Compilation of industry practices for control of hazards associated with backfill in underground mines - Part II underground transport and stope placement

Jamie Archibald
Queen's University, Kingston, Canada

Euler De Souza
Queen's University, Kingston, Canada

Luc Beauchamp
Mines and Aggregates Safety and Health Association, North Bay, Canada

ABSTRACT: The Department of Mining Engineering at Queen's University conducted a study of backfill practices in underground mines across Canada to assess the current state of backfill usage and to overview potential hazards associated with backfill practice, from preparation to transportation to placement. The primary aim of this study was to cover each component of a typical mine backfill system, and to identify potential incidents leading to the disruption of backfilling operations and any associated corrective actions. This paper, Part II of the study, deals with underground operations consisting of backfill transportation and backfill placement. Part I of the study, which deals with surface operations consisting of backfill material supply and backfill plant preparation, is also presented in these proceedings. A review of safety measures associated with current backfill operations and recommendations for procedures of best practice that should be implemented to reduce fill-related hazards in all mine backfill workplace environments are presented. In general it has been found that system failures normally lead only to minor losses to the operations.

1 INTRODUCTION

The primary aim of this study (parts I and II) was to study backfill practices in each component of a typical mine backfill system and to identify potential incidents leading to the disruption of backfilling operations and any associated corrective actions to mitigate against disruption or hazard occurrence.

In general, it has been found that, although mine fill types have become progressively more engineered products, the selection of fill components is usually site-specific, and the mix formulations used and cement additions made are still based on experience and various empirical techniques. Although typical backfill plants are well monitored, relatively little engineering data is gathered or known once the backfill enters the mine borehole, travels through the underground distribution system and is placed in stopes.

2 BACKFILL TRANSPORTATION AND DISTRIBUTION SYSTEMS

2.1 *Surface pipeline systems*

The mine backfill operations that were visited during the course of this study reported the manufacture of paste fill for underground deposition at average production rates of 145 tonnes per hour and the manufacture of hydraulic slurry fill at an average production rate of 170 tph. Both paste and hydraulic slurry backfills are manufactured in dedicated surface plants or batch mixers, and are directed to pipes or boreholes that are used to transport these materials underground to various distribution levels.

At the majority of mix plant operations, both paste and slurry fill products are pumped to transfer boreholes through steel pipelines, though several operations utilize trucks for the transport of manufactured paste backfill batches from the plant to borehole sites.

Potential blockage of paste and slurry flows into and through boreholes can often develop due to creation of vacuum conditions within the pipelines and boreholes when intermittent flows occur. An effective hazard control that has been implemented by some, but not all, mine operators is the addition of breather pipes at the pipe-borehole coupling flange to prevent vacuum conditions within the initial feed path route into mines.

Some operations use single boreholes, while others use twin or a larger number of boreholes to provide fill feed to underground sites. The use of multiple boreholes provides underground access from a number of independent feed sources and redundancy in case of borehole plugging. The majority of boreholes are uncased. Typical paste feed boreholes are developed at diameters ranging from 15 to 30 cm.

2.2 *Underground pipeline systems*

Typical mines that utilize paste backfill in underground applications use sectioned pipe for level transport that is typically fabricated from Schedule 80 steel. Such pipe is rated for paste delivery where average horizontal path pipeline pressure conditions range between 1.4-2.8 MPa.

At primary borehole breakout sites onto initial underground delivery levels, where backfill materials have been typically subjected to long vertical delivery drops from surface and are then subjected to rapid re-direction horizontally, special pipe design features must often be incorporated to prevent hazards associated with high induced pipeline pressures, impact effects from falling fill into empty pipes, vibration and shaking created by material re-direction and other transport effects. To offset the dynamic shock effects that can occur at such transition points, borehole-to-level pipe connecting elbows are typically constructed to be strong and well reinforced (Figure 1). Such reinforcement can range from application of light duty bolt-and-chain suspension hangers that will permit level pipe flexure, to the application of sturdy “D-flange” borehole-to-level pipe connectors and steel bracing that is rigidly bolted into the drift walls and back. All mine operators who utilize paste fill were seen to use steel brattice reinforcement to provide reinforcement at borehole-to-pipe transitions.

