Introduction of Mechanical Dynamic bolts as part of dynamic support system in rock-burst damaged areas at Copper Cliff Mine - A case study

D Reddy Chinnasane
Anneta Forsythe
Mike Yao

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Outline

• Introduction
• Rockburst history at Copper Cliff Mine
• Factors contributing to high stress and/or bursting conditions
• First version of dynamic ground support standards
• Damage due to rockbursts associated with large magnitude seismic events
• Revised dynamic ground support standards
• Issues with reconditioning of the rockburst damaged areas using resin grouted dynamic bolts such as D-bolts/Modified cone bolts.
• Introduction of Mechanical Dynamic (MD) bolts as part of dynamic support system
• Performance of MD bolts
• Conclusions
Introduction: Location of Copper Cliff Mine

- The mine is located within the Copper Cliff Offset in Sudbury Basin.
- Mining commenced in 1960s.
- Approximately 59 million tons of ore has been mined up to the end of 2016.
Rockburst history at Copper Cliff Mine

• Occurrence of the earliest known rockburst at Copper Cliff Mine dates back to 1986.

• A review was done on rockbursts occurred during 1998-2016.

• A total of 55 rockburst incidents occurred across different ore bodies during 1998-2016 (Seismic events that did not result in damage are excluded from the list).

• Out of 55 rockbursts, 42 rockbursts (76%) occurred in the 100/900 ore body.
Rockburst history at Copper Cliff Mine

• Out of the total 55 rockbursts, 23 considered to be significant (42%) as they were associated with seismic events greater than magnitude 2.0 (Nuttli).

• Out of these 23 significant rockbursts, 19 rockbursts (83%) occurred in the 100 and 900 ore body.
Factors contributing to high stress and/or bursting conditions

- Geological Structures - faults and dykes
- Diminishing pillars (Sill pillars)
- Mining induced stresses
- Rock/Ore type (Trap dyke and ore in the 100/900 OB are stiffer than other rock/ore types)
List of significant seismic events in the sill and diminishing pillar areas in the 100/900 OB.

- 2.9 Mn event on March 25, 2008*
- 3.8 Mn event on September 11, 2008*
- 2.9 Mn event on February 18, 2009
- 3.0 Mn event on October 8, 2014*
- 2.3 Mn event on January 6, 2016
- 2.2 Mn event on March 10, 2016
- 2.1 Mn event on May 15, 2016
- 2.0 Mn event on June 20, 2016
- 2.7 Mn event on June 20, 2016
- 1.9 Mn event on October 8, 2016
- 2.4 Mn event on March 4, 2017
- 2.2 Mn event on April 14, 2017

Majority of the significant events were associated with blasts.
(Crown/production/development)

* Only these events caused major damage
Impact of large magnitude seismic events

Damage due to 3.8 Mn event on September 11, 2008

Ground support system:

Back: Alternate rebars and mechanical bolts with #6 gauge welded wire mesh

Walls: Mechanical bolts with #6 gauge welded wire mesh
Introduction of dynamic support system

(First version introduced in 2008)
Damage following a 3.0 Mn event associated with the crown blast in the 9552 stope on 3710L on October 8, 2014

Primary support system:

Back:
8 ft Rebars with #4 gauge welded wire mesh

Walls:
5.5 ft FS-39 split sets with #4 gauge welded wire mesh

Secondary support system:

2”-3” thick shotcrete (back and walls)

18 ft twin cables in the back and shoulders

D-Bolts with 0 gauge strapping from floor to floor on 5 ft x 5 ft spacing
Evolution of Dynamic Ground Support System at Copper Cliff Mine (2nd version introduced in 2014)

**Scenario #1** - All drifts beyond the stope limits but within 100 ft of ore contact or stope limits:

- 8 ft D-Bolts in the back and shoulders and 6.5 ft FS-46 split sets on walls to the base of rail on 4 ft x 2.5 ft staggered pattern (i.e., 8 bolts per screen on 3-2-3 pattern).

**Scenario #2** - All drifts within the stope limits, diminishing pillars less than 150 ft wide and/or other structures of concern (Dykes, Faults, and Shears):

1st Pass:

- 8 ft D-Bolts in the back and shoulders and 6.5 ft FS-46 split sets on walls to the base of rail on 4 ft x 2.5 ft staggered pattern (i.e., 8 bolts per screen on 3-2-3 pattern).

2nd Pass:

- Install 3 rows of 0 gauge straps horizontally on walls 5 ft apart from 2 ft above the floor to 2 ft below the shoulders. Secure straps with 8” D-Bolts at 5’ spacing.
- Strapping to start 10 ft before and end 10 ft beyond the ore contact or the structure of concern. Ground control may specify other support elements (Shotcrete, Cable bolts, Super Swellex bolts) depending on observed ground conditions.

Burst-resistant support performed very well following crown blast in the 9631 stope:
- D-Bolts/MD Bolts
- FS-46 split sets
- #4 gauge screen and 0 gauge straps
Issues with the installation of D-bolts in rockburst damaged ground

- Crews experienced difficulties in rehabbing the rockburst damaged areas (mostly walls) using resin grouted 8 ft long D-Bolts as part of the dynamic support system.

- Initially, considered to use 8 ft long super swellex bolts (MN-24) as an alternate to D-Bolts. However, the idea was dropped in view of the fact that super swellex bolts are relatively weak in shear.

