Monitoring the In Situ Performance of Cemented Paste Backfill at the Lucky Friday Mine

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ABSTRACT

In cooperation with the Hecla Mining Company, NIOSH researchers have developed effective methods for monitoring the in situ performance of cemented paste backfill during underhand cut-and-fill mining more than 1,950 m (6,400 ft) beneath the ground surface. Robust and reliable instruments were installed at eight locations in two production stopes prior to backfilling, and monitored over a two-year period through five undercut advances. Horizontal pressures up to 5.50 MPa (798 psi) were measured in the paste fill along with 51 cm (20 in) of stope closure. From the instrument data, the in situ stress versus strain behavior of the paste fill was analyzed, providing an average in situ modulus of deformation of about 3.62 GPa (525 ksi) for the backfill during initial undercut mining. The initial elastic response of the paste fill was typically followed by strain softening and plastic deformation with additional closure. The onset of strain hardening behavior in the paste fill was measured during mining of a fifth undercut advance. The instruments are currently being monitored every two hours by data acquisition systems that are linked through the mine's communications systems to a corporate web site—thus providing the mine staff and NIOSH researchers with reliable, timely information about the backfill's behavior and stability.

INTRODUCTION

Ground falls are typically the leading cause of fatalities in underground metal mines and an important source of lost time injuries (Seymour et al. 2013). Because ground control is a critical concern in underground metal mines, a comprehensive ground support plan needs to be developed and consistently implemented to minimize ground fall accidents at these mines. One of the methods that is effectively used to provide both local and regional ground support is to backfill underground openings with a cemented waste product, usually either mill tailings (paste fill) or waste rock (CRF). In the Coeur d'Alene mining district of northern Idaho, cut-and-fill mining methods have historically been used to mine narrow, steeply dipping veins of Ag-Pb-Zn ore (Blake and Hedley 2003; Williams et al. 2007). At the Lucky Friday Mine, the use of cemented paste backfill in conjunction with mechanized underhand cut-and-fill mining methods has reduced the number of injuries and fatalities caused by mining in deep, high-stress, rockburst-prone ground conditions, thereby greatly improving the safety of underground miners (Peppin et al. 2001; Pakalnis et al. 2005). The cemented paste fill essentially forms a massive engineered beam that provides a safe, stable back for the miners who work beneath it on the next undercut.

Although the use of backfill has a sound safety record, implementation of a backfilling program is not without risk and requires technical oversight. While backfill ground falls do not occur frequently, these accidents typically result in a higher proportion of fatalities and lost time injuries than ground falls caused by a failure of the host rock (Seymour et al. 2013). Backfill ground fall accidents are especially hazardous in underhand cut-and-fill mining operations where employees work directly beneath the cemented backfill. Most of these backfill failures are attributed to inadequate backfill strength, insufficient or inconsistent quality control measures, or larger than expected mining spans (Seymour et al. 2013). Although cemented paste backfill is an engineered material, the in situ performance of the fill should be monitored to ensure that it is performing adequately and to assess the need for future operational changes. However, implementing an effective instrumentation program can be challenging because the installed instruments must be able to withstand submersion in the cemented paste fill during the pouring process and also deformation and crushing of the backfill as it is loaded during subsequent undercut mining. In cooperation with the Hecla Mining Company at the Lucky Friday Mine, researchers from the Spokane Mining Research Division (SMRD) of the National Institute for Occupational Safety and Health (NIOSH) are developing effective methods for monitoring the in situ ground support performance of cemented paste backfill on NIOSH's Ground Control Safety for Deep Vein Mines project. This paper provides an overview of this on-going backfill monitoring program and presents some of the current findings.

UNDERHAND CUT-AND-FILL MINING

The Lucky Friday Mine is located approximately 1.6 km (1 mile) east of Mullan, ID (Figure 1a) and has been owned and operated by the Hecla Mining Company since 1958. Historically, the principal ore-bearing structure at the mine was the Lucky Friday vein, but production began in 1997 from several mineralized veins in the Gold Hunter property located about 1.5 km (5,000 ft) to the northwest of the original Lucky Friday workings. The upper Gold Hunter deposit is hosted in the Wallace formation of the pre-Cambrian Belt Series and transitions into the St. Regis formation below the 5900 level at a depth of about 2,073 m (6,800 ft). The lithology of the Wallace formation consists of thinly-bedded argillite, argillite alternating with silt caps, and local siltite. The argillites of the transitional St. Regis formation below the 5900 level have increasing silt and quartzite content relative to those above this level. The Gold Hunter deposit lies between two west-northwest trending district faults, which are separated horizontally by about 457 m (1,500 ft), and consists of a system of several definable veins striking west-northwest and dipping 80 to 90° south. Most of the production is from the 30 vein—a composite of closely spaced veins and veinlets averaging more than 1.2 m (4 ft) in width. Development workings and the current extent of mining in the 30 vein are shown in Figure 1b.

In the Gold Hunter deposit, a series of slot drifts are driven perpendicular to the ore body from access ramps on the north or footwall side of the vein (Figure 2a). An undercut stope is mined horizontally in the vein for a distance of about 122 to 152 m (400 to 500 ft) on either side of the slot drift. Five successive underhand cut-and-fill stopes are usually mined in the vein from each slot drift as illustrated in Figure 2a. After an undercut stope is excavated, a layer of broken rock or "prep muck" is placed at a thickness of about 30 to 46 cm (12 to 18 in) on the floor of the stope. To reinforce the paste backfill, No. 7 Dywidag bolts, 1.8 m (6 ft) in length, are driven vertically into the loose muck on roughly a

1.2-m by 1.2-m (4-ft by 4-ft) square pattern. The bolts are fitted with steel plates and nuts and wired together as shown in Figure 2b.

