Compilation of industry practices for control of hazards associated with backfill in underground mines - Part I surface and plant operations

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ABSTRACT: The authors 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 I of the study, deals with surface operations consisting of backfill material supply and backfill plant preparation. Part II of the study, which deals with underground operations consisting of backfill transportation and backfill placement, 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.

A distribution of the types of backfill system failure, previously identified by the authors (De Souza, E., Archibald, J.F. and Dirige, A.P. 2003, 2004), is shown in Figure 1. Pipeline and borehole plugging events were the primary failure types followed by exposed fill sloughing and pipeline bursting. Other primary types of failures were found to be associated with events including pipe hammering, bulkhead failure and fill segregation. Such failures have been associated with a multitude of causes including operator error, poor drainage, inadequate bulkhead construction, poor quality control (low cement content or high variability in moisture), inadequate flushing practices, system wear (pipeline and pump), and indirect causes (excessive blast vibrations, stope wall failure, etc.). System failures normally lead only to minor operational losses.

Based on this study, the authors are of the opinion that there is much about backfill technology, specifically, that is not known; a number of improvements in current backfill operations, including production, transportation and placement, are still required to establish safer, more efficient and less costly fill practices. The areas that have been identified through the course of this study indicate that considerable research and industry education remains to be undertaken. Significant change is, however, noted to be underway, particularly in the areas of total tailings and paste backfill development and use.

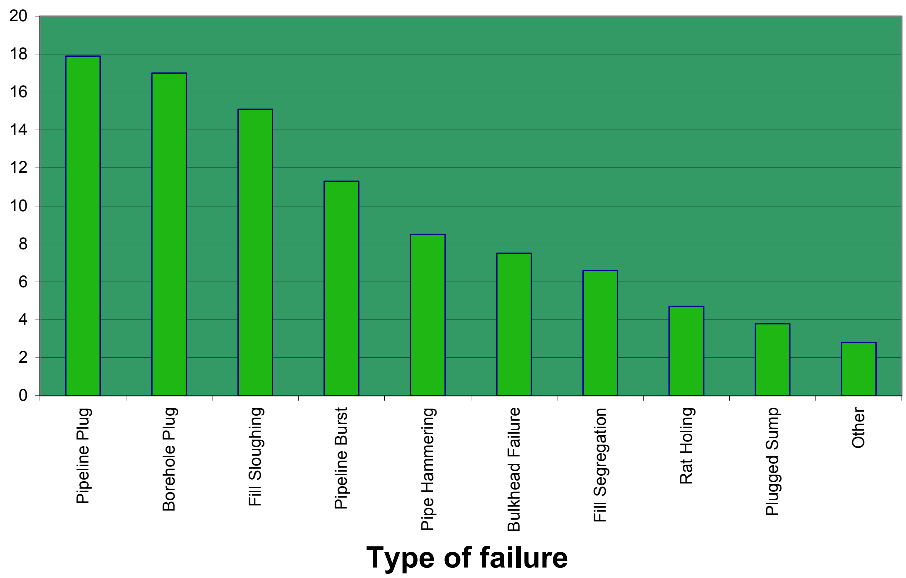

Figure 1. Backfill system failures.

2 BACKFILL PLANTS

2.1 *Plant Layouts*

A flow sheet of a typical backfill plant is shown in Figure 2. Tailing feed to the backfill plants can come directly from the mill or from the tailings pond. When reclaimed tailings from stockpiles are utilized, ore trucks haul tailings to the fill plant site where material is stored in large capacity stockpiles and allowed to drain excess water before use. The tailings feed is conveyed from storage and mixed with hot water in tanks to prepare a slurry and to avoid formation of sludge or clumped tails in the mix. In some cases screening of the tailings feed is required to remove rocks and oversize products (such as ice lenses formed during winter storage) prior to dewatering. Secondary supply via a conveyor system may exist to deliver tailings to the fill plant for cases when tailings filter cake is unavailable or when extra tailings are needed to yield higher production.

