In-situ measurements of cemented paste backfill in long-hole stopes

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ABSTRACT: Cemented Paste Backfill has proven to be of critical importance to the operation of a number of Canadian mines, primarily due to the rapid backfilling rate this method permits. In order to improve the efficiency of this backfill system (i.e. optimize binder contents, fill fence design, and the employment of two stage filling strategies) there is a requirement to better understand its geomechanical behaviour. In response, in-situ experiments have been conducted in long-hole stopes to quantify the evolution of total earth pressures and pore pressures at a series of instrumented points within both the core of the backfill and close to fill fences. The deflection of fill fences as a result of paste loading has been measured and additional instrumentation has also been employed to measure cement hydration, negative pore pressures, and blasting induced vibrations within fresh and cured paste backfill. Installing geotechnical instrumentation within an open long-hole stope can be an extremely complex procedure and this paper details the methods that have been successfully employed. Preliminary results are presented, and the pressures induced by backfill with differing binder contents, at a number of different in-stope locations are considered.

1 INTRODUCTION

Cemented paste is used as a backfilling method at a number of Canadian mines. It has gained popularity as its rapid delivery rate permits backfilling of a stope to be completed in a matter of days, rather than the weeks or months required by older methods such as Cemented Rock Fill. Cemented Paste Backfill (CPB) radically decreases stope cycle times, thereby not only providing cost savings, but the opportunity to generate additional revenue. Furthermore, CPB can be designed to reach specific strengths and reduce dilution, and can rapidly become self-supporting. However, there is currently a lack of data on the behaviour of CPB in-situ. Of particular importance are the pressures generated by the CPB on the barricades (fill fences) erected at the draw-points of stopes to contain the paste prior to cement hydration. This lack of data necessarily results in conservative design strategies. For instance, to avoid exceeding the strength of a fence, many stopes are poured in two stages, with an initial plug being allowed to cure for 24 or more hours, to provide a barrier between the fill fence and the main volume of the stope pour. Eliminating the two stage pour would further reduce stope cycle time. Fill fence design may also be improved with a better understanding of the pressures generated by the CPB.

In order to address the lack of field data, a series of in-situ tests are being conducted at three mining operations. The in-situ behaviour of CPB within a 150 m high Alimak stope was measured in 2007 at the Barrick-Teck Cominco operated Williams Mine (Grabinsky et al., 2007, 2008) in which arching was demonstrated to occur within drifts, with pressures falling off with increasing distance away from the stope brow. Here, results are presented from the first of two long-hole stopes which were successfully instrumented and backfilled at Xstrata Copper's Kidd Mine. Future fieldwork is to be performed at Inmet's Cayeli Mine in 2009.

2 STOPE GEOMETRY AND BACKFILLING STRATEGY

The test stope under consideration, 67-SL1, was 32 m high with a footprint of 28 x 19 m. A cross section and plan view of the stope are shown in Figure 1. The figure also contains a summary of the instrumentation, which is detailed later. The total volume of CPB delivered to the stope was 15,560 m^3. Kidd Mine CPB typically consists of approximately 45% tailings and 55% screened alluvial sand by mass. The stope was poured to a depth of 6 m with 4% binder, and the remaining 26 m with 2% binder. The binder consisted of 90% ground iron blast furnace slag and 10 % Portland cement. The paste is typically poured at 82% solids by mass.

3 INSTRUMENTATION OF A LONG-HOLE STOPE

Six instrument clusters were installed in the 67-SL1 stope. Each cluster contained three orthogonal total earth pressure cells (TEPC), a piezometer (for pore pressure), a heat dissipative sensor (for negative pore pressure), an electrical conductivity probe (for cement hydration information) and a tilt meter to record the orientation of the instrument cluster. The instruments were assembled within a wire cage, which in turn was mounted within a steel protective frame (Figure 2). Select cages also contained accelerometers.

