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In situ pressures in cemented paste backfill — a review of fieldwork from three mines

B.D. Thompson *University of Toronto, Canada*

M.W. Grabinsky *University of Toronto, Canada*

R. Veenstra *University of Toronto, Canada*

W.F. Bawden *University of Toronto, Canada*

Abstract

There is a requirement for better understanding of in situ cemented paste backfill (CPB) behaviour in order to optimise backfilling strategies, i.e. two stage versus continuous pours, pouring rates, time to blast alongside a CPB stope. Furthermore, such data is required to calibrate numerical and analytical models and provide input parameters for laboratory testing of CPB. In response to the requirement for in situ data, the University of Toronto has led an international research project in which six stopes at three partner mines have been comprehensively instrumented with geotechnical instrumentation. The aim of this project is to better understand CPB in situ behaviour in terms of quantifying cement hydration rates, consolidation and arching mechanisms, to provide some estimates of in-stope and barricade pressures and to ultimately improve backfilling efficiency at the partner mines. In this paper, we firstly review the instrumentation procedures to provide guidance for operations seeking to apply similar site-specific backfill investigation. Secondly, key results are presented from the field tests. Each site presents significant similarities and differences in terms of backfill pressure. New data are presented from Barrick's Williams Mine, in which low barricade pressures are measured when continuously backfilling a 50 m high, 70° dipping stope. The potential for increasing barricade pressures when flushing paste lines into the stope is demonstrated. Case studies from Inmet's Cayeli Mine provide a comparison of factors affecting backfill pressures, in terms of the relationship between backfill rise rate and cement hydration rates in controlling barricade pressure. The Xstrata Copper Canada Kidd Mine case studies provide evidence that pressures can increase during periods of downtime in backfilling, which we interpret due to thermal expansion of CPB. Pressures exceeding 1 MPa are measured in the Kidd CPB, as the effect of rockbursts and nearby mining are shown to transfer pressure onto the backfill. At all the sites, the exceptional value of instrumentation in backfilling has been demonstrated. The most efficient backfilling strategies will employ real-time barricade monitoring to backfill stopes on a case-by-case basis.

1 Introduction

CPB has been gaining popularity as an optimum backfilling material at many underground mines. However, there is typically limited understanding of how CPB behaves within a stope. This has significant implications when designing backfilling strategies. For instance, many mines choose staged pours with intermediate curing periods of between 1–7 days in order to minimise backfill pressures at barricades. Frequently, such backfilling strategies are designed without the benefit of in situ measurements of pressures at barricades, and so must necessarily be conservative to minimise risks of barricade failures. Improving the efficiency of backfilling has potential for significant cost savings, in terms of reducing stope cycle time by reducing cure times, or indeed moving to continuously pouring stopes. Such measures require an understanding of backfill pressure evolution for the range of binder contents, rise rates and stope geometries featured at a specific site.

In situ pressure data are also required to calibrate and provide proper input functions for numerical and analytical models of in-stope CPB behaviour (Helinski et al., 2010; Li and Aubertin, 2009), and laboratory studies (Helinski et al., 2007; Moghaddam, 2010; Yilmaz et al., 2009). However, there is a fundamental lack of such data in literature (notable exceptions are Hassani et al., 1998; Yumlu and Guresci, 2007). In response, a large field-based project has been undertaken by the University of Toronto, in conjunction with

Barrick Gold Corporation's Williams Mine, Inmet Mining Corporation's Cayeli Mine, and Xstrata Copper Canada's Kidd Mine. Two stopes have been instrumented at each site, and detailed information on site specific backfill behaviour has been reported (Thompson et al., 2009, 2010a, 2010b). This paper reviews the key findings and presents representative data from each site.

2 Large scale field tests

The instrumentation strategy was to install geotechnical instrumentation both at paste fill barricades, and at numerous locations within the open stopes. The most useful instrumentation was total earth pressure cells (TEPCs) and pore water piezometers. In addition to basic pressure data, orthogonally positioned TEPCs can be used to determine whether loading is hydrostatic or non-hydrostatic, and so provide information on the development of shear strength within CPB. Measurement of pore water pressure is frequently neglected in CPB field studies; however, it is very important in permitting consideration of backfill behaviour in terms of effective stress (Fourie et al., 2007). Orthogonal TEPCs and a piezometer were installed in instrument cages (Figure 1(a)). Electrical conductivity probes (Figure 1(b)) and heat dissipative sensors (Figure 1(c)) were also employed and are further described by Grabinsky (2010). The instrument cages were then installed in protective cages for deployment in stopes (Figure 1(d)).

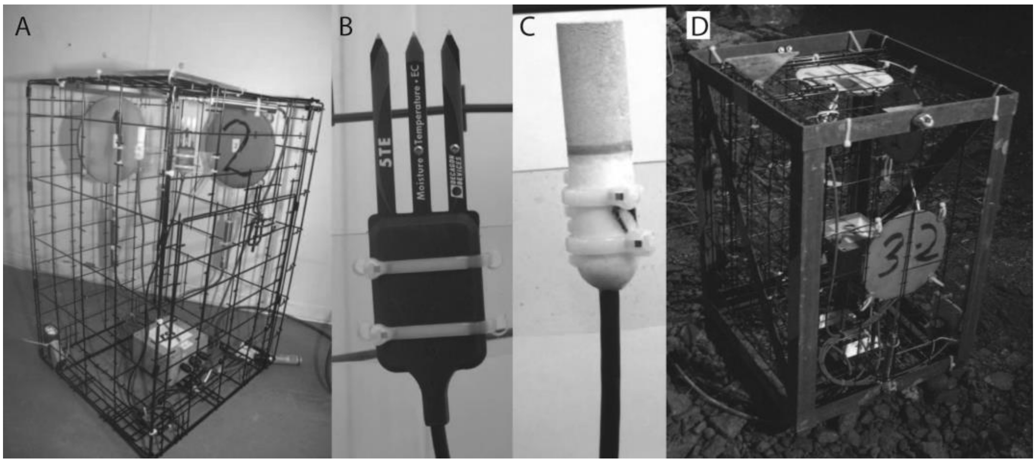

Figure 1 (a) Instrumentation installed in internal cages includes total earth pressure cells, piezometers; (b) electrical conductivity probes; (c) heat dissipative (suction) sensors; (d) protective external cages are used for deployment in stopes