In typical plant circuits, tailings slurry from the mill is pumped to a stock tank and to a cyclone bank. Cyclones are used, when required, to remove some of the fines from the tailings product.

The tailings slurry is routed to a thickener, to produce an underflow of typically 50% to 60% solids. Flocculants may be added for paste backfill manufacture. Flocculants may also be added to minimize the presence of fines in the manufacture of hydraulic backfill. The overflow product from the thickener is sent to the surface tailings pond, and the underflow is agitated within a tank before feeding it to the filter line.

In some cases two storage tanks are used with one tank being used for slurry manufacture and the second being used for tailings storage, with the tailings product being continuously stirred using air and water agitators.

The slurry is dewatered by vacuum filtration through a series of disk filters. Typical vacuum filters are able to produce 200-250 tonnes/hour paste feed. Tailings filter cake from the disk filters is conveyed into a mix hopper. At the mix hopper water is added back to the cake to produce fill of the desired consistency. For paste fill, water additions are made to control paste slump character. In some cases, a second side-feeding hopper that stores dry tailings is used to alter mix density.

Type 10 Normal Portland Cement, and sometimes flyash or slag, are added as binder. Binders are normally stored on surface in vertical silos of differing capacities (typically between 80-300 tonnes). Normally, binders are transported by truck to site, then are pneumatically fed into the storage silos. Cement binder can also be stored in horizontal “pig” transport containers, used for cement delivery, as well as to provide excess storage capacity. Binder materials are conveyed or fed by air slide feeders into the mix hopper.

Sand may also be added in some recipes. When used, sand is transported by conveyor into storage bins within the fill plant. All backfill ingredients are fed by screw conveyors onto belt conveyors that proportion the materials and transport them to a batch mixer. They are then mixed in mix hoppers or screw mixers to form the fill. The conveyors are equipped with weightometer scales to permit controlled proportioning of the backfill ingredients.

The final product is then pumped underground through boreholes. For paste fills, piston pumps are employed to move the backfill from the plant to the borehole site. The piston pumps typically deliver the backfill material into a single delivery pipeline from the plant that can feed to two or more boreholes (the others being kept as spares in case of primary borehole blockage). Gravity feed is also employed in some plants for fill delivery to boreholes.

At the end of a pour, excess tailings that are not needed for backfill manufacture are normally sent to the surface tailings management facility.

Some plants are very versatile in operation and can be used to manufacture paste or hydraulic backfill. Modern fill plants are fully automated for batch mixing of dry tails, sands, binders and water.

