NUMERICAL INVESTIGATION OF ROCK SUPPORT ARCHES

By

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PROBLEM STATEMENT

- Cut-and-fill and/or drift-and-fill is the most expensive of the underground mining methods
- Boliden (Swedish mining company) uses a variant of the C&F mining method called “Rill Mining” (a method with Austrian roots) to mine much of the VMS style polymetallic deposits in Sweden in extremely poor ground conditions (weak host rock in high rock stress environment)
  - In this method the stope heights are typically limited to 10 to 15m
- Because of the ever increasing costs Boliden has been contemplating the idea of modifying the Rill Mining method to help reduce costs
  - One approach is to improve the ground support system to achieve higher stope heights and thus the idea of using timely installation of ***rock support arches***

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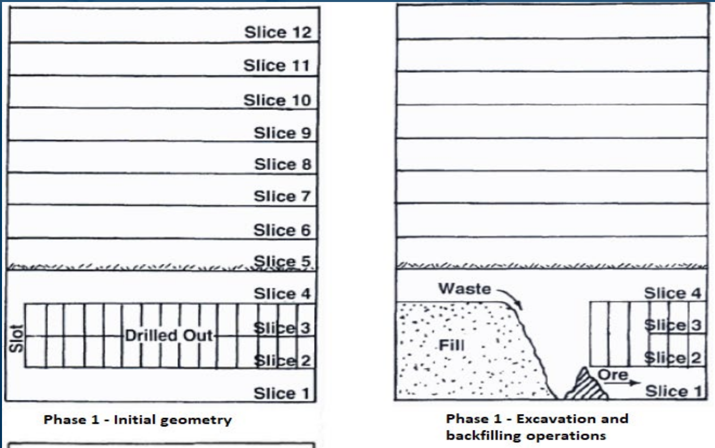
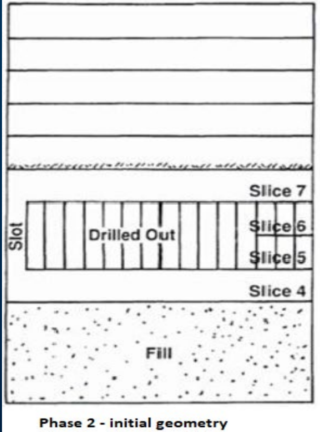
RILL MINING

(A MODIFIED/HYBRID VERSION OF C&F AND AVOCA)



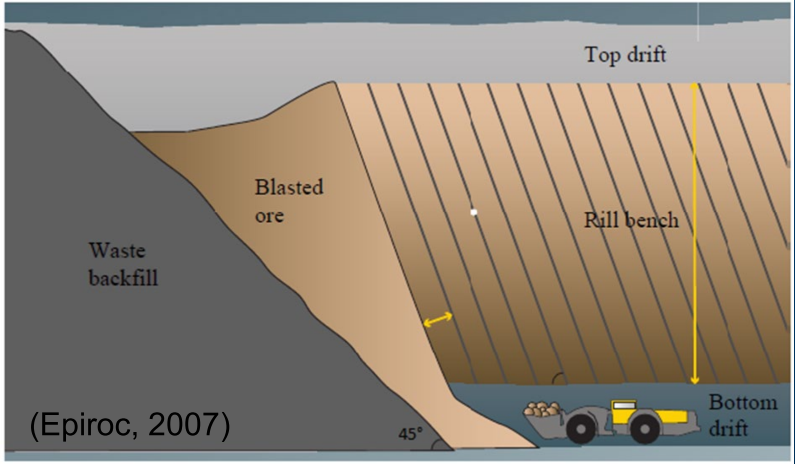


Typical slice dimensions

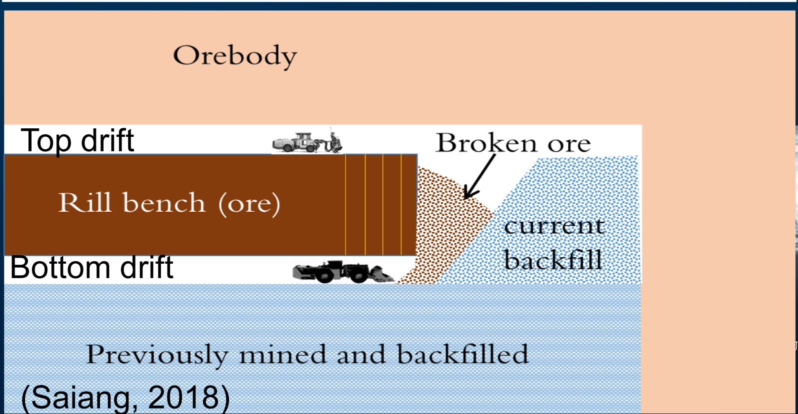
- width: 6-8m
- Length: 100m
- Height: 5-6m

Question:
Can we get more slices in rill bench while maintaining stability?

(Hustrulid, 2001)



(Epiroc, 2007)



(Saiang, 2018)

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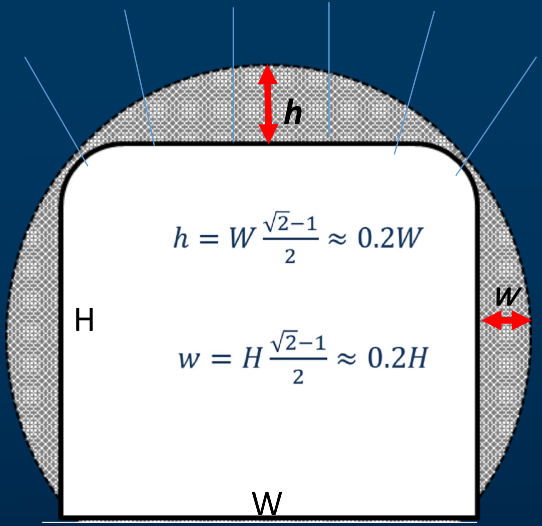
ROCK SUPPORT ARCHES

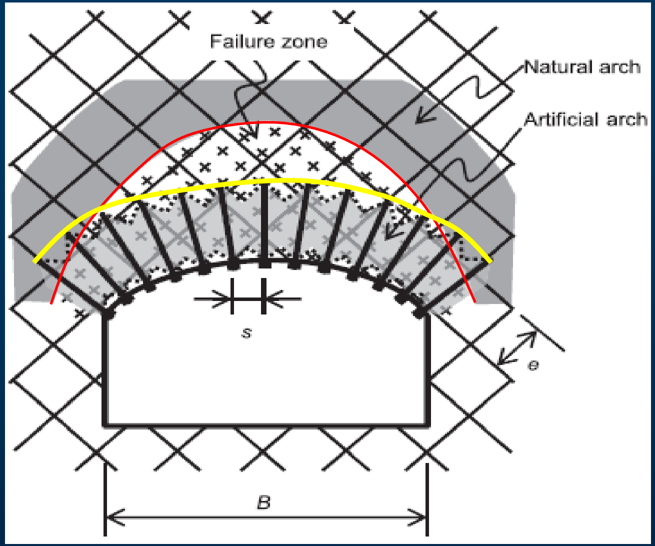
Concept of natural and artificial arches

Natural arch



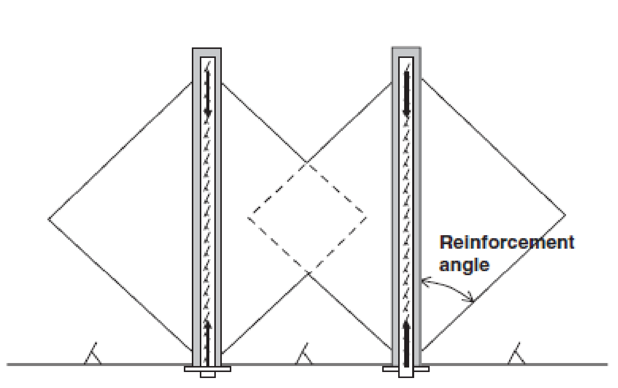
Kaiser et al (1996)

Artificial pressure arch



Stillborg (1996)

Spacing of rock bolts – essential for artificial arch formation



Li (2006)

$$\sigma_{max} = 0.9 \times \sigma_c \times \left(\frac{e}{B}\right)^2$$ (Krauland N., 1983 & Sihna R.S., 1989)

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INVESTIGATION OF ROCK SUPPORT ARCHES

- Numerical Modelling
  - To guide field investigation
    - spacing of rock support arches
    - Trial stope dimension (width, length and height)
  - To validate results from field investigation
    - spacing of rock support arches
    - Trial stope dimension (width, length and height)
- Field Investigation at Boliden’s Garpenberg Mine
  - Period of investigation: 2017 and on-going
  - Benching completed in September 2019
  - Rill bench tested – 20 m
- Implementation and design

