ROCK SUPPORT SYSTEM IN INTERACTION WITH THE ROCK

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Rock mass – rock support interaction
Objective

General
• Improve the understanding of the interaction between the rock mass and the rock support system

Mining companies
• Reduction of the number of production disturbances, thereby decreasing the risk for personnel injury and production losses.
Project outline

• Sub project
  – Weak ore contacts and large deformations
  – Mining-induced seismicity

• Main activities
  – Field measurements – tests
    • Kristineberg – Boliden: ~1200 m depth (has been done)
    • Malmberget – LKAB: ~850 m depth (Instrumentation starts 2011)
    • Optional: Garpenberg – Boliden
  – Large scale field test - seismically loaded rock support
    • Kiirunavaara mine (has started)
  – Numerical analyses
    • Conceptual analyses (has started)
    • Analyses of field experiments (has started)
Behaviour of drifts in weak rock
Squeezing conditions – Malmberget mine

Photo: LKAB
Mica-rich host rock – Malmberget mine
Field monitoring – Weak rock
Field test on rock support in the Kristineberg mine (March 2010)

• Objective
  – Increase the understanding of the interaction: rock - rock support system
  – Evaluation of the D-bolt in the field

• Details
  – Stope length 50 m
  – Every second round D-bolt and every second rebar
D-bolt

O-anchor D-Bolt

W-anchor D-Bolt

Overall length

Thread | Section 0 | Section 1 | Section 2 | Section 3
Damage in boreholes and in the footwall

Footwall

Footwall

Hangingwall

Cut #4
Additional measurements

- Cut #4: Max = 80 mm
- Cut #5: Max = 160 mm

Maximum convergence in Cut #4

Convergence
- Cut #4: Max = 80 mm
- Cut #5: Max = 160 mm
Numerical analysis of static conditions
3D numerical analysis of laboratory tests

- Evaluation of models for modelling of shotcrete – rock interaction
  
  \[ \text{Shear stress} \]
  
  \[ \text{Shotcrete} \]
  
  \[ \text{Rock block} \]

- Evaluation of models for rock – rock bolt interaction
  
  \[ \text{Rock bolt} \]
Not "normal" profile

1 – 10: Rounds

"Normal" profile
Analysis of the experimental stope – Cut #4
2D ("Pseudo 3D") - Ongoing
Analysis of the experimental stope – Cut #4
2D ("Pseudo 3D") - Ongoing

Sensitivity analysis of geometry
Analysis of the experimental stope – Cut #4

2D ("Pseudo 3D") - Ongoing
3D – Will start later

Sensitivity analysis of geometry
Sub-project: Mine-induced seismicity
Different source mechanisms

Fault slip/Shear rupture

Strain burst
Mining induced seismicity

- Strain bursts due to high statoc stresses
- Fault slip event
  - Superposition of static and dynamic stresses ⇒
    Higher stress level exceeding the compressive strength
  - Shaking ⇒ Block and wedge fallouts
  - Ejection (Close to fault slip event)
Test site – Cross-cuts in the Kiirunavaara mine

- Compare different support systems
- Demonstrate the capacity of the support system
- Is carried out during 2010 and 2011
- A military explosive, NSP 711, is used to reduce influence of gas pressure

The dynamic load is simulated by blasting.

High speed camera

Tested support system

Blast hole

3 m 7 m 3 m
Field test – dynamically loaded rock support

• Trial test
  – Objective: Design of the test ⇒
    Critical charge density and evaluation of instrumentation

• Main test (stage 1)
  – Objective: Test of the standard support used at LKAB.

• Main test (stage 2)
  – Objective: Test of yielding rock bolts with the standard surface support.

• Main test (stage 3)
  – Objective: Compare different surface support
    The rock bolt is the best one in Stage 2
Zero test 1
Zero test 1

- **Detonation** (NSP 711)
  - Gas pressure
    - The shock wave load < 1 ms after initiation.
    - Gas pressure loading ≈ 36 ms after initiation

- **Acceleration, velocity and displacement**
  - Maximum average-PPV 5.6 m/s
  - Deformation < 70 mm

- **What did not work as planned?**
  - The largest charge diameter (Ø76 mm) gave only limited damage to the rock support
    ⇒ Charging too small
Zero test 2, 3 & 4

• Zero test 2 (NSP 711)
  – The larger charge increased with 62% (6 inch hole diameter)
  – The smaller charge = the larger in Zero test 1
  – Result - Somewhat more cracks
Zero test 2, 3 & 4

• Zero test 2 (NSP 711)
  – The larger charge increased with 62% (6 inch hole diameter)
  – The smaller charge = the larger in Zero test 1
  – Result - Somewhat more cracks

• Zero test 3 (Bulk emulsion)
  – The 6-inch hole in Zero test 2 was re-charged with bulk emulsion
    ≈ 25 kg/m ≈ 190% greater than the charge in Zero test 1
  – Result - Ejection
Total damage after Zero test 3
Zero test 2, 3 & 4