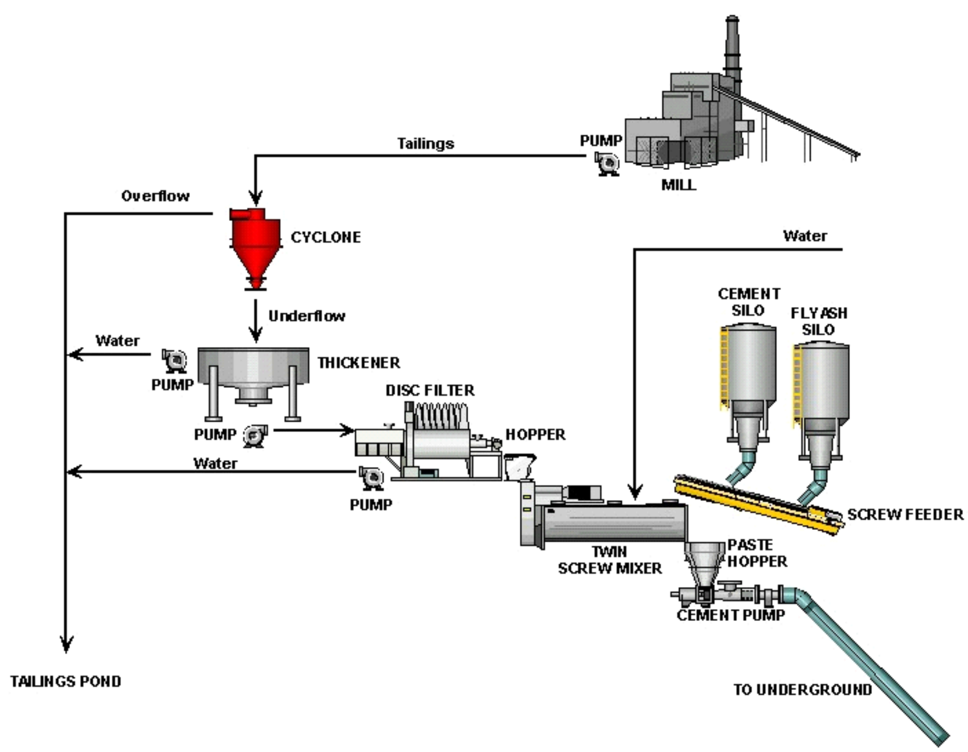

Figure 2. Typical paste backfill plant layout.

2.2 *Plant Operation*

Backfill systems are typically designed to produce and deliver between 60 and 200 wet tonnes/hour of backfill though larger plants can manufacture fill at rates of 500 tonnes per hour. Most plants are automated and require minimum supervision (1 to 6 operators). The backfill pours can be made in batches or can be continuous. Some fill plants operate 7 days per week and 24 hours per day while other plants operate on an 'as required' basis. Typical rates of back-fill pouring range between 600 tonnes/day to 2,500 tonnes/day, depending on the plant capacity and stope size. Typical backfill recipes that are reported by mines surveyed are listed in the following:

- Feed makes use of tailings with controlled size distribution depending on the type of backfill utilized. For paste fill, tailings with 20% finer than 20 μm is normally produced.
- Pastefill pulp density - 82-85%.
- Pastefill solids content - 74%-77%.
- Pastefill slump - 5 inch (12.7 cm) - 6.25 inch (16 cm) - 11.5" (29.2 cm).
- High density backfill total solids by weight - 74%.
- Hydraulic fill solids content - 65-68wt%
- Hydraulic fill density - 60% (minimum allowed, below which pouring is stopped)
- Binder addition typically ranges between 0.5% to 12% by dry weigh solids depending on the application. For example, working floors utilize fill at 8-12% binder content; a 5-9% binder content is normally used as plug pour material against fill barricade fences; and a 1-3% binder content is normally used in bulk pours.
- Cement / slag / flyash ratios are variable depending on the required strength.
- Common fill strength strengths reported are:
  2.5% binder fill rated at 0.3 MPa;
  3% fill rated at 0.4 MPa;
  5% fill rated at 0.8 MPa; and
  10% capping fill rated at 1.4 MPa.

All strengths are dependent on cure time. Sillmats made using backfill with 6-8% binder content have rated strengths at 1.5 $\pm$ 0.5 MPa, after a minimum 28 days cure.

2.3 *Plant quality control*

In typical plants, fill letters are recommended to accompany all fill operations to specify types and quantities of fill to be used within specific stopes, as well as to specify quality control testing necessary (slump, UCS or other characteristics) and process safety limits (such as maximum permissible borehole or pipeline pressure conditions that may be tolerated during a typical pour). Fill letters are normally completed prior to fill use and are circulated to delivery and level crews as an initial method of communicating timing and procedures for filling. This insures that a record of recommended safe practice is maintained during all fill pour operations.

