In-situ Measurements of Paste Backfill Pressure in a narrow, dipping Stope

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ABSTRACT
Cemented paste backfill (CPB) has many advantages as a backfill material in underground mines. However a lack of in-situ data requires mines to adopt conservative filling strategies, such as maintaining low rise rates, and pausing backfilling to allow 'plugs' to cure. To address this issue, an extensive in-situ CPB instrumentation project has been conducted at three mines. Results from Barrick Gold Corporation's Williams mine are presented herein. We review previous fieldwork at the mine, and present new data from a 50 m high Alimak, backfilled with 3% binder CPB. Backfilling induced loading was hydrostatic for less than 10 hours, and barricade pressures did not exceed 40 kPa during the pour, although flushing of water into the stope at the end of backfilling significantly increased pressures. Peak pressure in the stope was 206 kPa. This case study highlights the potential for instrumentation to be routinely employed by operations to safely maximise backfilling efficiency.

RÉSUMÉ
Le remblai en pâte cimenté (RPC) a de nombreux avantages comme matériau de remblayage dans les mines souterraines. Toutefois, un manque de données in situ nécessite que les mines adoptent des stratégies prudentes de remblayage, comme le maintien d'une vitesse lente de remplissage et des arrêts périodiques pour permettre le cure. Pour résoudre ce problème, un vaste projet d'instrumentation in situ a été effectué dans trois mines. Les résultats de la mine Williams de Barrick Gold Corporation sont présentés ici. Nous passons en revue le travail réalisé précédemment dans cette mine, et présentons les nouvelles données à partir du remblayage d'un 50m de hauteur Alimak, remblayé avec 3% cimenté RPC. Le remblayage de chargement a été induite hydrostatique pour moins de 10 heures, et les pressions de barricade n'ont pas dépassé 40 kPa au cours de la coulée. Cependant, le rinçage de l'eau dans le chantier à la fin du remblayage a causé les pressions à augmenter considérablement. La pression de pointe dans le chantier était de 206 kPa. Cette étude de cas met en évidence le potentiel de l'instrumentation à être couramment employé dans les opérations pour optimiser en sécurité l'efficacité de remblayage.

1 INTRODUCTION

Cemented paste backfill (CPB) generally comprises mine tailings, water, and binder (usually between 2 – 8% by weight, depending on required strength characteristics.) CPB is widely regarded as the optimum backfill material for many underground mines, due to rapid transport underground via pipe network, strength characteristics that can be engineered for specific situations, and diversion of tailings from surface disposal. Generally, CPB is piped into the stope via the overcut, and barricades are erected at undercut draw-points to contain the fill. Backfill induced pressure can potentially be high, if hydrostatic loading is assumed. However, at some point, non-hydrostatic loading will result from a combination of cement hydration, and self weight consolidation. The gain in shear strength enables pressures to be arched and so horizontal pressures at barricades can be relatively small. However, knowledge of these pressures, and indeed, the barricade strength, are required in order to design an appropriate backfilling strategy. In most cases, such data is not known and so mines must adopt conservative backfilling strategies, such as halting a pour at a height of approximately 1.5 that of the barricade, and allowing the backfill to cure to provide a plug. For an operation such as the Cayeli mine, where over 100 stopes are mined per year, the potential economic advantages of accelerating backfilling are significant

In addition to increasing backfilling efficiency and safety, in-situ data is required to validate and provide input parameters for laboratory (Moghaddam, 2010, Helinski et al., 2007, Yilmaz et al, 2009) and numerical modelling (Li and Aubertin, 2009,) of CPB.

Limited in-situ data for CPB exists in the literature. Some exceptions include Belem et al. (2004), Hassani et al. (1998), and Yumlu and Guresci, (2007). An extensive project, led by the University of Toronto has been conducted to instrument a total of nine stopes at three mines. Fieldwork from Inmet's Cayeli mine and Xstrata Copper Canada's Kidd mine are reported elsewhere (Thompson et al, 2009, Thompson et al., 2010). This paper summarizes the field results from testing in two stopes at Barrick Gold's Williams mine. In both stopes, backfill contained 3% binder, which comprised 50% normal Portland cement and 50% fly-ash. The grain size and bulk properties of the Williams CPB are summarized by Grabinsky et al., (2008).

