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Stability and access implications of open pit mining through old underground mine workings

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ABSTRACT

Increasingly, mining operations are looking at developing large open pits down through old, abandoned underground workings in order to extract remnant ore left within pillar zones. Maintaining pit wall stability while mining through major scale underground stoping zones presents both a risk and challenge that can have significant impact on overall pit economics and viability. Potential operational problems associated with the interactions between the stopes and the pit walls may occur, necessitating pit wall redesign, ground support installation and operational rescheduling. In addition, anticipated interactions of the pit shell with underground mine workings must be closely evaluated to maintain a safe working environment. Using illustrative examples, this paper discusses how operational hazards and risks to pit wall stability can be assessed and mitigated.

KEYWORDS: Open Pit mine; highwall stability; underground workings; stope interaction; hazard awareness

1. INTRODUCTION

Maintaining pit wall stability while mining through major scale underground workings presents both a risk and challenge that can have significant impact on overall pit economics and viability. Potential operational problems associated with the interactions between the stopes and the pit walls, such as shown in Figures 1 and 2, may occur. These interactions may require pit wall redesign, ground support installation and operational rescheduling.

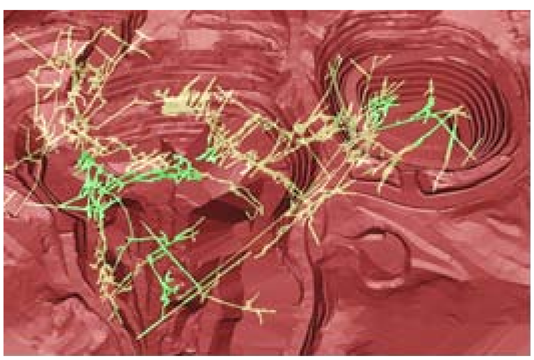

Figure 1: Example of underground workings within designed open pit mine (Kliche et al., 2000).

2. CASE EXAMPLE, DOME OPEN PIT

The Porcupine Gold Mining Camp, located near Timmins, Ontario, Canada, has been in continuous production since 1910. Over that period, approximately 65 million ounces of gold have been produced by more than 50 Underground mining operations. In recent times, Open Pit mining has been performed to exploit mineralization left by some of these underground mines. While each surface mine has unique design attributes, the practices initially established at the Dome Mine, were essential in permitting safe open pit mining practices.

The Dome Mine began underground production in 1910. Over the years, more than 900 underground stopes have been mined and hundreds of kilometers of drifts, sublevels and raises developed. Underground mining methods included shrinkage, cut and fill and longhole. Longhole stope tonnage may be in excess of 1.0 M tons with vertical heights of 300 m, widths of 60 m and lengths of 180 m. Not all stopes were backfilled upon completion.

Figure 2: Example of a Shrinkage stope daylighting into pit floor.

Open pit operations began in 1988 to supplement underground production. When completed in 2006, the bottom of the Dome pit had reached a depth of

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335m. The pit was mined with 9 m bench heights, with 11m-wide catch benches established at 27m intervals. Inter-ramp wall angles vary with lithology, ranging from 39° to 54° with average of 49°. Bench face angles were typically between 65° and 75°.

In 2002 the pit began to intersect voids in its final wall, and re-designs of the pit and alternate planning had to be undertaken. The intersection of underground stopes/voids with the Dome Pit's ultimate pit high wall resulted in stability issues that had safety, design, scheduling, operational, and economic impacts.

Much of the planning and design of the pit was driven by the interaction of large voids with the pit wall, as illustrated in Figure 3. The success of the Dome pit depended on the ability to design around the underground voids, profitably maximize ore recovery and maintain production, Miller (2003).

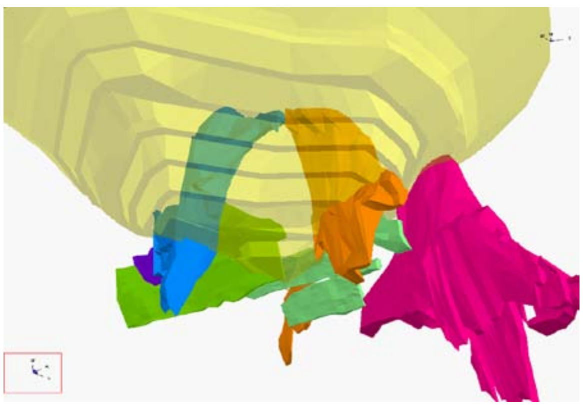

Figure 3: Interaction with mined underground stopes and the Dome pit (yellow colour).

3. INTERACTION WITH MINE WORKINGS

The interaction of the Dome pit with previously mined underground stopes presented a challenge to stability design in the walls, and pit floor. An examples of stope exposure in the pit wall is provided in Figure 4.

Stopes were assessed on a case-by-case basis. Special attention was directed towards stopes which may impact the pit ramp or catch bench due to location or size, stopes with unknown fill conditions, and stopes with unstable wall conditions. In addition, since some mine workings adjacent to the pit dated back more than 75 years, the exact location, geometry and condition of individual stopes and associated development is not always known.