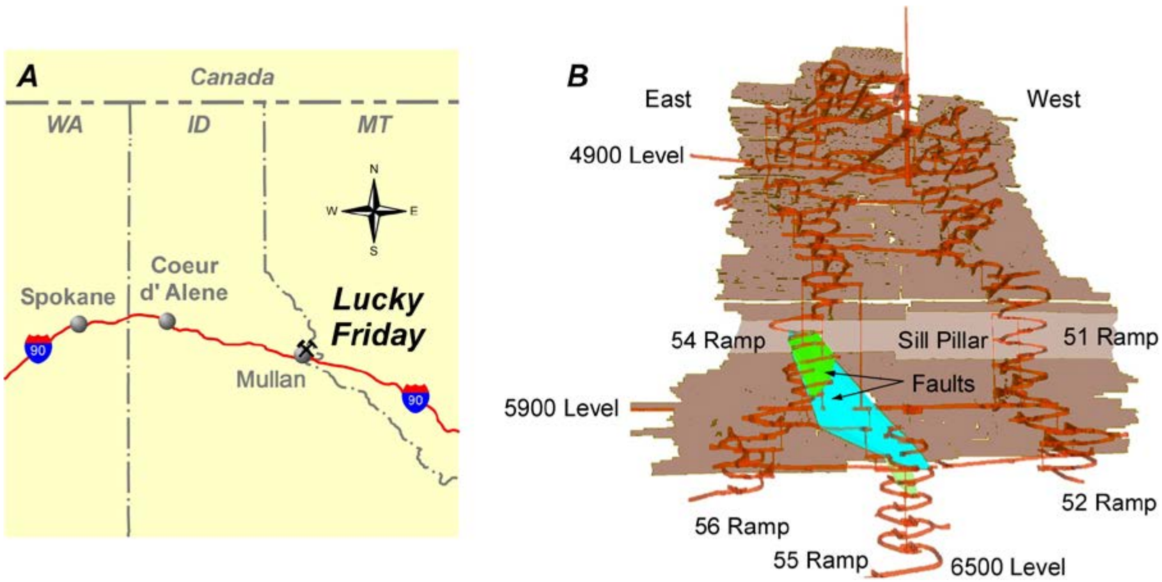

Figure 1. Lucky Friday Mine: (a) location and (b) schematic of development workings (red), backfilled stopes (brown), and faults (blue and green) in the Gold Hunter deposit

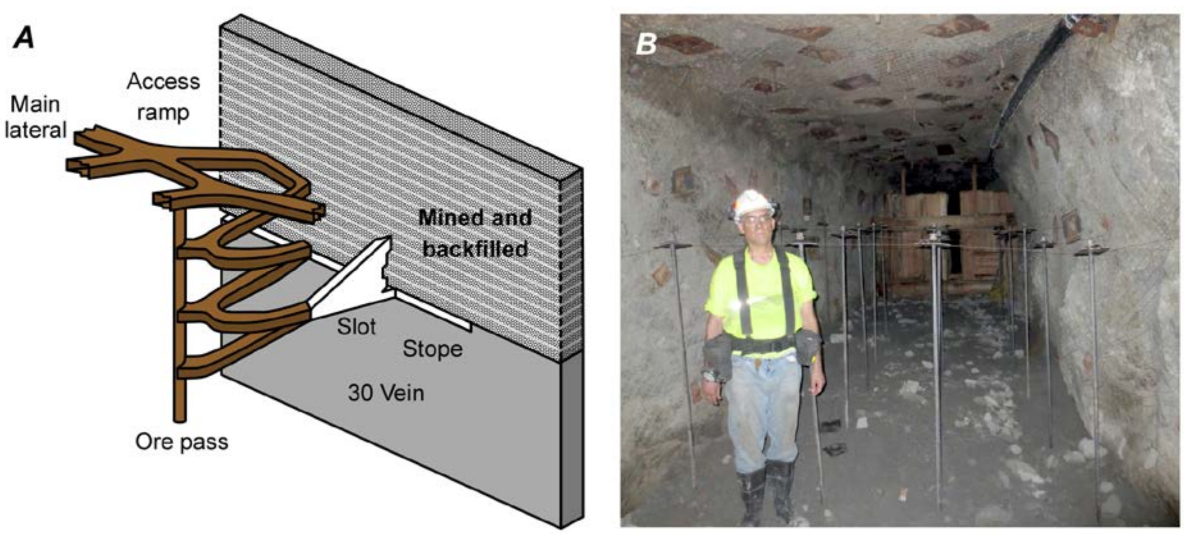

Figure 2. Underhand cut-and-fill mining method: (a) conceptual diagram of the mining configuration for the 30 vein, and (b) preparing 5550L-11E undercut stope for backfilling

Classified mill tailings are mixed with 11% binder (25% cement and 75% finely ground, granulated blast furnace slag) at a surface batch plant and delivered in a paste-like consistency to the stope via an underground pipeline distribution system. To contain the paste backfill during placement, a wooden fill fence is constructed across the width of the stope, which limits the lateral extent of the backfill pour to about 46 m (150 ft) and restricts the depth of the pour to about 70 to 90% of the stope height. This backfilling process creates a reinforced backfill beam, having a thickness of about 2.4 to 3 m (8 to 10 ft), and intentionally produces a void or gap, approximately 0.3 to 1 m (1 to 3 ft) in height, between the upper surface of the backfill pour and the bottom surface of the previously filled cut (Figure 3).

Figure 3. Gap between consecutive backfill levels: (a) 1-m (3-ft) gap above the 5550L-11E stope and (b) 0.3-m (1-ft) gap above the 6350L-15W stope

After the east and west stopes on either side of the slot drift have been backfilled, the cemented paste fill is allowed to cure and gain sufficient strength. A subsequent undercut stope is then mined in the vein beneath the newly formed backfill beam. Loose muck that was placed on the floor of the previous cut protects the cured fill during blasting and falls away from the underside of the backfill as the heading is advanced. To reinforce the bottom surface of the exposed backfill, chain-link mesh is installed overhead using the exposed Dywidag bolts and additional friction bolts as needed. Further rock bolts and mesh are installed to support the stope walls. The cemented paste fill, bolts, and mesh thus form a stable reinforced back under which mine personnel can safely work.