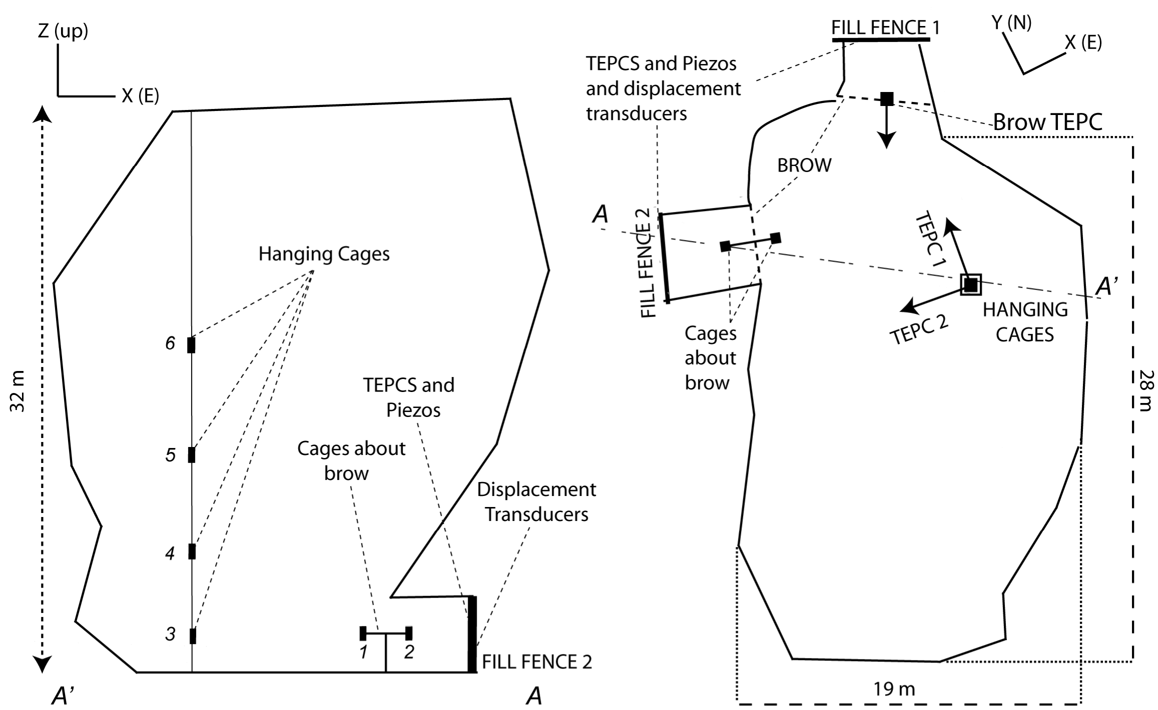

Figure 1: Cross section and plan of stope, with locations of instrument cages (numbered 1 – 6 in the cross section) and other instrumentation marked. The arrows in the plan view show pressure orientations of the TEPCs. The section is facing southwest, generally in direction of Figure 4c.

Preparation for the installation of the instrumented cages began before the stope was mined. Two pulleys were installed in the back of the stope (Figure 3a) and cables were run before the stope was blasted, with the cables being secured to the back of the access drift leading away from the stope (Figure 3b). Following mucking of the stope, the cables were attached to tuggers (pneumatic winches) in the overcut, and lowered down to the undercut where they were retrieved using remote equipment. The two cables were attached to the instrument cages (Figure 2b) and a concrete block was attached to the end of the cables. By winching from the overcut, the instrument cages were raised into the stope. The concrete block was carried into the stope by a remote scoop to maintain tension on the cage train and to prevent the cages being dragged and damaged along the floor (Figure 4). The final height of the cages was 3, 8, 15 and 22 m from the floor. Additionally, two instrument cages were attached to a "T" shaped frame pushed into the undercut by remote scoop and positioned on either side of the brow, in order to measure differences in pressure with distance along the drift from the stope. The "T" cages are shown in Figure 5a prior to construction of the fill fence, which was located 7 m from the brow of the stope.

The stope had two draw-points. Fill fences were erected at each draw-point to contain the CPB. TEPCs and piezometers were mounted on the stope side of each fill fence, as shown in Figure 5c. One TEPC and piezometer were attached to a strut extending 1.25 m towards the stope from the fence. The fill fences were constructed from three horizontally positioned steel arches, convex to the stope. Vertical rebar spanned floor to back, and expanded steel mesh was mounted to the steel structure. Shotcrete was then applied to the fence to a thickness of around 30 cm. Displacement of the fill fences was measured using an array of Linear Variable Differential Transformer (LVDT) transducers. Steel scaffolds were erected in front of each fill fence to support the LVDT's independently from the fence (Figure 6 a, b). Nine LVDT's were mounted on each frame, with their tips in contact with the fence as shown in Figure 6c. Deformation was measured against steel caps mounted on the arches.