• Zero test 2
  – The larger charge increased with 62% (6 inch hole diameter)
  – The smaller charge = the larger in Zero test 1
  – Result - Somewhat more cracks

• Zero test 3
  – The 6-inch hole in Zero test 2 was re-charged with bulk emulsion
    ∼ 25 kg/m ∼ 190% greater than the charge in Zero test 1
  – Result - Ejection

• Zero test 4 (NSP 711)
  – Only one charge density ∼ 133 % higher than in Zero test 1
Damage after Zero test 4
Summary Zero tests

• Ejection
  – occurs when the charge of NSP711 with a diameter of 120 mm is used (the length is 5 m)
  – does not occur when the charge diameter is 98 mm

• The position of the camera has to be changed to avoid vibrations from blast gases from the collar of the blasthole

• We know the way we will measure the deformations and damage
Numerical analysis of dynamic problems
Numerical analysis of large-scale dynamic tests

Blasthole

$P(t)$

0.12 m

60 m

60 m

60 m

7 m

6 m
Numerical results — Stress
Numerical results — Stress

UDEC (Version 4.01)

LEGEND

- 2-May-11 15:03
- cycle 102212
- time = 1.799E-04 sec
- block plot
- principal stresses
  - minimum = -2.897E+09
  - maximum = 1.250E+07
- 0 1E10

LTU
Numerical results — Stress

UDEC (Version 4.01)

LEGEND
2-May-11 15:16
cycle 105183
time = 4.199E-04 sec
block plot
principal stresses
minimum = -4.543E+08
maximum = 1.250E+07
0 2E 9

LTU
Numerical results — Stress

UDEC (Version 4.01)

**LEGEND**

- 2:May-11 15:44
- cycle 111085
- time = 5.998E-04 sec
- block plot
- principal stresses
  - minimum = -4.690E+08
  - maximum = 1.248E+07
- 0  2E  0

LTU
Numerical results — Stress

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**LEGEND**

- 2-May-11 16:46
- cycle 122869
- time = 1.860E-03 sec
- block plot
- principal stresses
  - minimum = -4.294E+08
  - maximum = 1.250E+07

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\[ \text{maximum} \]
Numerical analysis of seismically loaded openings

- Response of a drift exposed to different wave types

- Response of drifts exposed to seismic loads
...Thank you!!
Presentation of the project idea

• Conferences etc.
  – Bergforskdagen 2010
  – SOMP Annual Meeting, Tallinn, Estonia, June, 2010
  – Sonora Mining Expo, Oct., 2010
  – Workshop at the 2nd Australasian Ground Control Conf., Nov., 2010
  – Bergmekanikdagen, March, 2011

• Universities, companies etc.
  – University of Zambia, May, 2010
  – Polytechnic of Namibia, June, 2010
  – University of Dar es Salaam, Sept., 2010
  – Laurentian University Oct., 2010
  – Grupo Mexico, Mexico City, Oct., 2010
  – CFE, Mexico City, Oct., 2010
Field test – dynamically loaded rock support

Trial test

- Support system tested = Standard support in seismically active areas
  - 100 mm fibre reinforced shotcrete (40 kg/m³ - steel fibre)
  - Welded steel mesh, f=5.5 mm c/c 75 mm
  - Friction bolt Swellex Mn24 c/c 1 m
Field test – dynamically loaded rock support

Main test (stage 1)

• Surface support
  – 100 mm fibre reinforced shotcrete (40 kg/m³ - steel fibre)
  – Welded steel mesh, f = 5.5 mm c/c 75 mm

• Rock bolts
  – Grouted rock bolt, Kiruna bolt M20 c/c 1m
  – Friction bolt Swellex Mn24 c/c 1 m
  – $\phi$ 15.2 mm Cable bolt c/c 1m
Field test – dynamically loaded rock support

Main test (stage 2)

• Surface support
  – 100 mm fibre reinforced shotcrete (40 kg/m$^3$ - steel fibre)
  – Welded steel mesh, $f = 5.5$ mm c/c 75 mm

• Rock bolts
  – Yielding bolt No.1 c/c 1m
  – Yielding bolt No.2 c/c 1m
Field test – dynamically loaded rock support

• Main test (stage 3)
• Rock bolts
  – “The best” yielding bolt c/c 1m
• Surface support
  – Welded steel mesh, f = 5.5 mm c/c 75 mm +
    • 100 mm fibre reinforced shotcrete (12 kg/m³ - polypropylene fibre),
    • 50 mm fibre reinforced shotcrete (12 kg/m³ - polypropylene fibre),
    • Nothing
  – 50-100 mm fibre reinforced shotcrete – from MIGS test
  – 3M TSL (Sponsored by Canadian Deep Mining Research Project)
Example: Measurement profiles

- High density profile: 4 and 7, D-bolt
- D-bolt with strain gauge
- Extensometer profiles 3-4 och 6-7
- Convergence measurements with tape extensometer
- Measurement points for totalstation
- 6 m extensometer

Image credit: Vinnova, Boliden, HLRRC, LKAB