In several plants backfill is sampled at the surface fill plant and the fill unconfined strength (UCS) is tested 28 days after manufacture. Of the seven paste fill plants reviewed during the course of this study, approximately 60% perform scheduled and planned UCS tests. Of the four hydraulic slurry fill plants reviewed, only one (25% of total) has reported performance of planned UCS tests on their placed fill product. Paste fill plant quality control is more often maintained by slump testing of paste product that is retrieved at the exit from the mix tank or at the piston pump. Sampling is normally taken every 2 to 3 hours. In some cases, samples for UCS determination are taken and cast every 30 minutes during pour operations or are taken at the rate of one sample per 100 tonnes of fill produced. Most mines do not perform underground sample recovery for strength testing, though some mines occasionally sample at the end of the filling pipeline in stope access. Backfill density measurements of paste fill materials are performed in some plants. Conversely, at mines where hydraulic slurry fill is utilized, all plant operations perform regular slurry density analyses as a primary measure of product quality and consistency.

In some plants quality control is performed by comparing measured slump and paste moisture content versus pump power consumption conditions. In such cases, pump power measurements can be used to adjust for proper slump/moisture content/solids content in real time.

Some plants have dedicated laboratories to perform slump and UCS testing using systematic, well-controlled test procedures. UCS testing requires storage of samples at controlled temperatures (22-24°C) under high relative humidity curing conditions. Cast cylinder samples (nominally sized at 7.5 cm (3") diameter by 15 cm (6") long), are cured for 7, 14, 28 and 56 day intervals, and are tested using multiple samples per event (minimum 3 duplicate tests). Slump tests are performed on backfill samples that are recovered every 2-4 hours during pouring cycles.

In order to minimize variability in fill quality, surface preparation and underground filling operations in some mines are conducted using the same trained crews in the various operations (no separate shift crews).

Constant communication is maintained between the stope placement site and the surface preparation/pour site through dedicated telephone or radio communication systems. Radio, leaky feeder or telephone communication must be established between surface manufacture and underground placement sites before delivery is allowed to commence.

The mill supervisor and fill plant operator should share responsibilities for fill system safety, and both must be closely associated with underground coordinators and operators. Planning of procedures must be done in consultation with underground operators to eliminate any potential conflicts during operation.

When trucks are used to deliver fill, communications between the dump trucks and underground pour sites must also be established by telephone before truck dumping is permitted to occur.

Delivery lines are flushed both before and after any backfill delivery, using specified flush volumes (i.e 2000 liter volumes or timed flows) to clear lines of potential residues and blockages. On horizontal pipe paths, a double flush is performed to minimize blockage and to insure that clean water (unobstructed flow) conditions are achieved. At one mine site, the start of pouring begins with a water flush (typically of 20 minutes duration) until clean water flow is observed, followed by a compressed air flush. The operator must see vapour or liquid flow, and hear air to establish that no blockage exists. At another site, all lines are flushed with high pressure air (700 kPa (100 psi)) from a dedicated air compressor in the fill plant, followed by a water flush. When finished backfilling, water (4-16 m^3) and compressed air (at 100 psi) flushing are again conducted. Typically, a 5 minute water flush followed by a 5 minute compressed air flush are conducted. Both water and air flushing of pipelines at surface plants are normally manually activated.

Flush water is recommended to be diverted away from stope sites where backfill is to be placed to minimize its inclusion with the placed paste fill (to prevent weakening the fill).

In some operations paste backfill is used for stope bulk pour operations, followed by capping pours of hydraulic fill. Between bulk and capping pours, no flushing occurs.

Some operations reclaim mine tailings from surface stockpiles to produce feed for backfill manufacturing and to produce inventory for winter use. In more elaborate operations tailings and sands are stored under cover within insulated, heated domes to prevent winter freezing and to ease reclaim operations.

The tailings feed may have variable quality in terms of size distribution, thus compromising backfill quality. In such cases, the material must be blended on site and pre-mixed to achieve consistent size distribution character prior to plant manufacture and mixing of fill materials with binder.

In some cases mined tailings material is not stockpiled on site prior to use, and is only used as-recovered from surface tailings impound sites for batch manufacture. Lack of stockpiling provides little excess manufacturing capacity, if required. Also, tailings recovered from surface storage areas may sometimes include frozen water lenses, oversize "chunk" material and possibly organic matter that can prevent good blending of backfill feed.