As the backfilled stope is undercut, the stope walls begin to converge in response to the high horizontal ground stresses and compress the cemented paste fill. This horizontal loading causes the backfill to initially fail in tension near the midspan of the stope (Williams et al. 2001). While the reinforcement and chain-link mesh maintain the stability of the underside of the backfill where personnel are working, the upper surface of the paste fill is unconfined and deforms into the gap above. As the underhand mining front continues to advance deeper, the cemented backfill is subjected to further horizontal closure with each additional undercut. This closure eventually fragments and crushes the fill as illustrated conceptually in Figure 4. After substantial hanging wall-to footwall closure, the gap should theoretically be eliminated. At this stage of closure, the backfill should behave as a broken material and begin to strain-harden, gaining stiffness as it is compacted and its void spaces and fractures are compressed. The number of undercuts required to initiate this strain-hardening process will depend on the porosity of the cemented paste fill and the volume of voids in the gap above the fill.

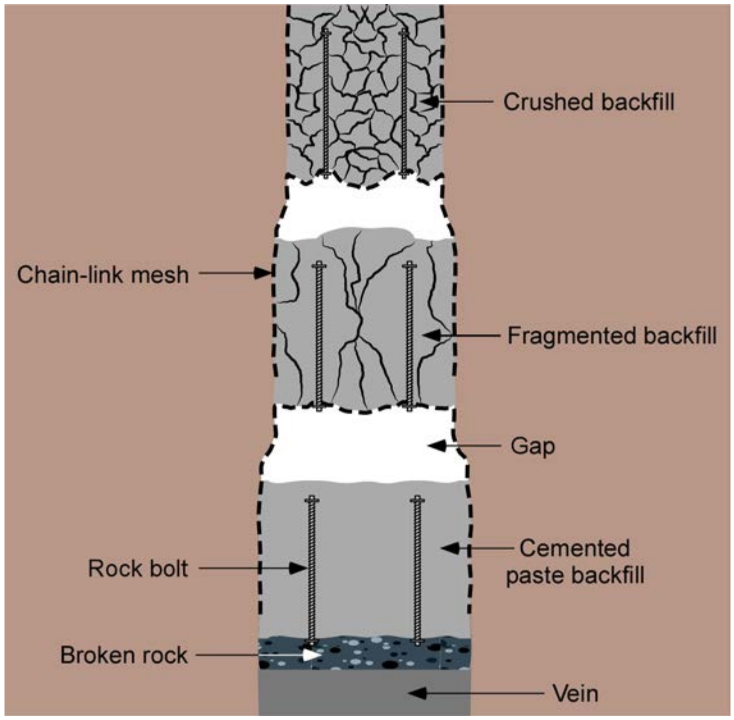

Figure 4. Conceptualized vertical cross section illustrating the progression of horizontal closure as successive underhand cut-and-fill stopes are mined

BACKFILL INSTRUMENTATION

In cooperation with the Hecla Mining Company, NIOSH researchers are conducting a systematic instrumentation study in the Gold Hunter deposit at the Lucky Friday Mine to quantify the stability and geomechanical behavior of cemented paste backfill during underhand cut-and-fill mining in rockburst-prone ground conditions. A set of robust and reliable instruments were installed at eight locations in two underground production stopes prior to backfilling. These instruments are currently being monitored through several stages of undercut mining by data acquisition systems that are linked through the mine's communications systems to a corporate web site. Although the design of the instruments is based on previous research by Williams et al. (1992; 2001), the instrumentation approach has been revised to improve the survivability of the instruments and to provide reliable measurements of stope closure and fill pressure to the mine staff, on nearly a real-time basis.

Hanging wall-to-footwall closure is being measured in backfilled stopes using robust, custom-designed closure meters equipped with UniMeasure HX-P510 linear position transducers. The body of the closure meter consists of telescoping sections of steel pipe and tubing attached to steel end-plates, which are bolted to the stope walls. A linear position transducer is mounted internally in the closure meter to measure displacement between the instrument's two end-plates as the stope walls converge. The position transducer consists of a rotary potentiometer that is encased within an environmentally sealed, waterproof housing. The rotary potentiometer measures a voltage output as a stainless steel wire cable is extended or retracted from the housing. These voltage measurements are in turn converted to displacement units to reflect a change in position of the cable. Two types of closure meters were fabricated and installed: single-acting closure meters with one position transducer for measuring displacement across the full length of the instrument (hanging wall-to-footwall closure), and double-acting closure meters equipped with a second position transducer for also measuring displacement to a center plate located at the midspan of the instrument (closure from the hanging wall to the midspan of the stope). For this study, the closure meters were equipped with position transducers having a measurement range of 63.5 cm (25 in). Given the quality of the closure meter data and the survivability of the instruments, the measurement range for the next version of these instruments is being extended to 127 cm (50 in).

Pressure or stress change in the cemented paste backfill is being measured using Geokon Model 4810 contact pressure cells with a measurement range of 7.5 MPa (1,088 psi). This type of earth pressure cell is specifically designed to measure soil pressures on an external structure. Like the standard earth pressure cell, this instrument consists of two circular stainless steel plates that are welded together around their edges, forming a narrow cavity between the plates which is filled with hydraulic oil. However, the contact pressure cell is equipped with a thick back-plate that protects the instrument and mounts directly to the structure. A thin front-plate is welded to the back-plate forming a flexible hinge for increased sensitivity to pressure changes. Pressure applied to the cell induces an equal pressure on the internal hydraulic fluid that is in turn sensed by a vibrating-wire transducer connected to the cavity between the two plates by high-pressure stainless steel tubing. A measurement of the change in the frequency of the vibrating wire is converted to pressure using a calibrated gage factor supplied by the manufacturer. The pressure cell is also equipped with a thermistor to help account for the influence of changes in temperature on the instrument's readings.