- Since MD bolts are strong in shear due to 20 mm rebar inside a FS-47 mm split set, a decision was made to introduce MD bolts as an alternate to D-bolt particularly in broken ground conditions where D-bolts cannot be installed effectively.
Mechanical Dynamic (MD) bolt as dynamic ground support at Copper Cliff Mine

**MD Bolt**

- MD bolt is a 47mm friction bolt (SS) reinforced with 20mm re-bar and a set of wedges at the top end.
- One wedge is welded to the tube and one screwed onto the bar.
- Once the bolt is fully hammered into the hole wedges are expanded to anchor the bolt.
- The wedges are expanded by rotating the "blind nut" to rotate the bar and to pull the mobile wedge.

**MD Bolt Installation**

**MD bolt installation steps:**

1. Drill hole using the same drill bits as for the Split Set (42.5 – 44.5mm) Use the smaller bits for poor ground.
2. Hammer the bolt fully into the hole (like the Split Set)
   a. Use percussion only – no rotation
   b. Water to be turned on during the hammering (required for cooling)
      Note: Driver and rod must be screwed tight for the first bolt installation
3. Once bolt fully inserted, turn water off and rotate the driver L/H until the drifter stalls
4. Disconnect the driver from the bolt nut

**MD Bolt components tensile strength:**
- Tube: 16t
- Bar: 23t

**Corrosion protection:**
- MD bolts are galvanised

**Low profile bolt head – no bar protrusion below the nut**

**Bolt weight**
- 2.4m - 13.7kg
- 3.0m - 16.7kg

**MD Bolt Pull Testing results – destructive tests**

- Typically 2.4m MD bolts achieved at least 20 t peak anchorage load before they start to slide
- The slide loads are mostly little bit lower than peak load
- Slide loads are most often relatively constant
Pull tests on MD bolts at Copper Cliff Mine

Video: Installation of MD-Bolt

Load V Displacement - Progressive

- Bolt 1
- Bolt 2
- Bolt 3
- Bolt 4
- Bolt 5
- Bolt 6
- Bolt 7
- Bolt 8
- Bolt 9
- Bolt 10
- Bolt 11
- Bolt 12
- Bolt 13
- Bolt 14
In situ dynamic test set-up (Courtesy: Sandvik)

- MD Bolt installed with rock plate and Dynamic collar
- Dynamic claws to allow connection of mass to bolt, Contain the Load cell and Accelerometer to measure load and displacement.
- Drop rod, transfers drop load to Dynamic claws.
- Drop mass, creates the dynamic load
- Load nut, stops motion of drop mass
### In situ dynamic test results on MD bolts
(Courtesy: Sandvik)

<table>
<thead>
<tr>
<th>Bolt Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tr>
<td>Static test torque reading (Nm)*</td>
<td>450</td>
<td>480</td>
<td>480</td>
<td>450</td>
<td>400</td>
<td>410</td>
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<tr>
<td>Static test slip at 5t (mm)</td>
<td>32</td>
<td>18</td>
<td>10</td>
<td>11</td>
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<td>Static test slip at 10t (mm)</td>
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<td>static test slip at 15t (mm)</td>
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<td>29</td>
<td>24</td>
<td>22</td>
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<tr>
<td>Loading mass (kg)</td>
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<td>1238.5</td>
<td>1238.5</td>
<td>1673.5</td>
<td>1388.5</td>
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<td>Drop height (mm)</td>
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<td>1600</td>
<td>1500</td>
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<tr>
<td>Theoretical Impact velocity (m/s)</td>
<td>5.3</td>
<td>5.6</td>
<td>5.4</td>
<td>5.6</td>
<td>5.4</td>
<td>5.4</td>
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<tr>
<td>Theoretical Input energy (kJ)</td>
<td>17.5</td>
<td>19.4</td>
<td>18.2</td>
<td>26.3</td>
<td>20.4</td>
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<td>Time to bring mass to rest (ms)</td>
<td>87.5</td>
<td>33.4</td>
<td>32.19</td>
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<td>Peak input load (kN)</td>
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<td>229</td>
<td>302</td>
<td>342</td>
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<td>Time to peak load (ms)</td>
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<td>Slip (mm) {Accelerometer}</td>
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<td>62.6</td>
<td>125</td>
<td>2384</td>
<td>581</td>
<td>61.6</td>
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<td>Slip top (mm) {REFERENCE ONLY}</td>
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<td>120</td>
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**Bolt #5: before and after drop test**

**Video: In situ dynamic test**
Performance of MD bolts

9510 sill_3710L Before rehab

9510 sill_3710L After rehab

9510 sill_3710L After rehab
Performance of MD bolts

- After introducing MD-bolts, two stopes (9511 and 9512) have been mined out between 3710L and 3880L in the 100/900 OB without any problems.

- Based on visual inspections of the top sill after the stopes were backfilled, it was evident that MD bolts performed very well without any indications of damage during the crown blasts.

- However, destress blasts introduced in the 100/900 OB helped in reducing the major seismicity associated with crown blasts (See re-entry times for the crown blasts before and after destress blasts).

Activity decayed to normal level within 2 hours following crown blast in the 9511 stope.
Conclusions

• MD bolts proved to be very good substitute for D-Bolts (Particularly in rockburst damaged areas, where installation of resin grouted dynamic bolts was challenging).

• Mechanical Dynamic (MD) bolts are easy to install in broken/fractured ground conditions.

• MD Rockbolt is a dynamic bolt which is able to yield and withstand changing ground conditions and provides much higher capacity in terms of pull strength.

• Two stopes have been mined successfully using MD bolt as part of dynamic support system on walls in the highly burst-prone 100/900 OB at Copper Cliff Mine.

• Unlike other friction bolts, the MD bolts have much higher shear resistance, which makes it suitable for use in seismic/burst-prone areas.
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Thank you for your attention!

D Reddy Chinnasane, P.Eng.
Sr. Ground Control Engineer
Copper Cliff Mine

Phone: 705 682 6967
Email: damodara.chinnasane@vale.com