Figure 4: Pit wall undercut by stope.

3.1 Void Definition

Potential voids are identified and defined using a variety of sources. A geometric model based on the open pit and underground mine plans, created with sophisticated design software, provides a 3-dimensional view of interactions between the pit excavation and mine workings.

Other data sources available for void definition include:

- Historical sections of underground voids
- Stope files and records of backfilling
- Underground visual confirmation of voids
- Confirmation of voids via diamond drilling
- Probe drilling from pit floor and measurement of rock, fill and void
- 3D survey via borehole scanner of intercepted voids

Based on the results of void definition, engineering planners design probe holes to verify underground voids. On the basis of proximity to voids, the pit floor is subdivided into non-restricted, cautionary and restricted lanyard areas to ensure safety of personnel.

3.2 Geotechnical design

Geotechnical information is used for the design the pit geometry and for ground support design to achieve acceptable factors of safety, quantify failure mechanisms and assess risk. Available geotechnical data includes:

- 3-dimensional lithological model for the pit
- Bench scale mapping for structure and rock mass quality
- Major feature recognition and mapping (fault, slips and joints)
- Underground level and stope mapping and history
- Rock and backfill characteristics and strength parameters

Problematic stopes were identified and their stability assessed using a range of techniques, including:

- Conventional kinematic analyses to examine potential for wedge, planar and toppling failure of the designed final wall in the vicinity of the identified stope,
- Detailed analyses of potential 3-dimensional wedge block geometry and necessary support capacity, and
- Numerical analysis (2-dimensional and 3-dimensional) to evaluate overall stability interaction issues and to quantify geotechnical assumptions.

Examples of stability modelling at the Dome pit are described in Carter el al. (2009), Henning (2009), and in Palmer et al. (2003).

4. STABILITY DESIGN TACTICS

Ground support or pit geometry re-design are used to establish stable walls conditions when in close proximity to mine workings or when regions of low quality ground are encountered.

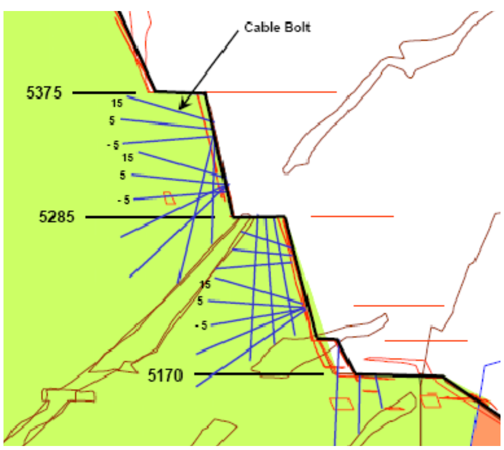

Figure 5: Example of Cable bolt support pattern around underground mine workings (Carter et al, 2009).

4.1 Ground support

Ground support is installed to locally stabilize the rockmass around mine workings or in sectors of low quality ground. Ground support measures used include:

- Cable bolting. Bulbed cables, up to 36m long are installed into the pit wall or floor. Support patterns, such as that shown in Figure 5, are designed on a case-by-case basis. Up to four 25 tonne cables are installed per hole. On occasion, the cables may also be plated, as illustrated in Figure 6.
- Rock bolting, strapping and/or screening is used to provide surface confinement in poor quality rock. Screening is draped over the wall or installed as catch fences (see Figure 7) to control the descent of small loose rock in sensitive areas or where catch bench spacing has been modified.
- Backfill exposures are stabilized by replacement of the existing fine grain fill (sand or tailings) with a covering of waste rock, allowing a steeper angle of repose. In sensitive areas, fiber reinforced shotcrete has been used to reduce unraveling risk.
- Voids are backfilled in advance of pit mining. Depending on proximity to the ultimate pit wall, unconsolidated and consolidated backfill are used. On occasion, some voids may be filled with concrete.
- Typically a minimum one-to-one pillar is maintained above voids, otherwise sill pillars are blasted down. In the case of large stopes, drop raises may be used to fill the voids with broken waste muck prior to blasting down the sill.


Figure 6; Cable bolt reinforcement above void in pit wall.


Figure 7: Catch fence installation along bench.

4.2 Pit wall geometry redesign

Pit wall geometry is redesigned to minimize impact of voids on pit wall stability. An example of pit re-design around a stope is shown in Figure 8. Design measures used include:

- Increase or decrease bench face angles and berm widths
- Alter ramp width or grade
- Change location of ramp

4.3 Wall control blasting

Preshear blasting is routinely performed along the final pit walls in order to create a smooth, stable face. The goal of the blasting is to create a crack in the rock along the line of the pit wall, but to not fragment or displace the rock.

In areas adjacent to voids, a single row of 114mm diameter preshear holes are drilled at an angle of 80°. Spacing between holes (usually 1.2 m) may be reduced in low quality rock. Elsewhere, 165 mm preshear holes were drilled at 1.8 m spacing.