From an operational viewpoint, the critical monitoring location is the barricade. Failures of paste fill barricades during backfilling have been reported by Revel and Sainsbury (2007) and Yumlu and Guresci (2007). However, as barricade pressures are a function of the backfill rise rate, cement hydration speed, geometrical features influencing arching and the specific material's geotechnical and geochemical properties, a true understanding of backfill behaviour requires instrumentation within the stope. For this reason, instrumentation has been suspended vertically in the centre axis of stopes at the Kidd and Cayeli Mines (Figure 2(a) and (c)). Instrumentation was also deployed either side of draw-points to measure arching effects with proximity to stope walls and in drifts (Figure 2(b) and (c)). A full description of the instrument installation of the long hole stopes at the Kidd and Cayeli Mines can be found in Thompson et al. (2009, 2010a), where cages were elevated into the stope via a pulley and cable arrangement attached to the stope back that was emplaced prior to stope blasting. Ten instrument cages were also installed in an Alimak stope at Williams (150 m high, 5 m footwall – hanging wall distance, 70° dip) by lowering down the raise, suspended by three guide cables (Grabinsky et al., 2008). In this field test, data cables were damaged when backfill flowing down the footwall dislodged rocks. This highlights the practical importance of protecting cables, and if available, utilising undercut accesses for cable routing to minimise their exposure within an open stope.

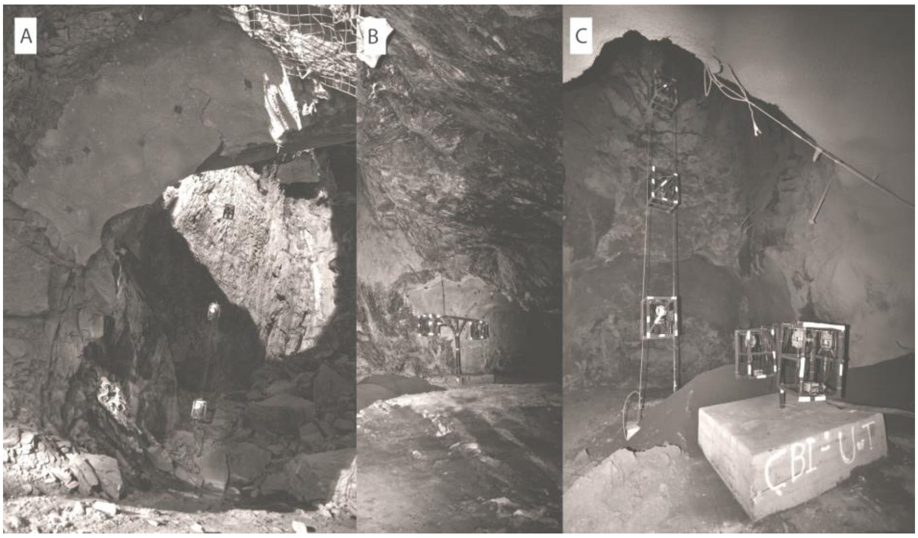

Figure 2 (a) Instrumentation suspended in the stope; (b) spanning the brow at Kidd Mine; (c) instrumentation at Cayeli Mine

3 Williams Mine fieldwork (2010)

Large scale installations have provided excellent results, but they can also be time and resource intensive. In 2010, a second stope was instrumented at the Williams Mine, this time with the mandate to complete a rapid installation with minimal impact on production while still providing useful information on cement hydration rates, arching within the stope and barricade pressures. This installation is shown in Figure 3, where two cages were positioned in the undercut, one in the main stope, and one under the brow to measure the pressure differential due to arching. Dimensions are shown in the figure. Each cage contained orthogonally-positioned TEPCs and a piezometer. The barricade also was instrumented with two TEPCS and two piezometers.

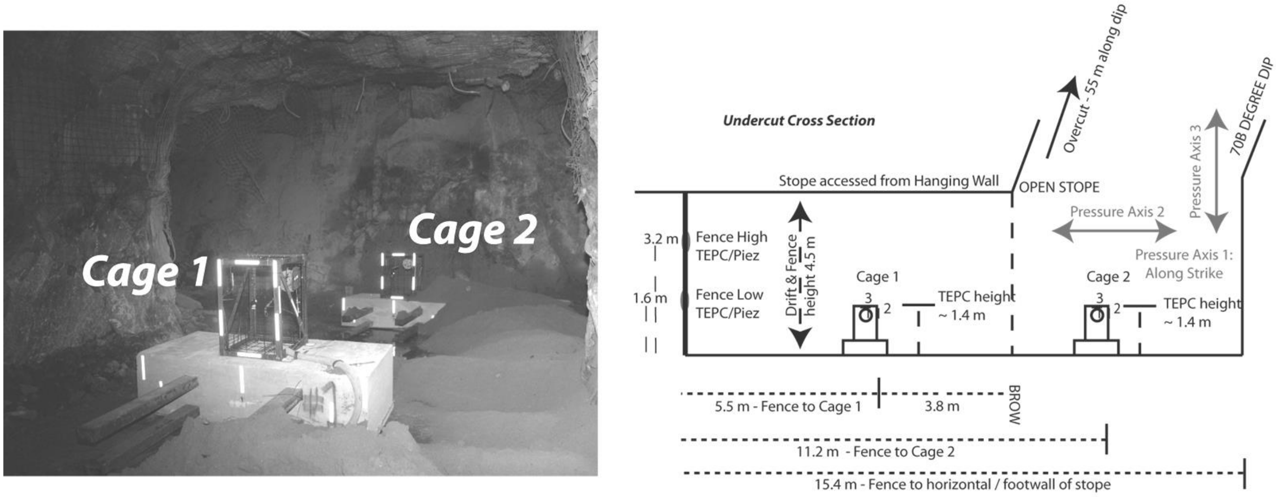

Figure 3 Instrumentation installed, and cross section of Williams 2010 test stope

The Williams Mine standard backfilling practice is to pour an initial plug of height ~7 m, which is allowed to cure before the remainder of the stope is backfilled. The previous test indicated extremely low peak barricade pressures of 35 kPa for a 150 m high Alimak stope (Grabinsky et al., 2008) and so a continuous pour was planned for this second test stope. Ultimately, the mine would like to adopt continuous pours as routine procedure, assuming safety can be assured. As per standard site practice, access to an undercut area equal to the stope volume was restricted during backfilling, and the data was networked to a safe location for 24 hour monitoring. The CPB binder content was 3% (50:50 ratio of Portland cement to flyash) in the lower stope and 2% in the upper stope volume. These are the lowest binder contents employed on site. Gravimetric water content was initially measured between 27–29%. Grain size distribution for Williams, Kidd and Cayeli Mine tailings are shown in Figure 4.

