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Utilisation of cemented rockfill, cemented hydraulic fill and paste to successfully achieve ore production expansion to 2 Mtpa at Chelopech Mine

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Abstract

Dundee Precious Metals Chelopech, gold/copper mine is an underground operation located adjacent to Chelopech village in Bulgaria. This paper presents a summary of the successful progression of Chelopech Mine from a 0.5 Mtpa sublevel caving operation to the current 2 Mtpa long hole open stoping operation with paste fill. It discusses the utilisation of various types of mine fill including cemented rockfill (CRF), cemented hydraulic fill (CHF) and paste fill. This paper also describes some of the significant challenges faced and several of the critical aspects of mine fill design, implementation and operational management.

1 Introduction

Mine fill has become a fundamental aspect of underground mining, allowing miners to economically maximise ore recovery, with the suitable selection and utilisation of mine fill. As all mining operations are vastly different, the site-specific risks, constraints and opportunities are particularly relevant during the investigation, selection and implementation of a particular mine fill solution to ensure an ongoing, economical and efficient operation.

This paper seeks to discuss only specific mine fill related items, highlighting some of the challenges and unique aspects of the ultimately successful implementation of various mine fill types at Chelopech. Furthermore, this paper attempts to emphasise that a holistic mine fill solution, purpose built infrastructure working within the limits of its design and suitable fill management system are critical to the success of a mining operation.

1.1 Chelopech Mine

Chelopech Mine is a gold/copper mine located adjacent to Chelopech village in Bulgaria, approximately 75 km east of the capital Sofia. Chelopech is situated at the foot of the Balkan Mountains, at an elevation of approximately 700 m above sea level.

Chelopech commenced underground sublevel caving, in 1954. In 2003, Dundee Precious Metals (DPM), acquired the Chelopech Mine and by 2005 had initiated the transition from a traditional sublevel caving operation, to a long hole open stoping mining method with backfill. The change in mining method was undertaken to mitigate the risk of surface subsidence and potentially losing the primary means of access to 60% of the mining inventory. Arresting the caving process in two of the major blocks was accomplished by leaving two crown pillars below the sublevel caving stopes, as described by GRD Minproc Ltd (2009).

1.1.1 Mine and mill expansion

A mine and mill expansion was undertaken from 2009 and completed in 2012. This expansion included the construction, commissioning and ongoing operation of a tailings high rate thickener and paste fill system.

Mined and processed ore at Chelopech mine has increased from 0.5 m tonnes per annum (Mtpa), in 2003 to 2.0 Mtpa in late 2012. With the Chelopech operation reaching its expansion project design rate, the current planned life of mine (LOM) extends to 2023.

1.1.2 *Mine geology*

The ore mineralogy of the Chelopech deposit as described by GRD Minproc Ltd (2009) is dominated by pyrite, marcasite and melnikovite, which forms, on average, some 50% by volume of the orebodies.

2 Chelopech mine fill

2.1 Mine fill history at Chelopech

A Backfill Project, Definitive Feasibility Study (DFS) was undertaken and completed in 2005. The project was defined with a phased implementation strategy including (Turnbery RPA Pty Ltd [Turnbery RPA] 2005):

- Phase 1 – Backfill system to supply early fill to Block 150 and Block 151 Stopes. This phase proposed the utilisation of fishtail cyclones to produce hydraulic backfill with a recovery close to 75% of feed solids. A system which was expected to be self regulating with a low capital cost.
- Phase 2 – Optimisation of the phase 1 plant to produce a better quality fill product and higher recovery of tailings material to backfill (paste fill). This phase proposed an upgrade to the Phase 1 plant, with the addition of a vacuum belt filter. However, it was also stated that if the hydraulic backfill plant prove acceptable, Phase 2 may be postponed indefinitely.

As part of the DFS, possible sources of fill material were investigated and the conclusions offered by Turnbery RPA (2005) included insufficient waste rock of suitable quality was available on surface, or arising from underground development, to provide a viable long term source of fill; and run-of-mine (ROM) waste could be used to augment the backfill supply if it were stowed into the centre core of the stopes being filled concurrently with backfilling operations.

2.2 Mine fill status at January 2008

The Phase 1 backfill system project implementation was continuously delayed. This was mostly due to belated permitting approvals and it was not until early 2008 that the plant was finally available for commissioning. During this period, with the expectation that the hydraulic fill plant would be operational in the near future, the mine continued to produce ore from primary stopes while temporarily storing all development waste into the empty stopes. The intention was to place all stored waste into the stopes during CHF placement, therefore CRF was not initially employed. In late 2007 however, CRF was implemented due to substantial quantities of waste rock still being produced and stored within the mine.

2.3 Placed mine fill summary

An annual summary providing all mine fill quantities placed at Chelopech to date can be found in Figure 1.

Figure 1 provides a summary of total placed mine fill, with reference to the average binder and solids contents utilised. The chart excludes a small volume of CRF placed prior to 2008. It can be observed that CRF and CHF were the primary fill media for 2008, 2009 and until August 2010, at which time the paste plant was commissioned.

The relatively low placement rates of CHF may be attributed to several key factors, including CHF production delays due to the system was not working within the limits of its design (discussed further in section 4); and there was rarely an alternative stope available to fill, during rest/ drainage cycles, which significantly impacted plant utilisation. Also, actual recovery of the full stream tails to CHF was 58% by weight (significantly less than the 75% recovery expected).