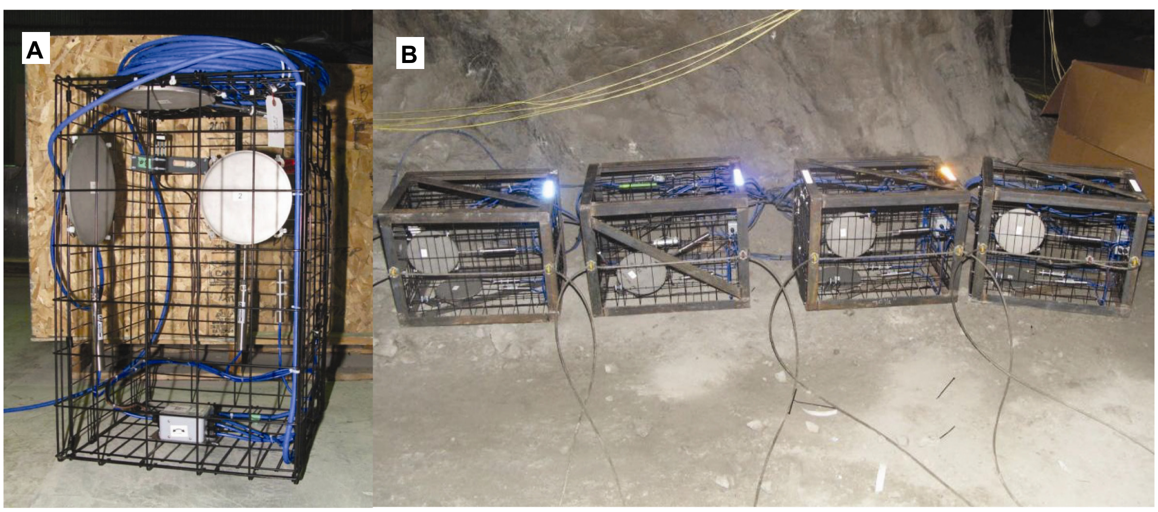

Figure 2: (a) Instrument Cage and (b) instrument cages within protective frames ready for installation into stope.

Figure 3: (a) Pulleys were installed in back of the stope and cables were drawn back out of the stope prior to blasting. (b) Post blasting, the cables were lowered into the stope.

