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AFRIROCK 2025

PIONEERING PROGRESS : THE FUTURE OF ROCK ENGINEERING

Prediction of mine tunnel conditions in a deep Austrian mine by means of numerical back- and forward analysis

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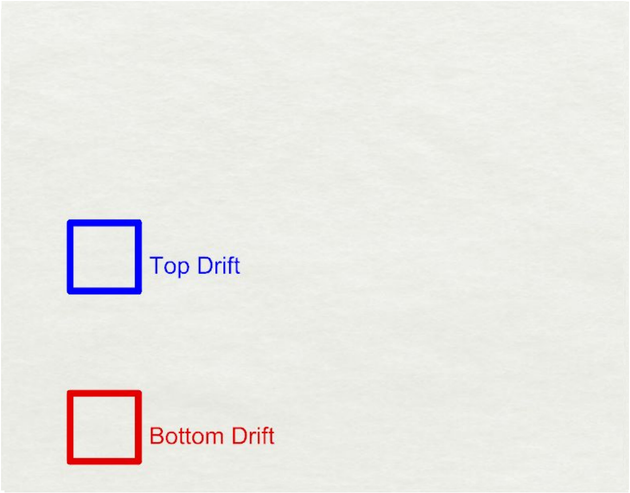
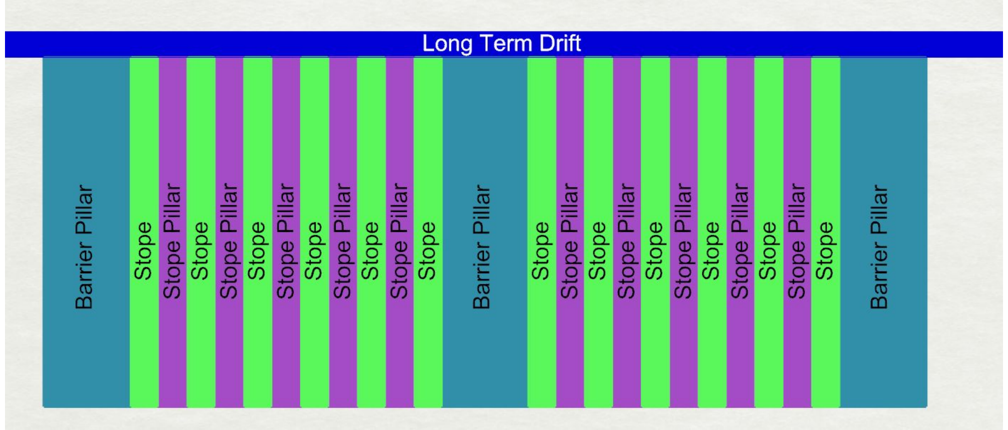
AGENDA

- Introduction
- Rock Engineering Approach
- Back Analysis
- Forward Analysis
- Conclusion

Introduction – The Mine

- Industrial Mineral Mine
- Bottom-up sublevel stoping with pastefill
- Stope pillars for local stability
- Barrier pillars for regional stability
- Positive experience with current mining method