The peak placement of CHF in 2009 can be attributed to the implementation of several initiatives focusing on maximising the placement of CHF, including a supplemental feed system, where tailings were reclaimed from the Tailings Management Facility (TMF), repulped and added to the CHF plant feed; and a section of the underground reticulation was replaced with a smaller diameter pipe, which minimised reticulation wear (at the surface borehole outlet) and therefore plant downtime.

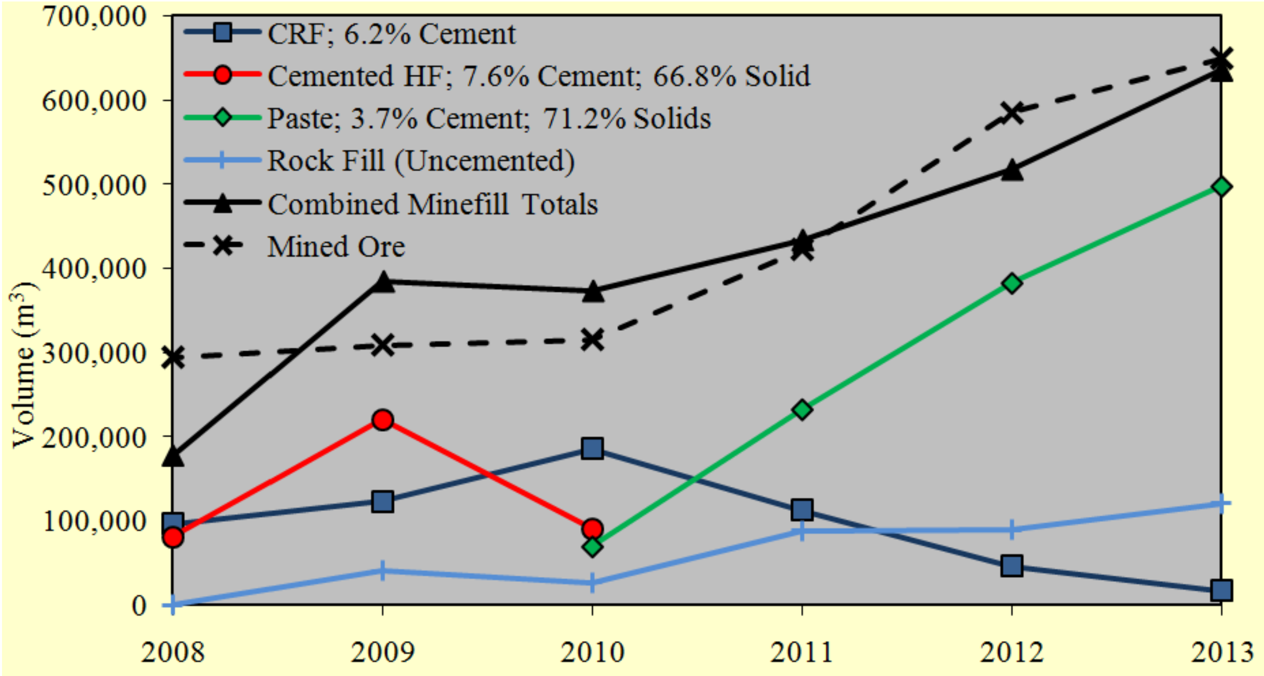


Figure 1 Annual mine fill placement volumes (2008 to October 2013 inclusive)

The peak placement of CRF in 2010, was driven by ore production targets. It was due to the additional focus and resources allocated to removing all remaining stored waste from the primary stopes and filling with cemented fill. Also a large amount of waste development occurred during this period.

The paste system, once commissioned, has steadily increased annual paste placement, which is currently the only source of cemented fill at Chelopech.

3 Cemented rockfill experience

CRF is no longer utilised at Chelopech Mine. This process was stopped in 2013 due to the reduction of waste development and no remaining stored waste underground. All current waste generated is placed in tertiary stopes (not requiring future exposure), or utilised to 'cap' paste fill stopes prior to stope production above.

3.1 Cemented rockfill process

Historically CRF included:

- The batching of a cement slurry at a concrete batch plant situated on the surface.
- Gravity transportation of the slurry through a surface–underground borehole to a high density poly ethylene (HDPE) reticulation system underground. Slurry was transported via this system to purpose built mixing sumps in close proximity to the stope being filled.
- Trucks or a loader (LHD), would tip waste rock into the sump, the LHD would mechanically mix the waste and slurry and subsequently dump directly into the stope.

3.2 Cemented rockfill materials

Binder addition in the CRF commenced at 8%, by dry mass. This binder design was established by rigorous site testing completed by Dundee Precious Minerals Chelopech (DPM Chelopech) (2007a), where a 10 m^3 CRF field trial was completed, within a purpose built cylindrical metal container as presented in Figure 2. CRF was mixed and placed into the container in three distinct layers, with binder contents of 10%, 8% and 6% respectively. This material was allowed to cure for 28 days, the container was cut away from the sample; a 100 mm diameter core was taken from the 10% binder layer and a subsequent unconfined compressive strength (UCS) test completed (on a 200 mm long, 100 mm diameter sample). Core samples from the other two layers proved impossible. However, based on the favourable results of the 10% UCS and the visual assessment of the field trial, 8% binder usage was utilised for the CRF system. This binder content can also be attributed to the high fines percentage and in particular, the high clay content of the waste material utilised.