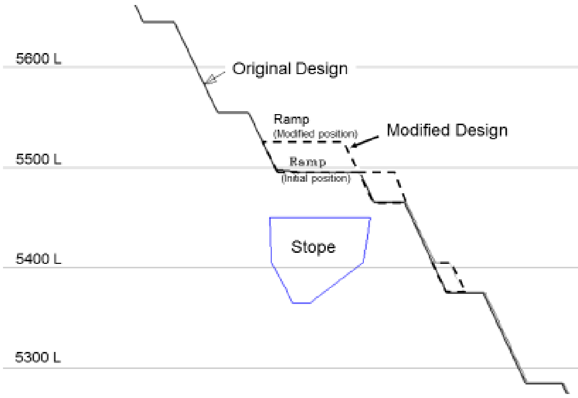

Figure 8: Pit wall re-design to increase pillar dimension around a stope.

5. HAZARD AWARENESS

In addition to hazards associated with pit wall stability, a major concern associated with working around underground workings is that areas of subsidence, or “sinkholes”, may occur unexpectedly. Most of the existing mine openings have been modeled in 3-D. However, there is always the possibility of the presence of unknown openings, or that some openings have failed / caved to a larger than anticipated dimension.

Subsidence can be defined as “the sudden collapse of material into a void beneath it”. Subsidence occurrences can be triggered by the thaw of frozen ground (spring time), heavy rains, and by nearby pit blast vibrations.

5.1 Identification of Hazard Areas

Areas where subsidence may be anticipated, where near-surface voids are known to exist, and mined areas connecting to surface are all considered to be Hazard Areas. In the Pit, these areas are identified by:

- Physical barriers (Temporary fencing, Berms, etc.)
- Delineator cones and pickets. The type and severity of potential hazard can be indicate by colour coding or delineator size. See example, Figure 9.

Safety procedures at the mine dictate what areas can be accessed, and what precautions are required.

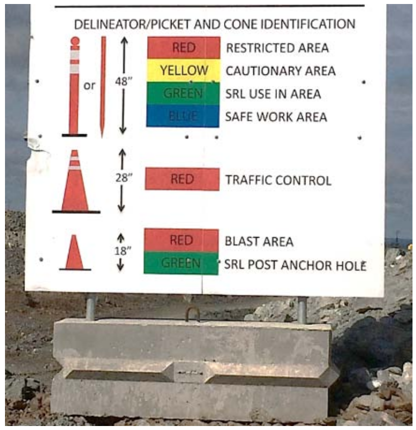

Figure 9: Example of visual hazard identification.

6. MONITORING

The objective of the instrumentation is to provide warning of the onset of movement in stope sidewalls, crown pillars, filled stope openings and final pit walls. Of particular importance to the monitoring program are zones of potential instability encompassing many stopes. Due to the absence of reinforcement in many of these zones, it is imperative that deterioration of stope sidewall stability or fill subsidence be identified promptly.

Monitoring is used to provide an early warning of ground movement to ensure safety of workers. The instrumentation program at Dome Mine consists of several different types of monitors to provide an early detection system, including:

Visual inspections

Visual inspections are performed on an on-going basis to identify evidence of instability, as indicated by crack formation, unraveling, falls of ground, loss of fill, damaged ground support, unexpected breakthrough into void, or subsidence. Unusual occurrences are reported for further review.

Multi Point Borehole Extensometers

Multi-Point Borehole Extensometer (MPBX) instruments are used on occasion as a quantitative early detection system for progressive ground failure in the vicinity of mine workings. Each MPBX consists of six nodes grouted in place and attached to the instrument head by a thin flexible rod. These instruments directly measure displacement of the nodes relative to the head.

Sloughmeters

Sloughmeters are installed into filled stopes to monitor for potential subsidence. These instruments are used as a qualitative early detection system for progressive ground failure. Consisting of ten nodes grouted in place, each node forms a loop for current flow. Should a node be lost (or sloughed), this will be indicated by no current flowing through the loop.

Monitoring of survey prisms

Survey prisms are mounted onto the surface of the pit wall at locations of anticipated instability, such as on potentially unstable wedge intersections. At locations adjacent to the intersection of the pit wall with large backfilled voids, prisms may be installed systematically on a dense (15 m x 15 m) pattern to permit close monitoring of a specific region.

The prisms are monitored several times per day by an automated Robotic Total Station (RTS) survey system, used in conjunction with Geodetic Monitoring software.

Radar

Slope Stability Radar can be used to remotely monitor pit highwall stability. Advanced analysis tools allow for long term trending and hazard identification. Alarms warn of accelerated slope movement prior to wall failure

7. CONCLUSION

Design and stability of Open Pits developed through historic underground workings are influenced by ‘typical’ factors, such as rock mass condition, and by ‘atypical’ factors – in the form of underground mine workings.

To anticipate and mitigate risks, voids intersecting the pit wall and floor are identified, defined, and assessed. Strict hazard awareness protocols are required. Pit designs are adjusted around anticipated and intercepted workings.

Highwall stability is monitored by an ongoing program of visual inspections for changing conditions, coupled with regular tracking of potential displacements both at the pit surface (survey prisms and radar) and within the wall (extensometers).

8. ACKNOWLEDGEMENTS

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