Rockburst Risk Management

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Rockburst Risk Management

- Rockburst Related Losses
- Seismic Monitoring Practice
- Seismic Hazard Quantification
- Seismicity and Mine Design
- Further development
Fatality and injury rates in South African gold mines

Gold - all causes

Per million hours worked

Year

Fatality rate
Injury rate
Fatality rate in all South African mines

All mines - by cause

- Rockfalls
- Transport
- Rockbursts
- Material handling
- Gas/dust/fumes
- Inundation
- Explosives
- Machinery
- Falling into/from
Rockburst Related Losses

Mine X - Deep level gold mine

Panels sets with multiple rockbursts

Number of shifts lost per rockburst

Top five workplaces affected by rockbursts

<table>
<thead>
<tr>
<th>Panels</th>
<th>70/3</th>
<th>92/29</th>
<th>76/34</th>
<th>80/32</th>
<th>82/32</th>
<th>78/17</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBs</td>
<td>30</td>
<td>19</td>
<td>15</td>
<td>13</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>
Rockburst Related Losses

Mine X
Deep level gold mine

Magnitude of damaging seismic events
## Rockburst Related Losses

### Mine X, annual costs of seismicity

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lost Shifts</strong></td>
<td>107</td>
<td>134</td>
<td>144</td>
</tr>
<tr>
<td><strong>F.O.G. area (m$^2$)</strong></td>
<td>1734</td>
<td>3366</td>
<td>1029</td>
</tr>
<tr>
<td><strong>Equipment (R)</strong></td>
<td>202700</td>
<td>286010</td>
<td>135946</td>
</tr>
<tr>
<td><strong>Total incl. injuries (Rm)</strong></td>
<td>7847</td>
<td>7955</td>
<td>4378</td>
</tr>
<tr>
<td><strong>Fatalities</strong></td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Rockburst Related Losses

Quarterly rockburst injuries (Mine X, cases)
Rockburst Related Losses

Major costs are incurred by...

- Injuries, especially fatal (R2m-R6m)
- Temporary loss of production
- Permanent loss of ground
- Rehabilitation costs
- Damaged equipment
In the context of injuries rockburst risk management aims to:

- Recognise the source of damaging seismicity
- Reduce the frequency of rockbursts
- Limit the maximum magnitude of rock mass failures
- Identify site-specific accident scenario
- Protect workers through effective support
- Implement procedures (communication, hazard recognition, making safe, support installation)
Seismic Monitoring Practice


“Identification of seismic hazards and assessments of risks under consideration of all possible relevant information”

“Description of the seismic hazard and/or emission sources in different ground control districts”

“Strategies for seismic energy emission control”
“Identification of seismic hazards and assessments of risks under consideration of all possible relevant information”
“Description of the seismic hazard and/or emission sources in different ground control districts”

**West (District 1):**
Low severity and frequency of seismic hazard, remnant mining (shallower, flatter dipping reef)

**Central (District 2):**
High severity and frequency of seismic hazard, remnant mining

**East & North (District 3):**
Low severity and frequency of seismic hazard, regular and dense mining (deep and steep reef)
“Strategies for seismic energy emission control”
Seismic Monitoring Practice

Standard seismic monitoring objectives

• 24/7 reporting of large events: “Quick Location”

• Short-term seismic hazard assessment of working areas: “Warning”

• Medium-term trend analysis: “Control”

• Input into mine design: “Prevention”

• Major event analysis: “Back-analysis”

Store-forward system (ISS, PRISM)

SM = Seismometer Box
MUX = Multiplexer

Geophone set
## Installation costs
(20 stations, 2005)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 SMs</td>
<td>900 000</td>
</tr>
<tr>
<td>20 sensor sets</td>
<td>175 000</td>
</tr>
<tr>
<td>60 channels</td>
<td>120 000</td>
</tr>
<tr>
<td>12km cables</td>
<td>290 000</td>
</tr>
<tr>
<td>3 Modem racks</td>
<td>105 000</td>
</tr>
<tr>
<td>2 COMs boards</td>
<td>40 000</td>
</tr>
<tr>
<td>RTS</td>
<td>35 000</td>
</tr>
<tr>
<td>XMTS</td>
<td>25 000</td>
</tr>
<tr>
<td>JDi</td>
<td>15 000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 605 5 000</strong></td>
</tr>
</tbody>
</table>
Seismic Monitoring Practice

Sources

- Fault slip
- Shear rupture
- Pillar burst
- Roof collapse
Seismic Monitoring Practice

Radiated wave field
Courtesy Dan Russel
Kettering University
www.kettering.edu/~drussell/demos.html