The closure meters and pressure cells are being monitored every two hours by a Campbell Scientific data acquisition system (DAS) located at a substation in a nearby slot drift. A typical DAS consists of the following components: CR1000 datalogger, AVW200 vibrating wire analyzer, AM16/32B multiplexers, and various communication interfaces depending on the specific link to the mine's communication system—either a fiber optic cable or a leaky feeder communications cable. Both of these systems are in turn connected to a computer server at the surface. Thus, the DAS can be accessed remotely, and the instrument data can be viewed on Hecla's corporate intranet web site by mine management and NIOSH researchers on an almost real-time basis. This allows the instrument data to be used by mine staff for daily operational decisions or safety concerns, and also enables the DAS to be remotely monitored for maintenance or timely repairs.

Closure meters and pressure cells were installed in two 30-vein production stopes prior to backfilling: the 5550L-11 stope immediately above the west side of the large sill pillar shown in Figure 1, and the 6350L-15 stope located on a deeper mining horizon beneath the center of the sill pillar. Compared with other active mining areas, both of these stopes were experiencing significant levels of seismicity when the instruments were installed. The 11-stope instruments were installed in September and October of 2014, whereas the 15-stope instruments were installed in March of 2016. To avoid interfering with the production crews, the 11-stope instruments were installed after the 5th and final cut had been mined from the slot drift. Modifications to the instruments and their installation procedures allowed the 15-stope instruments to be installed during the second cut, while production crews were preparing the stope for backfilling. As shown in Figure 5, closure meters (CM) and pressure cells (PC) were installed at four separate locations in each stope.

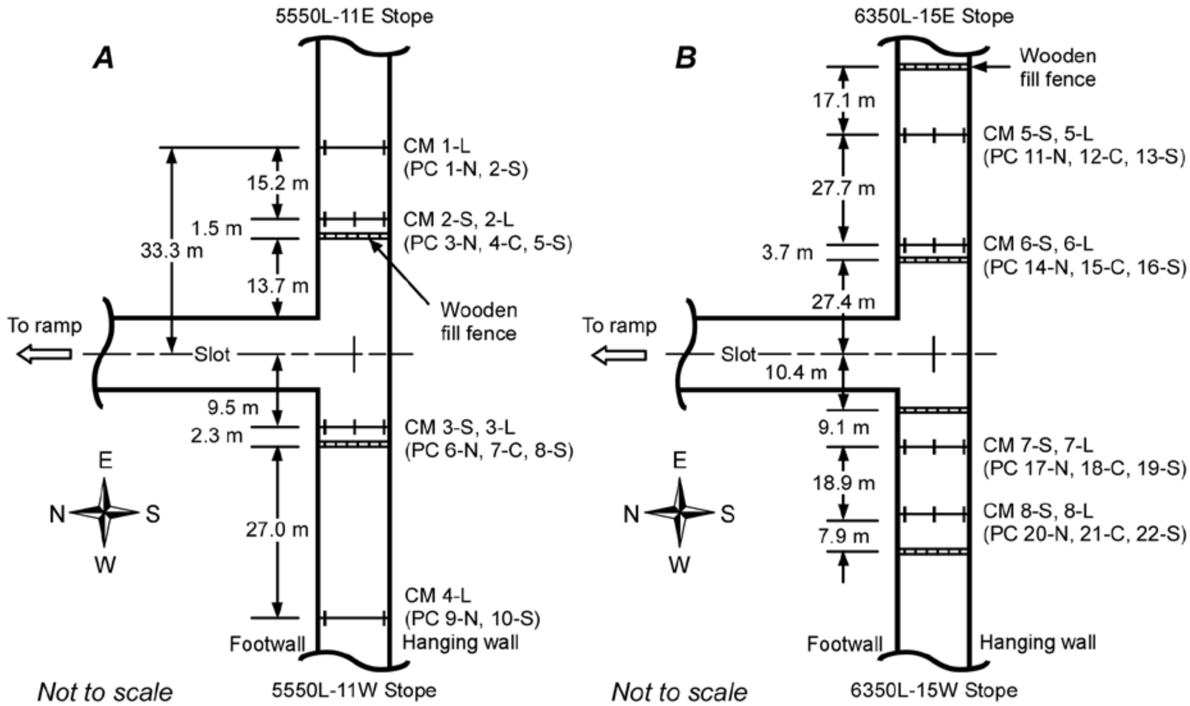

Figure 5. Plan view of backfill instrument locations: (a) 11 stope on 5550 level and (b) 15 stope on 6350 level

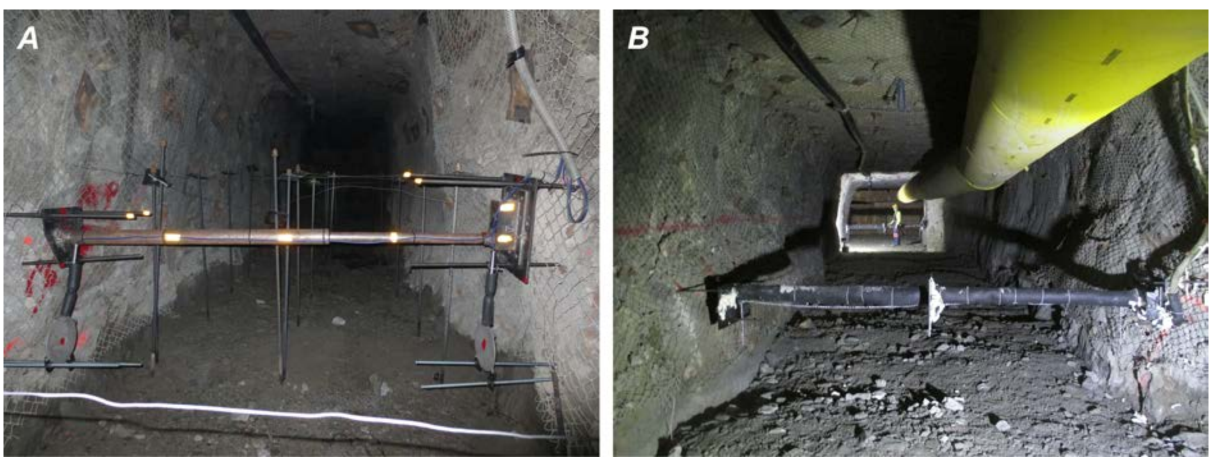

Figure 6. Typical backfill instruments: (a) single-acting closure meter installed with two pressure cells in 5550L-11W stope, and (b) double-acting closure meter installed with three pressure cells in 6350L-15W stope