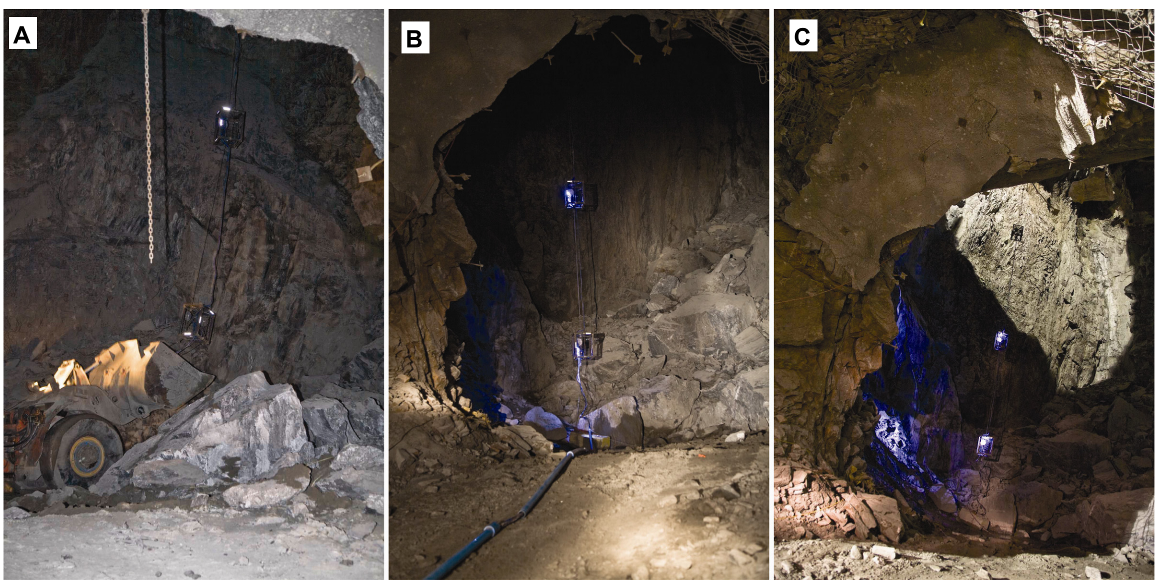

Figure 4: (a) The weighted base of cage train is driven into the stope using a remote controlled scoop, with cables being pulled using tuggers in the overcut. (b and c) shows cages hanging in the stope.

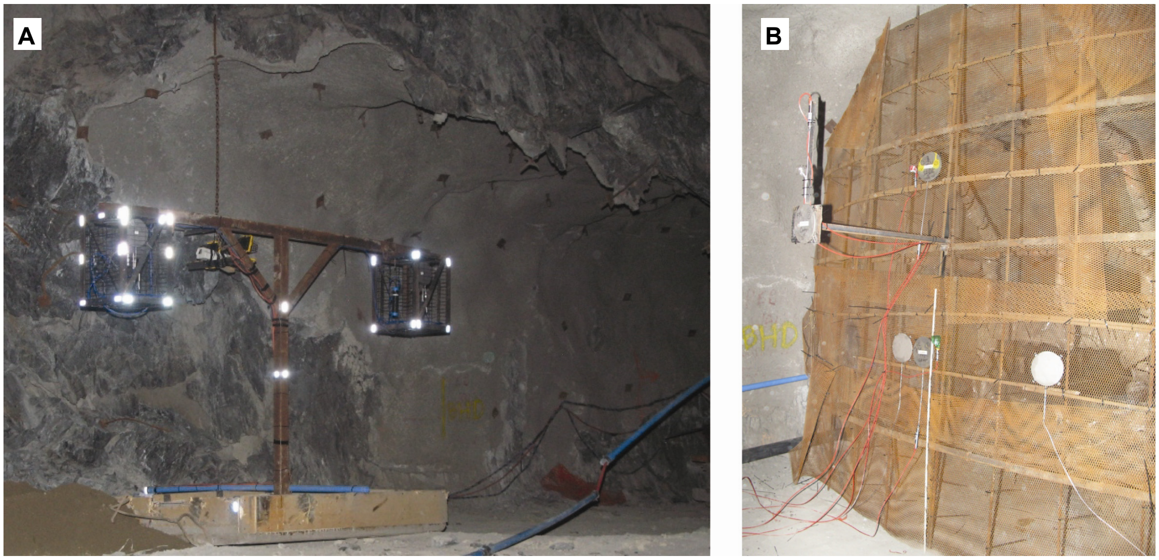

Figure 5: (a) Cages positioned about the brow, approximately 8 m from fill fence. (b) TEPCs and piezometers mounted onto fill fence.

Figure 6: Fill Fence displacement transducer array. Steel frames are built in front of each fill fence (a), (b) onto which displacement transducers are mounted (c). The numbering system for the transducers is shown in (b).

4 RESULTS

Backfilling of the stope took 6 days, including four periods in which operational issues halted backfilling. Figure 7 shows total earth and pore pressure data for the initial ten day period for cages 2, 3 and 5. The timing of this and subsequent graphs begins at 00:00 on the day backfilling started. Backfill entered the stope at 11:00, or 0.46 days. Cage 2 was located in the drawpoint in front of the fill fence, while Cage 3 was the lowest hanging cage and Cage 5 was approximately mid height in the stope. Pressures measured at Cage 3 were the first to respond to paste, after 6 hours of backfilling. The 3 m elevation of Cage 3 required an average rise rate of 0.5 m/hr to encapsulate the instruments. The later response of Cage 2 pressures, even though the cages were at approximately similar elevations, was due to the lava like flow of the CPB, as captured by a video camera mounted in the stope. For the entire stope the average rise rate was 0.26 m per hour.