(a) (b)

Figure 2 10 m^3 CRF field trial; (a) removing the 'mould' after 28 days; (b) the resulting field sample

The red arrow in Figure 2(b) shows were part of the sample broke away during removal of the metal container.

A retarder (Delvocrete 0.2%) was employed after site testing was completed, targeting suitable quantities to delay the binder hydration time by approximately 10-15 h. As described by PAR Innovations Inc. (2007), cement additives are often used to reduce the amount of cement scale in the pipelines, and improve the final performance of the CRF, by minimising damage of previously placed and curing CRF from the impact of freshly placed CRF in large stopes. Due to the mechanical mixing requirements, the retarder also aided with equipment cleaning.

3.3 Cemented rockfill mixing and fill rate

Several unsuccessful trials were completed attempting to reduce the mixing requirement for the CRF and move towards a less laborious solution, such as pouring the cement slurry directly into the stope at the waste dump point, and placing cement slurry directly into a truck filled with waste, tramming a set distance and dumping into a drive. However, due to unsuitable penetration of the cement slurry into the waste, mechanical mixing with a LHD was continued.

A full scale trial was completed and documented by DPM Chelopech (2007b), where a spray system was set up at the dump point in the stope and the cement slurry was sprayed directly onto waste being dumped into the stope. Based on visual inspections during filling and a three hole diamond drill coring campaign, the following conclusions were presented: a major portion of the cement slurry placed into the stope cascaded down the slope and pooled at the peripherals, very little cement slurry permeated through the waste mass at the dump point and therefore it's very likely a large portion of the stope contained less binder than required to expose the fill mass. DPM Chelopech (2007b) recommended leaving a 'skin' pillar, during the extraction of the adjacent stope, to minimise dilution, also recommending the continuation of mechanical mixing of the CRF, prior to placement. Potentially this method of CRF placement may be successful in situations where the waste material does not contain as high a proportion of fine material, and where the CRF, directly below the dump point does not require exposure.

The rate of CRF mixing, placement and waste extraction were directly related to each other, as there remained minimal underground surge capacity and surface storage was unavailable. The CRF process employed at Chelopech therefore remained extremely time-consuming, costly and maintenance intensive.

4 Cemented hydraulic fill experience

The CHF system (Phase 1) was commissioned in early 2008 and operated until August 2010.

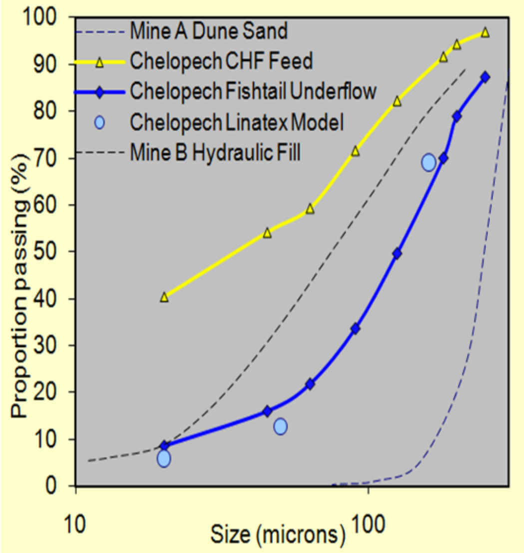
4.1 Cemented hydraulic fill process

The primary CHF process was based on tailings classification utilising a fishtail cyclone separator.

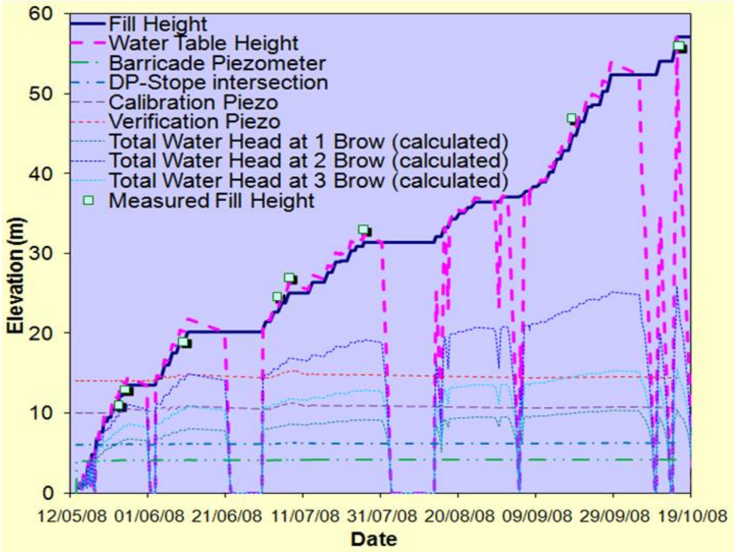
A CHF management system presented by Revell Resources Pty Ltd (Revell Resources) (2007), in the form of a technical manual, was utilised at Chelopech to ensure a safe and efficient filling operation. The manual included a drainage model, a series of practical operating rules and detailed information relating to all aspects of CHF management. The manual incorporated process design, exposure stability, material strength, drainage, plus water mass balance analysis and management with in situ monitoring, bulkhead loading, liquefaction, waste rock addition and mining works in close proximity to fill activities.