In the 11 stope, pressure cells were installed near the stope wall at either end of the closure meters as shown in Figure 6a. An additional pressure cell was mounted on the center plate of the double-acting closure meters near the midspan of the stope (Figure 5a). To better protect these instruments during compaction and crushing of the backfill, the pressure cells in the 15 stope were mounted directly to the end plates of the closure meters (Figure 6b). Four double-acting closure meters were installed in the 15 stope to provide a better comparison of the relative movement of the hanging wall and the footwall, and also to enable an additional pressure cell to be installed on the center plate of the instrument near the midspan of the stope (Figure 5b). As shown in Figure 6b, foam sealant and insulation were also applied to protect the instrument cables from damage during stope closure. After the 15-stope instruments were installed, they were immediately connected to a data acquisition system. This allowed the instruments to be continuously monitored before, during, and after the paste fill pour, capturing many details that were missed in the 11 stope.

BACKFILL STOPE CLOSURE AND HORIZONTAL PRESSURE

Measurements collected from the 11-stope backfill instruments from September 2014 through September 7, 2016 are shown in Figure 7, grouped by the monitoring locations noted in Figure 5a. Stope closure and horizontal fill pressure have been monitored in the 5550L-11 stope for over two years and through a total of five undercut advances. As the first undercut heading was driven beneath the locations of the instruments, the horizontal pressure in the paste fill increased rapidly followed by a significant increase in closure. An initial failure of the cemented paste fill occurred shortly thereafter, as depicted by the peaks in the pressure curves displayed in Figure 7. During this initial failure, the maximum horizontal pressure that was measured in the paste fill ranged from 1.59 to 5.40 MPa (231 to 783 psi) and averaged about 3 MPa (435 psi) for the ten pressure cells.

Fill pressure varied depending on the monitoring location in the stope and the specific placement of the pressure cell. As shown in Figures 7b and 7c, the largest fill pressures were measured at the midspan (center) of the stope rather than at the hanging wall (south) or footwall (north). In general, fill pressures also tended to be higher along the hanging wall than at the footwall, and the east side of the 11 stope appeared to have higher fill pressures than the west side. With each undercut mining advance, the closure meters generally measured a consistent increase in stope closure, particularly the instruments installed in the west side of the stope (CM 3-L and CM 4-L), which averaged about 7.6 cm (3 in) of closure with each undercut (Figures 7c and 7d). Most of the stepped increase in closure occurred as underhand mining advanced directly below the locations of the instruments. In contrast, the pressure cells generally exhibited a decrease in horizontal pressure with each undercut advance; however, these drops in pressure were not as consistent as the stepped increases in closure. Nevertheless, the sequential pattern shown in Figure 7c of increases in closure accompanied by complementary decreases in pressure is more than likely an indication that the cemented paste fill is progressively fragmenting with each undercut advance.

Two pressure cells are still functioning in the 11 stope: PC 6-N and PC 8-S, which are both measuring long-term fill pressures of about 1 MPa (145 psi). Although only four of the original ten pressure cells survived more than three undercuts, some of the instruments that stopped working are still providing reliable thermistor readings. This indicates that the instrument cable is still intact and that the body or transducer of the pressure cell is probably damaged. Closure meters CM 4-L and CM 3-L are still functioning after 42 and 46 cm (17 and 18 in) of closure, respectively. Although CM 2-S and CM 2-L temporarily stopped working, they are both still providing useful data and have measured 42 and 51 cm (17 and 20 in) of closure, respectively (Figure 7b). As shown in figure 7c, PC 8-S has also functioned sporadically. Although the source of these intermittent readings is not known, they may be caused by moisture intrusion.

Since September 2014, several mining-induced seismic events have occurred in the vicinity of the 11-stope instruments. Most of these events caused only small changes in the instrument readings and rarely affected more than a few instruments. However, on December 2, 2015, during the fifth undercut in the 11 stope, a 2.7 moment-magnitude seismic event occurred near the location of the backfill instruments. In conjunction with this event, nearly 9 cm (3.5 in) of closure was measured, suggesting that a foundation failure may have occurred in the hanging wall or footwall argillites, which are relatively weak in comparison with the ore-bearing rock in the sill pillar. The seismic event appears to have occurred closer to the second set of instruments installed near the slot drift on the east side of 11 stope (Figure 5a), as noted by the increased response of CM 2-L and PC 3-N to the event (Figure 7b). After the 5th undercut advance was completed, subsequent mining in the 11 stope was temporarily suspended on December 22, 2015.