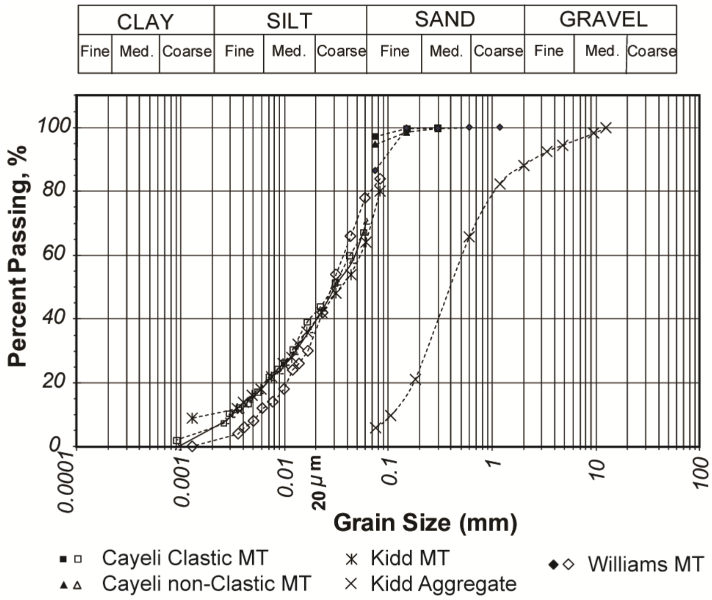

Figure 4 Grain size distributions for the mine tailings (MT) and aggregates for the Cayeli, Kidd and Williams Mines

Backfilling was completed in one continuous pour of duration 67 hours. Pressure data from cages 1 and 2 are shown in Figure 5(i) and (ii) respectively, showing initially hydrostatic loading for three hours, with vertical pressures increasing at a greater rate than horizontal pressures after this point. At the end of pouring, peak total pressures are 159 and 75 kPa in the vertical orientation, which are significantly lower than the potential ~1 MPa head pressure of the overburden in the 50 m high stope, indicating pressures have been reduced due to arching. At the barricade, pressures initially increase to ~30 kPa within the first 12 hours of backfilling, after which they remain relatively constant, peaking at 36 kPa at the end of backfilling. There is a ~45 kPa increase in total earth pressure and pore pressure at the end of the pour for the barricade, and cages 1 and 2, which corresponds with timing of the flushing of the paste lines with water (for cleaning purposes) into the stope. Peak pressures are 79, 120 and 206 kPa for the barricade, cage 1 and cage 2 respectively. The flush doubles the pressure measured at the barricade. Smaller flush-induced pressure increase were measured in the previous Williams Mine fieldwork, but were not observed when lines were flushed during the Kidd or Cayeli Mine fieldwork.

The initially periodic loading pattern at the barricade and cage 1 during the initial 14 hour period of backfilling is consistent with the flows of CPB into the drift observed on an in-stope camera. The more uniform loading observed after this point would concur with the drift being completely filled and the CPB rising in the main stope volume. There is a peak and then reduction in temperature at the barricade at 31 hours, which coupled with the increase in pore pressure, could indicate new material has reached the barricade. The level of the CPB would at this point be ~19 m and so one explanation is water could have travelled along hanging wall – paste contact. As with previous studies, pressures have been measured to be smaller with distance along a drift and away from the main stope. The magnitude of the pressures measured at the two Williams test stopes are much lower than would be expected if the CPB was considered a fluid mass. The CPB shows a rapid departure from hydrostatic loading, which is the reason that pressures are relatively low. It is speculated that the stope geometry, in terms of the 70° footwall dip and narrow hanging wall to footwall separation (~7–9 m) increase the arching potential. Both of the stopes featured the mines lowest binder content CPB, which is encouraging as higher binder contents would theoretically result in faster hydration, greater arching potential and so even smaller barricade pressures. We have demonstrated that continuous backfilling at Williams is possible, and results in low pressures at the barricade (although the ultimate barricade strength is unknown). However, as demonstrated in the Cayeli Mine fieldwork (Thompson et al., 2010b) a large variation in backfill pressure can result from differences in tailings chemistry and their geotechnical characteristics, binder content, pouring rates, and stope geometry even at the same mine site. For this reason, further testing is underway to better understand the potential range of barricade pressures at Williams. Ultimately, the regular use of barricade pressure measurements are recommended as a QA/QC procedure to ensure continuous backfilling can be safely employed at Williams.