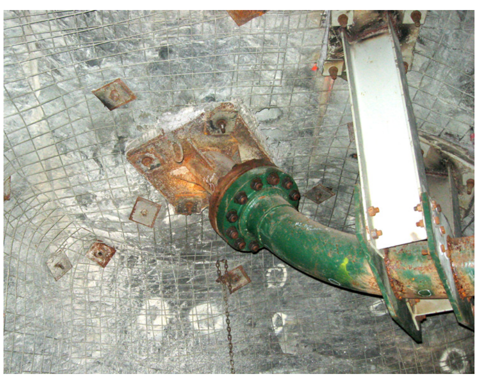

Figure 1. Reinforced borehole-to-level pipeline transition

Paste level distribution pipes were assessed to range in diameter between 10-20 cm. On level travel routes, the predominant support provided for main level paste delivery lines was by rockbolt and steel cradles, rockbolts with steel cradles plus wooden wedge stiffeners, or combinations of each plus bolt and chain. At mines where hydraulic slurry fill is used, level delivery pipes were installed over a narrow size range between 10-15 cm diameter. For all hydraulic fill users, the only pipe support provided for fill delivery pipelines was by bolt and chain supports.

2.2.1 *Pipeline components*

Connections between steel line sections in fill operations are traditionally made using Victaulic couplings, with several operators currently supplying double Victaulic couplings at critical joint sections (notably at elbow joins) for safety, or transitioning to use of "D-flange" connections in order to provide stronger pipe joins at borehole-to-level pipe and on-level pipeline paths.

2.2.2 *Pipeline branchings*

For all backfill users, path changes are largely facilitated by steel elbow transitions along levels to stope distribution lines, either using angled elbows or 90^0 "T" couplings, or, in some cases, flexible rubber tubing. Similarly, pipeline transitions from level to level distribution lines predominantly make use of angled steel elbows or flexible rubber tubing. As with borehole-to-level pipe transitions, the majority of paste fill operators utilize Victaulic couplings at elbow connections along level delivery lines. Some operators have adopted the use of "D-flange" connectors in order to strengthen connections between line sections.

At high pressure and high wear branching locations, and at borehole-to-level pipe transitions, elbow and straight pipe reinforcement is being provided through use of "D-flange" couplers, installation of Schedule 10 steel wear elbows and placement of ceramic inserts. Such features are applied to minimize the rate of wear of critical pipe sections and to provide additional strengthening of elbow joints at sites where high line pressure conditions may be indicated to exist and create pipe bursting or joint failure hazards.

2.2.3 *Pipeline pressure control*

A significant amount of research has been conducted in Canada and internationally to optimize backfill pipeline distribution designs, to develop techniques for assessing accurate fill system pressure distributions and to distribute information that can assist mines to improve transport efficiency of distribution systems. The majority of pipeline distribution failures underground are only partially due to backfill quality control issues and principally due to inadequate knowledge of design methodologies for the distribution system. Such knowledge gaps include inadequate understanding of backfill flow and pipeline hydraulic behaviour that can initiate flow blockages, inadequate flow delivery rates, excessive pipe wear conditions and, with high pressure gradients, potential pipeline failures.

At some mine operations, high pressure conditions have been observed at borehole-to-level transition sites and localized high pressure surges at transitions within level delivery lines.

Where localized high or variable pressure conditions exist, there may exist potential for pipeline rupture, valve failures and other potential hazard occurrences. It is common practice at many fill operations therefore to install and maintain monitoring equipment to assess pipeline pressure conditions and to effect various operational procedures to limit high pressure build-up within distribution lines. Some operations make use of air venting or breather tubing at points of transition into feed boreholes or along level piping to mitigate vacuum formation or high pressure build-up.

