Examples of Ground Support Practice in Challenging Ground Conditions at Vale’s Operations in Sudbury

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Outline

• Vale has operated a number of underground mines in the Ontario Operations in Sudbury for over a century. Geomechanics challenges are predominant and include both gravity-driven and burst-prone ground failure conditions, further exasperated by variable rock mass characteristics and ever-increasing mining depths.

• Ground support systems in two challenging areas are presented in this paper:
  ✓ Coleman Mine, 153 orebody: multiple sill pillar narrow vein mining
    • Highly stressed FW access drift
    • Highly stressed FW veins (in ore) with overhand mining
    • Highly stressed bottom sill of Uppers Stope (in ore)
    • Mining underneath consolidated sandfill in Underhand Cut and Fill (UCF) using Stopers and Jack Leg drills
  ✓ Creighton Mine, Division 6 Deep Zone: pillar-less open stoping with a top-down center-out sequence and mining below 6400L/2000m
    • Mining beneath consolidated sandfill stopes using Atlas Copco Boltec bolting unit to install ground support
    • Primary Support System at Depth
    • First-Pass Dynamic Support System
    • Secondary Dynamic Support System for Major Infrastructure
Coleman 153 Orebody: General Mine Configuration
- Narrow vein multiple sill pillar mining

- To reduce the risk from seismicity, overhand mining is switched to underhand mining.

- Calibrated numerical modeling tools are used to determine at which cut the switch should take place for each sill pillar.
Coleman 153 Orebody

Challenges associated with *Overhand mining* in narrow vein sill pillars
Coleman 153 Orebody
- Overhand mining in narrow vein sill pillars

**Diagram Notes:**
- Backfill
- F/W (Footwall)
- H/W (Headwall)
- Remaining Ore
- Major Principal Stress wrapping above the current cut
- Current Face
- Stress wrapping around the FW shoulder
Highly stressed FW access drift
- D-bolts with mesh straps as a dynamic support system

INSTALL D-BOLTS AND STRAPS IN THE BACK AND ON THE WALLS TO B.R. + 5'.

SHOTCRETE IN THE BACK ON THE WALLS TO B.R..
Highly stressed FW access drift
- D-bolts with mesh straps as a dynamic support system (continued)

20mm 2.4m long D-Bolts & #00 gauge Mesh Straps

Significant back peaking & over-break and design height = 18-ft (5.5m)
Highly stressed FW access drift
- D-bolts with mesh straps as a dynamic support system (continued)
Highly stressed FW veins (in ore) with overhand mining

- Is larger opening always unfavourable in highly stressed ground?
- In main footwall veins, in order to reduce the worker exposure to seismicity, the heading size is increased from 3mx3m to 4.5mx4.8m to accommodate the mechanized equipment, including Maclean Bolter instead of Stoper & Jack Leg.
- Dynamic Ground Support system (secondary support): 2.4m long Yielding Swellex (Mn12) (in fractured ground from previous seismicity) and #00 gauge Mesh Straps.
Highly stressed FW veins (in ore) with overhand mining (continued)

• All footwall vein drifts are to be driven 4.5m high to fit the Maclean Bolter to install ground Support.

3.0Mn Support to be installed:
• 1st pass shotcrete (75mm thick, minimum)
• #6 gauge screen & rebar in back and shoulders and FS-39 Split sets down to BOR +0.6m on FW and +1.5m on HW.
• #00 Gauge mesh straps with 3 cone bolts per strap. Option to install 4 yielding swellex bolts per strap where it is difficult to install the cone bolts (especially in ore).
• All support to be installed “1st pass” advancing simultaneously.
• De-stressing techniques on all Footwall drifts
Highly stressed FW veins (in ore) with overhand mining (continued)

Back support design - Dynamic support required to withstand major seismic events

*Dynamic support design for the back FW ore veins in 153 orebodies*

- Rock density: 2770 kg/m³

*153 OB - Major seismic events (up to 2.7Mn) occurred in the vicinity of mining areas.*

**BACK SUPPORT**

1. **Determine the ejection velocity**
   
   Using Fig. 5.10b to determine PPV pending on distance and event magnitude.
   
   \[
   V_1 = \frac{3.00 \text{ m/s}}{2.7 \text{ Mn with a distance less than 10m (right on 3500 level)}}
   \]

2. **Determine energy released from the events:**
   
   Average of 3' thick material is estimated to have moved from the entire back.
   