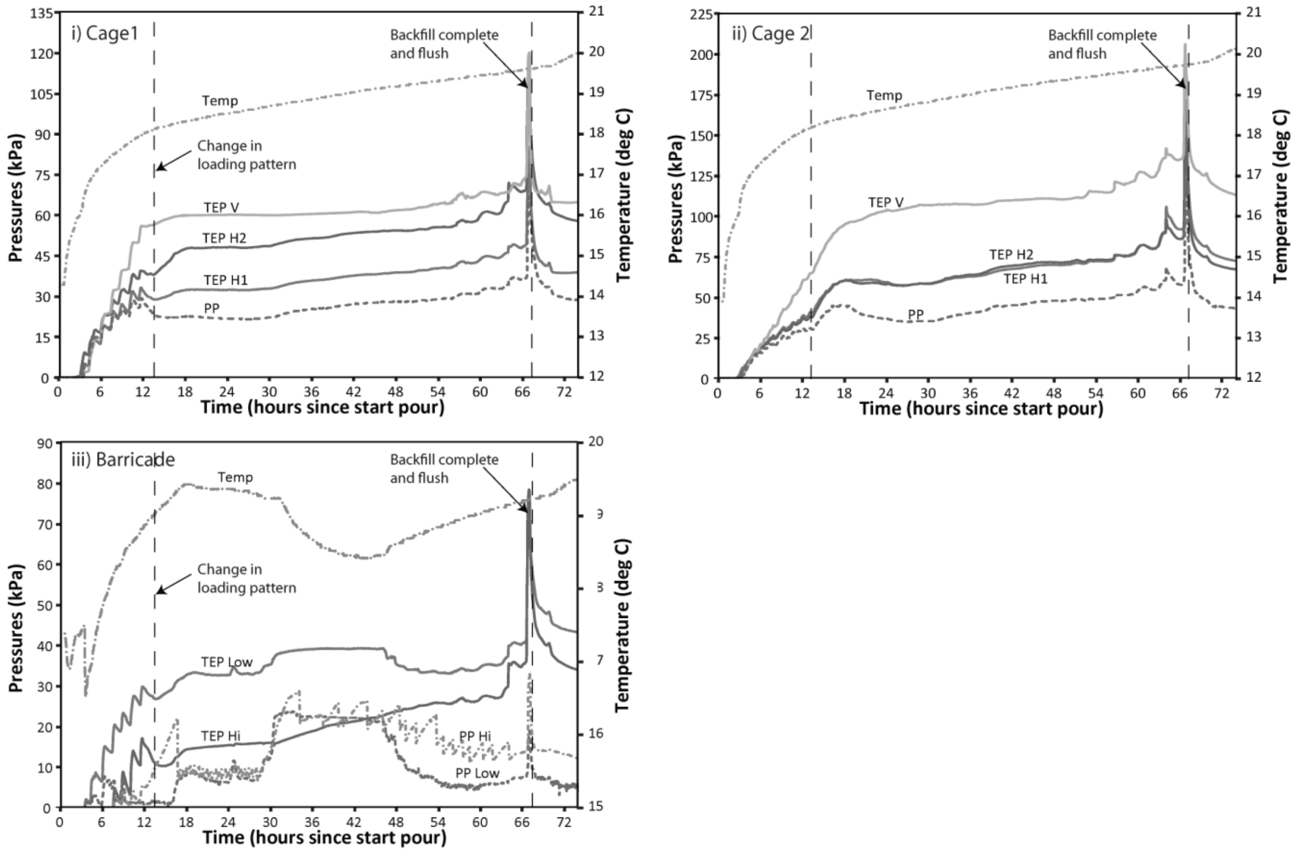

Figure 5 Total earth pressure (TEP), pore water pressure (PP) and temperature recorded at (i) cage 1; (ii) cage 2; (iii) barricade for a 74 hour period

4 Cayeli Mine fieldwork (2009)

The two instrumented stopes backfilled at Cayeli provide contrasting views on factors influencing barricade and in-stope pressures. The 685 (N20) stope was relatively large (25 × 10 m undercut area, 16 m floor to floor), featuring relatively high (8.5%) binder content in the lower stope. The 715 (N22) stope (Figure 2(c)) was small (15 × 8 m undercut area, 15 m floor to floor), with 6.5% binder content CPB throughout. Cayeli has complex ore geology and so two different tailings streams are used in backfilling. The 685 stope featured ‘clastic’ tailings whereas the 715 stope featured the ‘non-clastic’ tailings sourced CPB. Grain size distribution is shown in Figure 4 for both tailings streams. Gravimetric water content was measured between 23–28% during backfilling. CPB composition, instrument installation and results are described in more detail by Thompson et al. (2010b). In both stopes, pressure data was networked to the surface and used to define if the stope could be poured continuously, until a barricade pressure limit of 100 kPa was reached. The larger 685 stope was poured continuously, whereas the smaller 715 stope featured a three day intermediate cure period when barricade pressures reached 100 kPa.

Figure 6 presents a comparison of TEP, PP and temperature data for the 685 and 715 stopes at the barricade locations (a and b), the cage 1 locations under the brow of the stope (c and d), and the cage 3 locations in the stope at ~3 m elevation (e and f). The barricades have TEPC and piezometers installed at the horizontal centreline and at ¼, ½ and ¾ heights of the ~5 m high barricades. Barricade pressures at the 685 stope peak at 55 kPa, which is well below the 100 kPa shut down pressure. For the 715 stope pressures increase linearly to 100 kPa. A three day cure is then required after which pouring the remainder of the stope induced negligible further pressure change at the barricade.

Cage 1 and 3 for the 685 stope (Figure 6(c) and (e)) show vertical (V) and horizontal pressures acting perpendicular to strike and towards the barricade (H1) and along strike (H2). Pressures initially increase hydrostatically, with pore pressure equal to TEP. This pattern persists for 13–14 hours, before the rate of increase in horizontal pressure decreases, and pore pressure falls, demonstrating the backfill is gaining shear strength and pressures are arching. From this point, horizontal pressures do not significantly increase during the remainder of the pour, although vertical pressures increase to peak at 116 and 194 kPa at the end of backfilling. For the 715 stope, hydrostatic loading persists to the end of the initial pour. During the three day cure, pressures initially decrease, although subsequent pressure increases around day three during the cure is interpreted to be due to thermal expansion of CPB. During the second backfilling period, pressures continue to increase at cage 3. Peak pressures are 120 and 226 kPa at the completion of backfilling for cages 1 and 3, respectively.

In Figure 7, comparisons are made to highlight the controlling factors on pressures in CPB. Firstly, two temperature profiles are displayed from CPB in the 685 stope (Figure 7(a)), with binder contents of 8.5 and 6.5%. Assuming temperature is proportional to cement hydration then the higher binder content is shown to cause more rapid binder hydration. Pressure increase is also dependant on rise rate, as shown in Figure 7(b) for two locations within the 715 stope. Backfilling at cage 3 features a lower rise rate than at cage 5 due to the stope geometry and so the rate of pressure increase is greater at cage 5. TEP at the two barricades are compared in Figure 7(c). The 715 stope shows a greater rate of pressure increase, due to the faster rise rate, but also the rate of pressure increase slows to a peak around 0.55 days for the 685 stope, whereas pressure increase is linear for 0.74 days in the 715 stope due to the differences in cement hydration. The pattern of higher rate of pressure increase and no evidence of pressures ‘rolling over’ for the 715 stope is repeated in Figure 7(d) and (e) for cages 1 and 3.