4.2 Cemented hydraulic fill reticulation

The underground CHF reticulation system was problematic from the beginning. The main issue identified was that the CHF plant and underground piping were not operating within the limits of their design. The CHF infrastructure had been sized for almost double the operational throughput being experienced. Therefore, just to keep the plant operational, fill quality was being compromised with the addition of excess water and fines to ensure flow velocities were sufficient to prevent settling in the system. This resulted in higher binder content requirements, significant mine dewatering issues and additional mine safety concerns, plus filling delays due to ponding water within the stopes. All of these items negatively impacted mine production rates and operating costs. In addition, the surface–underground borehole was operating in complete freefall conditions, which resulted in significant wear in the borehole casing and the ‘elbow’ at the bottom of the borehole. Reducing the underground pipe diameter, as recommended by Revell Resources (2008a), would have rectified the majority of these issues. However, due to several reasons only a 50 m section of pipe was replaced which at least served to minimise the wear rate of the elbow. The reasons the whole reticulation system was not completely replaced included the proposal in the near-term to supplement the CHF system feed with an uncertain quantity of reclaimed tails from the TMF, substantial capital was required to change out the entire system, relatively long lead time for the piping, the proposal in the longer-term to install a paste plant, the lack of available resources to implement the modification, plus a major portion of the pipe was located in the main decline (which was the main production haulage route). An indication of the Chelopech feed and fishtail cyclone underflow, particle size distribution (PSD), is provided in Figure 3(a).



(a)



(b)

Figure 3 PSD and CHF drainage model output; (a) comparative PSD; (b) actual calibrated model using a CHF permeability of 8 mm/h

The negative impact of the addition of water and a greater portion of fines into the CHF was obvious with the water ponding issues underground. The calibrated drainage model utilised as part of the CHF management system, provided an in situ permeability of 8 mm/h, which as presented by Helinski and Grice (2007), is very low for CHF. The model output for the first CHF stope filled at Chelopech, 17A 150 Block, can be seen in Figure 3(b). Constant head permeability testing on the cyclone underflow material was completed in the site laboratory to attempt to optimise the cyclone operation. The results ranged from 9–15 mm/h, verifying the CHF model calibration.

Figures 3(a) and (b) indicate that the PSD of the hydraulic fill generated is very similar to the Linatex model and doesn't really account for the significantly low permeability measured in the laboratory and attained from the calibrated drainage model, post commissioning. Therefore understanding the controlling characteristics of CHF, through means of permeability verification, is critical during the CHF design phase as PSD alone is likely insufficient in all CHF applications.

It is expected however, that if the CHF plant had been operated within the limits of its design, it would have led to more favourable stope drainage, i.e. if it had been operated at the designed mill throughput (or with a smaller U/G pipe) and a coarser underflow material had been produced. To confirm this concept, at least in terms of CHF permeability and stope fill rest cycles, an input of 36 mm/h permeability was used in the same drainage model presented in Figure 3(b), with all other variables remaining constant. The modelling output, which is not presented, indicated that the entire stope could have been filled at the specified fill/rest cycles almost entirely without any water ponding. 36 mm/h is considered the lower end of the industry standard CHF permeability range.

4.3 Cemented hydraulic fill bulkheads

With the CHF plant nearing completion in January 2008 and the underground reticulation complete, only the CHF bulkhead design remained outstanding. An engineered bulkhead design was presented, which was both costly and extremely time consuming to construct, as can be seen in Figure 4.

(a) (b)

Figure 4 CHF reinforced concrete bulkheads (stope 17A 150 Block), during construction; (a) planar bulkhead; (b) arched bulkhead

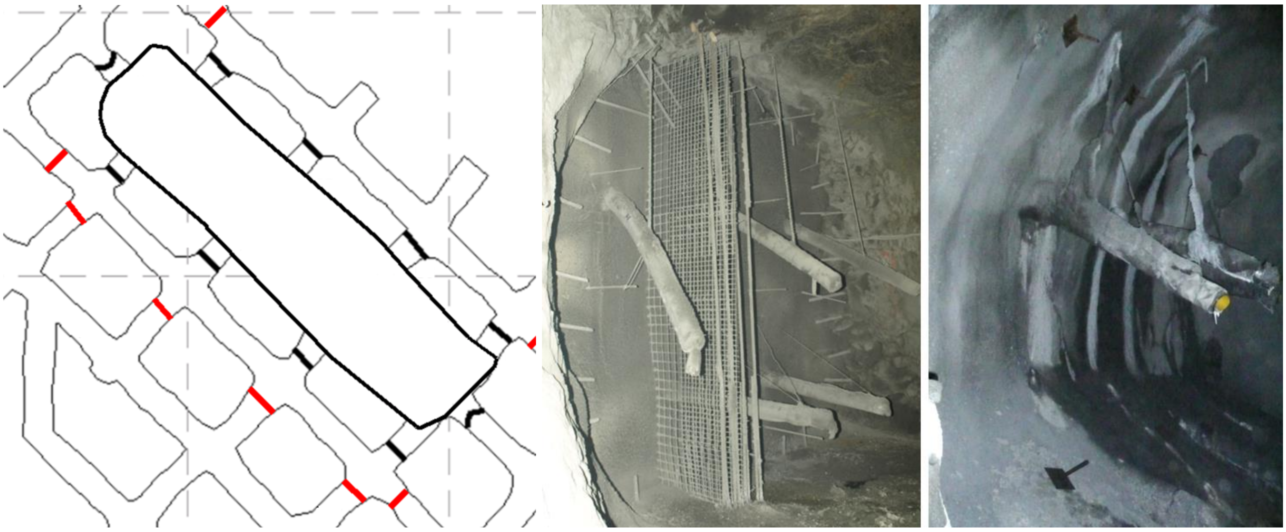
Figure 4 provides photographs, during construction, of the first CHF bulkheads constructed at Chelopech Mine. Fibrecrete bulkheads had been successfully used throughout the industry prior to January 2008, which highlighted that more practical construction methods were available. However, due to commissioning deadlines and inevitable delays associated with obtaining a fit-for-purpose industry standard design from a different consultant, four of these bulkheads were constructed. These four bulkheads required 11 construction personnel 43 shifts to complete.