In some plants process water for batch mixing requires heating to prevent freeze-up and batch sticking.

Sensing systems to remotely measure whether flow exists, leakage is occurring or blockages have developed are used in plant operations. Pipeline pressure meters within the surface plant can be used to provide indication of flow conditions at the plant. At the borehole distribution point, video feed can be established to verify proper operation. Video feed at the site of underground paste placement is also provided to the plant operator, and is continuously monitored during pouring, to insure that continuous pour flow is occurring.

Some plants have video feed from various operational sites to monitor and control all operations. Video monitoring systems within the surface fill plant and underground are used for monitoring of the plant operations and to indicate any flow spillages or leakage at the critical and most vulnerable points of the pipeline system. Video monitoring at stope pour points is vital for observation of pour conditions and for control at the plant. In some processes, if no video feed is available, no fill placement is allowed to occur unless underground operators are present and in full communication (by radio or telephone) with the plant.

Mill process controllers, in conjunction with underground flow sensors, are commonly used to monitor both mass and volume flow as well as slurry density of material that is sent underground.

Typical plant monitoring systems operate 24 hours/day and records of performance are kept (for up to 1 year) to permit quality control and performance checks of daily operations.

All safety and operating procedures should be well documented. The mine should have in place 'Work Instructions' of backfill practice. The documents should include such topics as 1) Starting a Pour; 2) Response to Fire; 3) Response to Loss of Water Supply; 4) Regular Shutdown Procedure; 5) Unload Binder Procedure; 6) Response to Closing Hole While Batching; 7) Installation of Bulkheads, and others.

Some plants have scheduled maintenance shutdown to permit repairs to system and to minimize downtime.

2.4 *Potential hazards and prevention management*

This section summarizes potential hazards that were assessed during the investigation and site visits to fill plants, and control solutions that have been employed at the various operations. Most plants were found to be relatively safe in operation. Typical plants are automated and require very little operator intervention.

Case 1 - Potential Hazard: Sand conveyor from stockpile to mixing tank suffers from (a) freezing of sand and sticking of agglomerated product to conveyor and (b) rollback of sand, either in granular or agglomerated state, on conveyor rise side. This may result in loss of sand content to mixer, thus generating improper proportioning of backfill aggregates. Control Solutions: Flow process operations taking place in mill, and paste fill manufacturing operation conditions, are displayed at each separate preparation facility to insure that paste operators are knowledgeable about tailings source operations and mill operators are knowledgeable about paste plant operations. Re-design of conveyor profiles and emplacement of conveyors within heated structures and/or storage of sand aggregate within heated structures is recommended.

Case 2 - Potential Hazard: When reclaimed tailings is used, the tailings stockpile may consist of material with relatively high moisture content (10-20%) and variable size distribution character due to recovery from different sections of the tailings facility. Excess moisture under cold winter storage conditions may generate frozen lumps or clumping, thus creating difficult conveyor transport conditions, and poor mixing conditions in plant. Variable size distribution character can result in a poorly blended backfill product. Control Solutions: High water content reclaimed tailings should be stored in insulated, heated dome structures during winter to minimize freezing. The material could be automatically blended within the storage facility to maintain a feed of uniform size characteristics. When preparing the batch tailings mix, hot, rather than cold, water should be used to insure that clumping and chemical sludge formation does not occur.

Case 3 - Potential Hazard: When alluvial sand is used in backfill preparation, variable quality of sand is recovered on a daily basis. Consistency of sand may vary considerably, resulting in frozen product in winter, inclusion of clay content that alters flowability, and variable sand aggregate size that, even with screening, can include frozen lumps that hinder proper fill preparation. Control Solution: Product quality control required, as suggested for Case 2 above.