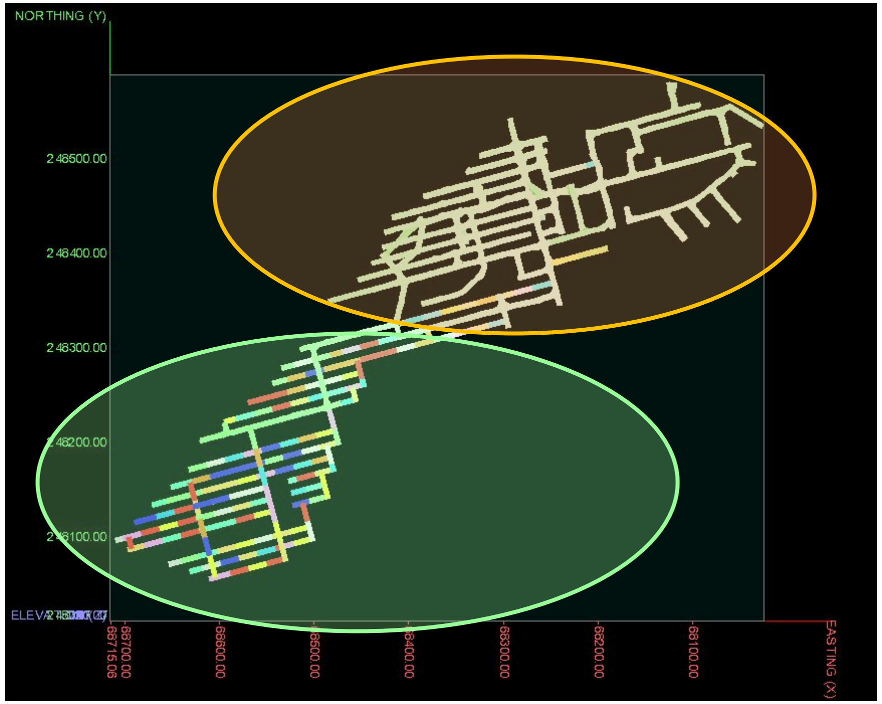
Introduction – Experience Mining Method

- Monitoring system:
  - Pillar monitoring
  - Photo documentation
- Regular numerical simulations

- **Site-specific design criteria**

Introduction – Challenge in a deep Austrian Mine

- Current part of deposit is mined
- Mining method should not be changed
- Orientation of geological structures changes with depth
- Primary stresses increase



Rock Engineering Approach – Research Questions

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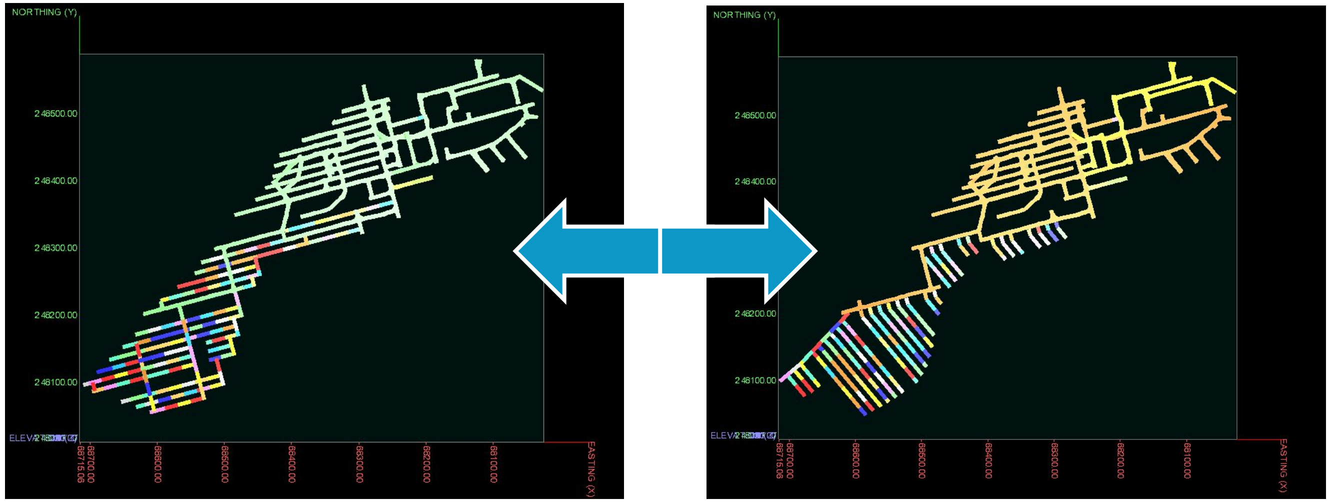
- **Adaption of stope orientation**

- Comparing two possible future mine layouts:
  - Stress redistributions:
    - Abutments
    - Barrier Pillars
  - Conditions of:
    - Long term drifts