In parallel with the construction of the four reinforced concrete bulkheads, a more practical fibrecrete bulkhead design was requested through Revell Resources and Itasca Australia Pty Ltd (Revell Resources and Itasca Australia). The design was based on the previously completed hydraulic fill load study by Revell Resources (2008b). The outcome was a practical and versatile design tool for both planar and arched fibrecrete bulkheads with engineered drainage, matching the imposed stresses to the bulkhead capacity.

During the preparation of the CHF bulkheads for stope 3A 151 Block, it became apparent that most did not comply with the design guidelines presented. One of the design guidelines stipulates for example, that bulkheads should not be built at or close to intersections. To comply with the design guidelines provided, an assessment of alternative options was completed. This assessment highlighted the possibility of moving the bulkheads back to more competent ground away from the intersections. This alternative would have required the same quantity of bulkheads. However, it would have also required the additional filling (and subsequent mining) of more than 200 m of development drive. In addition, this option would have prevented the use of a secondary access between mining blocks for several months. The situation and the two alternatives are roughly presented in Figure 5(a).

The stope presented in Figure 5(a) is nominally 90 m long and 20 m wide. The red lines indicate the closest bulkhead locations to the stope which would comply with the provided bulkhead design guidelines. The black lines indicate the implemented bulkhead locations.

A detailed risk assessment was completed and during the site inspections, it was identified that there was competent rock mass conditions in the backs and floors. This site-specific opportunity led to the implementation of two types of bulkheads in these locations; one with a steel reinforced vertical beam or buttress, after Kuganathan and Grice (2007) and an arched bulkhead in the vertical plane, as can be seen in Figures 5(b) and (c) respectively.



(a) (b) (c)

Figure 5 (a) plan view of stope 3A 151 Block 330 Level showing two separate CHF bulkhead location alternatives; (b) CHF bulkhead with reinforced vertical beam, shown during construction; (c) CHF bulkhead with vertical arch, shown post filling

The other key factors associated with deeming the bulkhead placement acceptable included a large stope 'footprint' (~1,800 m^2), the very low rate of fill height rise, the large number of drainage channels (bulkhead with engineered drainage) available, plus the bottom portion of this particular stope had previously been filled with CRF, which was expected to increase the drainage rate during filling. Due to these favourable drainage boundary conditions the imposed bulkhead stresses were lowered. The assumed favourable drainage was verified and managed through in situ pore pressure monitoring. Also with adequate drainage management the imposed stress could be maintained at these low levels. Additional risk management included the establishment of an exclusion zone and bunding beyond the bulkheads.

Revell Resources and Itasca Australia were also requested to undertake further investigations to analyse the capacity of several variations of planar and arched fibrecrete bulkheads, and to verify the risk mitigation strategies being undertaken at Chelopech. In addition to this, analyses were completed relating to the implications of constructing bulkheads at intersections and where the bulkhead–rock interface was less than ideal.

A summary of several of the models utilised during the investigation, including an indication of the failure mechanism of a barricades, can be seen in Figure 6.