In Figure 7(f), a comparison of temperatures between the two stopes is presented at the cage 5 locations. The 685 stope shows a rapid temperature increase, whereas the 715 stope data indicates a 2.5 day delay before the temperature increases significantly. This indicates that cement hydration is delayed by 2.5 days for the 715 stope. The only difference between the CPB at the two locations is the non-clastic (685) and clastic (715) tailings streams, as 6.5% binder CPB was used in the upper volume of both stopes. This implies tailings chemistry even within the same ore body can have a significant effect on cement hydration, and any backfill instrumentation study should recognise all the potential variables when recommendations are made with regards to modifying a backfilling strategy. Cayeli is an example of how routine monitoring of backfill pressures would enable the most efficient backfilling strategy to be employed, i.e. continuous pouring is possible for some stopes, and could reduce the cycle time of such stopes by between 3–7 days. Clearly however, the standard two stage pour is necessary for other stopes to limit the barricade pressures.

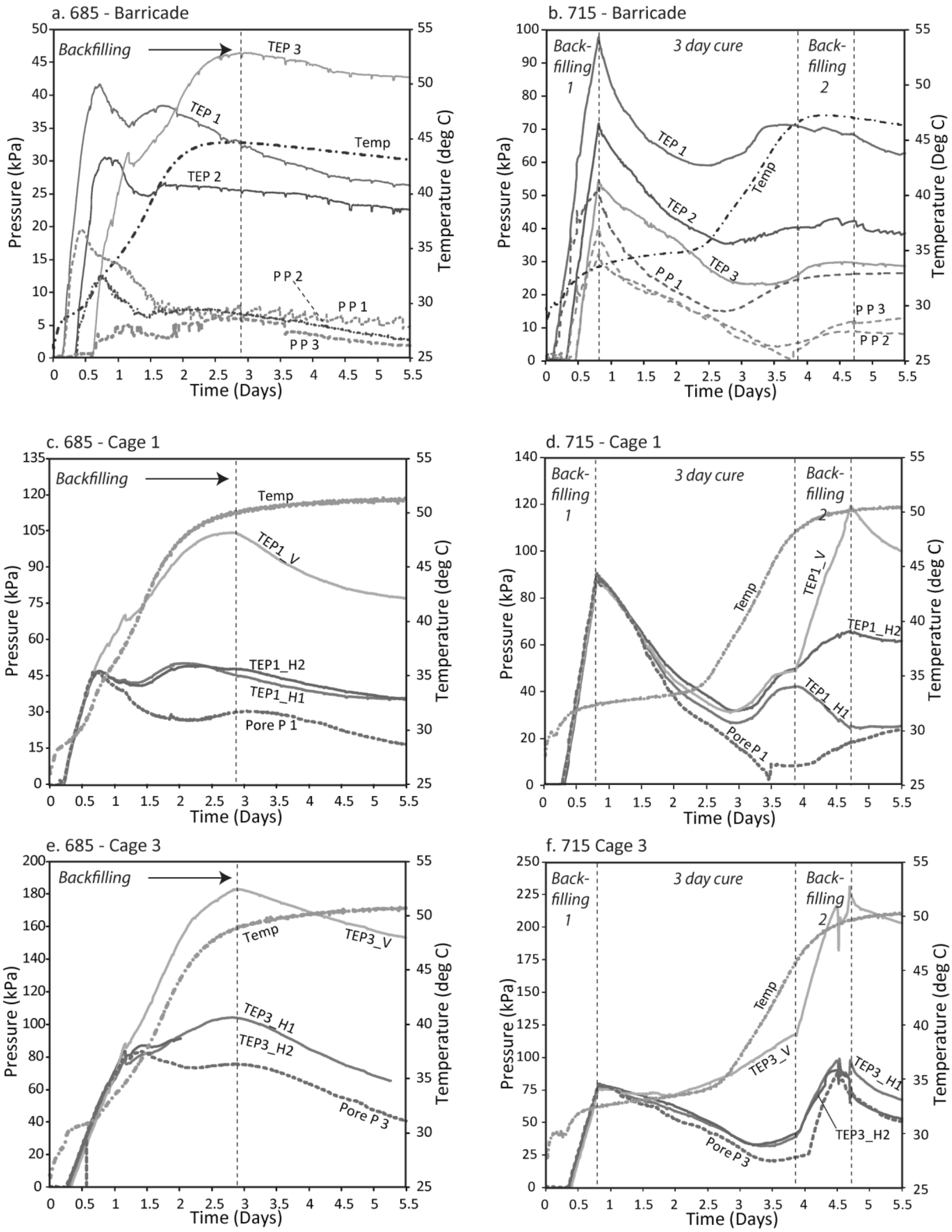

Figure 6 Comparison of in-stope TEP at barricade (locations 1–3 at ¼, ½ and ¾ barricade height) and for cages 1 and 3 (pressure orientations horizontal 1 (H1) and 2 (H2) and vertical (V), PP and temperatures for the 685 and 715 Cayeli stopes

