practice for use of masonry

When a wall is built solidly between rigid supports arching action can develop. The British masonry Standard BS5628 provides a method of design of walls based on the assumption that, under lateral loading, a horizontal arch is developed within the thickness of the wall (refer Figure 8). The horizontal arching is assessed on the basis of the wall span, depths and the compressive strength of the masonry.

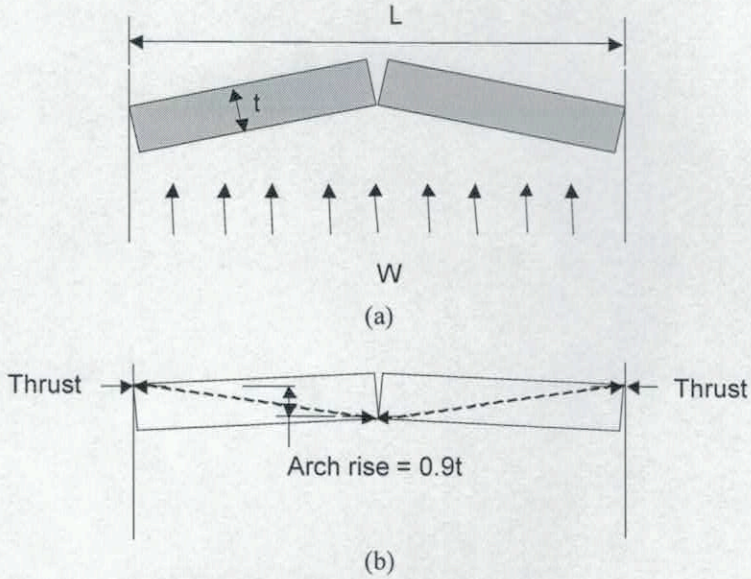


Figure 8: A horizontal one-way arch action in a masonry wall.

For wall length (L) to thickness (t) ratio of less than 25, the design lateral strength per unit area of the wall (w) is given by

$$w = \frac{f_k}{\gamma_m}\left(\frac{t}{L}\right)^2$$

where:
t = overall thickness
f_k = characteristic compressive strength of masonry
L = length of wall

γ_m = partial factor of safety for materials (ranges between 2.5 and 3.5 depending on level of manufacturing and construction control)

The same concept was used to analyse the brick barricade to estimate its capacity. Specific parameters used in the analysis for the failed barricade were:

L = 6000mm
t = 400mm
f_k = 13MPa (characteristic strength of masonry units as specified by the manufacturer)
γ_m = 1.0 (taken as 1.0 determine the actual strength rather than the design strength)

Thus, the resulting design lateral load capacity of the barricade, based on one-way arch action is 58kPa.

It should be noted the design lateral load based on this approach is directly related to the characteristic compressive strength of masonry (i.e., doubling the compressive strength of masonry would result in double the design lateral load).

This approach is still inadequate in its approximation of a barricade as it assumes that the barricade is only supported on two sides and is only developing a horizontal arch. In fact, the barricade is supported on four sides and arching in two directions is likely to take place.

c) Fully restrained slab according to Park and Gamble, (2000)

The structural action of a barricade may resemble a concrete floor slab subjected to uniform pressure. Park and Gamble (2000) developed an analytical approach to analyse floor reinforced and unreinforced concrete slabs which are fully restrained at four sides with the supports capable of resisting arch thrust. The developed analytical model is based on yield lines developing as shown in Figure 9.