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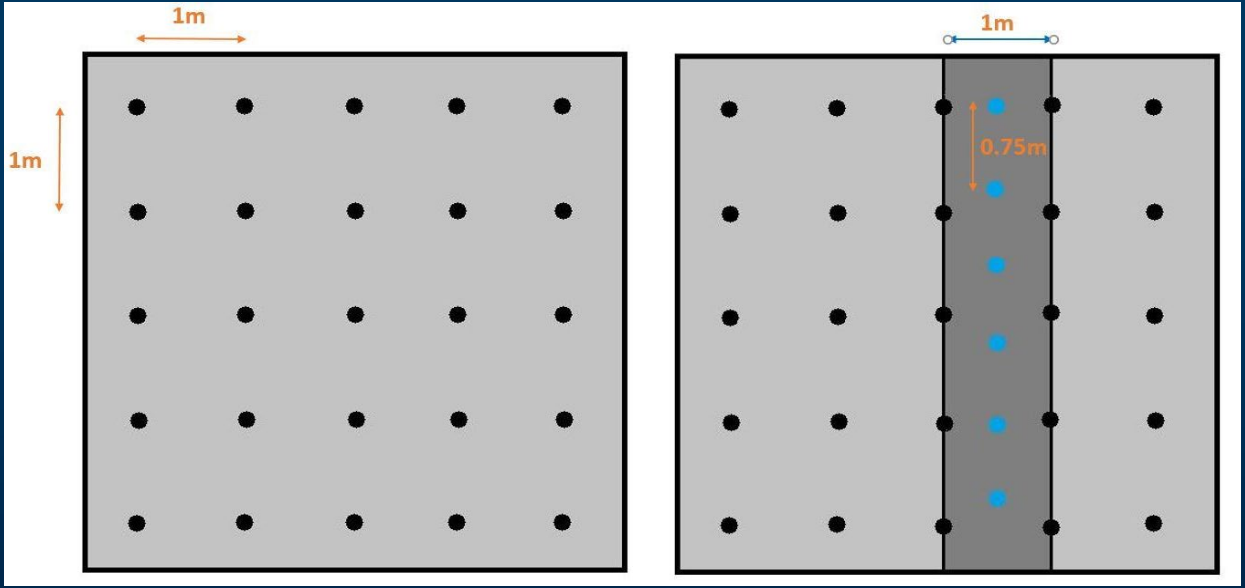
ROCK SUPPORT ARCH TESTING SCHEME – ON BOTTOM DRIFT



Routine support installation

Shotcrete-rockbolt arch installation

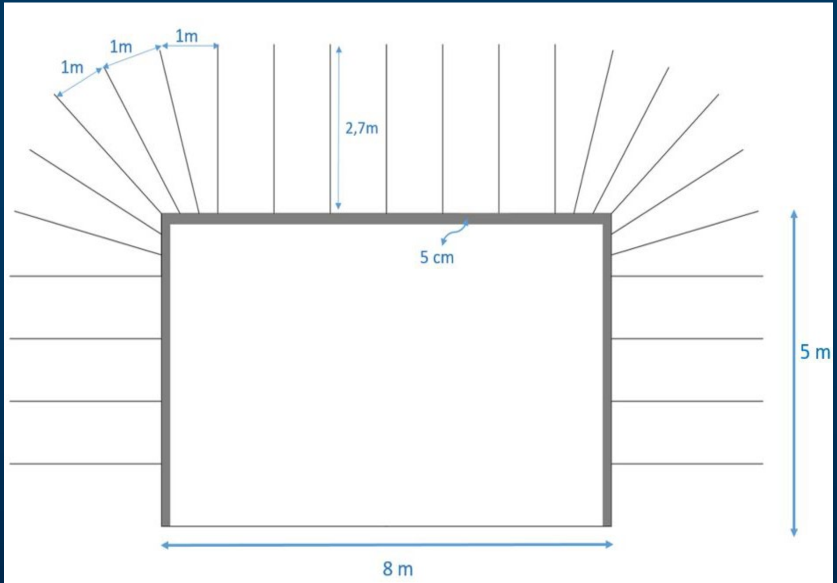
Routine support installation

- 2.7 m rock bolts
- 1 m x 1 m spacing
- 5 cm thick shotcrete

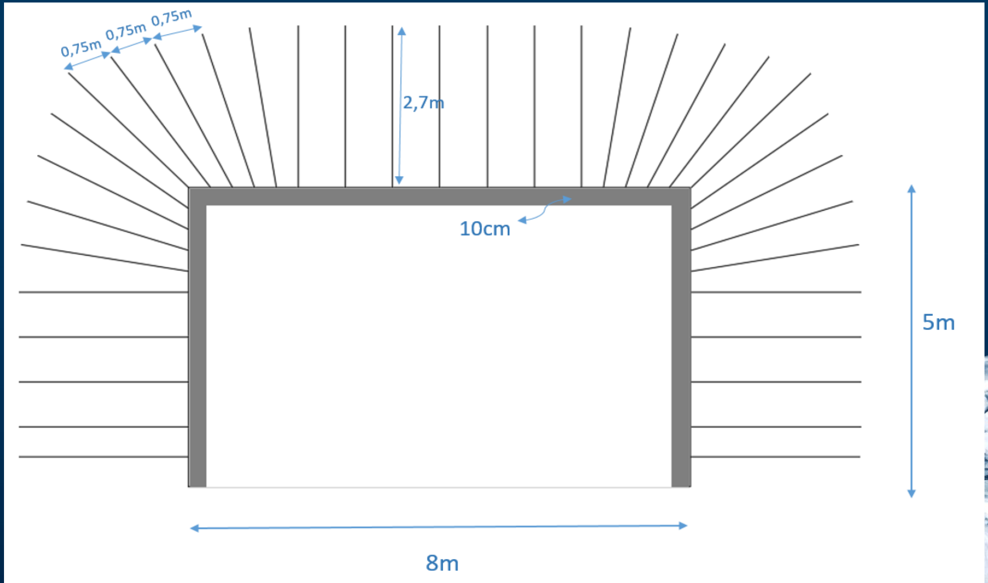
Rock support arch scheme

- 0.75 m in plane
- 6 or 3 m out of plane
- 10 cm shotcrete

ROCK SUPPORT ARCH CROSS-SECTION



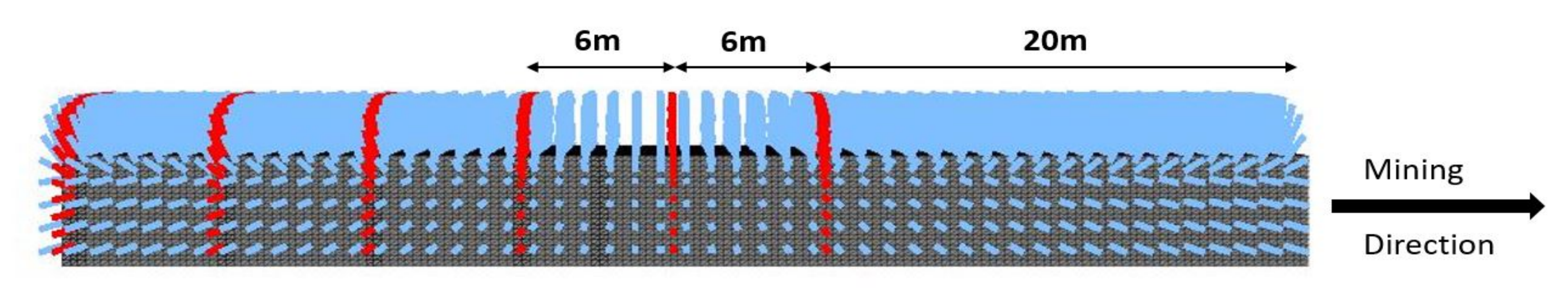
Routine support installation

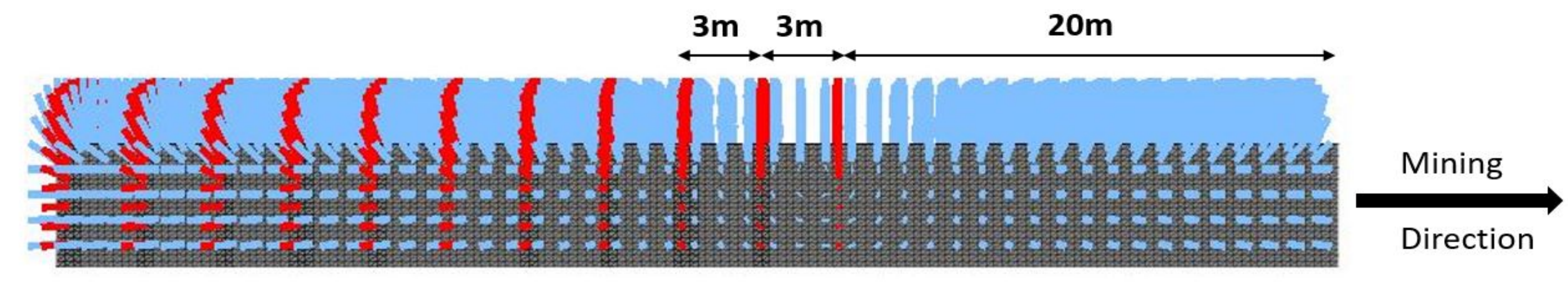


Arch scheme

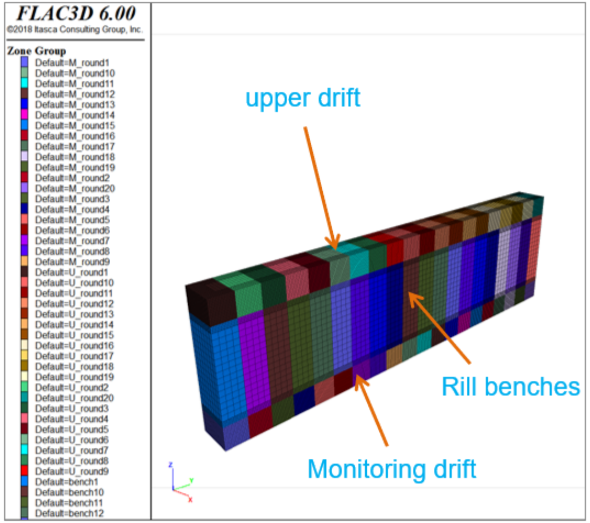
A high precision (laser guided) bolting rig is used in rock bolt installation