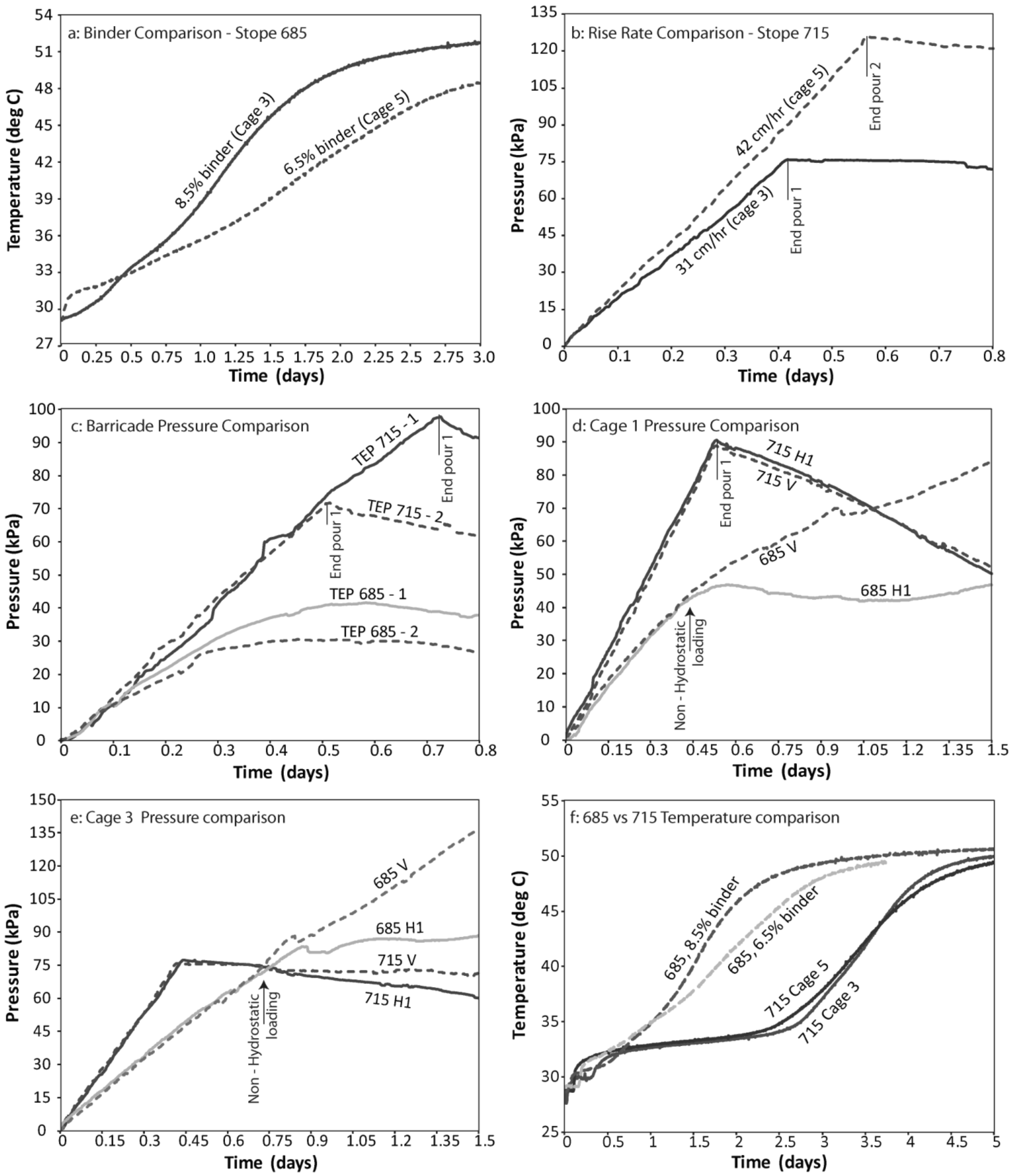

Figure 7 Comparisons of TEP and temperature from the two Cayeli stopes to highlight key factors that control pressures. For each graph, the time of the first arrival of CPB has been zeroed for each instrument. (a) Temperature history for the 8.5 and 6.5% binder content CPB in the 685 stope; (b) pressures generated in the 715 stope for 31 and 42 cm/hr rise rates; (c) pressures measured at the low (#1) and mid (# 2) height barricade TEPCs for the two stopes; (d) and (e), cage 1 and cage 3 vertical and horizontal 1 pressure axes from the two stopes; (f) the temperatures from both stopes illustrating the difference in onset of cement hydration

5 Kidd Mine fieldwork (2008)

Backfill tests at Kidd Mine featured two large long-hole stopes of dimensions 28 × 12 × 32 m height and 18 × 12 × 40 m height. Details of the installation method and results are contained in Thompson et al. (2009). Kidd Mine backfill consist approximately 45% silica tailings and 55% screened alluvial sand by mass. In both stopes, backfill contained 4.25 and 2.25% binder (90:10 ratio of blast furnace slag and Portland cement) in the lower and upper stope volume respectively. Gravimetric water content was measured at 19–22% during backfilling. Figure 8 shows total earth pressures, pore pressure and temperature for cages in the centre of the 67SL1 stope hanging at 3 and 8 m height. For cage 3 in the 4.25% binder content CPB, hydrostatic loading persists for 10 hours. A significant difference is measured for cage 5 in the 2.25% binder CPB where hydrostatic loading persists for 2.5 days. Similar to the Cayeli results, binder content is important in controlling the rate of cement hydration and the time to non-hydrostatic loading. This is also apparent from the higher temperatures measured within the higher binder content CPB (Figure 8).

The Kidd test stopes were both monitored for over a year.

Figure 9 shows the long term TEPs for a 240 day period in the 67SL1 stope for cages about the brow (1 and 2) and hanging at 3 and 8 m in the main stope. The end of backfilling is marked ‘1’ in the figure. Pressures during backfilling peaked at 546 kPa (cage 3, vertical pressure, 6.5 days). After backfilling, pressures decreased for ~40 days in the brow area. In the main stope, pressures increased after backfilling in the horizontal stope short axis, and to a lesser extent in the horizontal long axis. Vertical pressures decreased. Production blasting in the vicinity of the stope causes rapid changes in the pressures, as marked by numbers 2–8 in the figure. Events 9 and 10 are the two production blasts from the stope directly above the test stope, which induce pressure increases in all pressure axes, of up to 200 kPa (cage 1, horizontal 2 pressure component). Indeed, at this, point pressures have exceeded the range of some TEPCs and so magnitude increases could be higher than 200 kPa. A magnitude 3.8 rockburst located 190 m from the test stope is marked 11 on the figure, causing pressure increases of 321 kPa (cage 1, vertical component). The pressure increases measured over the 240 day period are interpreted to be induced by closure of the stope walls, increasing the confinement on the CPB. Pressure changes can either be near instantaneous in response to a significant event, or more gradual over long periods. Changing stress fields as a result of mining activities and seismic activity are responsible for the changing backfill pressure. Currently, pressures in the CPB are measured as high as 1.4 MPa, and this represents a lower bound as pressures at several of the TEPCs have exceeded the instrument range.