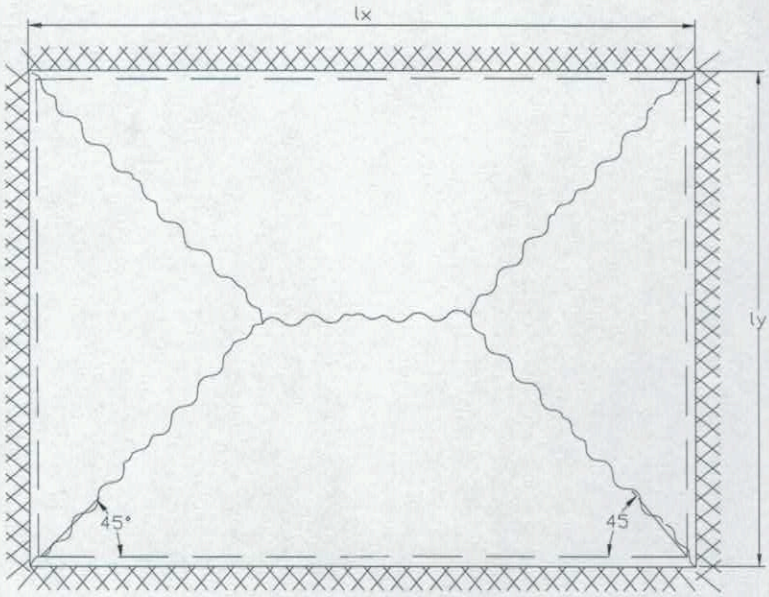


Figure 9: Assumed yield line pattern for uniformly loaded slab with restrained edges.

For unreinforced concrete slab the ultimate uniform lateral load (w_u) that can be sustained is obtained from the following expression.

$$\frac{w_u l_y^2}{24}\left(3\frac{l_x}{l_y}-1\right)=0.85f_c'\beta_1 h^2\left[\frac{l_x}{l_y}(0.188-0.141\beta_1)+(0.479-0.245\beta_1)\right]$$

where

l_x = length along the x axis
l_y = length along the y axis
h = slab thickness
f'_c = concrete cylinder strength
β_1 = ratio of the depth of the equivalent rectangular stress block to the neutral-axis depth, as defined in ACI 318-95 (β_1= 0.85 for $f'_c \leq 30$ MPa)

The properties of the barricade are matched to the parameters in this model as follows:

l_x = 6000 mm
l_y = 5300 mm
h = 400 mm
f'_c = 13 MPa
β_1 = 0.85

The resulting ultimate load (w_u) is 186kPa.

This formula is based on the assumption that the slab reaches its ultimate load at central deflection of one-half the slab thickness. This assumption may be conservative for slabs with span (l_y) to thickness (h) ratio less than 20 (for the barricade the ratio is 13.3) (Park and Gamble, 2001). On the other hand, it is assumed the barricade is fully rotationally restrained on all four sides, which is over and above what is provided by the steel pins as shown in Figure 1. In addition, no safety reduction factor has been applied.

The load capacity based on this model is directly proportional to the strength of masonry. The experimental findings indicate that the concrete blocks/mortar have f'_c in the range from approximately 9.5 – 26.3 MPa. Such variation translates to potential ultimate capacity of the barricade from 136kPa to 377kPa. Given the mine was saturated during the backfill operation the upper bound result may be regarded as unrealistically optimistic.

A typical outcome where the barricade is saturated with mine water the results for f'_c of the concrete blocks/mortar range from 9.5 – 14.7 MPa. It should be noted that the maximum compressive strength for mortar as tested was 14.0kPa. However, in the actual barricade the mortar is confined more than in the laboratory test, hence, it is considered reasonable to include the saturated strength from the concrete block (14.7MPa) as an upper bound result. Such variation translates potential ultimate capacity of the barricade from 136kPa to 210kPa.

It should be noted that the ultimate capacity of the barricade is also sensitive to the physical dimensions of the slab (barricade). This is demonstrated in Figure 10 where the capacity of several square barricades is calculated. A small change in dimensions would result in a significant change in capacity.