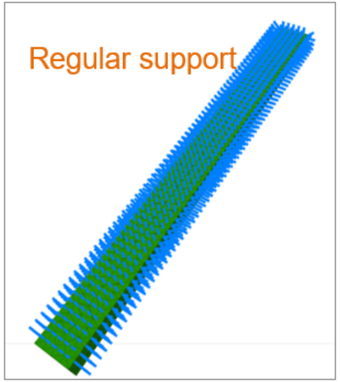
ROCK SUPPORT ARCHE INSTALLATION

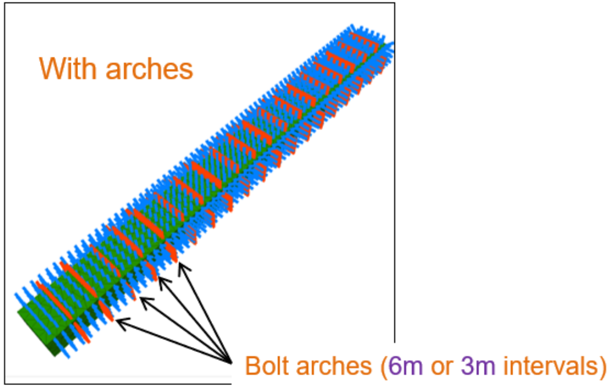




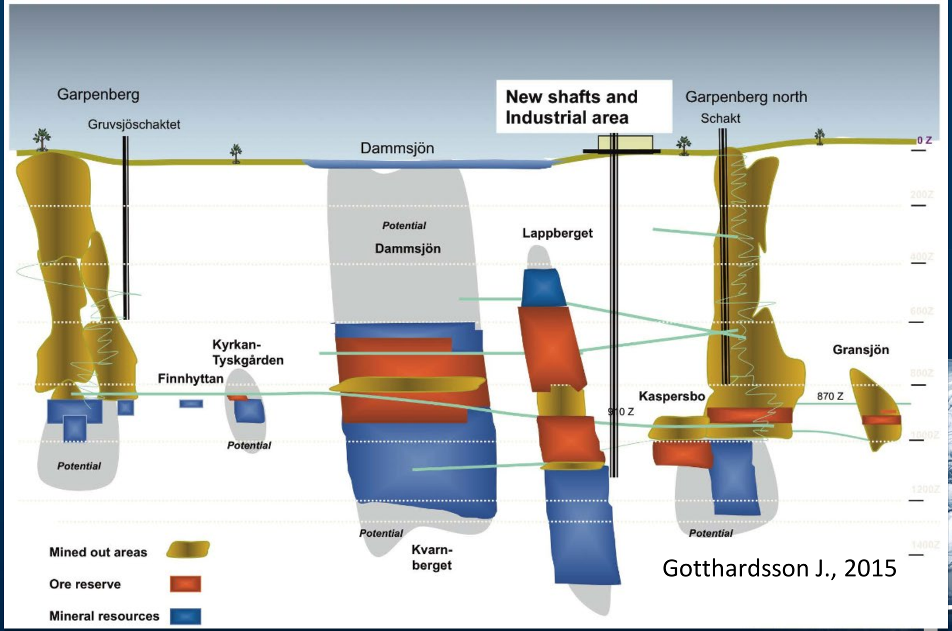
ROCK SUPPORT ARCHE INSTALLATION



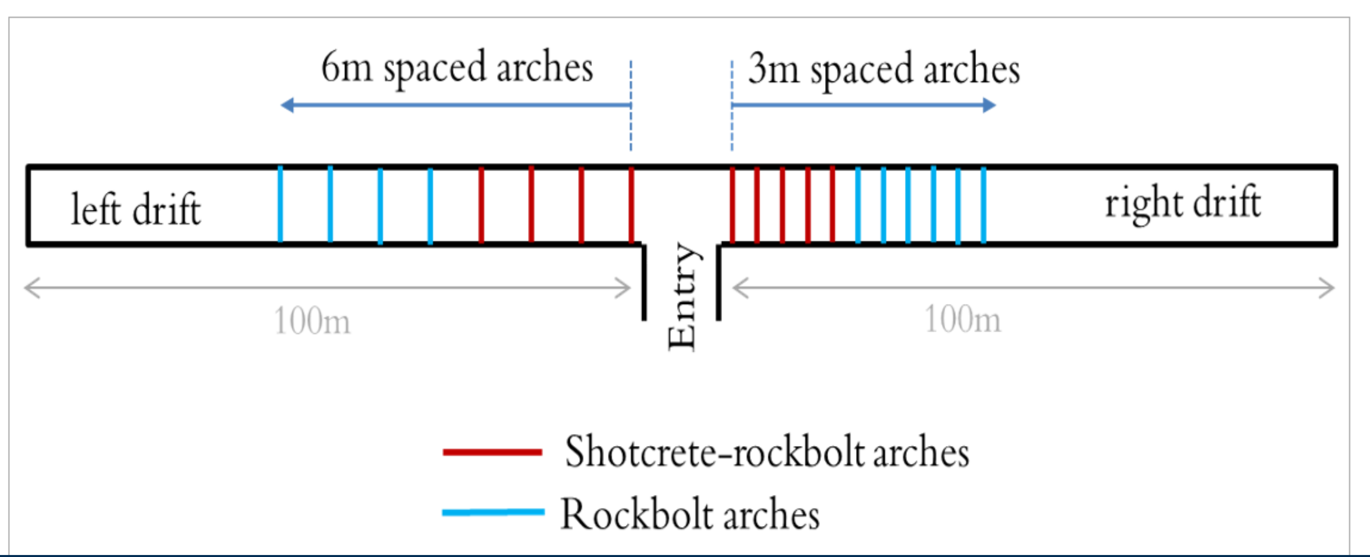




FIELD TRIAL SITE - DAMMSJÖN OREBODY (GARPENBERG MINE)



TRIAL SCHEME



- Test area
  - 882m Depth
  - 25 m rill stope height
  - Different support patterns (3 m and 6 m spaced arches)
- Instrumentation
  - Extensometers in roof and walls
  - Instrumented rock bolts
  - Total station survey + prism survey
  - Borehole camera survey

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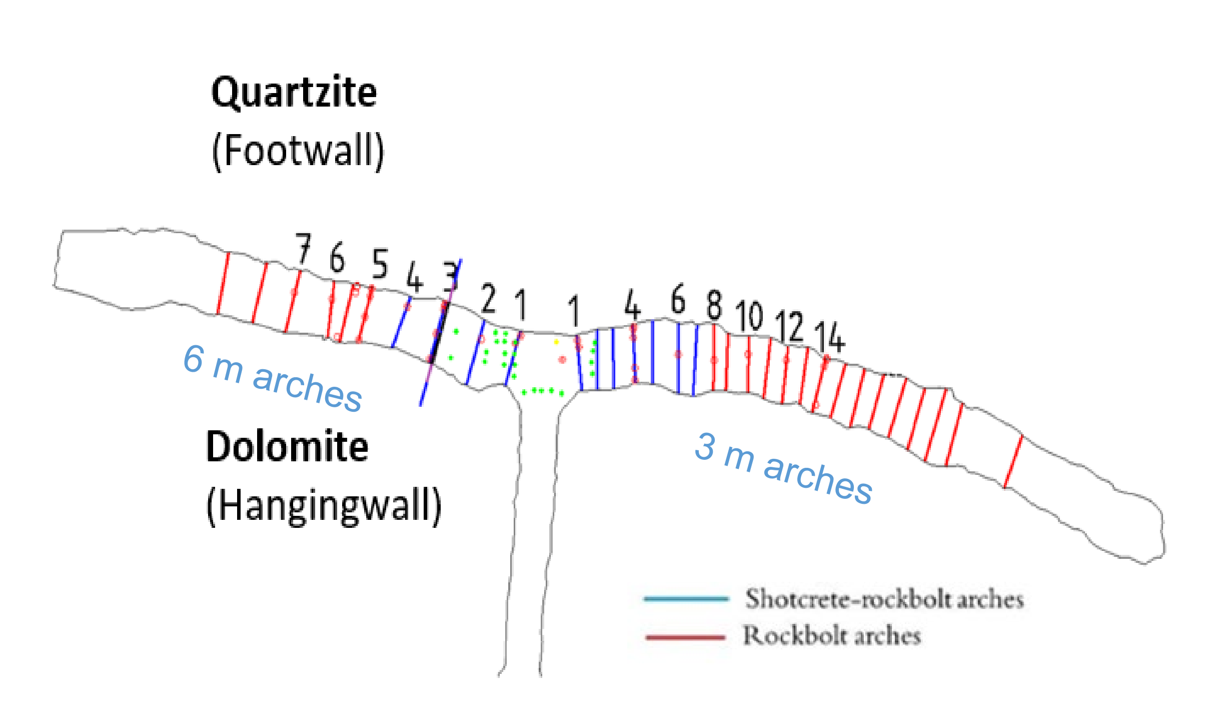
TRIAL IMPLEMENTATION



