Underground instrumentation and monitoring to determine the interaction of shotcrete and rock under high stress and dynamic conditions

As part of SIMRAC project - SIM 04 02 04

By : Jody Thompson

Independently contracted to SRK Consulting, JHB offices
Objectives

- Identify, establish and instrument and monitor suitable underground test sites that collectively cover high and lower deformation quasi-static as well as dynamic loading conditions.

- Investigate and describe the interaction of the shotcrete and rock at these depths and under these conditions.
Site Monitoring

- Site Investigations (crack mapping)
- Detailed photographic records
- Numerical Modelling (Map3D)
- Instrumentation (Sidewall deformations & strain)
- Seismic network
Site Instrumentation

- Laser range finder
- Peak velocity detectors (PVD)
- Strain gauges
- Borehole Extensometers (SPBX, MPBX)
- Ground Movement Monitor (GMM)
# Site contributions

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Refer to Table 4.2 in paper
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South Deep site 2

- VCR only
- Massive ore body
- Quartzite
- Lava
- Test sites

Narrow tabular de-stress and fill

SITE 2

Massive mining – mechanised drift and fill

Rock breaker and bp area

Test site 1

Test site 2

Extracted and filled
Remaining pillars

SITE 2

Massive mining –
mechanised drift
and fill
Discussion points

• Primary vs. Secondary stages of failure
• Blast induced deformations
• Common modes of failure
• The interaction of shotcrete and rock at depth
Discussion points

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Instrumentation results

Pillar B

Displacement (mm)

Modelled APS (Npsi, PPV (cm/s))

- GMM displ. (3.8m)
- SPBX displ. (3.8m)
- MPBX displ. (2.8m)
- MPBX displ. (1.8m)
- Laser displ. (T2)
- Laser displ. (M2)
- Average pillar stress
- Recorded PPV’s from PVD
Instrumentation results

Pillar B
Detailed crack mapping

- Remaining pillars
- Final pillars
- Mined and oxidised
- Chosen instrumentation walls

Graph showing:
- 25mm resin grouted rebar
- 0.50m Scaling around tendon
- *(4.08m)* Measured elevation above "grade" line
- Fault

Drift 4

HW

(3.17 m?)

(3.40 m)

(3.60 m)

(3.57 m)

(3.46 m)

(3.60 m)

(4.08 m)

(4.22 m)

(4.17 m)

(3.98 m)

(4.06 m)

(4.18 m)

FW

(-1.8 m - estimated)

SOP

0

1

2

3

4

5

6

7

8

9

10

EOP

0.50 m
Def vs. damage – 26 April 2007

Mining of Drift 6

Seismic event

GMM

Primary cracks
Def vs. damage – 19 June 2007

Primary cracks

Remove bench 6
Def vs. damage – 29 July 2007

Start of drift 4

Primary cracks
Def vs. damage – 9 Aug 2007

The shotcrete enters a secondary stage of failure

Start of drift 4

Passing of drift 4 and formation of loose slab

4 Aug 2007

Cracks join

Loose slab

MHSC
Slab formation

Formation of loose slab on 4 August 2007

Primary stage of failure

Secondary stage of failure

3.3 cm/day

0.6 cm/day

1.16 mm/day

0.22 mm/day
Primary vs. Secondary stage failure

- Two distinct stages of shotcrete failure are identified.
  - In the **primary stage**, isolated primary cracks form at random positions on a monitored face. Primary cracks are independent of one another and the performance of shotcrete is not believed to be significantly affected during this stage.
  - Once primary cracking has propagated far enough, shotcrete failure enters a **secondary stage**. Secondary failure involves the joining or interaction of primary cracks after which sidewall deformations are noted to increase significantly. The onset of the secondary stage of failure is believed to be a good indicator that the support capacity of applied shotcrete has been compromised.
Discussion points

• Primary vs. Secondary stages of failure
• Blast induced deformations
• Common modes of failure
• The interaction of shotcrete and rock at depth
Blast induced deformations

Seismic event of $M_s = 0.8$
Calc. PPV = 4.3 mm/s (largest)

Seismic event of $M_s = 0.3$
Calc. PPV = 1.1 mm/s

Nearby Drift blasts

Loose slab
4 August 2007

GMM deformation

Measured PPV
Blast induced deformations

Instantaneous closure in a stope after a blast (Malan, 2003)

Instantaneous sidewall displacement after a blast (SD Pillar B)
Conclusions

• Strong ground motions from nearby blasting can result in significant jumps in sidewall deformations. These jumps closely resemble the recorded response of closure in a tabular stope after a blast as proposed by Malan (2003)

• Other topics available in the paper are
  • Analysis of a very large and nearby bench blast
    • The vibrational intensity of an event and its influence on deformations
  • Analysis of seismicity at Mponeng mine
    • Relationship between PPV and induced deformation
Discussion points

- Primary vs. Secondary stages of failure
- Blast induced deformations
- Common modes of failure
- The interaction of shotcrete and rock at depth
Loss of adhesion is expected
P&S Crack interactions are common

Secondary cracks

Primary cracks

Flexural failure
Secondary crack formation

Typical flexural failure

- Distributed load
- Compression
- Direction of crack propagation
- Tension
- Propagating crack
- Forming secondary crack
Discussion points

- Primary vs. Secondary stages of failure
- Blast induced deformations
- Common modes of failure
- The interaction of shotcrete and rock at depth
MPBX reactions

Almost all the deformation occurs in the first 1.8 m depth

Sudden increase on 4 August 2007 corresponding with the joining of cracks within the shotcrete

8mm
Role played by shotcrete

Loose slab
Role played by shotcrete
Mechanisms of primary failure

Case 1
Failure driven primarily by movements from near zone dilation
Very common during the secondary stage of failure but also possible during the primary stage

Case 2
Failure driven primarily by movements from far zone dilation
Expected where the fracture zone extends past the working tendon length.
Shotcrete is pulled apart as larger portions of the sidewall deform.
Mechanisms of secondary failure

Front view
Primary failure

Sectional view
Secondary failure

Example

- Adhesion failure
- Flexural failure
- Punching shear failure
- Loss of adhesion and squeezing of crushed rock

Legend:
- Shotcrete lining
- Intact rock
- Crushed rock
Conclusions

- Shotcrete has been shown to work well in the following situations
  - Where spalling is a concern (reinforced shotcrete is recommended at deep level stresses whilst un-reinforced shotcrete appears adequate at intermediate depths).
  - Where large seismic events are expected in the far field. Events close to a working place will result in failure of shotcrete.
  - Under any other condition in which the failure of the shotcrete can be limited to the primary stage.