At points of transition from boreholes to level distribution pipes and at end-of-line distribution points into stopes, these being locations where high line pressures often develop, various measures have been adopted to minimize high stress development. For some operations that make use of paste fill, specially fabricated "burst" disks are attached to the pipelines that are designed to rupture when line pressures exceed designated levels that approximate 200-250% of the normal rated line pressure.

It is well known that high pressure conditions develop where flow transitions from boreholes to level pipelines exist, thus measures are often taken to reinforce such transition elements to resist potential damage that might result from excessive pressure. Measures such as placement of reinforced brattices and placement of high strength elbows are common proactive procedures used to reduce potential damage hazards that are created at such high pressure flow zones. An additional approach to reducing high pressure elements in pipelines is through incorporation of flow loop assemblies into level pipeline sections immediately following the borehole-to-level transition, or at any site where normal high pressure conditions may exist.

2.3 *Backfill instrumentation and monitoring*

All paste and hydraulic backfill users surveyed make use of one or more forms of instrumentation to monitor borehole, level pipe or stope delivery line conditions of flow, though not all use the same or consistent forms of instrumentation.

Most backfill operators utilize flow pressure sensors on main level delivery pipes (Figure 2). Data relayed from pressure sensors provides indication of potential zones of line blockage or restriction where paste flow can be maintained, or of zones of absent flow when no line pressure exists. Additionally, paste operators place less reliance upon use of flow velocity monitors for fill. Some have provision for remote monitoring by plant personnel while the other operations require such sensors to be read manually and data to be recorded for later interpretation.

Figure 2. Backfill line pressure sensor

All backfill operations make use of a variety of communications devices, including dedicated telephone, leaky feeder radio and television monitoring, to maintain constant communication between plant operators and underground personnel during all primary filling operations. Effectively all operations maintain constant verbal communication between plant and stopes, and points between, during fill pouring operations in order to initiate, stop and monitor flow operations in real time. The use of closed link television monitoring of stope pours by surface plant operators is less common.

Internal wear of pipe sections is of concern to all backfill operations surveyed. For 50% of operations reviewed, direct wear measurement and inspections are not conducted, rather replacement of pipe materials is conducted according to either planned schedules (by time or quantity of backfill delivered) or as pipeline failures are reported. Additionally, some mines utilize 90° pipe rotation procedures while others facilitate 120° pipe rotations, thereby tripling or even quadrupling the life expectancies of pipe systems that do not undergo regular rotation.

In operations where both paste and hydraulic fill materials are distributed, both visual surveys of pipe thickness and external instrumentation (ultrasonic thickness monitors) are regularly utilized by approximately 50% of both types of operations to monitor the thickness conditions of pipe sections as indicators of pipe wear and potential for failure. When wear is considered to be excessive, pipe replacement is performed. At the remaining 50% of operations, pipeline replacement is mandated in reactive fashion only when visual leaks are noted.

2.4 *Potential hazards and prevention management*

Common operational procedures exist at all operating fill sites that make use of timed or mandated volume water flushes before and after fill pouring activities. In paste fill operations, additionally, compressed air flushes are also used in conjunction with water flushes to insure that unobstructed pipeline systems are maintained prior to use.

As part of mandated activities at all fill operations, minimum compliance requires that “Fill Letters” be completed and signed off by both surface and underground operators prior to any fill pouring. Such Letters are circulated to all supervisory personnel associated with fill operations to ensure that communication strategies, filling procedures, emergency standards and other pertinent procedures of safe practice are followed at all times. Typically, these Letters mandate that effective communication between the surface fill plant and pour points within stopes at the end of the fill distribution lines underground must be effected, or that provision of real-time video monitoring of pour sites, must be in place in order that pouring may commence. Similar communication protocols are detailed in such Letters to cover procedures that are to be followed by all associated fill crews during and after pouring is complete. Typical inclusions in such documents would be designation of timed or quantity rates of flushing water and air to be used to insure that lines are clear before fill is poured, and similar quantities to be used to insure line clearing after pouring is complete.