Rock Engineering Approach

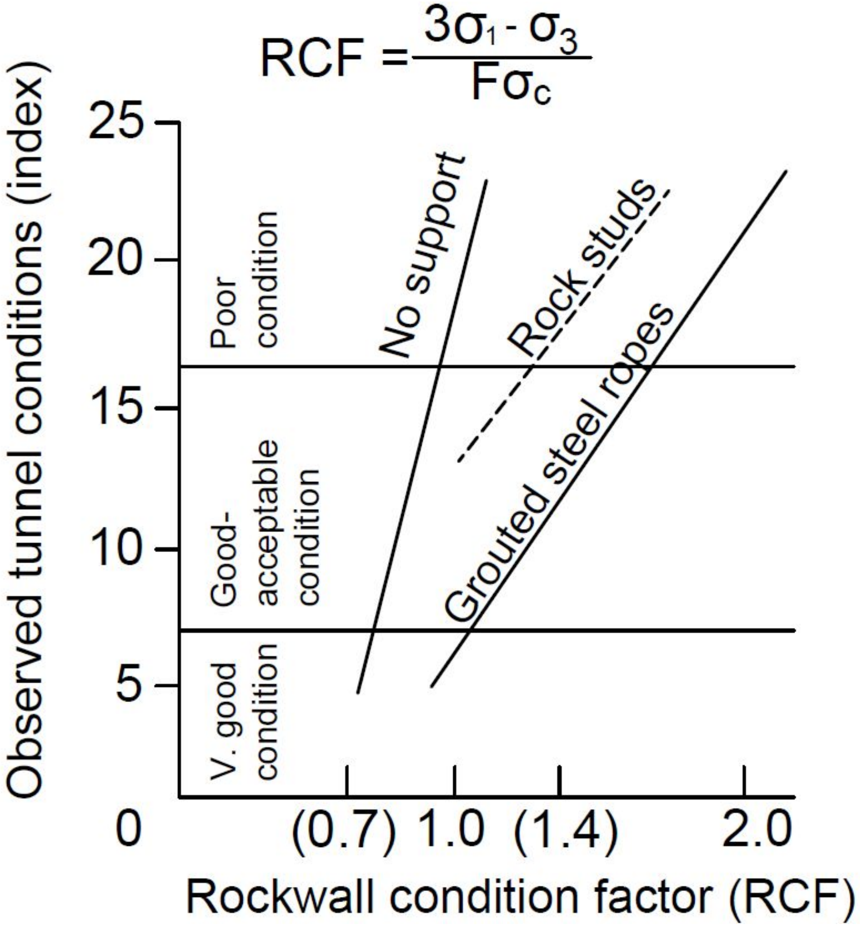
Underground observations → Numerical simulation of real mining sequence → Back analysis and calibration → Forward analysis

Rock Engineering Approach – Rockwall Condition Factor

$$RCF = \frac{3\times\sigma_1 - \sigma_3}{UCS\times F}$$

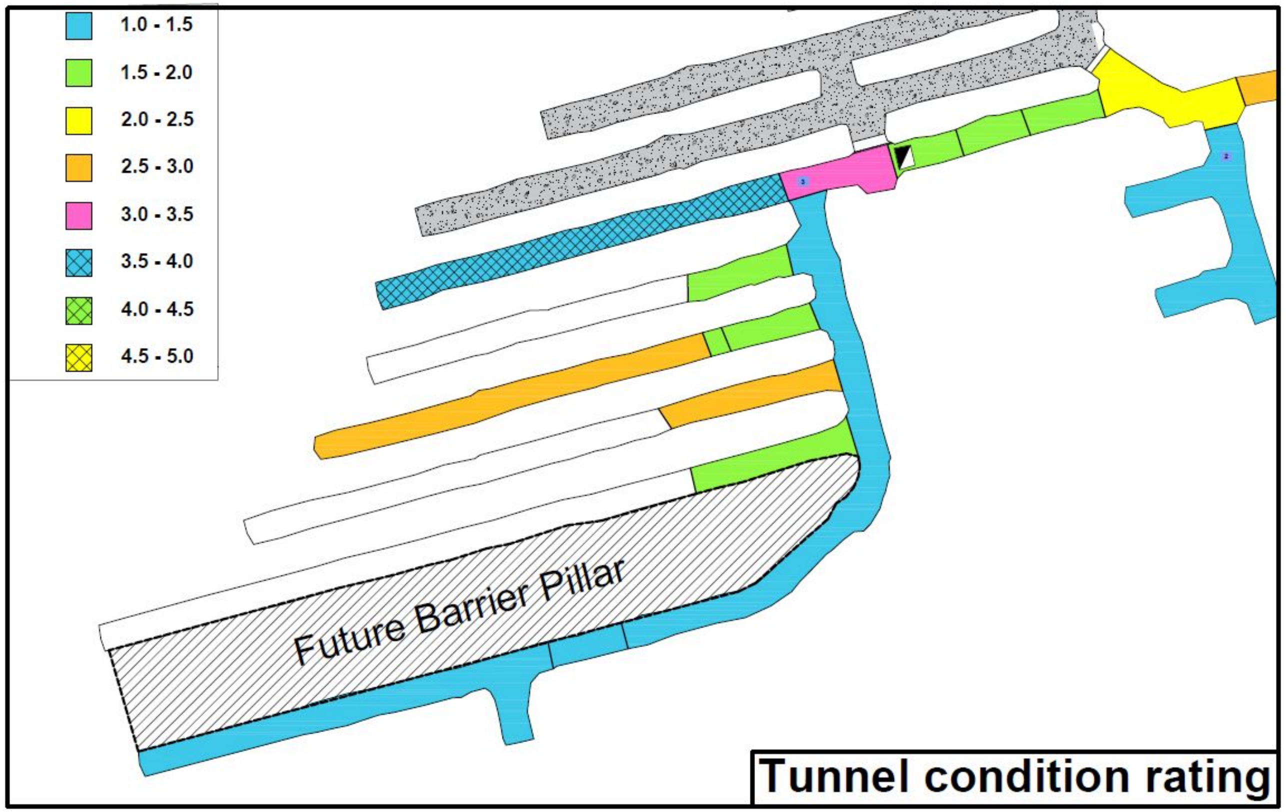
where:

RCF	**=**	**Rockwall condition factor**
σ_1	**=**	**Maximum normal field stresses acting perpendicular to the tunnel axis**
σ_3	**=**	**Minimum normal field stresses acting perpendicular to the tunnel axis**
UCS	**=**	**Uniaxial compressive strength of the rock**
F	**=**	**Downgrade factor to account for the discontinuities of the rock mass**



Rock Engineering Approach – Condition Rating

	Condition rating (1)	Observed tunnel condition
Very Good	1.0–1.5	Excellent tunnel conditions; solid tunnel walls; no support required
	1.5–2.0	See 1.0–1.5; tunnel walls with minor joints or fracturing; occasional spot bolting, where required.
	2.0–2.5	Tunnel walls with more fractures; compared to 1.5–2.0 more frequent spot bolting but no systematic support pattern required; no signs of stress related fracturing or loosening.
Good	2.5–3.0	First signs of stress-induced fracturing; limited strata loosening; isolated rock falls.
	3.0–3.5	Signs of stress induced rock fracturing; strata loosening isolated rock falls; introduction of systematic support systems.
Poor	3.5–4.0	Increased signs of overstressing of tunnel walls, stress damage extends over larger areas of tunnel walls; rock slabbing; formation of rock wedges between supports; visible signs of strata loosening.
	4.0–4.5	Marked signs of rock fracturing extending over full tunnel wall, formation of rock slabs; local overstressing of support; high risk of rock falls from roof and sidewalls of tunnel; tunnel no longer suited for normal operations; special precautions are necessary to enter tunnel.
	4.5–5.0	Tunnel in process of collapse; severe extent of fracturing and loosening; support has failed largely; severe rock fall hazard.



Rock Engineering Approach – Design Criterion

Condition rating (1)	RCF <0.7	RCF 0.7–0.8	RCF 0.8–0.9	RCF 0.9–1.0	RCF 1.0-1.1	RCF 1.1-1.2	RCF 1.2–1.3	RCF 1.3-1.4
1.0–1.5								
1.5–2.0								
2.0–2.5								
2.5–3.0								
3.0–3.5								
3.5–4.0								
4.0–4.5								
4.5–5.0								