The highest pressure in the stope during backfilling was 546 kPa as measured on the vertical axis of cage 3 (C3 V in Figure 7) at the time backfilling was complete (6.5 days). At this time, the vertical axis of cage 5 (C5 V) measured 382 kPa, which was the second highest pressure. The depth of burial at cage 3 was 29 m and at cage 5 was 17 m; the density of the CPB was 2100 kg/m^3 and the head pressures were ~ 600 kPa and 350 kPa respectively. In both cases, the measured vertical load was within 10% of the expected head pressure. For Cage 2, in the drift, the maximum pressure was 246 kPa, acting along the drift towards the fill fence.

Pore pressures show different trends for each cage. In the drift, pore pressures were low (25 kPa) and fell off after 0.3 days. In the main stope at the 3 m elevation (Cage 3), the pore pressure initially rose to 73 kPa before falling off after 1 day. At an elevation of 15 m (Cage 5) in the stope, the pore pressure reached 281 kPa after 3.2 days. For this cage, the CPB behaved hydrostatically for 2 days, where as for Cages 2 and 3 in the higher binder content plug, a deviation from hydrostatic behaviour occurred in less than 1 day.

It has previously been demonstrated for an Alimak stope that pressures in CPB were reduced with distance into a drift by arching (Grabinsky et al 2008). To demonstrate this behaviour in this stope, total pressures acting in the direction of the fill fence were plotted against time for four TEPCs which were mounted at different distances from the stope brow along the drift (Figure 8). TEPCs were mounted on the “T” ~ 1 m into the main stope, (8 m from the fill fence), 2.5 m from the stope brow (4 m from the fill fence) (Figure 5), on a strut 1.3 m from the fill fence, and directly on the fill fence. Over the 6.5 day period of the pour, the pressures decreased with increasing distance from the stope brow, demonstrating arching of the fill. The pressures were very similar for the first 6 hours, due to the early stage of cement hydration and the limited head pressure. Between 22 and 24 hours after burial, the pressures measured on or close to the fence began to decline.

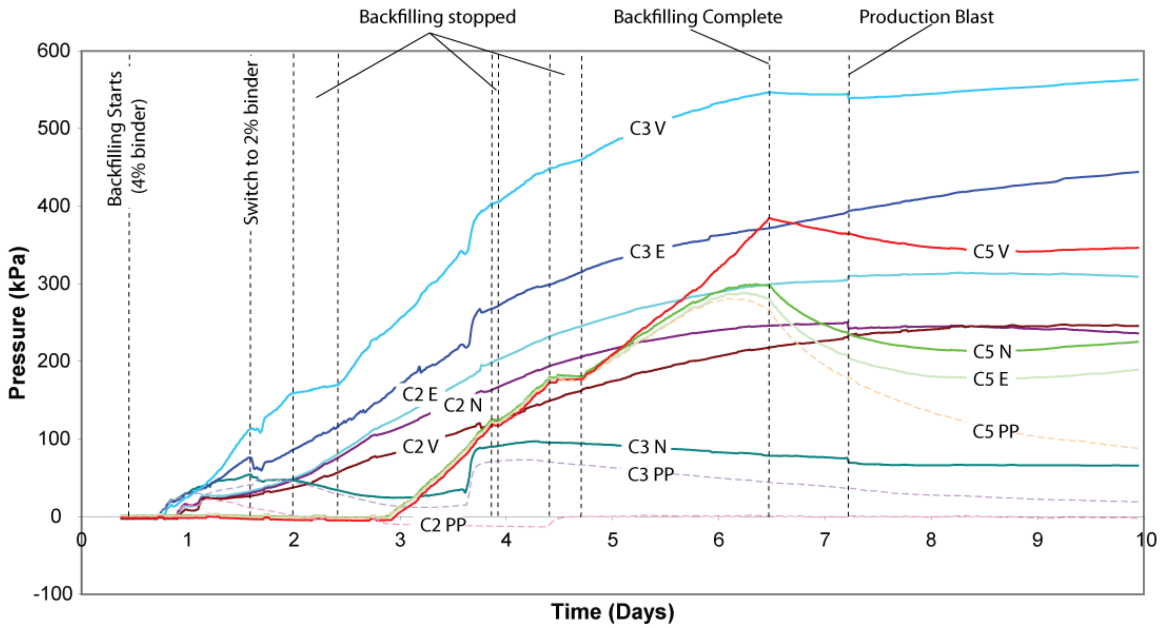

Figure 7: Total Pressure and pore pressure data (PP) for 10 days from cages 2 (C2), 3 (C3) and 5 (C5). The TEPCs are oriented either north (N), east (E) or vertically (V) with the orientation of the stope marked in Figure 1b. Notable events during the backfilling are marked.