Fill operators were noted to make use of two or more feed boreholes from surface delivery plants in order to provide redundant delivery capacity underground in the event of borehole blockage. Procedures exist that may be used to prevent such occurrences, including: performance of regular borehole camera surveys to insure that no flow blockages exists; regular borehole flushing to clear obstructions; grouting of steel pipe within boreholes to enhance the structural integrity of borehole walls and thereby prevent sloughing; installation of borehole pressure meters at takeoff elbows in order to provide real-time assessment of flow conditions; grouting of borehole wall fractures to restrict inadvertent water inflows that may alter paste fill physical characteristics (increasing fill slump and tendency for aggregate to settle out in flow); and others.

A primary area of concern during initial borehole and level access transport of backfill, and particularly of paste fill, exists at the borehole-to-level elbow access point. At such locations, where long free fall drop heights may exist, high pressure wear and dynamic shock impact can create potential transition failure hazards. The sudden impact shock in paste fill operations may be reduced somewhat by insuring that the borehole transition zone is never left completely empty, and that some quantity of paste fill is always present at the start of full pour operations.

Rupture and separation of the transition elbow may be mitigated by application of regular pipeline pressure monitoring at critical transition points (as at the transition zone from borehole to level pipe sections), reinforcement of critical elbow connections by use of high strength elbow materials or wear-resistant inserts, provision of regular replacement of elbow units to avoid excessive wear problems, placement of reinforced steel brattice structures to prevent pipe deformations and use of appropriate valve mechanisms for restricting or re-directing flow volumes. The utilization of lengths of flow loop piping at the immediate zone of borehole-to-level transition can also be used to reduce high line pressure and flow velocity conditions further downstream. In all cases, instrumentation should be considered to enhance monitoring capabilities for such critical distribution elements. Many mines make provision for manned access to such sites during the pouring process, and, should problems develop during pouring, good communication must be maintained at all times between underground and plant personnel to forestall any critical incidents that may arise. If no personnel are regularly available at critical path junctions such as this, then the use of remote sensing devices such as dedicated video camera stations must be established to provide plant operators with hazard warning capabilities in the event of pipe rupture or failure.

Additional high quality instrumentation that can be effectively installed and well maintained should also be utilized. The effective application of instrumentation can provide operators with knowledge of flow stoppages (low flow velocities), high pressure development (flow blockages), or loss of pressure conditions (pipe leakage). As indicated by site reviews, the predominant form of line instrumentation used for flow indication is pressure gauge technology that can be rugged in construction and remotely monitored.

Along level transport routes and at many directional change sites, excessive pipe or elbow wear can often result in pipe ruptures, loss of feed and potential plugging of lines. It is recommended that some standardized system of pipeline replacement be adopted by the industry at large that incorporates best practices in use of instrumentation, response management, maintenance scheduling and the like that can be used to mitigate potential problems that could result when only reactive responses to pipe failures are in effect. Features that have been applied at some, but not all, fill sites to mitigate pipeline failure events, and which should be considered for standard practice at all fill use operations, include:

- making use of flexible rubber piping, where feasible, at elbow connections to reduce pipe wear and better facilitate changeouts or repairs;
- making use of “T” flanges instead of elbow connectors to reduce pipe wear;
- making use of “D-flange” pipe section, rather than Victaulic, couplings to provide stronger section joins;
- application of “pressure pill” surveys to assess zones of high pressure development that may represent critical failure sites;
- provision of air breather lines from borehole and level pipe paths to mitigate detrimental line vacuum effects;
- systematic placement of “burst” disks to provide high pressure relief when potential blockage situations develop;
- creation of a dedicated communication system between all critical fill delivery line locations and the surface plant operator using radio, telephone or video monitoring instrumentation that has the capacity to provide real-time contact response;
- dedication of full-time and task specific teams of mine personnel to whom sole responsibility for failure or critical event response reaction exists (thus staffed only by trained and dedicated workers with a good working knowledge of operational and hazard aspects of fill operations); and
- where no mine-specific reaction team is available, the contracted use of professional backfill critical event response teams should be considered.