Numerical Simulation

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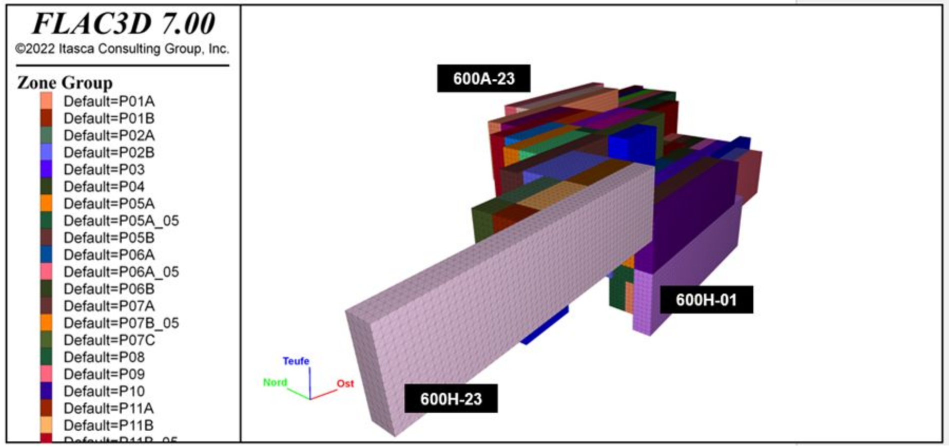
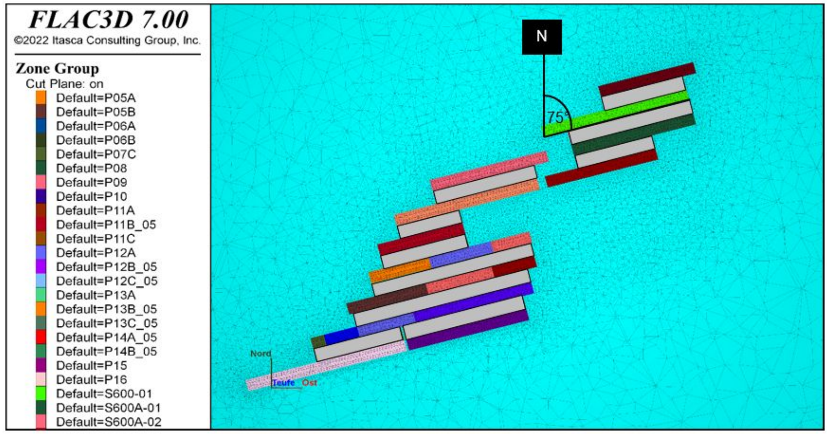
- Linear Elastic Simulation in FLAC3D
- Connection between linear elastic model and the actual situation in the mine is the design criterion.
- Simplifications:
  - Backfilling of stopes is neglected.
  - Stopes including top-and foot drifts are modelled.
  - Stopes excavated to full length.