2 INSTRUMENTATION – PHASE 1

Measurement of pressures at the barricade is the most important location from an operational point of view. However, in order to understand the mechanisms causing such pressures, one must first consider the pressures in the main stope volume, which can be arched with proximity to stope walls. As will be shown later, barricades located in drifts and offset from a main stope volume will experience further pressure reduction to due to enhanced arching. In order to measure the full spatial and temporal evolution of pressure within the stope, the instrumentation strategy in the first Williams test stope (9415-55, tested in 2007) was to install instruments throughout the fill mass. The stope was a 150 m high Alimak stope, with a strike length of ~ 30 m and footwall – hanging wall separation of 5 m. The instrument installation was achieved by passing cables down the stope via the raise access. The cables were anchored in the undercut (Figure 1). Eight instrument clusters were subsequently lowered and suspended at vertical intervals throughout the stope.

Figure 1. Cages were lowered down the Alimak raise at Williams mine (left), and anchored in the undercut (right)

Two instrument clusters were positioned in the alimak nest. Each instrument cluster consisted of a wire cage, with three total earth pressure cells (TEPC), a piezometer, a heat dissipative sensor (for negative pore pressure), a electrical conductivity probe and a tiltmeter to track cage orientation. The instrumentation was supplied by RST Instruments of Vancouver and further detail is contained in Grabinsky (2010). The three TEPCs were mounted orthogonally in the vertical, along strike and perpendicular to strike orientations. TEPCs and piezometers were also positioned behind the barricade, as shown in Figure 2. The plan of the stope shows instrument locations (Figure 3).

Both total earth pressure and pore pressure are required to calculate effective stress, which is very important in understanding CPB behaviour (Fourie et al. 2007). Orthogonal TEPCs measure the transition from hydrostatic loading to non-hydrostatic loading, which occurs when CPB gains shear strength.

A recent test conducted at a different mine featured two TEPCs that were positioned at the same location. One was manufactured by RST and the other was from a different manufacturer. The results were not corrected for temperature, and demonstrated significant differences in TEPCs performance after the initiation of non-hydrostatic loading. The second TEPC measured a marked increase in pressure whereas the RST cell measured a small pressure increase. The different response is presumably due to differences in cell construction. It is critically important to understand a specific manufacturer's TEPC response to temperature, as CPB curing can result in ~ 20 ^{o}C temperature increases.

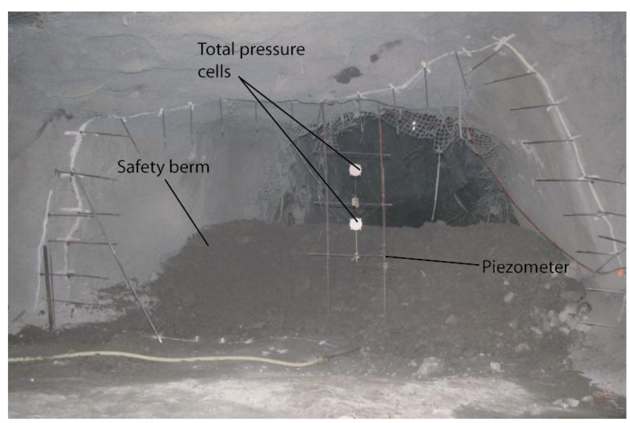

Figure 2. TEPCs and piezometer to measure barricade pressure. The location of the barricade is indicated by the white line and rebar.

3 RESULTS – WHOLE STOPE INSTALLATION

Backfilling of 9415-55 was completed using the mines standard procedure, whereby a plug of 8 m is poured and allowed to cure, in this case for 36 hours. This provides a plug onto which the remainder of the backfill can be continuously poured. Backfill was subsequently poured to a height of 82 m. The remainder of the stope was filled at a later time due to operational reasons. During the plug pour, pressures measured at the 2 m and 3 m heights on the barricade peaked at 36 kPa and 19 kPa respectively (Figure 4a). During the 36 hour cure, pore pressure and total pressure decrease. At the resumption of pouring, pressures increase instantly due to water entering the stope as paste lines are flushed. During the second pour however, pressures remain relatively constant.