2.5 *Stope preparation and fill delivery*

Most fill operations provide stope delivery using 10 cm diameter steel or plastic. All fill users make use of steel elbow or “T” fittings to re-direct level pipe flows into stope feed lines that are universally supported in place using bolt and chain link hangers. Single or multiple pour points, ranging in number from two to four, are commonly developed within the fill stopes.

In practically all stope filling operations (paste and hydraulic) initial pours are placed in multiple lifts, with the initial one being placement of a fill plug immediately behind a reinforced bulkhead or barricade system. The initial plug is typically placed to the brow height of the bulkhead opening. Following a period of cure (and drainage in the case of hydraulic fill pours) bulk material pours are made to fill the remaining stope voids immediately above the bulkhead horizons.

2.6 *Backfill pour monitoring, instrumentation and control*

Most fill operations utilize active video surveillance monitoring of backfill pouring operations. Additional communication between plant operators and underground fill personnel is established at all times using either telephone or radio communication. Verbal or visual contact is required by all operations prior to, during and immediately following pour activities to insure that proper pouring requirements are met and that no unsafe operating conditions will develop that could pose potential hazards to workers and the fill infrastructure. While operations do make use of telephone and radio contact networks, they are still dependent upon having personnel in place at sites where fill deliveries are taking place or at sites where critical monitoring is required (such as at takeoff elbows ahead of stope feed lines and at drainage points on bulkheads). Where staffing underground or in fill plants is less than optimal, the ability to offer real-time assessment of hazard situations may be difficult to achieve if this is the sole system of monitoring in place.

It is noted that additional pour monitoring capabilities have been implemented through use of video surveillance. The application of redundant monitoring capabilities, as listed, would also enhance plant operator ability to provide warning of and control over potential hazardous events that may result during pouring (such as pipe breaks or bulkhead failures). Aside from flow control surveillance using ultrasonic pipe flow meters, as was detailed in previous sections, the ability to control fill delivery quantities and heights, and thus fill stability conditions at pour sites, is also monitored through use of visual assessment, water leak detectors, water level indicators, bulkhead drains, drain pressure meters, bulkhead pressure cells and in-situ fill pressure cells.

In typical fill operations, drainage pipes are installed in the upper bulkhead brow (ranging in number from one to three per bulkhead) to provide an alternate means of visual indication of the level of filling of plug pours within stopes. As well as providing a method of monitoring fill height conditions in hydraulic fill stopes, such drains, in combination with bottom drain structures and/or pressure gauges mounted directly onto drainage pipes, are also used for facilitating water drainage and measuring whether designed conditions of fill pressurization are being attained or exceeded.

The measurement of drainage pressures within hydraulic fill and bulkhead pressures at paste fill sites, using pressure gauges mounted on drains and Glotzl cells mounted on the inside surfaces of bulkheads, as well as adoption of leak probes mounted within seepage containment structures at the base of bulkheads, are used to monitor conditions of excessive pressure buildup (due to lack of adequate drainage flow) or leakage from bulkheads due to containment structural failures.

Based on survey data from all hydraulic fill operations visited, no bulkhead failures have been reported. Alternately, a review of paste fill operations has indicated that, at one site, a limited bulkhead failure incident was experienced that occurred when the rate of paste filling was too rapid, resulting in localized fracturing of a shotcrete bulkhead at the mid-span centre location. The failure, the only one recorded to have developed over a seven year operational period at this singular mine site, was localized and did not result in catastrophic bulkhead collapse.