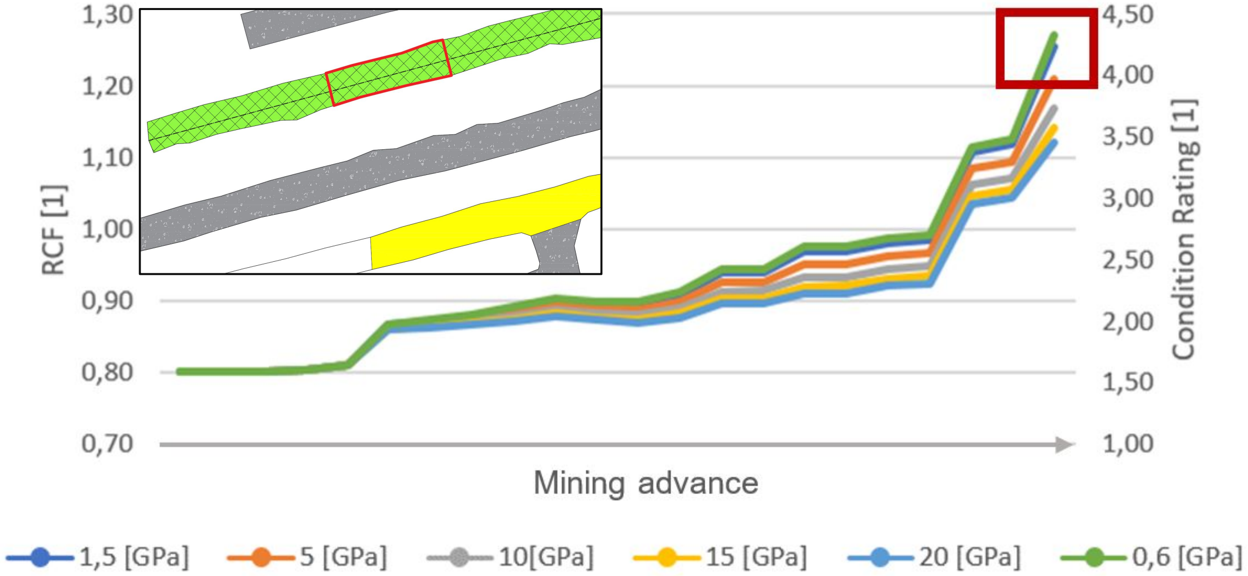


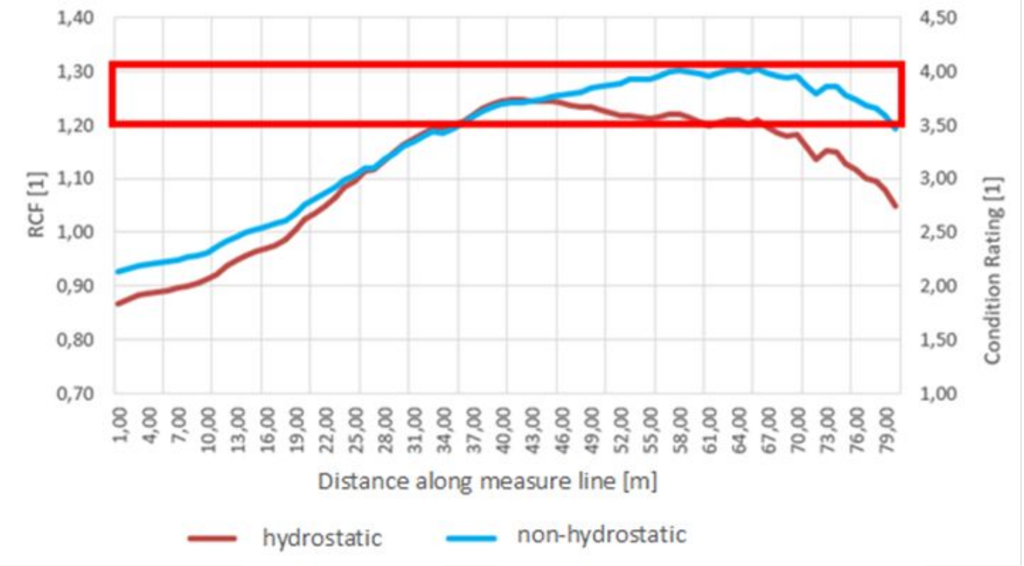


Back Analysis – Calibration

- Calibration of:
  - Primary Stress Situation (hydrostatic or non hydrostatic)
  - Behaviour of the stope pillars

  based on the actual mining conditions.