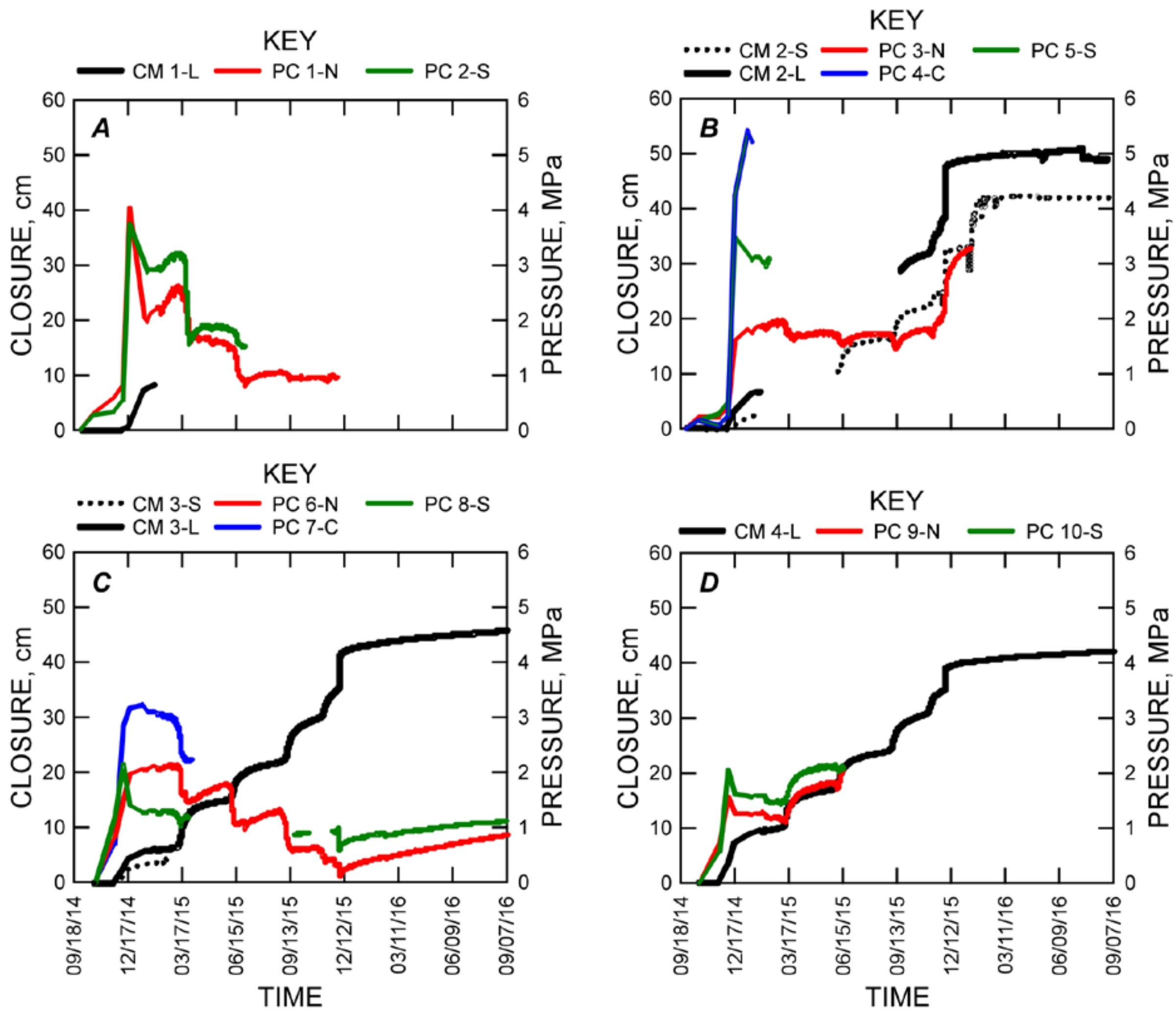

Figure 7. Horizontal pressure and closure measurements from 11-stope backfill instruments: 5550L-11E stope (a) and (b), and 5550L-11W stope (c) and (d)

Measurements recorded from the 15-stope backfill instruments from March 16, 2016, to September 7, 2016, are provided in Figure 8, grouped by the monitoring locations shown in Figure 5b. After almost six months and three undercut advances, all of the instruments installed in the 6350L-15 stope are still functioning, except the linear position transducers for two midspan closure meters: CLM 5-S and CLM 7-S. Compared with the 11-stope instruments, this is a significant improvement in instrument longevity, especially for the pressure cells. During the early stages of the first undercut advance, the pressure cells typically measured a steady increase in horizontal fill pressure before any significant amount of closure was measured (Figures 7 and 8). The small elastic displacements associated with these initial increases in pressure are often not detected by the closure meters and are therefore not apparent on the graphs until more substantial stress change and closure have occurred. As noted by Tesarik et al. (2006), temperature changes can significantly affect pressure cell measurements in cemented backfill. As paste fill is poured in a stope and begins to cure, its temperature rises due to the heat of hydration of the curing cement. This increase in temperature as the backfill cures causes the pressure cells to give a false indication of initial stress increase—in this case about 0.21 MPa (30 psi). However, this temperature effect soon becomes negligible as the backfill temperature stabilizes, and the in-place paste fill is subjected to significant horizontal loading through convergence of the stope walls.