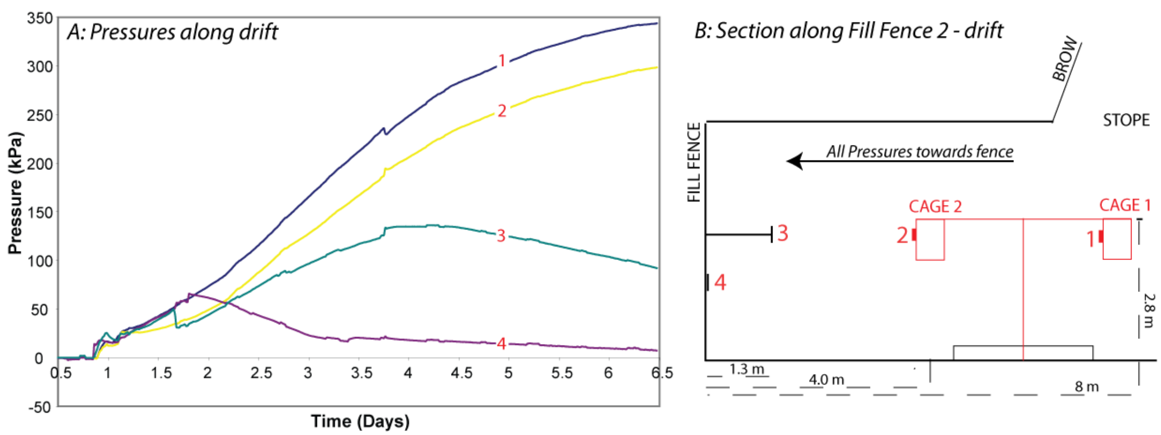

Figure 8: (A) Total earth pressures during the 6 days of backfilling, for TEPCs on the fill fence, in the drift and just under the brow as shown in (B). All pressures are oriented towards the fill fence.

5 FILL FENCE DISPLACEMENT

Displacements were measured on both fill fences and are displayed in Figure 9 for the initial 7 days of backfilling. The LVDTs were aligned in 3 columns (A - C) and 3 rows (1-3) as shown in Figure 6. The output from a TEPC is plotted for each fence to demonstrate the relationship between total pressures and displacement. Fill fence 1 was situated approximately 4 m from the stope brow. It underwent a maximum deflection of 0.9 mm as indicated by transducers B2 and C2 which were located close to the centre of the fence. The other LDVTs show deflection of < 0.55 mm. Movement of the fence had essentially stopped after 4 days. Fill fence 2 was located 7 m from the stope brow and had a maximum displacement of < 0.5 mm. Again, the central (B2, C2) LDVTs showed the greatest movement. The sudden changes in displacement were due to production blasting in the area causing abrupt relative movement between the steel frame and the fence.