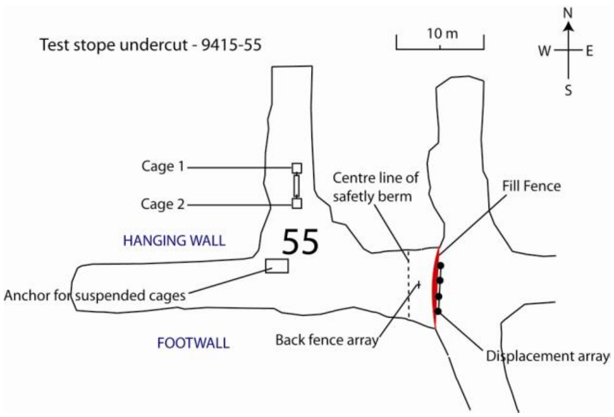

Figure 3. Plan of stope undercut showing instrument locations.

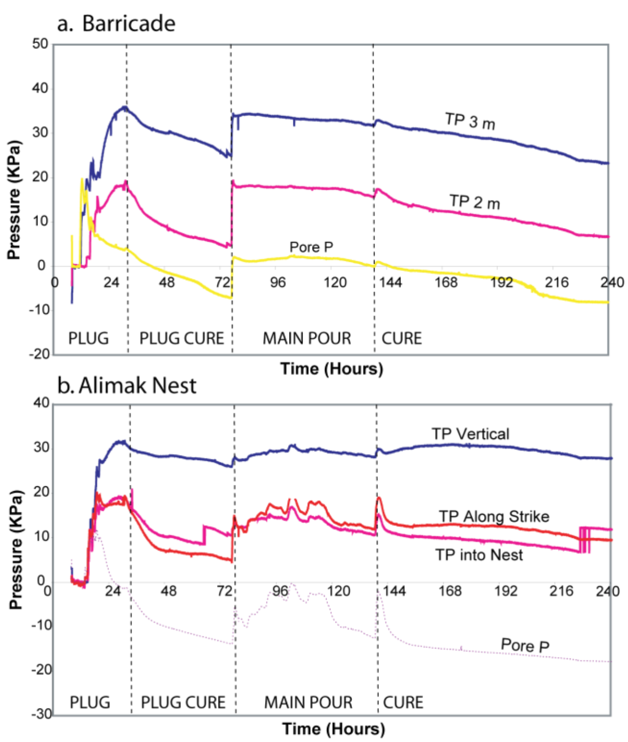

Figure 4. Total earth pressure (TP) and pore pressure measured at the barricade and mouth of the Alimak nest during 9415-55 backfilling.

At the cage location at the mouth of the Alimak nest, pressures follow a similar trend, peaking during the plug pour at 32 kPa in the vertical, and 17 kPa and 20 kPa in horizontal orientations perpendicular to, and parallel to the strike of the footwall. In this case, the orthogonal TEPCs demonstrate that the break in hydrostatic loading occurred within 6 – 8 hours. At the Cayeli and Kidd mines, (i.e. Thompson et al, 2009, 2010) hydrostatic loading in low binder CPB persisted for over two days, resulting in pressures of the order of hundreds of kPa. Therefore, the pressures measured at Williams during backfilling are relatively low. Unfortunately, rocks dislodged in the stope during backfilling resulted in data cables being damaged, and so limited data was recorded in the stope from the suspended cages.

Long term pressures are displayed in Figure 5 for days 75 to 260, at the barricade and Alimak nest location. Initially, the large pressure increase correlates with raise driving of the adjacent stope. The next notable increase in pressure occurs around day 125 when production blasting in the #50 stope occurs. This stope, as shown in the plan of the area in Figure 6 is 100 m from the test stope. Perturbations in pore pressure and total pressure around 175 days are interpreted to be due to production drilling activity in the adjacent stope. Similarly, at 220 days, diamond drilling in the CPB of the test stope increases pore pressure.