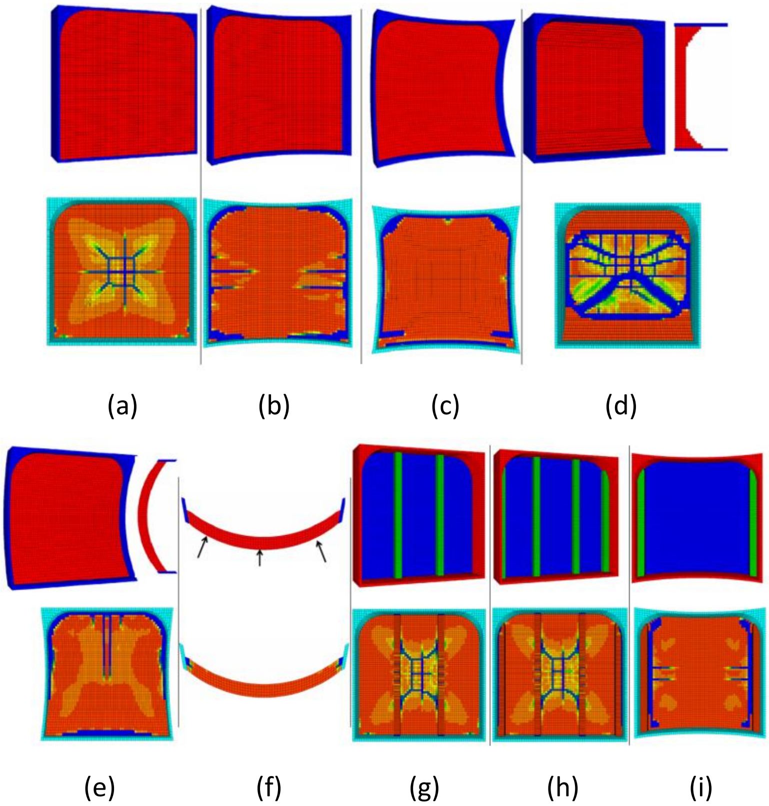


Figure 6 Various section and long section views of the fibrecrete bulkhead models, with the overlying sketch providing the preloaded geometry and the underlying figure providing an indication of failure mechanism; (a) planar; (b) arched; (horizontal plane); (c) arched (horizontal and vertical plane); (d) planar (with 'arching' – backs and floors); (e) arched (vertical plane); (f) plan view of an arched bulkhead (with unfavourable 'opened up' wall angle [10°]; (g) planar (two reinforced vertical beams or buttresses); (h) planar (with four reinforced vertical beams or buttresses); (i) arched (horizontal) – two vertical beams at the side walls

A summary of the modelled ultimate capacity of various bulkheads is presented in Table 1. The labels in the table correspond with those detailed in Figure 6.

Table 1 Modelling results: ultimate capacity for fibrecrete bulkheads, normalised to a planar (flat) bulkhead (Revell Resources and Itasca Australia 2008)

Item	Fibrecrete bulkhead description	Normalised ultimate capacity
a	Planar bulkhead	100%
b	Arched – horizontal plane	166%
c	Arched – horizontal and vertical plane	177%
d	Planar – with 'arching' at the backs and floors	145%
e	Arched – vertical plane	167%
f	Arched – with unfavourable wall angle (10°)	123%
g	Planar – with two reinforced vertical beams (buttresses)	103%
h	Planar – with four reinforced vertical beams (buttresses)	107%
i	Arched (horizontal) – with two vertical beams at the side walls	201%

Of the many conclusions that can be made from the modelling investigation in relation to ultimate bulkhead capacity, the most interesting from a practical construction perspective include:

- Horizontal or vertical arching of a bulkhead (b, e) provide considerable capacity increase (~66%), compared with a 'standard' planar bulkhead (a), with the same dimensions and thickness.
- A planar bulkhead with 'arching' at the backs and floors (d), can provide a substantial increase in ultimate capacity (~45%), compared with a 'standard' planar bulkhead (a).
- The installation of vertical beams or a fibrecrete thickening along the sidewalls of an arched bulkhead in the horizontal plane (i), can provide an additional increase in ultimate capacity (~21%) compared with an arched bulkhead (b, e).

The results of the modelling investigation provided a means of comparison for various bulkheads based on the site-specific conditions, constraints and opportunities at a particular bulkhead location. The mine fill engineer was therefore able to assess the advantages and disadvantages of key aspects relating to the bulkhead options, including; modelled capacity, available resources for implementation, construction cost and duration. Most importantly, the engineer was able to quantify the bulkhead capacity of a practical bulkhead construction and manage the risk through controlling the fill/resting campaigns. Ensuring the imposed stress did not exceed the working capacity of the adopted bulkhead.

To emphasise this point, it is pertinent to mention that the risks associated with personnel safety and bulkhead capacity were considered unacceptable at several subsequent bulkhead locations. It was therefore necessary to move the bulkheads further away from the stopes, which resulted in filling several access drives. This requirement to move the bulkheads away from the stope, though necessary, also presented negative implications including a reduced rate of stope drainage, production schedule implications, and additional costs associated with the placement and subsequent mining of cemented fill.

The investigation emphasised the following salient points:

- Bulkheads should not be constructed at intersections, particularly in locations where the drive starts to 'open up' and the primary stress transfer from the bulkhead is into the side walls.
- To manage the risks associated with CHF placement, it is necessary to define the bulkhead capacity and adjust the imposed stress to match the working capacity.

Arched bulkheads in the vertical plane, as shown in Figures 5(c) and 6 (e), have been successfully utilised at Chelopech. There were however additional quality control concerns associated with this type of bulkhead related to adequate cleaning of the floors, and poor fibrecrete properties in the lower portion due to 'rebound'.

Another potential application for an arched bulkhead in the vertical plane is where the height of the required bulkhead is considerably less than the width. Site-specific analysis would be required to verify this as an adequate alternative.

5 Paste fill experience

The paste fill system, described as Phase 2 in the backfill project DFS, was commissioned in August 2010 and has been operational since.

5.1 Paste fill process

The paste system generally consists of the following infrastructure:

- High rate thickener.
- Vacuum filtration (disc filters × 2), with agitated surge tank for feed material.
- Vortex mixer, combining unfiltered slurry from the surge tank and dry binder.