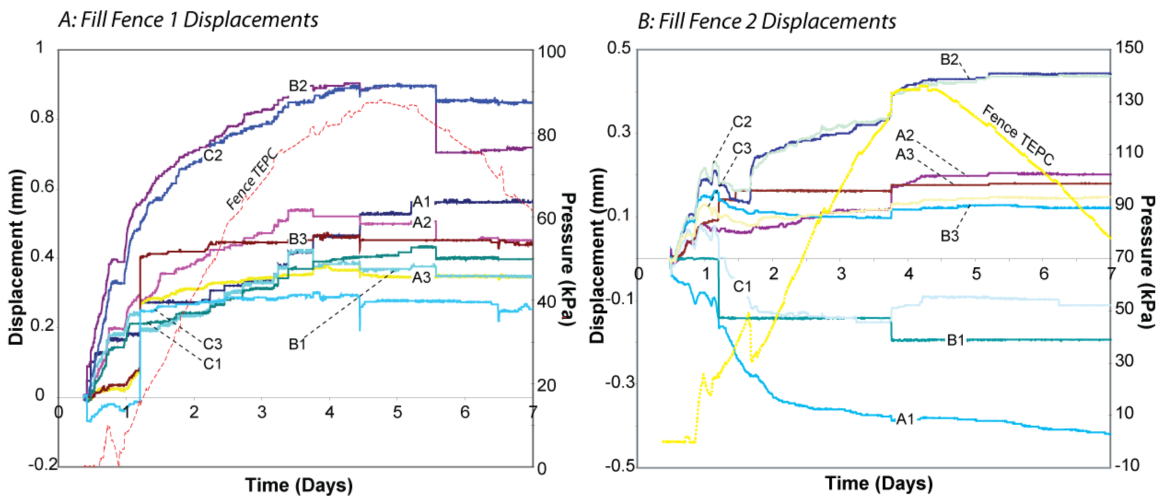

Figure 9: Displacement data for fill fence 1 (A) and 2 (B) during the initial 7 days of backfilling. The displacement transducers are identified by column (A - C) and row (1 – 3), as shown in Figure 6. A representative TEPC for each fill fence is shown on the secondary axis.

6 LONG TERM PRESSURES

The initial intention was to monitor pressures in the stope for a period of up to three years to determine the effects of adjacent mining activity on the CPB. Figure 10 shows total pressures recorded for representative cages (2, 3 and 5) for a 240 day period since the start of the backfilling. ‘BC’ marks the completion of backfilling. After 38 days the east pressure component of cage 3, which was aligned normal to the stope footwall, exceeded the vertical component as the maximum pressure. This is thought to be driven by closure of the stope walls. Indeed, several production blasts (PB) are noted in the near vicinity of the stope. Pressures in the drift, close to the fill fence (Cage 2) reduce significantly up to ~ 40 days. This is thought to be due to the loss of heat generated by hydration through the bulkhead, and into the nearby rock mass, which could cause the constituents of the CPB to contract. Laboratory work to confirm the magnitude and effects of temperature driven expansion and chemical shrinkage is underway.

Blasting of the stope directly above 67-SL1 began 131 days after the start of filling, with the slot blast (SL B). This induced a very large compressive strain in the backfill, causing instantaneous pressure increases of greater than 100 kPa followed by a more gradual increase. At 144 days, the final stope blast (SF B) caused further large (< 100 kPa) increases in pressure. Unfortunately, the maximum induced pressures could not be determined as the pressures exceeded the range of some TEPCs. The instruments were selected for the relatively small pressures anticipated to be generated during the pour rather than the near MPa pressures that later developed. Finally, at day 222 a very large rock burst (Nuttli magnitude 3.8) occurred approximately 190 m down dip from the stope. This caused local displacements of up to several centimetres and induced significant pressure changes in the backfilled stope.