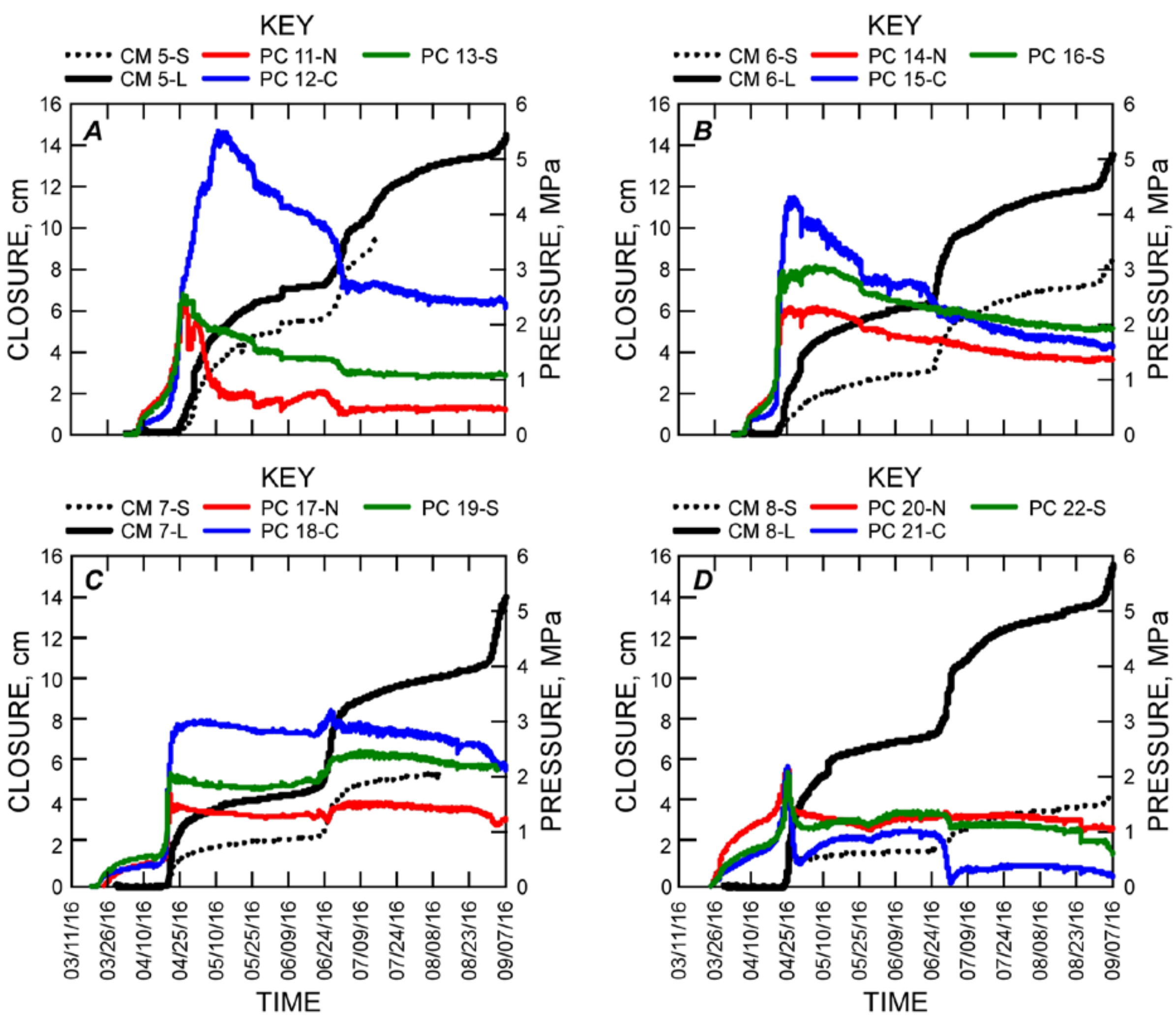

Figure 8. Horizontal pressure and closure measurements from 15-stope backfill instruments: 6350L-15E stope (a) and (b), and 6350L-15W stope (c) and (d)

The maximum horizontal pressure that was measured in the cemented paste fill during the first undercut ranged from 1.66 to 5.50 MPa (241 to 798 psi) and averaged about 3.69 MPa (535 psi) for the midspan pressure cells. As with the 11-stope instruments, higher fill pressures were generally measured along the hanging wall and on the east side of the stope. As shown in Figure 8, the response of the east side pressure cells was markedly different than the west side instruments. The different response in the west stope at this stage of mining is probably attributable to local variations in stope wall behavior.

Hanging wall-to-footwall closure in the 15 stope was fairly uniform ranging from 13.6 to 15.7 cm (5.3 to 6.2 in) through the beginning of the third undercut. As shown in Figure 8, a consistent increase in closure is occurring with each undercut advance, comparable to the closure measurements in the 11 stope. Midspan closure readings obtained from CM 5-S (Figure 8a) and CM 6-S (Figure 8b) are larger than half the total closure measured by CM 5-L and CM 6-L, respectively. This indicates that on the east side of 15 stope, the footwall or north side of the stope may be moving more than the hanging wall or south side of the stope, and appears to support a similar conclusion from CM 2-S installed on the east side of 11 stope (Figure 7b). However, midspan closure measurements from CM 8-S (Figure 8d) on the west side of 15 stope indicate that the hanging wall (south) is moving more than the footwall (north). Consequently, further information is needed to more thoroughly understand the relative convergence of the stope walls in relation to each other.

BACKFILL IN SITU STRESS-STRAIN

To gain additional information regarding the geomechanical response of the cemented paste fill to undercut mining, the in situ stress versus strain behavior of the backfill was plotted using closure and fill pressure measurements obtained from the 11 and 15 stopes. Because some of the 11-stope instruments have stopped functioning (Figure 7), in situ stress vs. strain curves could not be plotted for the backfill at each monitoring site. However, measurements from the remaining instruments were averaged to plot stress vs. strain curves for the east and west sides of the stope. Data from CM 2-L, PC 1-N, and PC 3-N were used for the 5550L-11E paste fill, while data from CM 3-L, CM 4-L, PC 6-N, and PC 8-S were used for the 5550L-11W paste fill (Figure 5a). Although some of the instrument data is intermittent or incomplete, the in situ stress vs. strain curves are fairly consistent for the east and west sides of the stope (Figure 9a).

The 11-stope instruments were initially read manually on a weekly basis before they were connected to a data acquisition system. As a result, the backfill's response to initial undercut mining is not well defined until after about 2% strain (Figure 9a). During the second through the fourth undercut advances, the paste fill in the east side of 11 stope displays gradual strain softening from about 3% through 12% strain. The paste fill in the west side of 11 stope behaves in a similar manner but exhibits a more plastic response to additional loading from about 6% through 14% strain. During the fifth undercut and particularly following the seismic event on December 2, 2015, the backfill in the east and west stopes have a pronounced change in behavior with significant strain hardening occurring at about 13% and 14% strain, respectively. The backfill's response to the seismic event is shown by the straight-line sections of the curves immediately preceding the strain hardening. The shift in the paste fill's behavior from strain softening to strain hardening may indicate that the gap above the backfill has closed and that the backfill is beginning to compact and take additional load.