- Continuous paste mixer, combining the filter cake and binder slurry.
- Borehole feed hopper, fitted with load cells and control valve, ensuring a level is maintained in the hopper and a vacuum is maintained in the borehole.
- Cased, surface–underground borehole, in which paste is gravity fed through to the underground reticulation system.
- The reticulation system includes paste specific cuddies, dump valves, flow and pressure indicators, burst pipes, high pressure steel piping with high pressure Victaulic couplings in main accesses and HDPE piping in stoping area's (stub flange and backing ring).

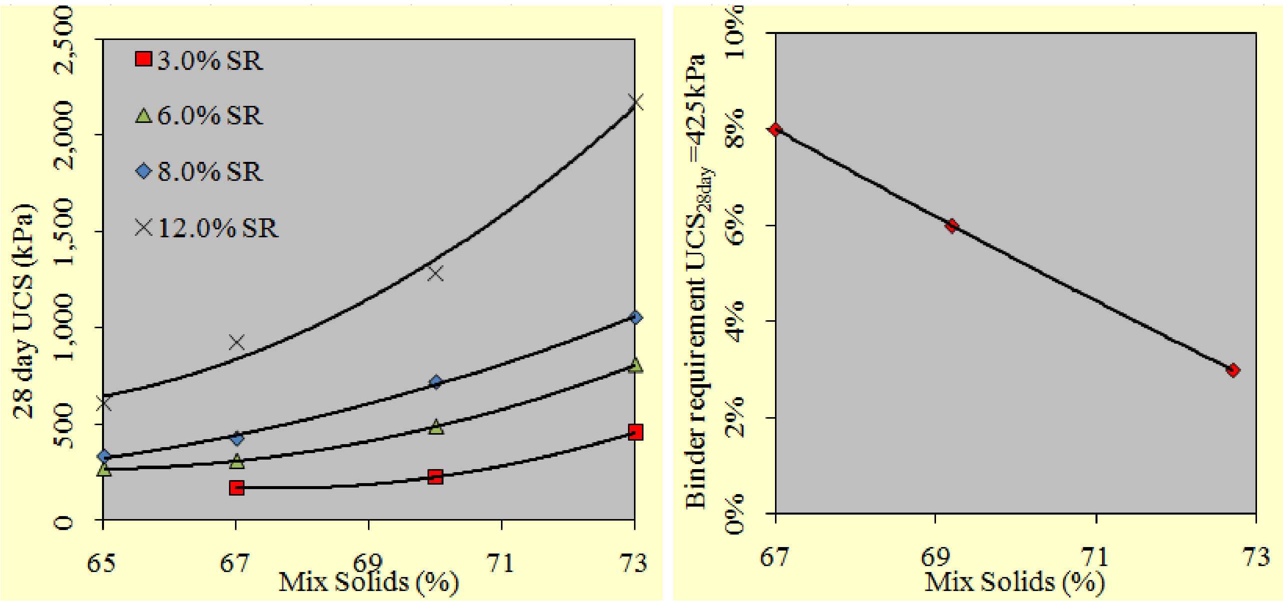
Table 2 presents some of the site-specific design criteria, as detailed by DPM Chelopech (2009).

Table 2 Paste plant design parameters

Paste plant design criteria	Design input
Particle size – D80	175 µm
Particle size – D50	70 µm
Particle size – D35	2 µm
% passing below 20 µm	30
Binder concentration in paste backfill	2-8%

5.2 Paste solids and binder mix relationships

A paste test work campaign was completed by Outotec Pty Ltd (Outotec) (2013), to assess the influence of binder addition, mix solids content and hydration time on the UCS. The results of this test work are presented in Figure 7(a) as paste UCS against mix solids content. This Figure indicates that the mix solids content of Chelopech paste has a significant impact on the resulting paste strength. To illustrate the impact of mix solids content on the paste fill operational expenditure (OPEX) the data presented in Figure 7(a) was used to determine the relationship between binder requirement and mix solids content for a set strength target (of 425 kPa). This relationship is presented in Figure 7(b).



(a) (b)

Figure 7 (a) 28 day UCS against mix solids; (b) binder requirement against mix solids content

Figure 7(b) illustrates the significant opportunity to save binder and reduce OPEX through maximising the delivered solids content. These Figures also illustrate that any reduction in solids concentration is expected to result in a significant reduction in paste strength, if not accompanied by an increase in binder addition.

5.3 Paste reticulation

The paste reticulation infrastructure at Chelopech, forms a robust well designed and implemented system. However, there remains one primary issue related to the paste reticulation system. It is currently not possible to place the targeted high quality material the plant was designed for at the required system throughput. A minimum surface–underground borehole diameter of 200 nominal bore (NB) was specified by Revell Resources (2009) and ideally it was recommended that a 250 NB casing be utilised for filling. During construction of the two boreholes (duty/standby), both boreholes were lined with a 250 NB casing, as per the recommendation, with the intention to install a 200 NB casing inside, when required. However to minimise borehole maintenance requirements in terms of abrasive wear, it was decided to trial the use of a 225 outside diameter (OD), PN40, HDPE casing, with a 125 mm internal diameter (ID) (less than half the internal pipe area of the minimum recommended). This casing is still in use, as the borehole is continuously operating full and therefore has not seen significant wear. It could therefore be concluded that from a maintenance perspective this HDPE liner was a great success. However from an operational throughput and cost perspective it is not ideal. It was found that the HDPE liner was affecting both the throughput and solids content of the paste. The low solids and low throughput are required to be placed to overcome the restriction in the HDPE liner, which is also causing the settling of solids in the underground reticulation system as the pipe was designed for a much larger flow. Two means of rectification were proposed by Outotec (2013):

1. Revert to the original design of a 250NB and subsequent 200NB casing.
2. Place paste down the two HDPE lined boreholes in parallel, which would increase internal pipe area, though also counteract the duty/standby philosophy, increasing operational risk.