Case 4 - Potential Hazard: When reclaimed tailings from stockpiles are utilized and screening of the tailings feed is required, polyurethane screen wear is common. Because of screen wear, large rock pieces enter the mixing system and may cause severe pump damage. Control Solution: Establish a frequent inspection and maintenance program. Some plants dedicate one day per week for maintenance. Conduct product changeover as required. Replace with classification technology or screen materials that are less prone to significant wear and breakdown.

Case 5 - Potential Hazard: When conveyor belts are used in a sandwich system format, they constantly rip and need repair. Control Solution: Replace with technology that is less prone to significant wear and breakdown.

Case 6 - Potential Hazard: Failing pump seals in plant. Control Solution: Establish regular pump maintenance program.

Case 7 - Potential Hazard: Blockage of vertical borehole due to freezing. Control Solution: Insulate pipeline leading from plant to borehole. Install heated housing at pipeline elbow connection to borehole. To guarantee uninterrupted plant operation, backup feed could be made possible using other holes in a satellite network of boreholes.

Case 8 - Potential Hazard: When borehole plugging occurs, the plant is unable to continue feeding paste tailings to underground stopes, compromising production targets. Control Solution: The fill plant should operate multiple feed boreholes underground, so that one will always be operational if others become plugged.

Case 9 - Potential Hazard: Vacuum effect and flow retardation developing within the borehole due to falling paste material. Control Solution: At union between surface delivery pipeline and underground boreholes, vent piping should be installed to minimize vacuum effects and flow retardation.

Case 10 - Potential Hazard: Due to a lack of adequate quality control measures in place, differences in backfill mix content (fines etc.) and backfill of variable quality may cause significant change in placement properties and may compromise stability during mining. Control Solution: Regular sampling for quality control testing (slump, strength) should be done during pouring at the surface preparation plant and at the underground pipeline pour point. Underground sampling and in-situ testing are essential to verify whether designed and delivered material properties are similar. Where possible, in-situ monitoring of backfill physical properties (cured porosity, density etc.) should be attempted.

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 as follows:

- When reclaimed tailings from stockpiles are utilized, ore trucks haul tailings to the fill plant site where material is often stored in large capacity stockpiles that may be exposed to various climatic effects before use. The tailings feed is conveyed from above ground storage sites and mixed with hot water in tanks to prepare a slurry and to avoid formation of sludge or clumped tails in the mix. In some cases screening of the tailings feed is required to remove rocks and oversize products (such as ice lenses formed during winter storage) prior to dewatering.

It is common when reclaiming from tailings stockpiles that do not host well-blended tailings that significant size segregated feed products can be reclaimed for backfill use. Additionally, winter freeze conditions often generate ice lens materials that can clog or otherwise hinder the feed processes at a mill. At least one operation studied, tailings and sand aggregates are separately stored within covered and heated structures (at least in winter intervals) to minimize detrimental effects on tailings/sand reclaim and processing within the mill that may be caused by frozen feed materials. Where feasible, such storage procedures should be implemented to minimize inventory reclaim problems, lack of plant feed and surging of feed conditions.

- In typical plants, fill letters should accompany all fill operations to specify types and quantities of fill to be used in specific pour operations, as well as to specify quality control testing necessary (slump, UCS) and process safety limits that must be adhered to in order to minimize risk to workers and infrastructure underground and in plants (for example, maximum permissible borehole or pipeline pressure conditions that may be tolerated during a typical pour). Fill letters must be completed and circulated prior to fill pouring as a primary method of communicating timing and procedures for filling. This insures that a record of recommended safe practice is maintained during all fill pour operations.