2.7 *Backfill retaining structures*

2.7.1 *Sillmats*

In many underground operations where underhand cut and fill methods are used, special reinforced layers of reinforced, consolidated paste fill (sill mats) are constructed to enhance the strength of fill above downward progressing excavations. In many operations, these mats are designed to make use of high strength paste layers (having unconfined strengths approximating 1.5-2.0 MPa or better) in combination with a variety of reinforcing elements that can include waste rock capping materials, rockbolt arrays (both vertical and horizontal placement), and mesh or other screen materials (Figure 3).

Figure 3. Reinforced backfill sill mat

For hydraulic fill operations, it was noted that erratic placement or reinforcement materials often resulted in non-uniform strength character of the reinforced fill layer. Similarly, and because of the potential to create layering when placing hydraulic fill in several pour intervals where pooling of decant water may occur, the presence of weak fill layers may also develop that results in poor fill performance adjacent to sill mats. Based upon site observations made, no reported sill mat failures have been noted at any mine sites. However, the additional presence of pooled water (where poor drainage exists) has been seen to cause rockbolt and screen corrosion within sill mat layers that reduces their strength and effectiveness. In several cases where detrimental water effects were noted to develop, weld mesh screen and rockbolt reinforcement layers have been applied in conjunction with thin shotcrete layers below sill mat layers to provide extra reinforcement. Such efforts have been noted to be problematic if shotcrete layers applied are too thin (thus too brittle and subject to flexural failure), or if sill mat fracturing occurs that will permit water flow through the lower reinforcement layer (thus permitting rusting and weakening of screen and bolt reinforcement).

The effective use of sill mats and auxiliary support measures in situations such as these requires that proper fill placement and drainage be maintained to reduce incidents of potential layering and water ponding. Operational changes to sill and reinforcement layer designs can also be implemented to reduce the potential for corrosion weakening of support layers, using techniques such as: placement of grouted rockbolts into wall hitches that will be more resistant to corrosion effects and failure of mat anchorage; use of split set anchors placed into dry, consolidated fill as additional mat anchors; and use of galvanized screen to provide better corrosion resistance.

2.7.2 *Bulkheads*

Bulkhead or barricade designs for paste or hydraulic fill operations are well advanced in the mining industry, where a long history of development and practice has been achieved. The predominant forms of bulkheads used as paste fill retaining structures within excavated stopes comprise: shotcrete sprayed over fabrene-covered, arched steel frames; shotcrete sprayed over weld mesh screen that is tied back using wall and roof bolts; shotcrete sprayed over top of cable lacing that is tied back using similar arrays of rockbolts; and fabrene-wrapped timber frames. Where mesh is used to prepare shotcrete bulkheads, either in linked wire mesh sections or in the form of wire mesh sheets linked with formed gabion baskets, thicknesses of bulkheads are found to range between 20-50 cm.

The inclusion of gabion baskets is used to provide structural strength (beam stiffeners) and set the depth of shotcrete fill in the final bulkhead construction. In many cases, designs for bulkheads are standardized at mines within organizations and, as with arched frame constructions, are manufactured so that rapid installation and size alteration to accommodate various site width, height and other placement geometries can be facilitated using a single modular design.

In normal applications of filling using paste, operators place an initial plug of reinforced material to between 1.5 and 3 meters above the floor of the bulkhead, and then permit the material to cure in place for intervals ranging from as little as 0.5 days to as much as 3 days before commencing bulk pour operations. Other operators place fill to the bulkhead brow.

During such operations, only one operator has reported any incidence of bulkhead failure during a seven year cycle of operation, this being by center span cracking (without rupture) of a shotcrete bulkhead following fill placement at an excessively high rate.

Where hydraulic fill use has been conducted, all bulkhead designs normally consist of weld mesh sheeting plus gabion basket structural support elements, all oversprayed using shotcrete at thicknesses ranging between 20 and 35 cm. Of the shotcrete structures developed, some utilize shaped or arched configurations, while others exhibit flat restraining surfaces that are commonly reinforced using placed 1 meter high waste rock berms at their bases. In all cases, either top drains or top drains plus base-mounted fabrene-wrapped drainage pipe and/or weeping tile are incorporated into bulkheads to accommodate water drainage after hydraulic fill placement and curing.