An example providing an indication of a significant cost reduction potential proved that if Chelopech increased the solids content from 71.2% to 73% solids, the overall consumption of binder could be reduced by 30%. This example incorporates Figure 7 and the following points:

- Targeted paste strength after 28 days hydration is 425 kPa, for various stopes.
- Utilising 73% solids content and a targeted strength of 425 kPa at 28 days, the binder requirement equates to slightly less than 3% cement.
- The average solids content from commissioning to date was 71.2%, equating to a 4.3% binder requirement utilising the targeted strength of 425 kPa at 28 days hydration.
- This provides a potential reduced binder content requirement of 1.3%, therefore an overall binder usage reduction of 30% would be possible, for the given example. This also highlights a substantial potential OPEX reduction.

It is expected that once implemented, the proposed borehole liner modification will result in a significant paste solids content increase up to and potentially exceeding 73% solids, without compromising plant throughput.

5.3.1 Critical infrastructure

One of the primary components of the reticulation system is the surface–underground boreholes. To ensure adequate protection of each borehole, 'dump' valves are commonly utilised to reduce the risk of borehole blockages. While there are a variety of suitable valves available for this application, the hydraulic actuated valve shown in Figure 8 is the one currently used underground at Chelopech.

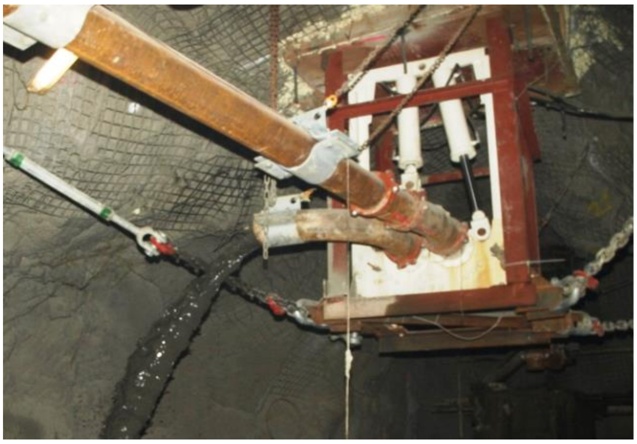


Figure 8 Paste dump valve, at the base of the surface–underground borehole (during paste plant commissioning)

Whilst the installation requirements of this valve may be more onerous than other dump valve options, this valve presents a robust, low maintenance, purpose built valve for cemented materials (it is primarily used in the concrete industry). The s-tube and swing plate design provides a dump valve solution without 'dead' or 'no−flow' zones, where cemented material could build-up during extended filling periods. A valve with a smaller pipe diameter was previously installed and successfully utilised in the CHF system at Chelopech.

The valve type in Figure 8 has not yet been trialled as an operational diversion valve, however based on the excellent performance demonstrated to date, it is the author's opinion that the valve would be suitable for such an application. The case for installing a diversion valve would be to minimise plant downtime during reticulation line changes between stopes. This application would likely require two valves installed in series (dump and diversion), ensuring adequate borehole protection and providing a means for reticulation diversion. The proposal would enable a reasonably short duration for stope changes at the completion of a fill run, once the reticulation has been flushed out as per normal operating procedures.

Another important consideration would be to ensure the diversion valve is able to be locked out (isolated) in either position from underground during plant operation. This would enable the construction crew to safely work on the pipeline connected to the unused valve outlet without necessitating travelling to the surface to isolate a borehole. It should be noted that a dual borehole system with adequate surface infrastructure is commonly employed at mining operations allowing similar flexibility regarding line changes between stopes.

6 Summary and conclusion

From a modest beginning in 2008, the safe placement of competent fill at Chelopech has increased substantially in recent years, which has assisted Chelopech reach the 2 Mtpa expansion target. The following provides a brief summary of relevant points discussed throughout this paper:

- Site-specific risks, constraints and opportunities are particularly relevant during the investigation, selection and implementation of a particular mine fill solution to ensure an ongoing, economical and efficient operation.
- A holistic mine fill solution; purpose built infrastructure working within the limits of its design and suitable fill management system are critical to the success of a mining operation.
- Allowances for mine fill related infrastructure (such as bulkheads), during mine design, is critical in mitigating operational risks associated with personnel safety and ultimately production schedules and costs.
- To manage the risks associated with CHF placement, it is necessary to define the bulkhead capacity and adjust the imposed stress to match the working capacity.

- Arched bulkheads in the vertical plane and planar bulkheads with additional fibrecrete 'arching' in the vertical plane, provide a significant increase in ultimate capacity over planar bulkheads and have been successfully utilised at Chelopech.
- Mix solids content of Chelopech paste has a significant impact on the resulting paste strength and there remains significant opportunity to minimise paste binder requirements, through maximising the delivered solids content.

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