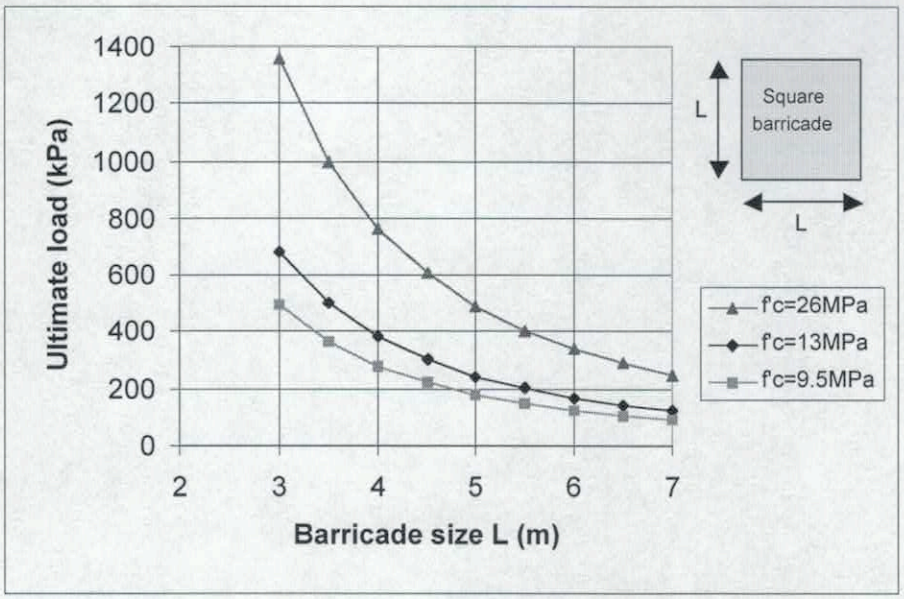


Figure 10. The ultimate load (w_u) for square barricades with 400mm thickness and various compressive strengths (f'c).

In this prediction, it was assumed that the masonry units are cut to closely match the profile of the rock face as much as possible and sound mortar is used to create coherence between the barricade and the rock face and to fill any gaps.

It should be emphasised that the development of arch thrust requires rigid supports (in this case, the support is the rock at the interface with the barricade). A small change in span of the arch can considerably reduce the arch resistance.

Shear Strength

In addition to the possible failure under arching action, the shear capacity of the barricade was investigated. The bond shear strength between the mortar and bricks was assessed as part of the experimental program (refer to Table 1). It was determined that the most critical shear plane is the interface between the barricade and the rock face. Thus, the shear capacity along this interface is the cumulative contributions of the:

(i) shear rupture strength of the bond between the mortar and the bricks,
(ii) shear friction strength due to the compressive arching action along the brick-rock interface, and
(iii) shear strength of the steel pins embedded in the rock and barricade.

Parts (i) and (ii) above were estimated based on the experimental results and provisions in the Australian Standard for masonry structures (AS3700). The shear strength of the steel pins was evaluated based on first principles (shear capacity of steel bars). It was found that the shear capacity of barricade is higher than the capacity under two-way arching. Hence, for the failed barricade, it was concluded that the failure was more likely to be due compressive failure under arching rather than shearing around the perimeter.

Barricade tested at Mount Isa Mines

A major investigation including a full-scale test of an underground brick barricade was conducted at Mount Isa Mines in collaboration with CSIRO (Commonwealth Scientific and Industrial Research Organisation), Beer (1986) and Grice (1989). In this investigation, a brick barricade measuring 4m by 4m by 460mm thick was subjected to an increasing uniform pressure up to failure. This test barricade failed at a pressure of 750MPa (Grice, 1989). The results from this test have been used as verification to many barricades which were constructed after the test. Further, the results from this investigation have been extrapolated to barricades which are larger and thinner than the tested barricade.

It should be noted that the failed barricade investigated in this paper was considerably larger (6m x 5.3m) and thinner (400mm) than the tested Mount Isa barricade (4m x 4m x 460mm). As was demonstrated in Figure 10, the arching action is sensitive to the length and height of the barricade. In addition, thinner barricades would have an even lower strength as bearing/thrust areas would be reduced.