3 GENERAL PROCEDURES FOR HAZARD PREVENTION

A summary of observations concerning current backfill hazard control measures that are in place at operating mines and recommendations for procedures of best practice that should be implemented to mitigate fill-related hazards in the workplace are presented in the following section:

- Potential blockage of paste and slurry flows can often develop due to creation of vacuum conditions within the pipelines and boreholes when uncontrolled free fall and intermittent flows occur. An effective hazard control that has been implemented by some, but not all, mine operators is the addition of breather pipes at pipe-borehole coupling flanges to prevent vacuum conditions within feed paths into mines.

Where restricted or blocked access flow may result, the ability to deliver backfill in appropriate quantities and in timely fashion may be compromised. Such results are detrimental to the production capacity of mines and may result in worker hazards where frequent pipe changeouts might be required to clear blocked pipelines. The use of multiple boreholes provides underground access from a number of independent feed sources and redundancy in case of borehole plugging.

• At borehole breakouts onto underground delivery levels, special pipe design features must be implemented to prevent hazards associated with high induced pipeline pressures, impact effects from falling fill into empty pipes, vibration and shaking created by material re-direction and other effects. To offset the dynamic shock effects that can occur at such transition points, borehole-to-level pipe connecting elbows should be well reinforced and be of durable construction against wear.

Many backfill operators are trending towards use of robust pipe connection techniques and suspension designs to prevent excessive pipe movement and weakening of these joints. Although costly, the application of "D-flanges" at borehole-to-level connections and in high pressure flow sites would provide stronger section joins, and should be given consideration for safety benefits alone.

• Regular pipeline surveys are strongly recommended as measures to assess locations of potential high stress loading, where pipe or coupling failures would be most likely to occur and where pipe reinforcement would be most needed, and/or leakage. Where possible, all measures that can be utilized for pipeline surveying should have the capacity for real-time monitoring of critical pipeline sections to enable fill plant operators the capacity to detect and immediately respond to failure incidents, should they occur.

Paste fill operators are also recommended to perform regular borehole camera surveys to determine the integrity of borehole walls as well as to assess water inflow conditions existing that might result in segregation of aggregates from paste feed or dilution and alteration in slump character of the paste being delivered.

In hydraulic fill operations, hydraulic fill operations make use of water level or leak probe sensors along fill distribution lines to monitor for the presence of water (as indicators of pipe leakage) at specific sump collection points. This monitoring precaution is also strongly recommended.

• At sites where multiple delivery paths may exist, operations may be complex and potentially hazardous when workers are required to manually handle and change multiple delivery pipelines in tight quarters, in overhead reach situations where inadequate hoisting equipment may be available, and in sites where limited access room may be available. These operations can create potential worker lifting and fall hazards.

To mitigate such hazards, alteration of pipe changeout and re-direction operations should be considered. Some operators currently make use of flexible rubber pipe at re-direction sites to make handling of pipes easier. Additionally, adoption of manual and remotely-operated hydraulic or pneumatic gate valve assemblies to automatically permit switching between fill delivery lines should also be contemplated to enhance worker safety during dangerous line switching operations, to permit more rapid switching and to provide real time monitoring and control capacity.

• Where localized high or variable pressure conditions develop, there may exist potential for pipeline rupture, valve failures and other potential hazard occurrences. It is recommended that installation of remote monitoring equipment to assess pipeline pressure conditions be considered as a primary means of limiting high pressure build-up within distribution lines.

• In over half of surveyed fill sites, wear measurement and inspections are not conducted, and replacement of pipe materials is only conducted according to either planned schedules (by time or quantity of backfill delivered) or as pipeline failures are reported.