The excellent quality of the data from the 15-stope instruments allowed the in situ stress vs. strain behavior of the cemented backfill to be determined at each of the four monitoring sites in the stope. Horizontal stress in the paste fill was calculated by averaging the pressure measurements obtained from the three pressure cells at each site, while horizontal strain was computed by dividing the displacement measurements collected from the long closure meter by the initial span of the instrument. Because the

15-stope instruments were connected to a data acquisition system soon after their installation, readings from the instruments were recorded every two hours during the first undercut advance. As a result, the elastic response of the paste fill to undercut mining is clearly indicated by the initial straight-line portion of the in situ stress vs. strain curves in Figure 9b. An average in situ modulus of deformation for the paste fill was determined at the CM 5 and CM 6 sites by analyzing the slope of their in situ stress vs. strain curves over a stress range equivalent to 30 to 60% of the average maximum stress during the first undercut advance. The resulting values for modulus of deformation were 3.68 GPa (533 ksi) and 3.57 GPa (517 ksi), respectively. The average of these values, 3.62 GPa (525 ksi), is comparable to the Young's modulus of 2.28 GPa (330 ksi), which was reported by Johnson et al. (2015) for unconfined compression tests with strain-gauged core samples of cemented paste backfill from a different paste fill mix over a similar stress range, and also in situ modulus of deformation values previously reported for cemented paste backfill at the Lucky Friday Mine by Williams et al. (2001), which ranged from 0.68 to 5.09 GPa (99 to 739 ksi) and averaged about 2.41 GPa (350 ksi).

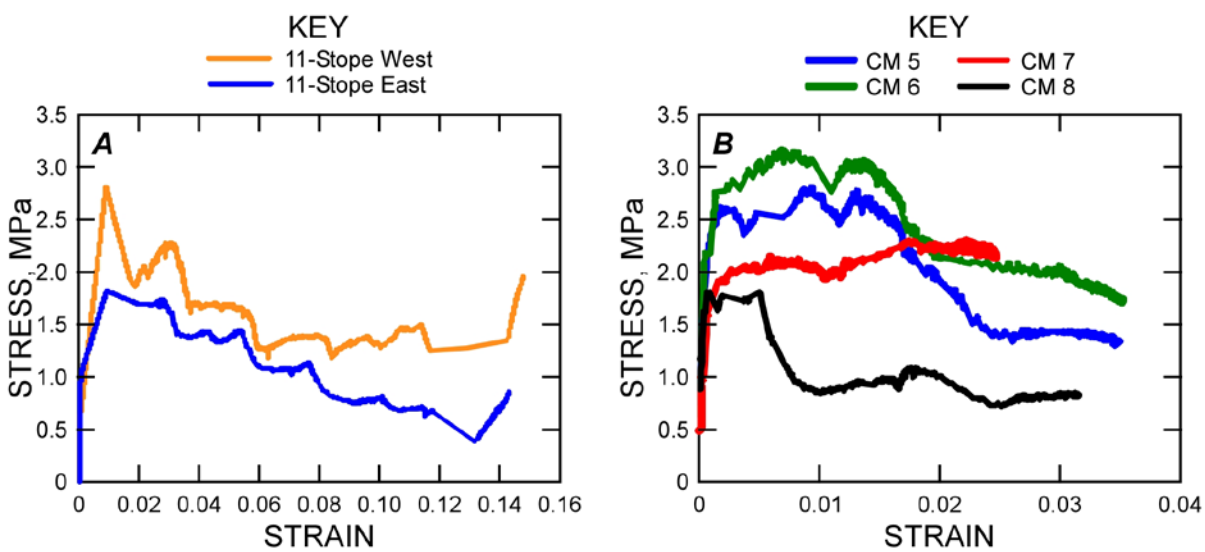

Figure 9. Backfill in situ stress versus strain: (a) 5550L-11 stope and (b) 6350L-15 stope

As noted in Figure 3, cemented paste fill was placed in the 11 stope with a 1-m (3-ft) gap above the backfill, whereas in the 15 stope, the paste fill was poured leaving only a 0.3-m (1-ft) gap above the fill. Although the response of the 11-stope and 15-stope instruments is similar, strain hardening is expected to occur in the 15-stope backfill after much less closure. Future measurements from these instruments will hopefully provide an important quantitative assessment of the effect of gap height on fill behavior and thus, help optimize the paste fill's ability to provide regional support and minimize strain bursts.

CONCLUSIONS

NIOSH researchers, in cooperation with the Hecla Mining Company, have developed a systematic instrumentation approach for monitoring the geomechanical behavior and stability of cemented paste backfill through several stages of underhand cut-and-fill mining. Prior to backfilling, a set of robust, reliable instruments have been installed at eight locations in selected stopes in the Gold Hunter deposit. Measurements from these instruments are currently being monitored by data acquisition systems that are linked through the mine's communications systems to an intranet web site, where pertinent data regarding the in situ performance of the paste fill is available on almost a real-time basis for mine personnel and NIOSH researchers. Maximum horizontal fill pressures are typically measured at the midspan of the stopes during the initial undercut advance and have ranged as high as 5.50 MPa (798 psi). As a general rule, hanging wall-to-footwall closure consistently increases during undercut mining and in some cases, has averaged about 7.6 cm (3 in) of closure with each undercut.

Over a two-year period, 51 cm (20 in) of stope closure have been measured through five consecutive undercut advances. Using stope closure and fill pressure measurements, the in situ stress vs. strain behavior of the paste fill has been determined, providing additional understanding of the backfill's response to underhand cut-and-fill mining and also mining-induced seismic events. An analysis of the in situ stress vs. strain plots indicates an average in situ modulus of deformation of about 3.62 GPa (525 ksi) for the cemented backfill during initial undercut mining and also the beginning of strain hardening behavior in the paste fill following a fifth undercut advance. Measurements from these instruments have confirmed that the backfill is performing as intended. It is able to maintain its stability during the initial undercut, and also as underhand mining advances deeper. Even though the cemented backfill fractures and becomes progressively more fragmented through a steady succession of stope closure during underhand mining, the paste fill still maintains a long-term horizontal pressure of about 1 to 2 MPa (145 to 290 psi).

In summary, measurements from these instruments are not only useful for mine design, but they also help confirm observations and justify long-standing assumptions regarding the backfill's role in ground support and rockburst abatement.

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DISCLAIMER

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health. The findings and conclusions in the report are those of the authors and do not necessarily represent the official position of NIOSH.

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