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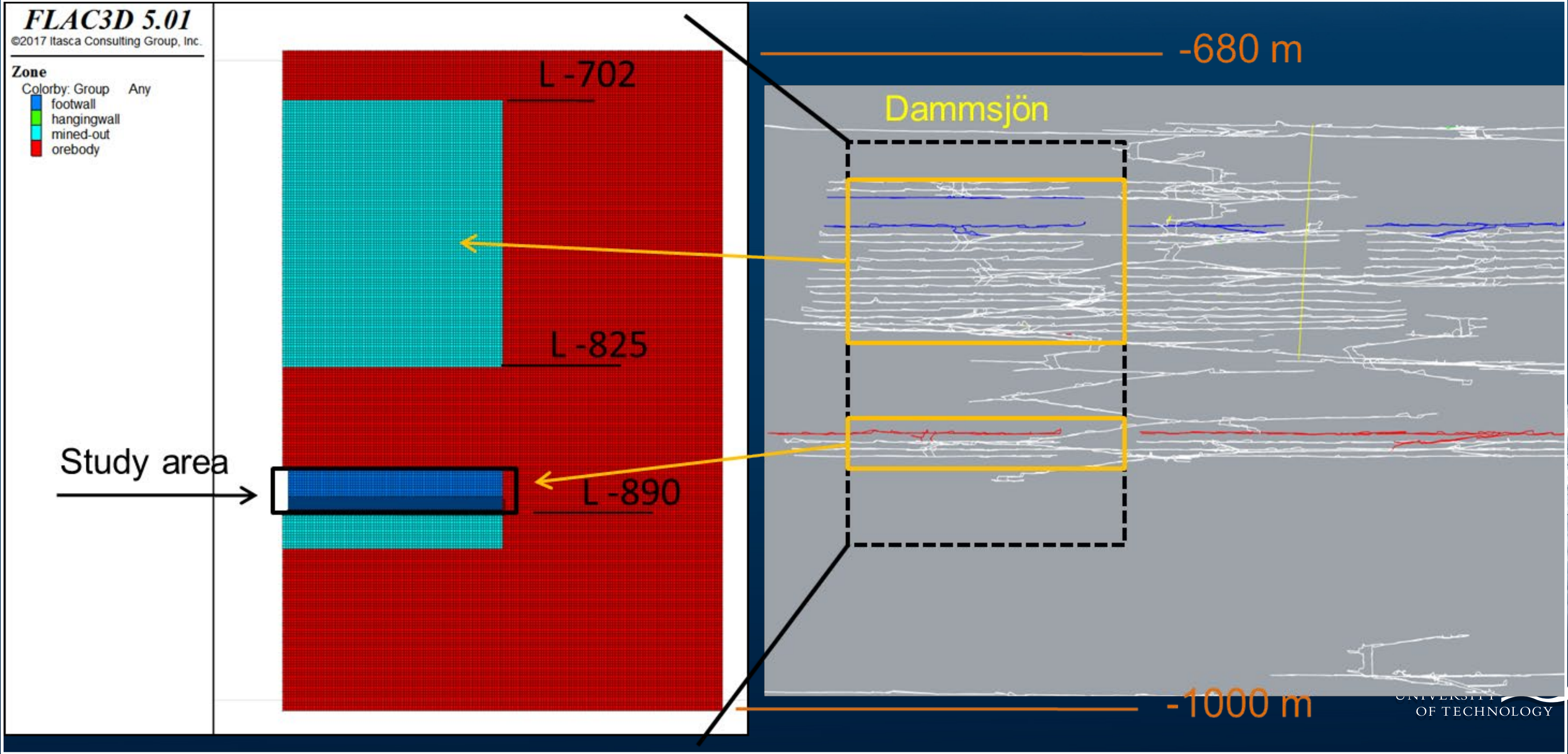
FLAC3D MODELLING



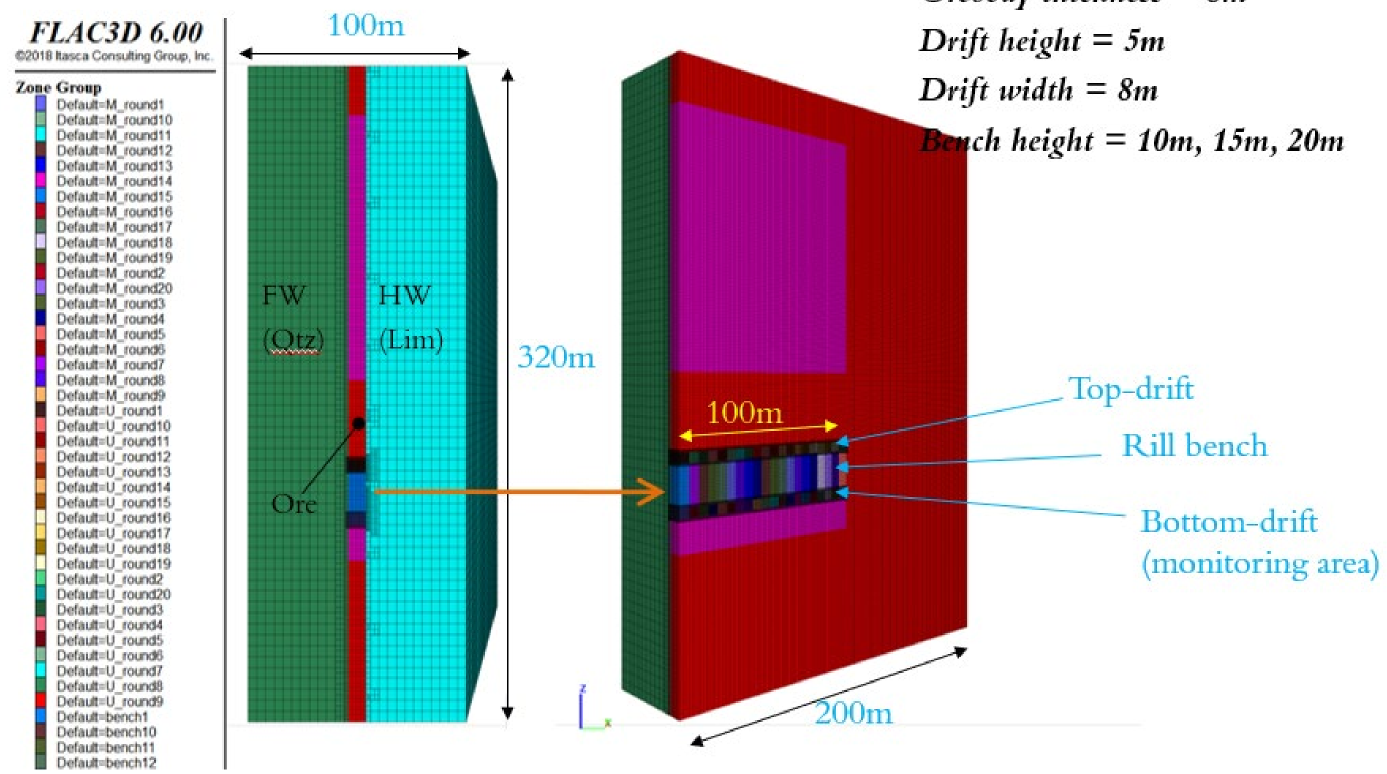
FLAC3D MODEL SETUP

Orebody thickness = 8m

Drift height = 5m

Drift width = 8m

Bench height = 10m, 15m, 20m



FLAC3D MODEL FEATURES

Shotcrete shell added

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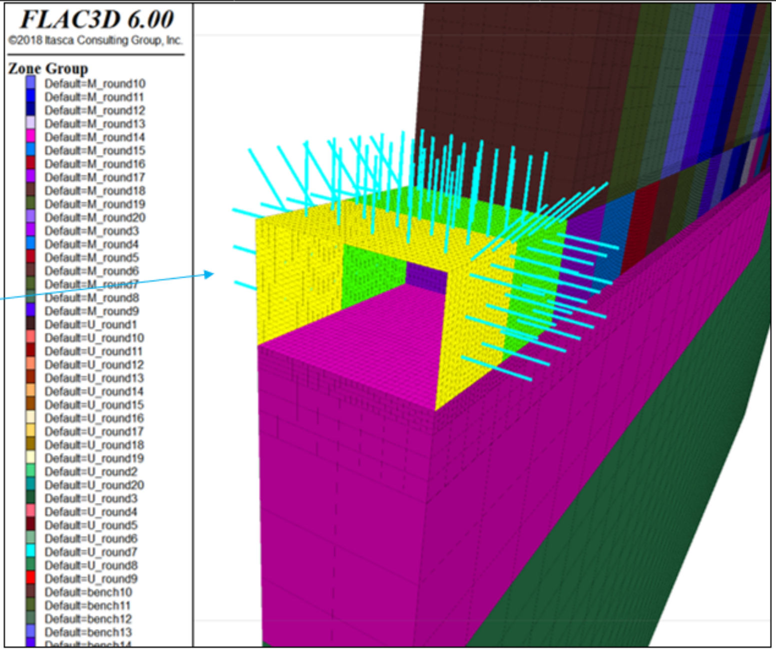
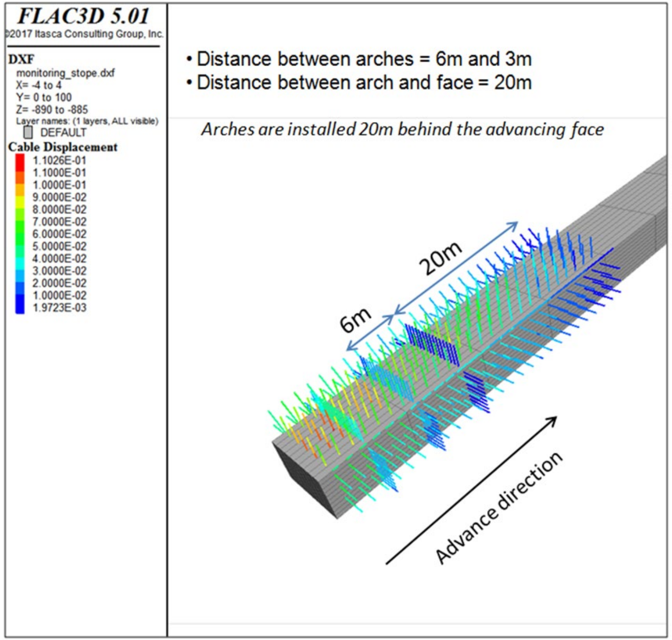