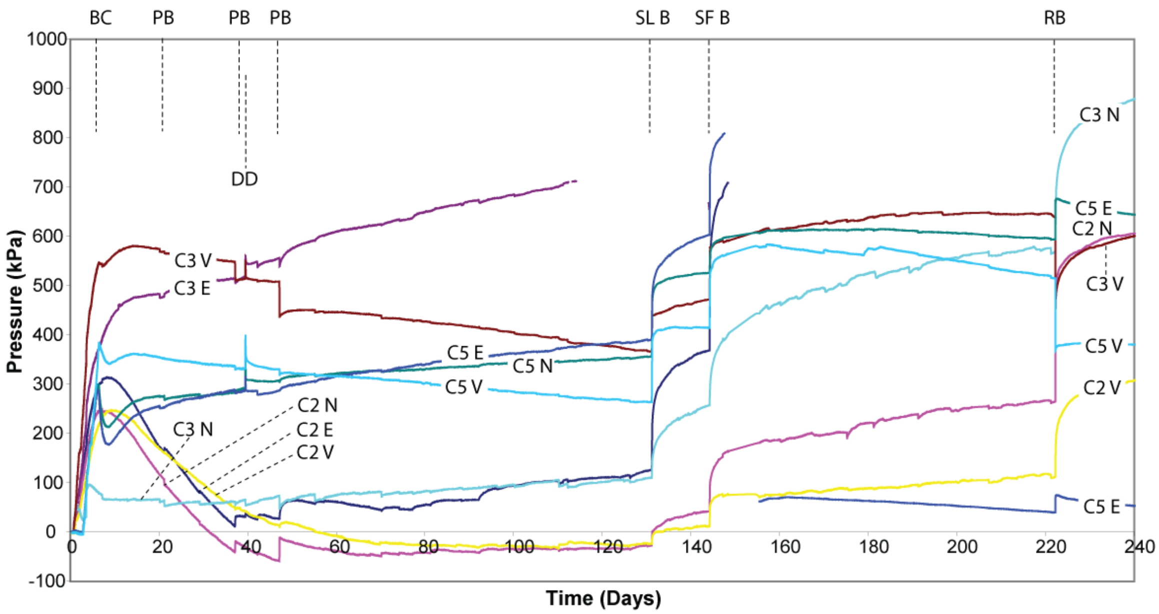

Figure 10: Total pressures during a 240 period from the start of backfilling, from cages 2, 3 and 5, with TEPC notation described in the Figure 7 caption. Significant events are marked, including the completion of backfilling (BC), numerous production blasts (PB), diamond drilling in the backfill (DD), the slot blast (SL B) and stope final blast (SF B) of the stope directly above the test stope, and a magnitude 3.8 rockburst (RB) with hypocentre 190 m down dip from the stope.

7 SUMMARY AND CONCLUSION

We have successfully instrumented two long-hole stopes at Kidd Mine in order to monitor the spatial and temporal variation of total earth and pore pressures both during, and in the months after, backfilling. The data are unique in terms of the quality of measurements and the wide range of instrumented sites within the stope. Maximum pressures during the pour were 545 kPa vertically 3m above the bottom of the centre of the stope, which corresponds to the overburden at that time, 300 kPa acting horizontally into a drift 2 m from the stope brow, and 65 kPa on the fill fence. Maximum displacements were measured as 0.9 and 0.4 mm for the two fill fences.

During backfilling, different trends were observed for instrumentation buried within the plug containing 4% binder, and within the main volume which contained 2% binder. Within the plug, pore pressures fell off after less than a day, and total pressures rapidly deviated from hydrostatic loading. In the portion of the stope filled with 2% binder, the pore pressure was equal to the total pressure for two days, after which the rate of increase in pore pressure and the total pressures measured in the horizontal axes declined for a further day. The vertical pressure continued to rise at a constant rate (except for shutdowns in backfilling) until the stope was backfilled. These results demonstrate the sensitivity of the system to binder content and the differences in the development of effective stress. The reduced pore pressures measured close to the fill fence compared to those measured in the main stope at the same elevation (i.e. cages 2 and 3) are consistent with observations of water seeping through joints in the fill fence. The low pore pressures could explain the low total pressures at the fill fence. Such leakage of water could therefore be viewed as a positive factor in the barricade design.

The reduction of pressures with increasing distance along the drift away from the stope brow is thought to be due to arching of the paste along the drift walls. This agrees with results from a previous field study at Williams Mine (Grabinsky et al., 2008), where total pressure was found to be less than 40 kPa in the drift, and in front of the fill fence. That pressures were significantly lower at Williams is thought to be due to differences in stope geometry, where the tall (150 m), narrow (20 m x 5 m) Alimak stope offers greater arching potential within the stope proper than the relatively short, wide stopes at Kidd. The properties of the tailings and sand/tailings blend may also have an effect on the arching properties of the two pastes. A further difference between the two mines is that temperatures were observed to increase by 15^{O} C in the Kidd CPB, which could result in substantial thermal effects. There are periods during which backfilling was halted but pressures continued to increase in the stope (i.e. Figure 7, C3 V). The hypothesis is that thermal expansion is driving pressures in this case, a theory that has been tested in the laboratory with some success. However there are also field observations of (probably chemically induced) shrinkage to account for. Further work is continuing in this area.

In the medium to long term, total pressures in the CPB are observed to exceed by more than 100% the pressures measured during backfilling. This is due to regional stresses and the closure of the walls of the stope, as demonstrated by the measured horizontal pressures exceeding the vertical pressures in the 30 – 60 day period after backfilling. A future research aim is to calibrate wall closure based on pressure changes in the CPB.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

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