   Total ejected material for an area of 4'x4' = 3647.36 kg
   
   Area: 1.44 m²
   
   Initial kinetic energy = 11.40 kJ/m²
   
   Ultimate kinetic energy after 50mm movement = 12.64 kJ/m²
   
   (Fig. 3.7 can be used to estimate ground movement pending Mn and distance)

3. **Proposed support energy capacity:**
   
   1. Resin rebar = 1.08 kJ/m², 4' x 2.5' pattern
   
   1. Shotcrete and #6 gauge mesh = 9 kJ/m²

   **Secondary dynamic support**
   
   Yielding swelllex with 0 gauge straps = 6.89 kJ/m², 5' x 2.5' pattern
   
   Total support energy capacity: 16.97 kJ/m²
   
   Factor of Safety: 1.34

*Figure 5.10b: Peak particle velocity for recommended design conditions (90 to 95% confidence and normal stress drops: \( a^* = 0.5 \) and \( C^* = 0.25 \text{ m/s}^2 \)). Higher ppv is expected inside the "near-field" zone.*

*Figure 3.7: Typical wall displacements in openings with standard support caused by a remote seismic event*

Highly stressed bottom sill of Uppers Stope (in ore)

- High stress wrapping around the immediate F/W shoulder.
- Dynamic ground support (secondary) in the back and walls (secondary support): 2.4m Yielding Swellex (Mn12) and #00 gauge Mesh Straps in fractured ground from previous seismicity.
Coleman 153 Orebody

Challenges associated with *underhand cut and fill mining* in narrow vein sill pillars
Why underhand mining becomes more and more popular in highly stressed ground condition?

• It is a safer method of mining in highly stressed ground because:
  • it reduces the risk of worker exposure to highly-seismic solid ground in the back, and;
  • it allows mining to take place underneath the backfill (an engineered product) that requires a ground support system for stabilizing the gravity-driven risks only.

• Two examples of underhand mining at Vale operations:
  1. Coleman Mine, 153 orebody:
     • underhand cut and fill in narrow vein sill pillars
  2. Creighton Mine, Division 6 (below 6400 level):
     • The deep ore zones are mined with a pillar-less open stoping and a top-down center-out sequence
Underhand cut and fill mining in narrow vein sill pillars

Ground support system when mining underneath the consolidated sandfill depends on sandfill strength/quality and drift span.

Sandfill quality/strength:

- Sandfill segregation forms cold joints
- Recent test results reveals that sandfill strength @28 days is inconsistent and does not achieve > 1 MPa average strength.
Underhand cut and fill mining in narrow vein sill pillars (continued)

Sill mat to be placed for the underhand Cut and Fill (UCF) sill pillar mining (for Person-entry)

- Sill mat must be installed before pouring sandfill to reduce the risk of formation of cold joints in the sandfill mass.
Underhand cut and fill mining in narrow vein sill pillars (continued)

Ground support system when mining underneath the consolidated sandfill depends on sandfill strength/quality and drift span.

- Empirical analysis reveals that Uniaxial Compressive Strength (UCS) of 1.0MPa is required for a drift span up to 4.5m.
Underhand cut and fill mining in narrow vein sill pillars (continued)

Back support:

- If backfill strength is less than 1MPa, a minimum of 75mm thick shotcrete is required to be part of the support system for a drift span up to 4.5m, and
- Longer bolts, 1.8m long Swellex with #6 gauge screen, are required on top of the shotcrete.

Assumptions: bond strength = 2.5t/m, cold joint = 1m to 1.5m
Load = 4.5m x 2 t/m^3 x 0.9m x (1.0m to 1.5m) = 8.1 to 12.15tons
Capacity = 5 bolts x 2.5t/m x (0.8m to 0.3m) = 10 tons to 3.75 tons

FOS = 10 or $3.75 / 8.1$ or 12.15 = 1.2 or 0.3

FOS = 1.2 if cold joint is 1m thick while FOS = 0.3 if it is 1.5m thick.
Underhand cut and fill mining in narrow vein sill pillars (continued)

Ground support system and mining procedure when drifting (3.0m high x up to 4.5m wide) underneath the consolidated sandfill (<1MPa @28 days) in the UCF with Stoper & Jack Leg?

- Prep face
- Drill 2.4m round as per layout
- Load and blast based on the Mine standard
- Muck out heading
- Apply a minimum of 75mm thick plain shotcrete or steel fiber reinforced shotcrete to Base Of Rail.
- Allow shotcrete to cure a minimum of 8 hours with accelerated mix (or 2 hours for rapid-set shotcrete)
- Install #6 gauge screen with 1.8m long Swellex in the back and 1.8m long split sets on the walls at a 1.2m x 1.0m pattern. ** Resin rebar can be used in the back to replace Swellex in solid ground.
- Secondary support may be required depending upon the opening span.
Mining underneath consolidated sandfill in sill pillar mining (with Stoper and Jack Leg)

- #6 Gauge Galvanized Mesh Screen
- 2.4m long Plastic coated Swellex (Pm 12)
- 75mm thick shotcrete
Creighton Deep

Challenges associated with mining below 2000 m
Creighton deep (below 6400 level)
- A pillar-less open stoping and a top-down center-out sequence
Mining underneath consolidated sandfill stopes
Mining underneath consolidated sandfill stopes with Boltec bolter

Ground support system and mining procedure when drifting (4.5m high by 4.9m wide) underneath the consolidated sandfill (approx. 1MPa strength @ 28days) for the top sill of bulk mining.