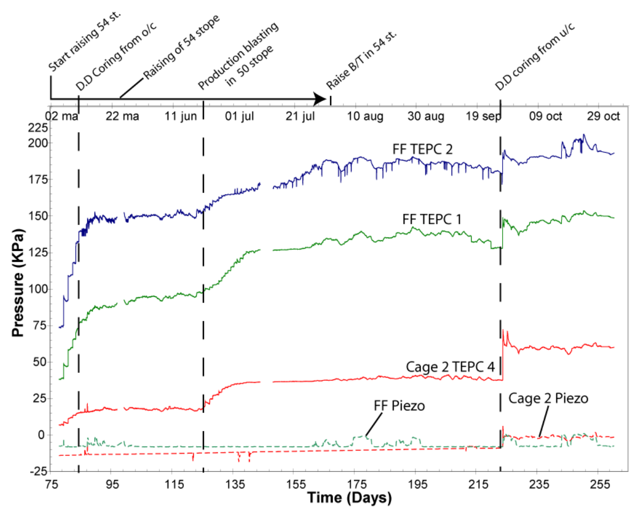

Figure 5. Pressures at barricade (FF, 'Fill Fence') and Alimak nest between 75 and 260 days, with events marked inducing pressure increases.

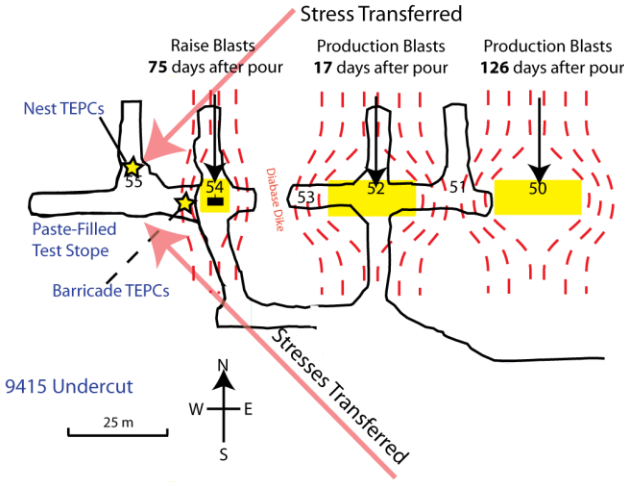

Figure 6. Interpretation of stresses transferred onto test stope due to blasting of nearby stopes.

4 INSTRUMENTATION – PHASE 2

The pressures measured in the 9415-55 test stope were significantly lower than what would be expected given the height of the test stope. Clearly, hydrostatic loading, which for a 150 m high stope could result in very high pressures, was not a factor. If such low pressures were measured routinely at Williams barricades, then the possibility of pouring stopes continuously, without an intermediate cure period could be considered. This would reduce backfilling time by ~ 20% per stope.

The fieldwork campaigns at the Cayeli and Kidd mines (Thompson et al., 2009, 2010) provided the critical data required to understand in-situ backfill behaviour at these sites. However, the loss of instruments in the main stope volume during the 9415-55 fieldwork meant such data was lacking at Williams. To remedy this deficit, a second phase of fieldwork was conducted using an optimised installation with reduced instrumentation. Full stope installations can provide excellent data, but they require non-trivial preparation and are resource intensive. The mandate for this test was to deploy instruments into undercut locations only. This minimizes stope preparation and causes minimal delay in stope cycle time while still providing the critical data required to evaluate the possibility of a continuous pour.

Two instrument cages were driven into the 9500-L70-5 stope via remote scoop. One was positioned in the main stope body, and one at the brow of the stope. The cages contained three orthogonal TEPCs and one piezometer. TEPCs and piezometers were also affixed to the barricade, and barricade displacement was measured using an array of potentiometers. This instrumentation is displayed in Figure 7. The cross section of the undercut of the stope is shown in Figure 8.