Shotcrete-rockbolt support systems

"excavate relax" sequence is used to eliminate "shock loads" on the support system

A new layer of shotcrete can added to create shotcrete-rockbolt arch



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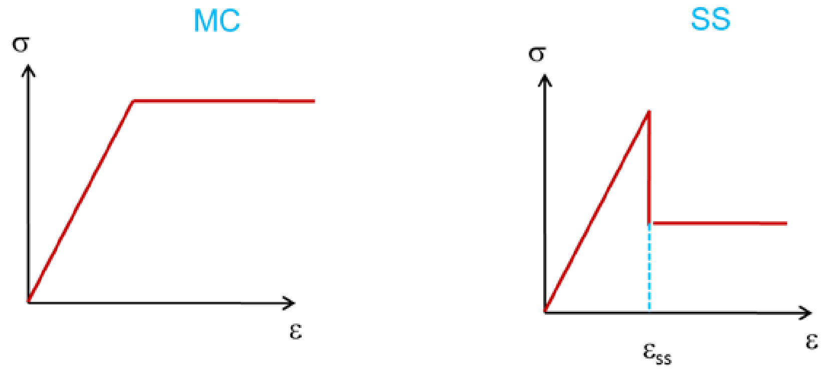
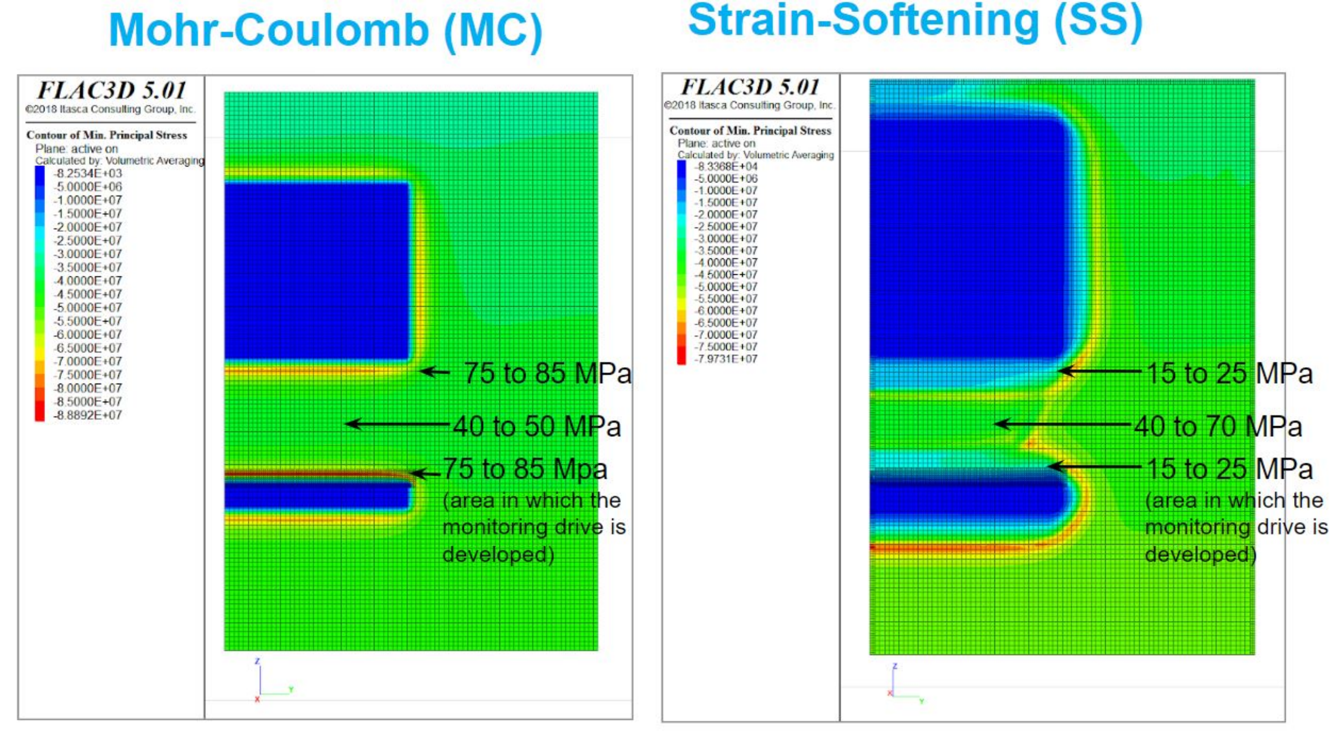
MODELLING APPROACH

- The first stage of the modeling was in done 3DEC. It became clear it wasn't efficient. So FLAC3D was the next best option.
- The first stage of modeling were done utilizing the Mohr-Coulomb (MC) constitutive model. The results were not consistent with field observations.
- Hence, the Strain Softening (SS) constitutive model was utilized. The results became consistent with field observations.
- The initial MC models were used as a guide for chosing the strain for reducing the material properties.



- Code:
  - 3DEC
  - FLAC3D
- Constitutive Model
  - Mohr-Coulomb
  - Mohr-Coulomb-Strain-Softening

RESULTS FROM TESTIN CONSTITUTIVE MODEL



(Saiang, 2019)

STRESS ANALYSES

Boliden’s engineers confirm that the strain-softening model gives stress observation results that conform to experience.

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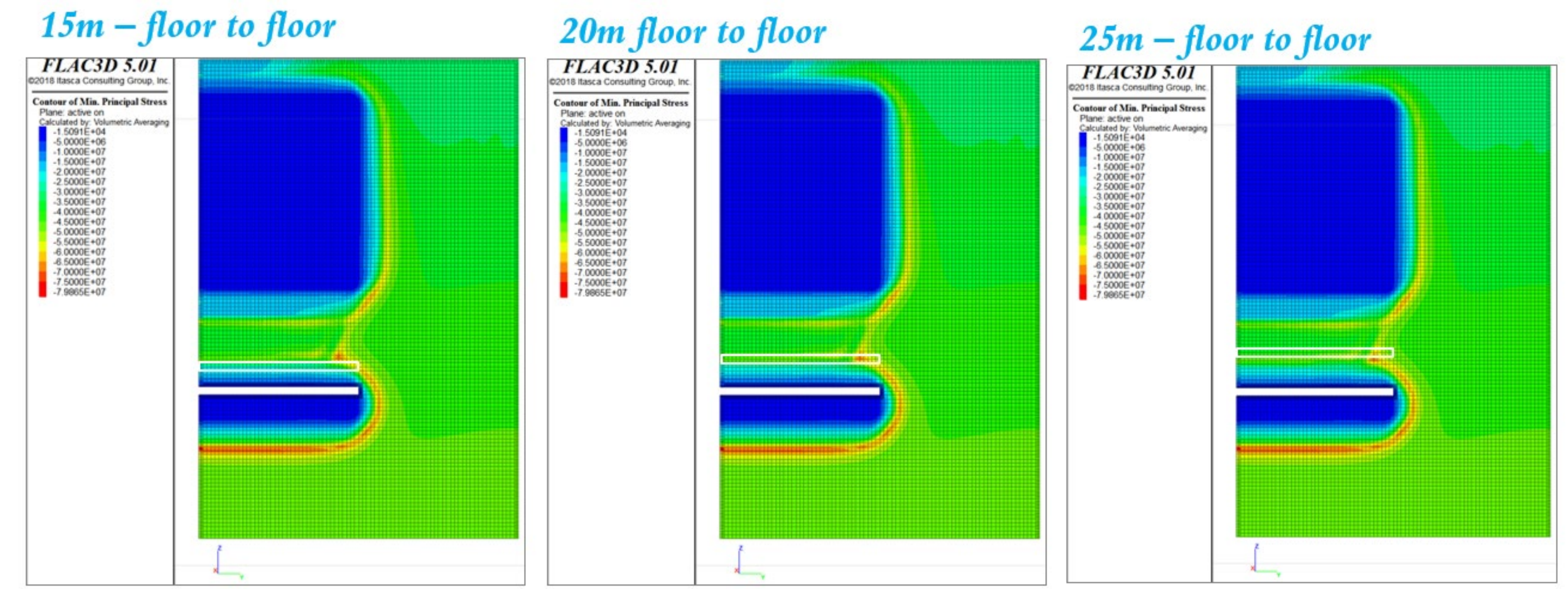
INDUCED STRESSES FOR DIFFERENT RILL STOPE HEIGHTS



- *Drift developed in a 15m rill stope height is <u>within the area of stress influence</u> from the development of the bottom drive*
- *Drift developed in a 20m rill stope height is <u>on the edge of the area of stress influence</u> from the development of the bottom drive*
- *Drift developed in a 25m rill stope height is <u>outside the area of stress influence</u> from the development of the bottom drive*