- Prep face
- Drill 3.6m round as per layout
- Load and blast based on the Mine standard
- Muck out heading
- Install #4 gauge screen with 2.4m Mn12 plastic-coated swellex in the back (or 2.4m rebar in solid) with FS46 on the walls to the floor on a 1.2m x 1.5m staggered pattern (8 bolts/1.5mx3.4m screen) using the Atlas Copco Boltec.
- Apply a minimum of 75mm plain shotcrete to cover all screen to Base of Rail.
- Allow shotcrete to cure a minimum 4 hours with accelerated mix before drilling the next round.
- At intersections, with spans in excess of 8.5m, either 3m or 3.6m long plastic-coated manganese Mn24 super swellex are installed as a secondary support.
Primary support at Creighton Deep (below 6400L, 2000m)

- **In the back/shoulders:**
  - 2.4m length 20mm rebar bolts installed on a 1.2m x 1.5m staggered (3-2-3) pattern through #4 gauge welded wire mesh with a 150mm square, 6.4mm steel washer plates.

- **On the walls:**
  - 2m FS46 (46mm friction bolts) and screen installed to within five (1.5) m of base of rail within 3.5m of the face.
#4 galvanized welded wire mesh possesses much high energy capacity.

This 2005 photo demonstrates the effectiveness of #4 gauge mesh when subject to a 2.2Mn pillar burst.
Primary support at Creighton Deep (below 6400L, 2000m) (continued)

2m length, FS46 (46mm) friction set bolts

- In this photograph, the extent of deformation of the ground support is revealed at approx. 0.75m up the bolt, a measure of rockmass bulking. This demonstrates the FS46 (46mm) friction bolt’s ability to maintain the integrity of the plated end while under load. #4 screen is an integral piece of the wall bolting system.

A. Punkkinen, M. Yao (2007)
First Pass Dynamic Support in burst-prone conditions

• **In the back and shoulders:**
  • #4 gauge 1.5m x 3.4m screen is installed with alternating rows of 2.4m length 20mm rebar and modified cone bolts (MCB33) on a 4-3-4 pattern.
  • Each 150mmx150mm dome plate is supplemented with a single #0/0 gauge 300mm mesh square to provide additional surface support.

• **On the Walls:**
  • #4 gauge screen is installed with alternating rows of 2.0m length 46mm friction set bolts on a 3-2-3 pattern. Where stress conditions warrant, 2.4m MCB33 may be substituted in the upper wall portion of an excavation.
Second Pass Dynamic Support for major infrastructure

• #4 gauge mesh installed with 2.4m MCB33 with #0/0ga 300mm squares over shotcrete (from the current mesh strap design).
• The change provides ultimate protection against spalling of shotcrete and damage to the mesh from between dynamic support components while optimizing installation time.
• Although shotcrete remains an integral part of the ground control system, shotcrete spalling and cracking has become an issue in high stress ground as mining reaches greater depths.
Conclusions:

- This paper presented the ground support systems in use at two challenging areas at Vale’s Ontario Operations:
  - in multiple sill pillar mining in the 153 Orebody at Coleman
  - in high stress regimes at Creighton Mine below 6400L, 2000m depth.
- These systems reflect our current practice at Vale’s the other mining operations in Ontario for safe production when dealing with similar ground conditions.
- In designing ground supports systems in highly stressed ground, one of the critical factors (i.e. the reduction of the worker exposure to seismicity) is to consider the use of mechanized equipment where feasible.
- Although shotcrete remains an integral part of the support system in highly stressed ground, shotcrete spalling and cracking, depending on the failure mechanism, has become an issue when mining at ever-increasing depths. Surface ground support, such as welded wire mesh, must be provided on top of the shotcrete to prevent falls of shotcrete due to seismicity.
Conclusions (continued):

• The above mentioned support systems have been demonstrated to be successful at Vale’s operations. At the design stage, extraction of the ore reserves has been economically optimized while adhering to critical factors associated with seismicity and rockbursting through:
  • Optimization of mining sequences, and,
  • Utilization of hazard map tools for identification of high risk zones.
• Recently, new face support guidelines have been implemented at all of Vale’s Ontario Operations mines.
• Ground support systems are continuously being evaluated with the development of new technology and tools.
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Thank you!

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