The test stope was 50 m high, 20 m along strike, and 7 m footwall – hanging wall distance. Data was networked to a refuge station, and monitored in real time. The decision was taken to backfill continuously, with barricade condition assessed from video footage, and displacement and pressure data monitored in real time. At the Cayeli mine, barricade pressure limits of 100 kPa are defined by management and pressures have been measured close to this magnitude on three occasions by the authors. The design of the Williams barricade is stronger than the Cayeli barricade, and so barricade pressures up to 100 kPa at Williams were thought acceptable. It is noted that an exclusion zone in the undercut area, to the full volume of the stope was established to ensure the safety of workers.

Figure 7. (a) Cages in undercut of stope. (b) TEPCs and piezos on barricade. (c) Barricade displacement array

5 RESULTS – UNDERCUT INSTALLATION

The 9500-L70-5 backfilling was completed continuously with a peak barricade pressure of 76 and 79 kPa for the

TEPCs mounted at 1.6 m and 3.2 m height, respectively (Figure 8). Initially, pressure at the barricade increased in an irregular pattern, which was similar to that observed during the 9415-55 field test. At around 14 hours, the loading pattern became more consistent, with a gradual pressure increase generally observed to the end of the pour when barricade pressures are ~ 40 kPa. The change in loading pattern is assumed due to the transition from filling of the drift to filling the main stope volume. At the end of backfilling, water is flushed through the paste pipe lines for cleaning purposes. This flush induces a 35 – 40 kPa pressure increase at the barricade, with pressures reducing to the pre-flush level within a few hours.

At the brow (cage 1) and main stope (cage 2) locations (Figure 8 c, d), similar patterns to the barricade are observed, with a rapid increase in pressure reducing after ~ 13 hours, and a gradual pressure increase persisting until the flush induces an pressure increase in the range 30 – 49 kPa. Peak pressures at the brow and in the main stope are 75 kPa and 159 kPa prior to the flush, demonstrating the role of stope geometry in the magnitude of backfill pressure at different locations in a stope. We hypothesise that positioning of a barricade effects the backfill induced pressure, i.e. increasing barricade distance from a stope brow would result in reduced pressure due to enhanced pressure arching.