Ground motion recording
Seismic Hazard Quantification

Moment Tensor

Gutenberg-Richter Graph

Energy-Moment Graph

Time history analysis
Seismic Hazard Quantification

Mine A - Seismic Ratings Table

<table>
<thead>
<tr>
<th>Poly</th>
<th>Last Event Data/Time</th>
<th>Raw Events</th>
<th>Vs</th>
<th>Log</th>
<th>Schmidt</th>
<th>Act</th>
<th>Large events</th>
<th>Current rating</th>
<th>Comments &amp; observations</th>
<th>Signature 1</th>
<th>Signature 2</th>
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</thead>
<tbody>
<tr>
<td>A57_1WMB</td>
<td>2005-04-15 18:31:44</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2.05</td>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A60_023W</td>
<td>2005-04-15 18:30:45</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>M1.0 @15/04/1</td>
<td>7.05</td>
<td>Initial deformation, Act high, Schmidt dropping, M1.0 yesterday afternoon, n/a today</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>A62_5G0E</td>
<td>2005-04-15 12:05:45</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3.05</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>A62_2WEC</td>
<td>2005-04-20 00:47:04</td>
<td>23</td>
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<td>1</td>
<td>1</td>
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<td>M1.2 @19/04/39:59</td>
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<td>Initial deformation and Schmidt low, M1.2 yesterday morning</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>A55_1W4E</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1.55</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>B07_2WEC</td>
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<td>5</td>
<td>2</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>4.50</td>
<td>Accelerated deformation</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>B50_3A_1W</td>
<td>2005-04-15 12:39:43</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.50</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>B55_WTM3</td>
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<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0.50</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>B50_VCDp</td>
<td>2005-04-20 03:32:06</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>1.55</td>
<td>Accelerated deformation</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>B50_3WVE</td>
<td>2005-04-24 04:35:33</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.05</td>
<td>Accelerated deformation and Act increasing</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Daily instability analysis

Hour-of-day distribution
Seismic Hazard Quantification

Month-of-year distribution

BMB: Average monthly events M>=0
7/99 - 5/02

Frequency-severity chart

Emission sources
Seismic Hazard Quantification

Peak Particle Velocity estimate

Possible location of regional failures
Medium-term hazard assessment: Seismic deformation vs. Apparent Stress

Comparative seismic hazard ratings of mining areas (ISSI)
In the context of seismic hazard quantification rockburst risk management attempts to:

- Detect leading indicators of large seismic events
- Identify unfavourable medium-term trends
- Identify hazardous geological structures & critical mine design elements
- Raise awareness of and focus attention on problem areas
- Enable the implementation of precautionary measures
- Quantify the success or failure of remedial actions
There is evidence for a ‘critical pillar width’ at which seismic deformation peaks.
Seismicity and Mine Design

Introduction of 30m strike pillars, reduced dip span from 350 to 180m, lower rate of production and control of abutment lengths.

![Seismicity and Mine Design](image)

Savuka (Scheepers, 2004)
Overhand mining

- violates the mine-to-solid rule,
- creates remnants of continuously decreasing size
- leads to high stress concentration in the abutment.

Seismic energy release per area mined is 70% higher (9 cases).

Normalised cumulative seismic source volume is lower.

Activity rate $M>1$ is roughly equal.
Seismicity and Mine Design

Seismicity on dip stabilising pillars remains within a manageable magnitude range.

Activity is observed up to three raise lines back from current stoping.

No catastrophic foundation failures observed as known from early strike pillar layouts in (ultra) deep longwall mining.
Seismicity and mine design

Intersections of tunnels with active structures below a dip pillar are vulnerable to rockburst damage.
Seismicity and mine design

Mining on different reef horizons

Seismic energy release per area mined is higher on p-reef than on q-reef (sample case, not to be generalised!)
Evaluation of seismic data contributes to rockburst risk management by:

- Quantifying the relationship between production and seismic response
- Identifying mine design elements prone to failure
- Measuring the effectiveness of regional support strategies
- Quantifying the effect of changes to the mining system
- Calibrating rock mass models
Mine seismology will have to face a general increase in mining depth, i.e. stress levels.

Production pressure and the proportion of remnant mining in the overall gold mining output is expected to grow further.
Resources are required for the long-term maintenance of mine seismic networks.
Further development

- Quality of seismic raw data
- Calibration of source parameters
- Success rate of instability analysis
- Planning and upgrade of networks
- Competence in mine seismology of rock engineers & production personnel

A strategic approach to continuous improvement in seismic hazard amelioration needs to be developed and entrenched.