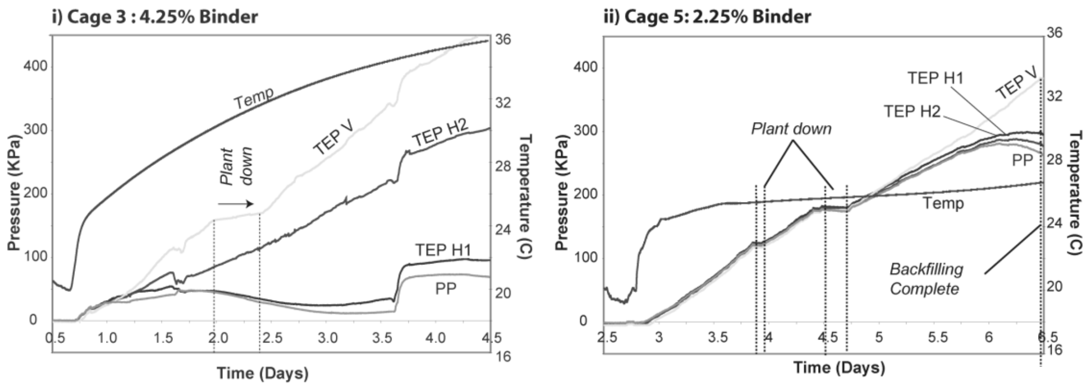

Figure 8 TEP, PP and temperature measured at (i) cage 3 (3 m elevation); (ii) cage 5 (15 m elevation) for a four day period after CPB reaches the cages. TEPs are measured in horizontal long axis (H1), and short axis of the stope (H2), and in the vertical axis (V)

Backfilling of the Kidd stopes was interrupted on several occasions for operational reasons. During some of these shutdowns, total earth pressures continued to increase even though no CPB was entering the stope. This was only measured in the higher (4.25%) binder content CPB. For instance, Figure 10 (i) and (ii) shows pressures during backfilling of the 88,947 stope for cages 3 and 5 hanging in the centre of the stope at 3 and 15 m elevation. Backfilling stops for two hours at 0.9 days during which no pressure changes are seen. At 1.3 days however, pressures continue to rise even though backfilling stopped for 6 hours. Finally, backfilling was halted for 20 days at 2.3 days after which time pressures continue to rise. In Figure 10 (iii) and (iv) the change in pressure is plotted against change in temperature from the time backfilling stopped at 2.3 days. For cage 3, pressures increase in a linear trend at ~35 kPa/°C, whereas for cage 5 the relationship is not linear but a similar pressure increase (~300 kPa over a 10°C temperature increase) is observed. A laboratory and analytical calibration of the TEPCs suggests a 0.5 kPa/°C (Grabinsky and Thompson, 2009) correction factor is required to correct measured pressures for temperature changes, which is significantly smaller than the pressure changes measured in the field.

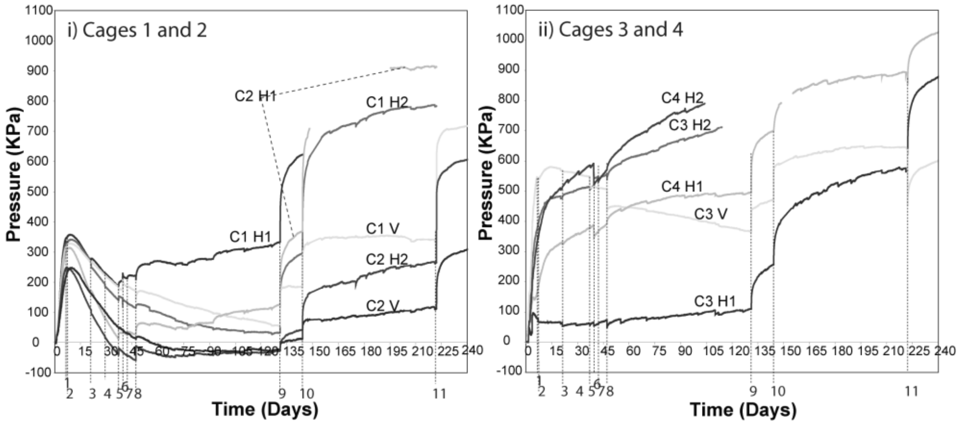

Figure 9 TEPs measured in cages spanning the brow (1 and 2) and cages hanging at 3 and 8 m in the centre of the stope (4 and 5). TEP pressure axis notation as in Figure 8. Number 1 indicates the end of the pour, 2–8 are production blasts, and 9 and 10 are slot and stope blasts directly above the test stope. Number 11 is a magnitude 3.8 rockburst located 190 m from the stope

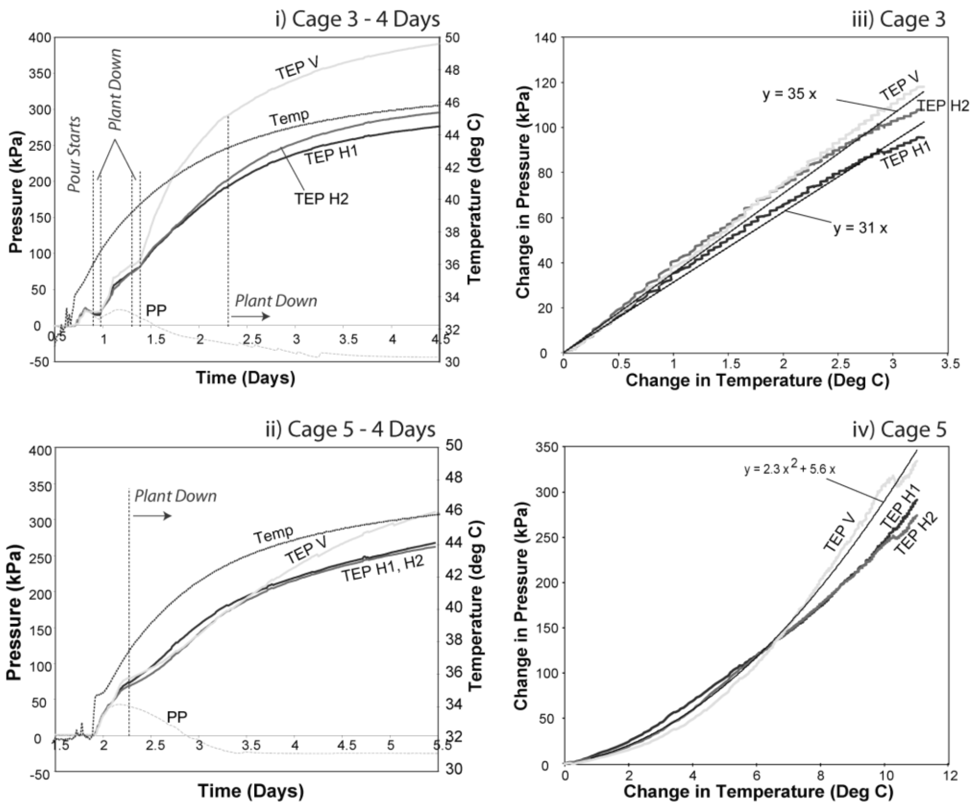

Figure 10 (i) and (ii) show total earth pressure (TEP) (notations as per Figure 8), pore pressure (PP) and temperature data during backfilling of the 88,947 stope. Paste plant shutdowns, and the ultimate end of pouring are indicated. The change in pressure is plotted against temperature from the moment the plant shut down for the two cages in (iii) and (iv)