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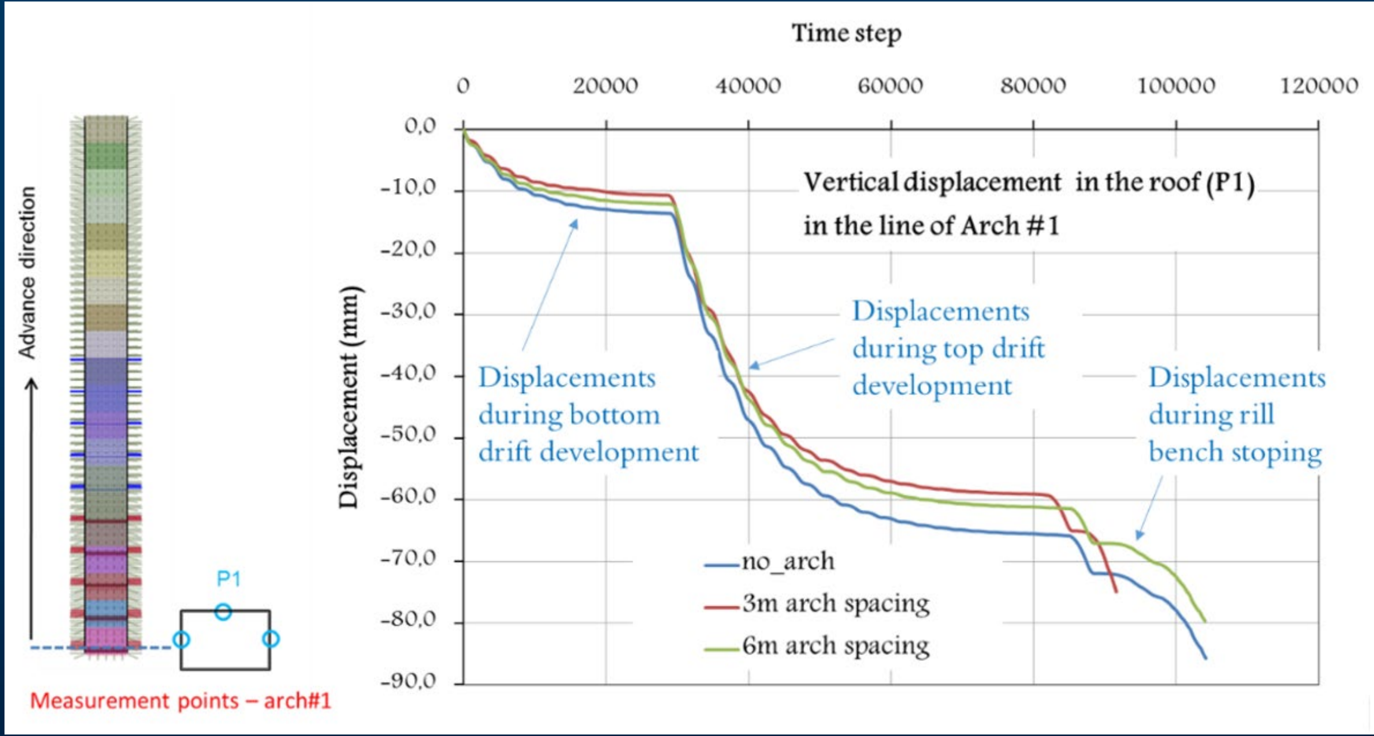
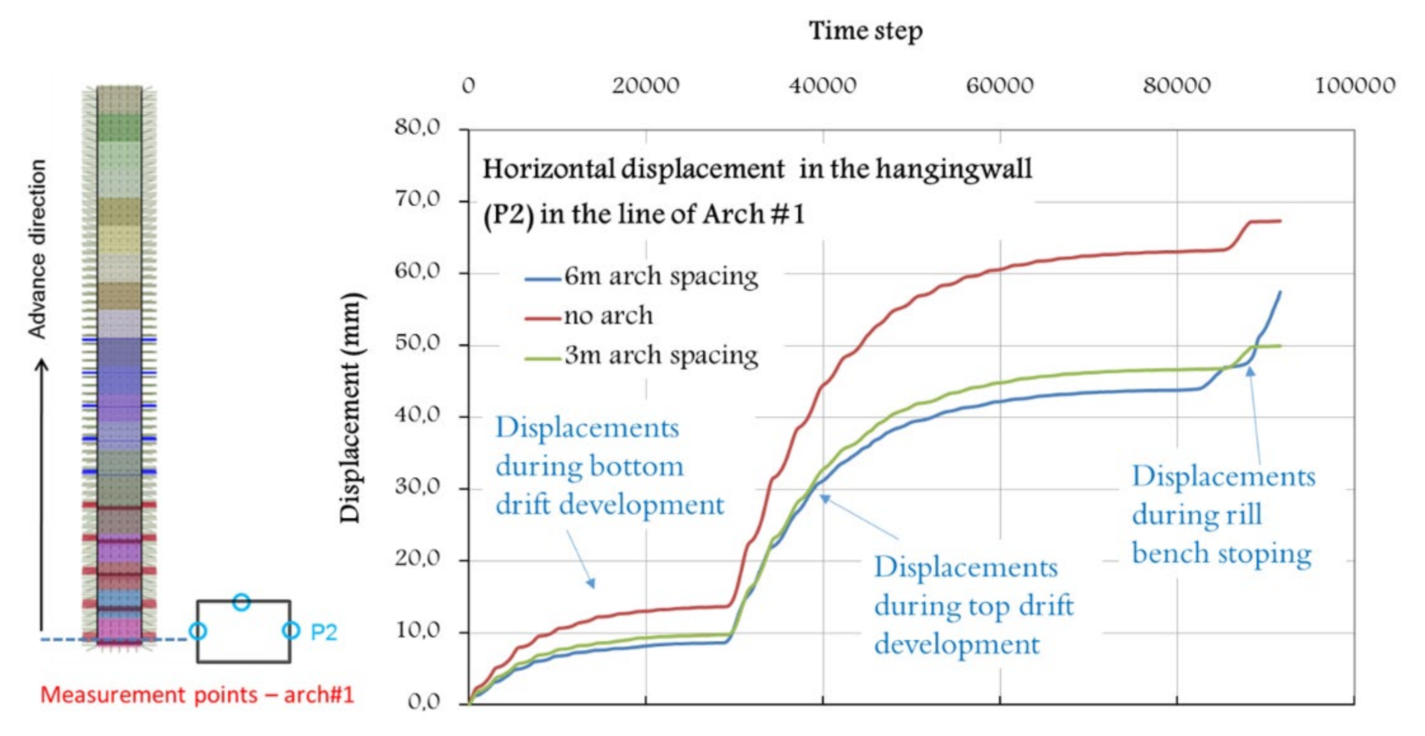
FLAC3D MODELLING RESULTS



FLAC3D MODELLING RESULTS



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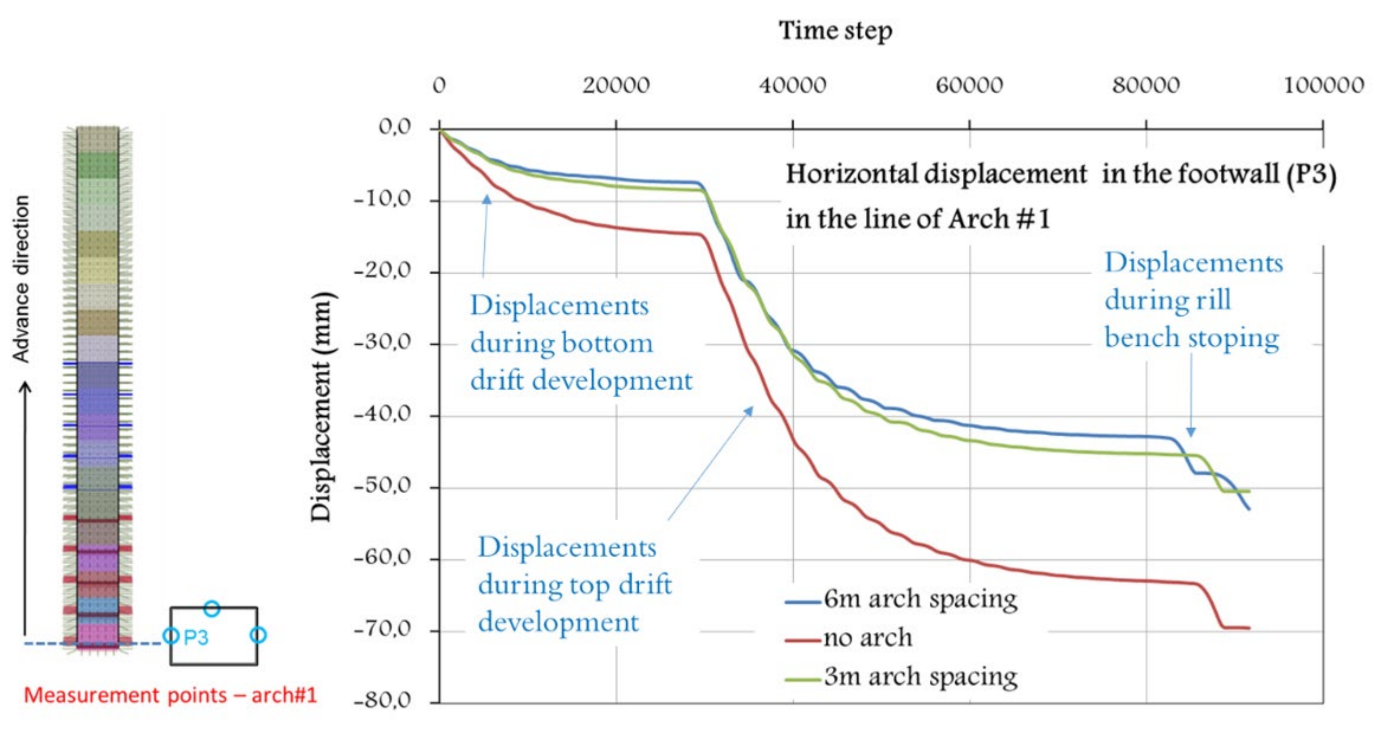