In operations where both paste and hydraulic fill materials are distributed, both visual and instrumented (ultrasonic thickness monitoring) surveys of pipe thickness conditions are regularly utilized by half of operations to monitor the thickness conditions of pipe sections as indicators of pipe wear and potential for failure. Such surveys should be universally adopted to effect proactive, rather than reactive, planning for pipeline replacement and hazard mitigation.

• The use of single pour points is acceptable when filling operations make use of hydraulic fill media due to the fluid nature and long runoff character of the slurry product placed. The use of single pour point placement for paste fill products that may exhibit low slump character may, however, be problematic. The inability of such paste products to flow easily and fill existing stope voids may result in loose surface contact and creation of excessive stope voids behind bulkheads. This lack of paste flow capability may also result in cases where feed proportion alteration by operators, through the addition of water to “enhance” or increase the paste slump, is condoned as a method to permit paste fill to better flow into and through stope voids to be filled. This results in decreased solids content of paste fill and potential transition of material from paste to high density slurry form. Such physical changes may detrimentally impact pipeline delivery operations and the quality of backfill to be placed in stopes. In order to utilize paste backfill for its designed purposes, the flow character should never be arbitrarily altered to accommodate operational factors. It is therefore recommended, that, where feasible, multiple pour points be established in each paste fill stope to maximize distribution and minimize creation of “dead” zones of filling.

- In all stope filling operations surveyed, backfill is placed in multiple lifts, with the initial lift consisting of a high binder strength fill plug immediately behind a reinforced bulkhead or barricade system. Following a period of cure (and drainage in the case of hydraulic fill pours) bulk material pours are made to fill the remaining stope voids immediately above the bulkhead horizons.

The ability to control fill delivery quantities and heights, and thus fill stability conditions at pour sites, must be well monitored to provide continuous indication of bulkhead pressure conditions and warning of impending danger due to improper fill material placement or overloading of bulkhead structures. The advantage of remote monitoring procedures is recommended, as they do not require manual (and potentially infrequent) reading effort, and can provide real-time indication of potential site instability conditions.

- The effective use of sill mats and auxiliary support measures requires that proper fill placement and drainage be maintained to reduce incidents of potential layering and water ponding. If water is a concern, operational changes to sill and reinforcement layer designs should be implemented to reduce the potential for corrosion weakening of support layers.
- The predominant forms of bulkheads used as paste fill retaining structures are standardized at mines within single, large organizations. The majority of operations surveyed place an initial plug of reinforced backfill and then permit the material to cure in place before commencing bulk pour operations.

No significant concerns regarding problematic bulkhead designs were evident based upon the survey of mines conducted, though recent international research has provided indication that bulkhead failures, for both paste and hydraulic fill operations, have and continue to develop to pose considerable risk to workers and the continuity of underground mining operations,

4 CONCLUSIOSN

A study of backfill practices in underground mines has been conducted to assess the current state of backfill usage and to overview potential hazards associated with backfill practice, from preparation to transportation to placement. This paper (Part II) deals with underground operations consisting of backfill transportation and backfill placement. A review of safety measures associated with current backfill operations and recommendations for procedures of best practice that should be implemented to reduce fill-related hazards in all mine backfill workplace environments have been presented. In general it has been found that, by adopting appropriate management practices, system failures normally lead only to minor losses to the operations.

REFERENCES

De Souza, E., Archibald, J.F. & Dirige, A.P. 2004. Underground Backfill Practices in Canadian Mines. Gulf Rocks 2004 Proceedings, 6th North American Rock Mechanics Symposium. Houston:ARMA. 485-502.

De Souza, E., Archibald, J.F. & Dirige, A.P.E. 2003. Economics and Perspectives of Underground Backfill Practices in Canadian Mining. Proceedings of the 105th Annual General Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum. Montreal:CIM.15.

Dirige, P. A. & De Souza, E. 2007. Engineering Design of Backfill Systems in Undercut Mining. Proceedings of the 9th International Symposium in Mining with Backfill (Minefill 2007). Montreal.