- Scheduled and planned UCS testing for backfill characterization and quality control assurance is strongly recommended. The majority of fill producers perform such characterization using plant output product only, while only few report performance of planned UCS tests on their placed fill product. It is questionable whether the backfill design character can be maintained through the process of transport and placement within stopes, especially where unanticipated water inflows into boreholes or excessive flow shearing may induce significant change to the fill properties desired. The process of fill manufacture within plants can be carefully controlled, and the ease of sample procurement on surface prior to borehole delivery can insure that adequate quantities of samples for test can be obtained. However, as soon as the fill product enters the underground delivery system, no means to insure that product quality can be maintained exists. It is therefore prudent to attempt to assess placed fill quality, in addition to plant product quality, as an additional measure for quality control. Paste fill plant quality control is most often maintained by slump testing of paste product, thus this process should also be maintained at the placement end to insure that the placed fill retains its desired consistency. On the basis of the site surveys conducted, it is evident that some operations have dedicated laboratories within fill plants that are used to perform systematic slump and UCS testing using regulated and controlled test procedures. Commonly, sampling is performed on a batch-by-batch or timed basis as backfill is produced. Such practice must be rigidly enforced to permit assessment of quality variations in fill materials that are produced. In order to minimize variability in fill quality, surface preparation and testing, as well as similar underground sampling and testing, should always be conducted using dedicated and well-trained trained personnel.
- The mill supervisor, fill plant operator and underground backfill supervisor should share responsibilities for fill system safety, and there should always exist close association and communication between surface and underground coordinators and operators while fill pouring operations are underway. Planning of procedures must be done in consultation with surface and underground operators to eliminate any potential conflicts during operation. Constant communication must be maintained between critical underground delivery sites (such as at borehole-to-level transition and stope placement sites) and the surface preparation plant through dedicated telephone or radio communication systems or some form of video monitoring that will always be operational and manned by the plant operator. All forms of communication and monitoring must be fully established and operating before backfill delivery can be allowed to take place. Based on survey evidence from this study, 100% of operations maintain constant verbal communication between plant and underground fill site (as well as points between) during fill pouring operations in order to initiate, stop and monitor flow operations in real time. The implementation of video camera monitoring is, however, not universal, but is recommended for adoption to provide real-time video monitoring and hazard control capabilities for operators.
- All borehole and level delivery pipelines must be flushed both before and after any backfill delivery, using specified timed or volumes of water or slick (dilute fill) pours to clear lines of potential backfill residues and blockages. Where feasible, water flushes should be followed by a compressed air flush to remove excess water from the pipeline system in order to minimize fill dilution problems. The underground operator, or plant monitor, must see vapour or liquid flow from the delivery pipeline to establish that no blockage exists. All flush water that is used should, if possible, be diverted away from stopes where backfill is to be placed to minimize its inclusion with the placed paste fill.
- Remote sensing systems that can be used to remotely measure whether flow exists, leakage is occurring or blockages have developed can include pipeline pressure meters, video monitoring systems (within the surface fill plant and underground), and ultrasonic flow sensors. Typical plant monitoring systems can operate 24 hours/day and records of performance can be kept for extended intervals to permit quality control and performance checks of daily operations. At underground sites studied, such instrumentation is either manually or remotely read. It is recommended that all instrumentation be designed for remote sensing and observation by

the fill plant operator to minimize hazards that may arise from site occurrences that are not manned and therefore not under constant and real time surveillance.

- All safety and operating procedures should be well documented. The mine should have in place working instructions for backfill practice. At a minimum, "Fill Letters" should provide basic rules of operating practice to be maintained while pouring of fill is taking place. Additionally, other documentation must be developed and in place to cover all operating contingencies in cases of system malfunction, and should specify best design practices for all activities relating to backfilling operations on surface and underground. These documents should, at a minimum, reference topics such as: -Starting a Pour; -Response to Fire; -Response to Loss of Water Supply; -Regular Shutdown Procedure; -Unload Binder Procedure; -Response to Closing Hole While Batching; -Design for Bulkhead Retaining Systems; -Installation Procedures for Bulkheads; -Rates of Backfill Placement, Heights of Filling and Curing Intervals Between Pours.

4 CONCLUSIONS

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 I) deals with surface operations consisting of backfill material supply and backfill plant preparation. 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.

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