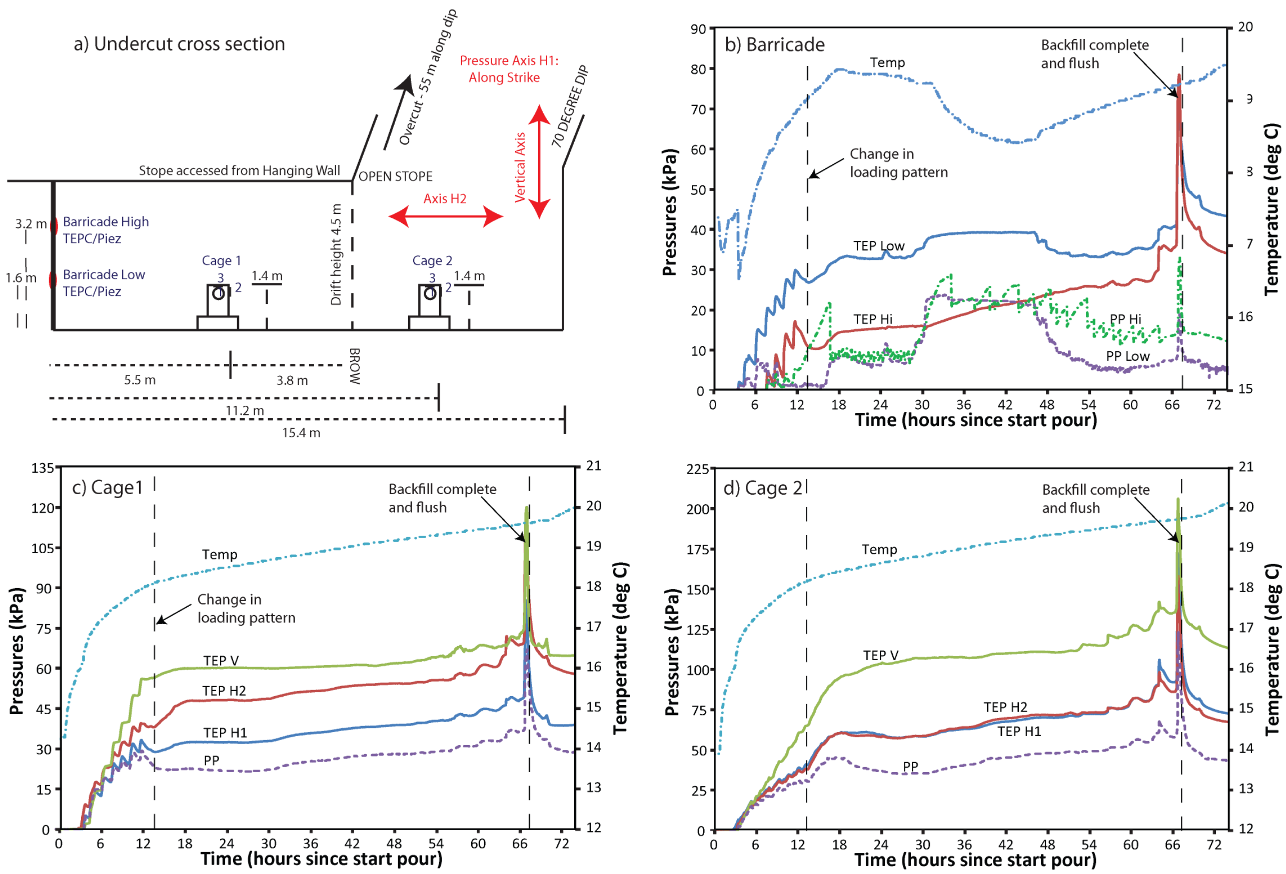

Figure 8. Total earth pressure (TEP), pore pressure (PP) and temperature measured at three locations in the 9500 Williams test stope as marked on the cross section

The divergence from the pattern of hydrostatic loading (and the divergence of total earth and pore pressures) is critical in identifying the development of shear strength in CPB. For instance, under hydrostatic loading, pressures equivalent to the head pressure of CPB could theoretically exceed 1 MPa for this 55 m high stope. However, the transition to non-hydrostatic loading occurs within ~ 6 hours, which is consistent with the 9415-55 results. This could either be due to consolidation or cement hydration, which induces a pore pressure reduction due to the volume reduction that occurs during hydration, as demonstrated by Helinski et al., (2007) in laboratory tests. This break in hydrostatic loading is very rapid in comparison to the Cayeli and Kidd field tests, where the highest binder content CPB recipes required periods of at least 12 hours before CPB gained shear strength. The Cayeli and Kidd test stopes were relatively wide, with minimum horizontal distances of ~ 12 m, whereas the Williams stopes were relatively narrow. Also, the Williams stopes have footwalls that dip at ~ 70^{o} compared to the near vertical walls of the Cayeli and Kidd stopes. Either of these factors could enhance the arching potential of the Williams backfill.

At the instrument cage locations, temperatures in the backfill increase from ~ 16.5 ^{o} C to 19.8 ^{o} C during backfilling. Temperatures at the barricade are initially similar, but a plateaux and subsequent decrease in temperature during backfilling are observed. This is not consistent with cement hydration, and the pattern is interpreted to be due to new material, for instance, water running along the hanging wall – CPB contact, reaching the barricade location. This interpretation is supported by the changes in pore pressure at the barricade.

6 DISCUSSION AND CONCLUSIONS

The 9500-L70-5 fieldwork demonstrated for the first time that continuously backfilling stopes at Williams was possible. Indeed, that the test stopes featured the lowest binder content employed at the mine suggests these pressures should represent the worst case situation, as increased binder content should increase hydration rates. However, there are many variables, including rise rates, stope geometries, binder contents, and changes in tailings characteristics over time that can affect pressure. We therefore recommend that the mine instrument barricades with TEPCs in order to measure backfill pressures. These measurements should be used in real time to control how individual stopes are filled on a case by case basis, using to-be defined barricade pressure limits.

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