For the Mount Isa barricade the compressive strength of the bricks was reported to be 10MPa (Beer, 1986) which is believed to be the characteristic value or minimum value guaranteed by the manufacturer. The compressive strength of the mortar was reported to be 11MPa. Based on this data and using the Park and Gamble model described above, the ultimate capacity of the barricade is 427MPa. This is well below the pressure at which the barricade failed.

This apparent discrepancy can be attributed to the degree of saturation of the test barricade, exposure of the barricade to fresh water rather than mine waste, the real compressive strength of masonry and the boundary condition between the barricade and the mine wall. For the tested barricade at Mount Isa, it was necessary to seal the barricade in order to build up the applied pressure (Grice 1989). It is understood that some water penetrated this seal as the wall approached its ultimate state, however, the extent of saturation of the wall block and mortar remains an uncertainty in the interpretation of these test results. It has been demonstrated, in the experimental results shown in Table 1, the strength properties are significantly higher for dry components compared to fully saturated.

Based on the limited experimental results it seems that the characteristic compressive strength for the bricks and mortar are closer to the strength of saturated components rather than dry. Indeed, the compressive strength of dry brick could be as high as double the strength of saturated bricks (Table 1). Thus, for the tested Mount Isa barricade the compressive strength of the bricks and mortar could be significantly larger than the 11MPa reported. Figure 11 illustrates the sensitivity of the predicted capacity of the barricade to the compressive strength of the components and the barricade dimensions.

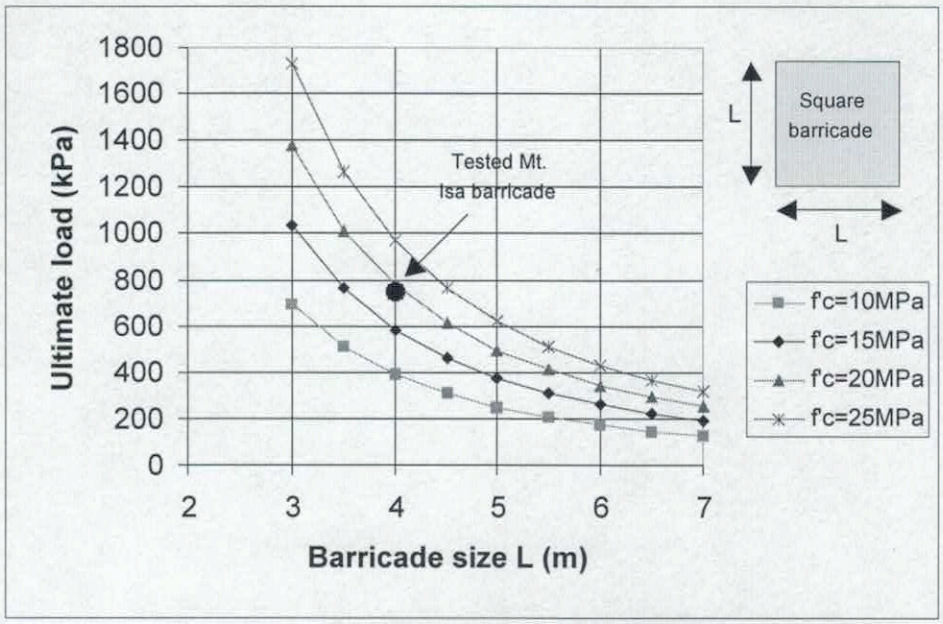


Figure 11. The ultimate load (w_u) for square barricades with 460mm thickness and various compressive strengths (f'c).

It is clear from Figure 11 that the actual failure pressure for the Mount Isa barricade (750 MPa) falls within the bounds of the predicted capacity for compressive strength of masonry between 15 and 20MPa. While this range is higher than the reported characteristic values, they may be representative values of the tested situation.

Conclusions

This paper has described the use of permeable brick barricades in underground mines to retain hydraulic fill. While such construction has been widely used in the industry, the mechanism of the action imposed on the barricade from the backfill and the restraint provided by the wall is not sufficiently understood to prevent failures from occurring.