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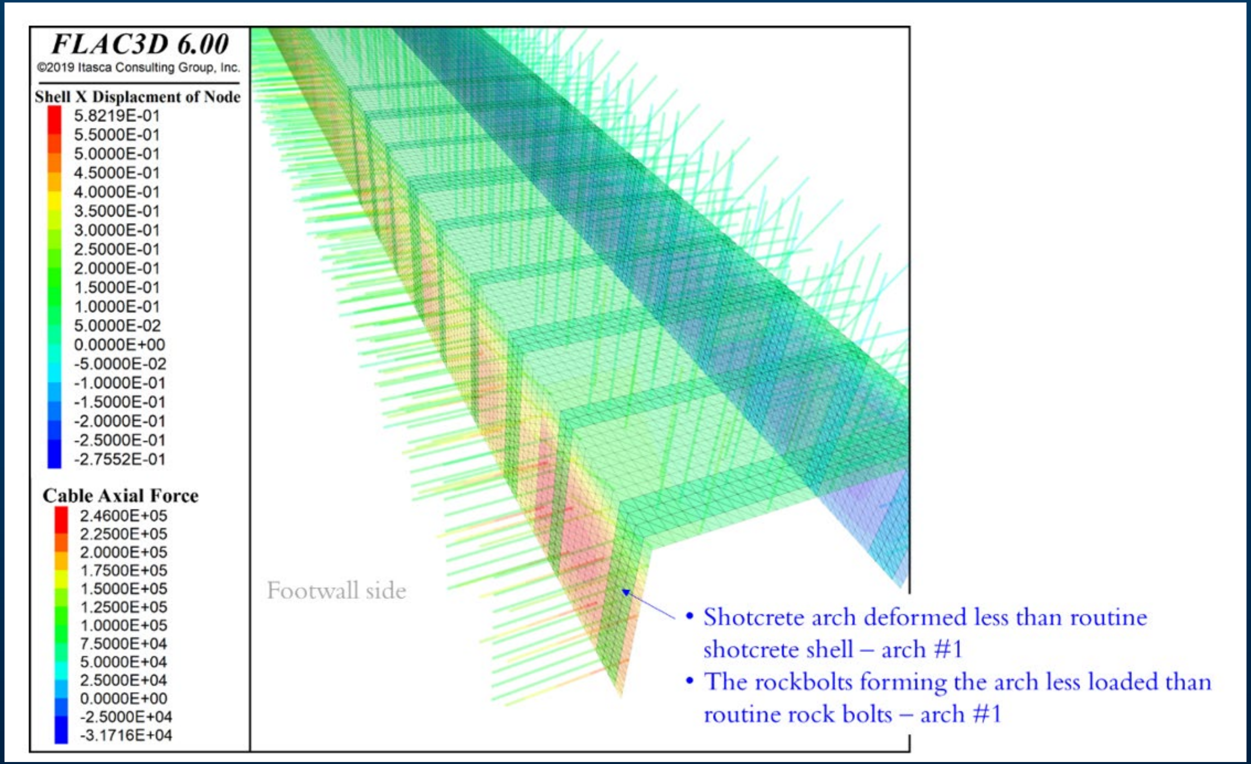
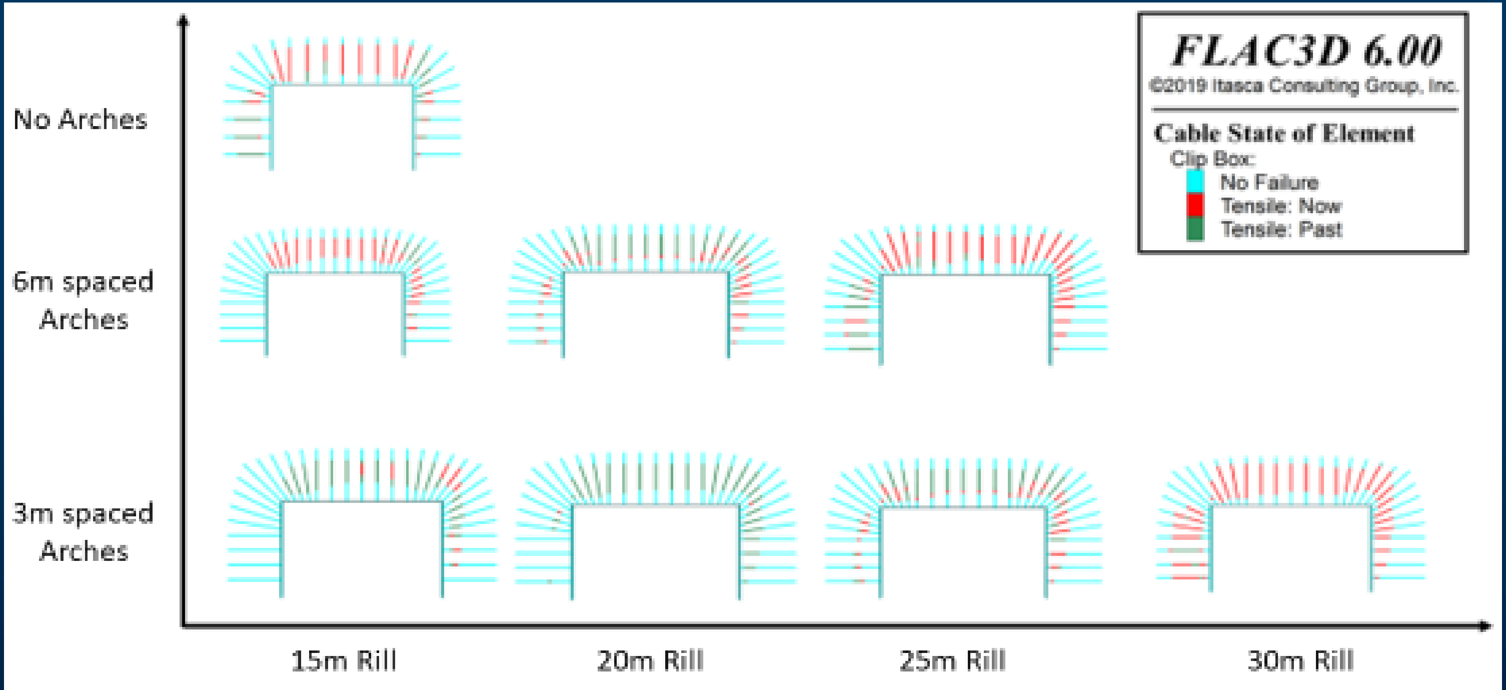
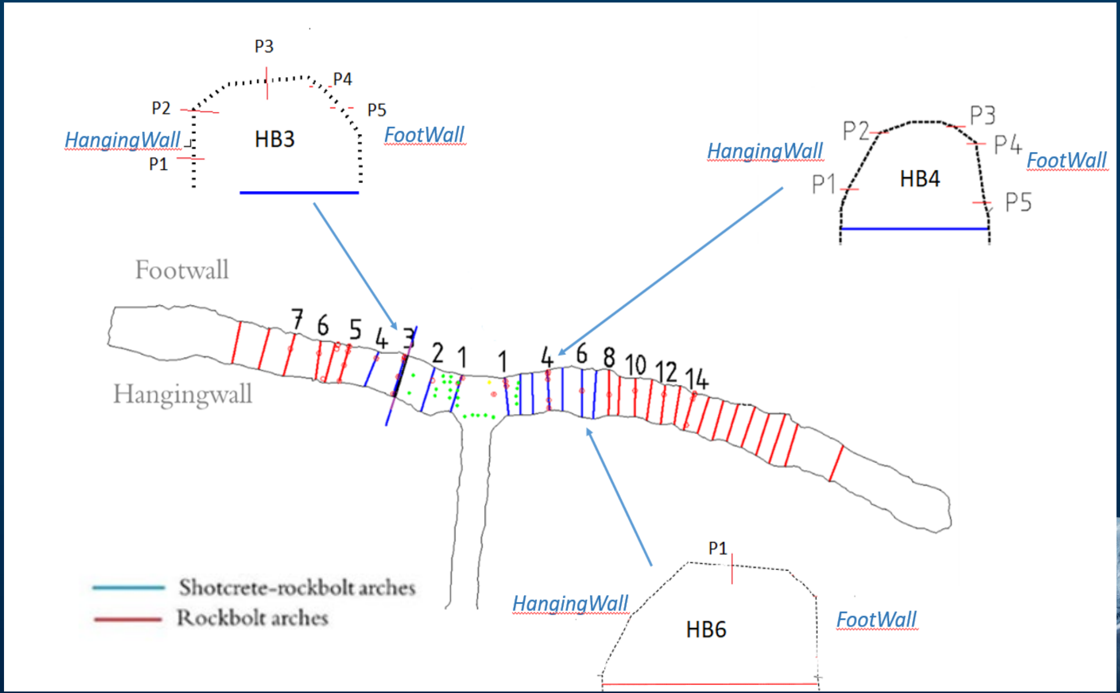