It is thought that the thermally correlated pressure increases are induced by thermal expansion of CPB. A similar relationship can be observed, albeit to a lesser extent, for Cayeli 685 stope CPB, where TEPs at the barricade and the cage 1 location (Figure 6(a) and (c)) show secondary peaks that roughly coincide with a reduction in rate of temperature increase. Similarly, pressures in the 715 Cayeli stope (Figure 6(b), (d) and (f)) increase during the cure period at approximately the same time the temperature within the backfill shows significant increase. Similar thermally induced (or correlated) pressure changes in CPB during downtime in backfilling have been measured at Barrick Gold's David Bell Mine in high-binder sill mats.

The conclusion that backfill pressures are increased by thermal expansion is of relevance to operators at Kidd Mine as their backfilling is conducted continuously until measured barricade pressures exceed a certain threshold, following which a cure period occurs. Analysis of the Kidd fieldwork barricade pressure data demonstrated that a significant portion of pressures could in fact be attributed to the thermal expansion of paste fill (the temperature correlated pressure increases were relatively small at Cayeli, and not observed at Williams). Further consideration is required as to whether thermal expansion would in fact increase the stability of the backfill due to the advanced state of cement hydration that is required for the temperature increase, and reduce the liquefaction risk, especially in terms of the risk of paste fill flowing in the case of a barricade failure. These observations are also important from the point of view of operations or consultants conducting paste fill pressure measurements. For instance, the authors are aware of cases where measurement of pressure increases during down times in backfilling has led to instrumentation reliability and calibration being questioned. The studies presented herein give confidence that thermally induced, or at least thermally correlated, pressure increases within CPB can occur, especially for high binder content CPB. Such field observations are reported and compared with laboratory tests in Thompson et al. (2011).

6 Summary

This fieldwork project has demonstrated that with careful planning and preparation, installation of in situ instrumentation of CPB is possible and can provide good quality data that can address fundamental questions related to how mines manage backfilling with CPB. Large-scale instrumentation of stopes provides detailed information leading to good understanding of backfill behaviour and offers a greater perspective of the variables that could affect barricade pressures, especially in terms of different binder contents within the same stope. However, such installations require significant planning and resources during installation and so are not practical for routine deployment. The Williams 2010 fieldwork demonstrates a good compromise where instrumentation was quickly installed within the main stope and under the brow in the undercut level, to offer a much better appreciation of CPB behaviour than would be available if only barricade pressures were measured. Subsequent instrumentation of barricades can then be interpreted with the benefit of understanding of backfill behaviour within the stope. It is also important to recognise that measurements at a barricade may be affected by the paste-barricade interface. For instance, pore pressures measured at the barricade in the 715 Cayeli stope deviate from total earth pressures relatively quickly in comparison to pore pressures at the cage 1 location, approximately 1.8 m from the barricade (Figure 6(b) and (d)). This is considered to be due to enhanced drainage at the interface. Effective stresses at the barricade therefore do not represent the effective stresses in the fill mass, and so numerical modelling studies should avoid using barricade pressures to represent the effective stress state of the CPB fill mass.

The behaviour of CPB within the stope has been demonstrated as initially a function of the rise rate controlling loading. Subsequently, as cement hydration occurs, CPB gains shear strength and so CPB overburden pressures can be arched and the rate of horizontal loading decreases, to the extent that horizontal pressures, i.e. those acting on barricades, can reach a plateau. These observations support the 'self desiccation' effect described by Helinski et al. (2007) who demonstrated cement hydration in CPB results in a reduction in volume. This causes a decrease in positive pore pressure and so, development of effective stress. After backfilling, pressures tend to drop unless mining in surrounding areas induces changes in stress and relaxation of stope walls to further confine the CPB and increase the in situ pressure. Indeed, pressures in the Kidd backfill increased above 1 MPa due to mining directly on top of CPB, and due to rockburst induced ground movements. At Kidd and Cayeli, evidence of in situ pressure increases correlate with temperature increases (of order ~30 kPa/°C at Kidd) for high binder content CPB. Such pressure increases are interpreted to be caused by thermal expansion of CPB, as discussed by Thompson et al. (2011).

From an operational perspective, the fieldwork case studies have demonstrated that continuous backfilling is possible at the Williams and Cayeli Mines under certain circumstances. Continuously pouring would decrease the cycle time of stopes, and reduce pipe and paste plant wear and tear, and increase paste plant efficiency. However, as shown at Cayeli, backfill recipes and stope geometries can induce very different barricade pressures. The limited number of field tests performed cannot encompass the complete range of variables that could be expected to influence barricade pressures at the partner sites. To this end, instrumentation of barricades is recommended as a routine QA/QC procedure to allow the most efficient backfilling with CPB. This recommendation will be implemented going forward on a small scale at the partner mines and the data base of barricade pressures will assist in better understanding and quantifying the effect of binder content and CPB recipes, rise rate and stope geometry, upon backfill pressures. Generally the binder content of CPB is selected based on providing an appropriate uniaxial compressive strength for a specific stope span and required stand up time. This research highlights that changes in binder content can significantly affect the hydration rate of CPB and so changes in barricade pressures should be anticipated when mines adopt new backfill recipes. Indeed, whereas operations have historically looked at reducing binder content as a cost saving measure, consideration should be given to increasing binder content if it can be shown to increase backfilling efficiency given the financial benefits of decreasing stope cycle times.

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