The details of a barricade, measuring 6m wide, 5.3m high and 400mm thick, which failed recently have been briefly discussed. Specimens from this failed barricade were tested to determine the compressive strength of the bricks and mortar as well as the bond strength between them in both shear and tension. The tests were conduced on dry and saturated (in mine water) samples. In all the tests, the saturated samples yielded significantly lower strengths compared to the dry samples. While the number of samples tested was limited because of the availability of salvaged specimens, the trend observed was consistent. Thus, in the design of such barricade, it is important that the saturated properties to be used in estimating the barricade capacity.

In order to investigate the barricade capacity a number of structural models were considered. The structural action of the barricade closely resembles that of a fully restrained unreinforced concrete slab under uniform pressure. A model developed by Park and Gamble (2000) was used to predict the capacity of the failed barricade. The ultimate failure mode is dependent on the compressive capacity of the masonry due to arching action and the assumed cracking pattern of the barricade. The predicted ultimate capacity based on saturated material properties is very close to the measured pressure in middle of the barricade at failure.

Another possible failure mode, the shear failure along the interface between the barricade and the rock face, was briefly discussed. The shear strength along this interface is the resultant of three components, (a) shear strength of the bond between the bricks and mortar; (b) the shear friction strength along the barricade/rock interface due to the compressive arching action; and (c) the shear strength of the steel pins (reinforcing bars) which are embedded into the barricade and surrounding rock. It was found for the failed barricade that the shear strength was higher then the predicted capacity under arching action.

A brief review of results from a destructive test on a full-scale barricade at Mount Isa Mines was presented. The model used to predict the capacity of the failed barricade in this paper was used to estimate the capacity of the tested Mount Isa barricade. The predicted capacity based on the published material properties was significantly lower than the measured value. However, the test was conducted on a sealed barricade which would possess higher material strength being in dryer condition. Using sensitivity analysis, the measured failure pressure is actually within the range of possible material strengths.

It is evident from the number of barricade failures still being experienced that significant research effort is required to better understand the action and restraint mechanisms for such barricades. The predictive technique outlined by Park and Gamble adds to the understanding of structural behaviour of the barricades, but more work is required to assist in the predication of cracking patterns, boundary conditions, the magnitude of backfill loads and the distribution of such loads.

Acknowledgements

The support from Newmont NFM in providing field data and critique by the Australian Mining Consultants (AMC) is gratefully acknowledged.

References

Beer, G. (1986),"Design of brick bulkhead: numerical modelling", CSIRO report, Institute of Energy and Earth Resources, Division of Geomechanics. Qld, Australia.

Bloss, M.L. and Chen J., (1998), "Drainage research at Mount Isa Mines Limited 1992-1997", MineFill 98. (The Australian Institute of Mining and Metallurgy: Melbourne).

British Standards, (1992), "BS:5628 Code of practice for use of masonry"

Grice, A.G. (1989), "Fill research at Mount Isa Mines Limited", Innovations in Mining backfill Technology (Ed: Hassani et al), Balkema, Rotterdam, PP. 15-22.

Grice, A.G. (1998), "Stability of hydraulic backfill barricades", MineFill 98. (The Australian Institute of Mining and Metallurgy: Melbourne).

Harr, M.E., 1977. Mechanics of particulate media. pp174-178 (McGraw Hill).

Lawrence, S.J. and Marshall, R.J. (1998), "The new AS3700 approach to lateral load design", Proceedings of the 5th Australasian Masonry Conference, Qld, Australia, PP. 227-237.

Park, R. and Gamble, W.L., (2000), "Reinforced concrete slabs", John Wiley and Sons Inc.

Standards Australia, (1984), "AS2701.4 Methods of sampling and testing mortar for masonry construction- Pt 4: Methods for determination of compressive strength"

Standards Australia, (1997), "AS/NZS4456.4 Masonry units and segmental pavers – methods of test, Methods 4: Determining compressive strength of masonry units"

Standards Australia, (2001), "AS 3700:2001 Masonry structures"