SUPPORT BEHAVIOUR – BOTTOM DRIFT

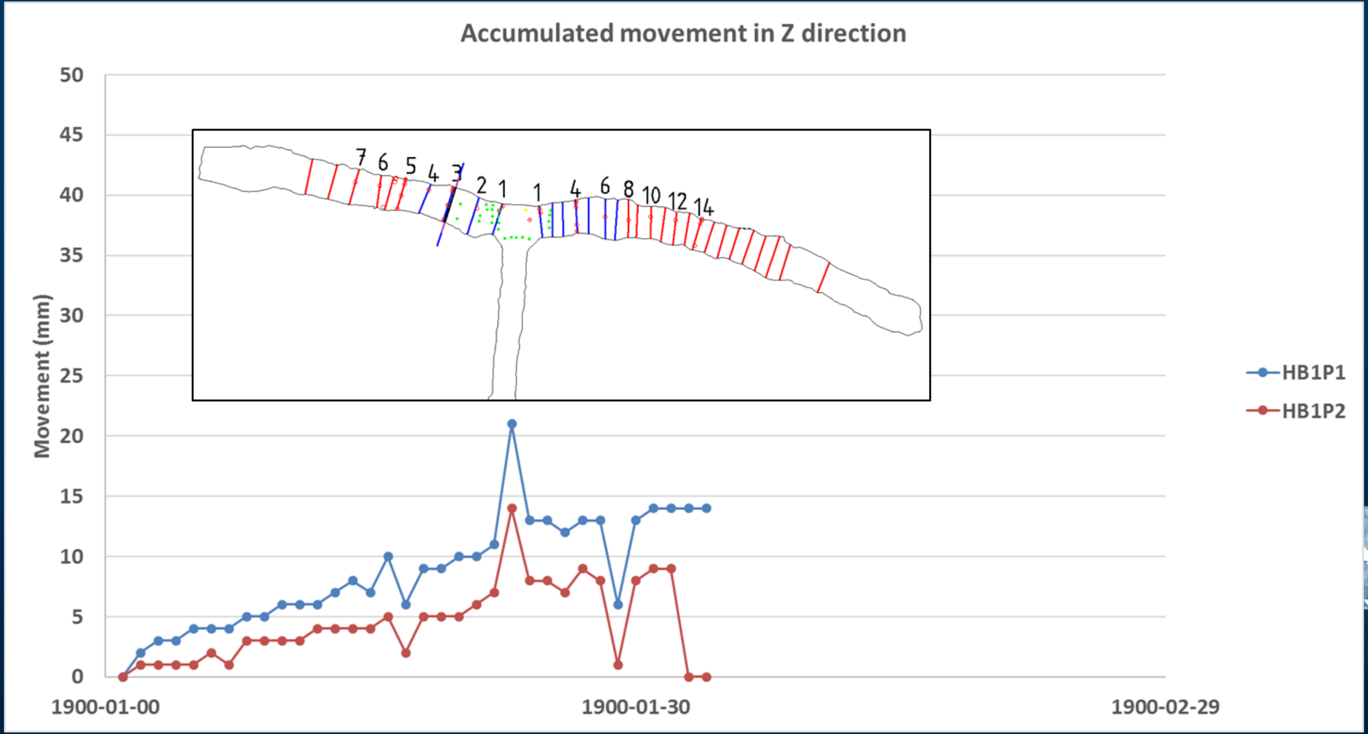


MONITORING – CALIBRATION

- Prisms & extensometers
- 3 Profiles selected
- Close to the entrance

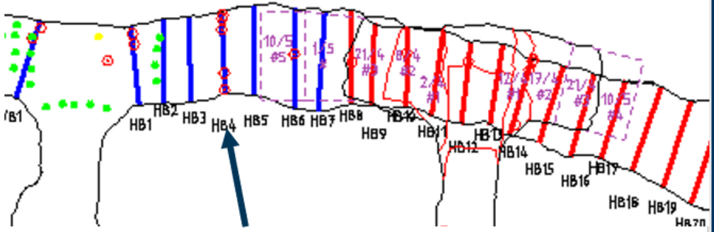


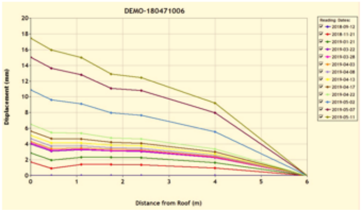
RESULTS FROM PRISM MONITORING

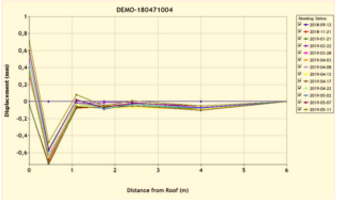


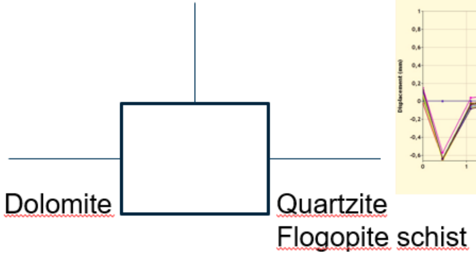
RESULTS FROM MONITORING

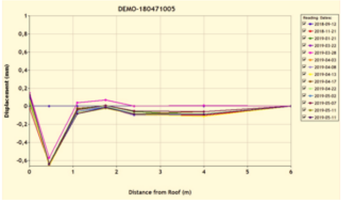
Extensometers HB4











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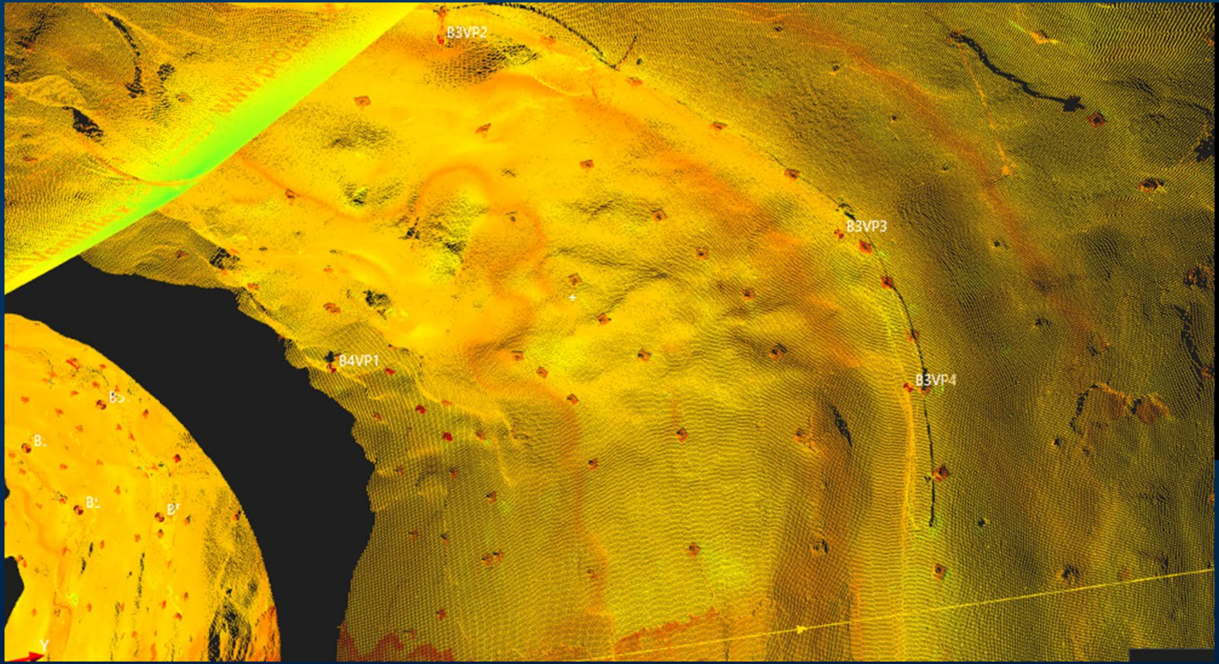
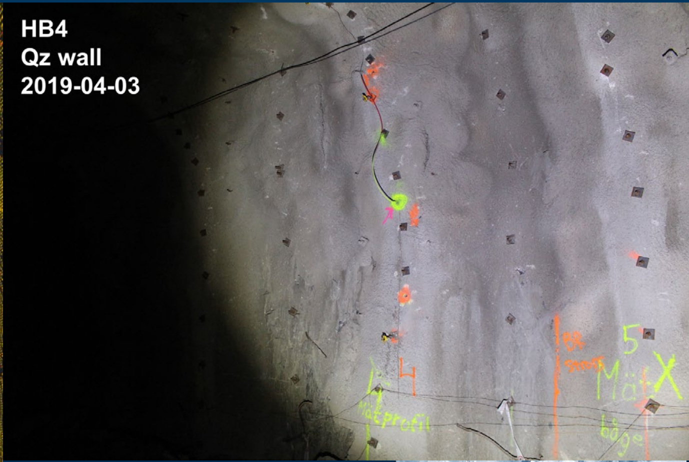
RESULTS FROM MONITORING

Laser scanning with Leica M60





WHAT WE HAVE LEARNT SO FAR

- Ground support (routine rock bolts and shotcrete, rock bolt arches and shotcrete - rock bolt arches) show noticeable ground displacement. The displacement magnitudes are reduced when the arches are introduced. The 3 m arches slightly reduce the displacement but not very significant compared to 6 m arch.
- The arches are seen to be active during the development of the top drive and later rill benching. This is actually the intention for the use of the arch. The modelling demonstrates it works!
- After the excavation of the bottom drift the displacements about 10 to 15mm, which conforms to the readings from the prisms.
- The displacements increase to 40 to 70mm when the top drift is excavated. This is to be validated with the monitoring data.
- The interaction between the bottom and top drift depends on the rill bench height.

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CONCLUSIONS

- ❖ Positive Impact of the Arch installations
  - ➢ Larger Impact at Larger rill heights
  - ➢ Larger impact on the Footwall
- ❖ Limited improvement between the two Arch spacing
  - ➢ Insignificant for the lower rill heights
  - ➢ Measurable for higher rill heights
- ❖ Possible to increase rill height

$$15\text{m} \longrightarrow 20\text{m}$$

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