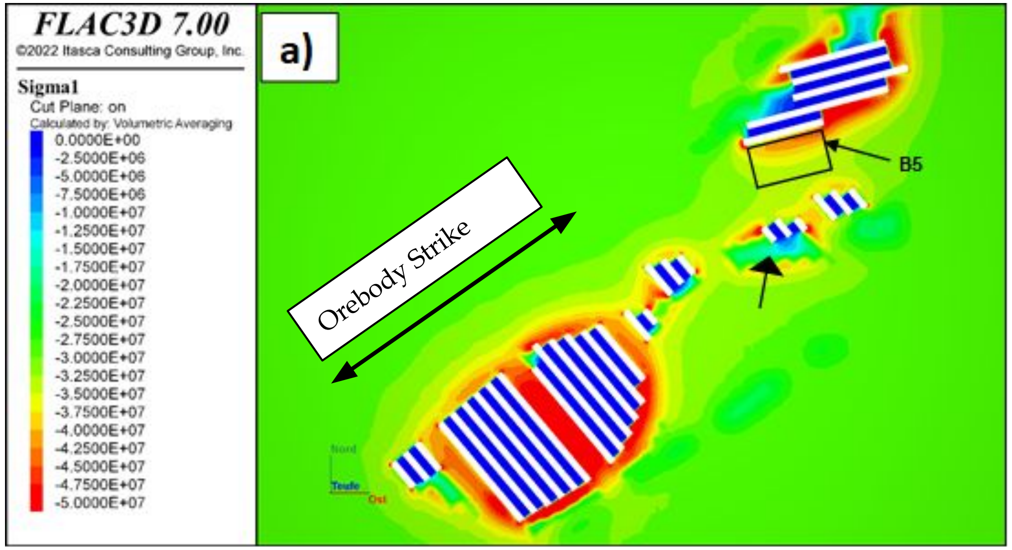


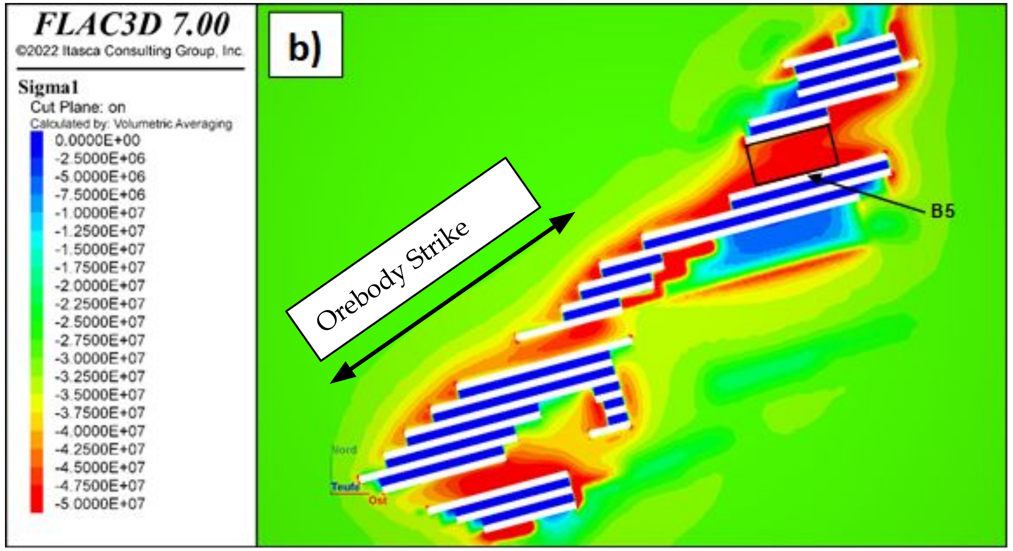


Forward Analysis

- Prediction of:
  - Loads on barrier pillars and abutments

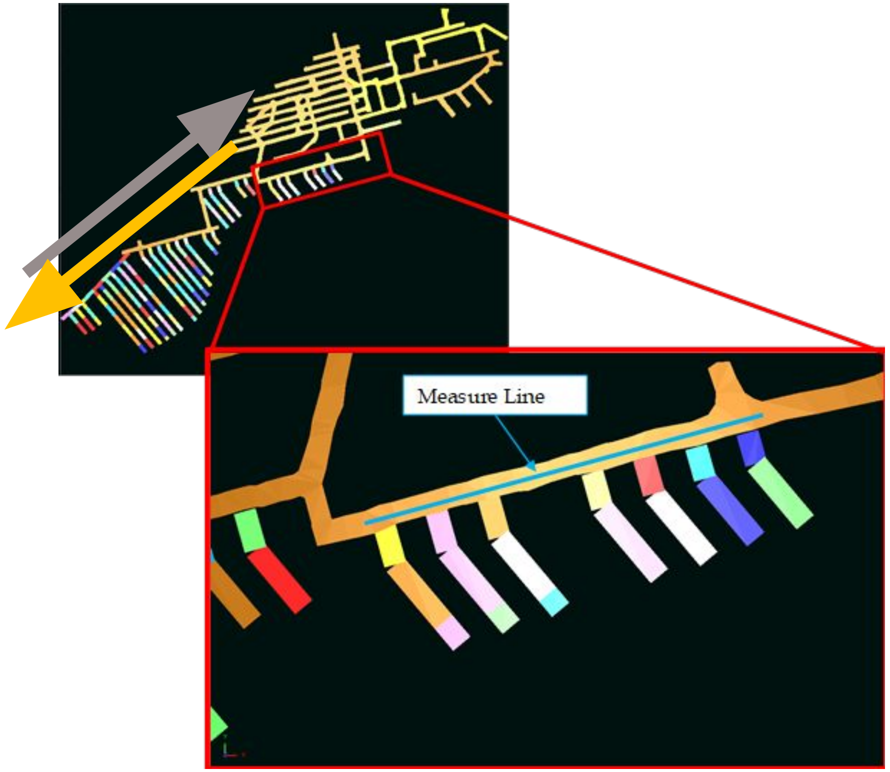
  - Zones of high stress

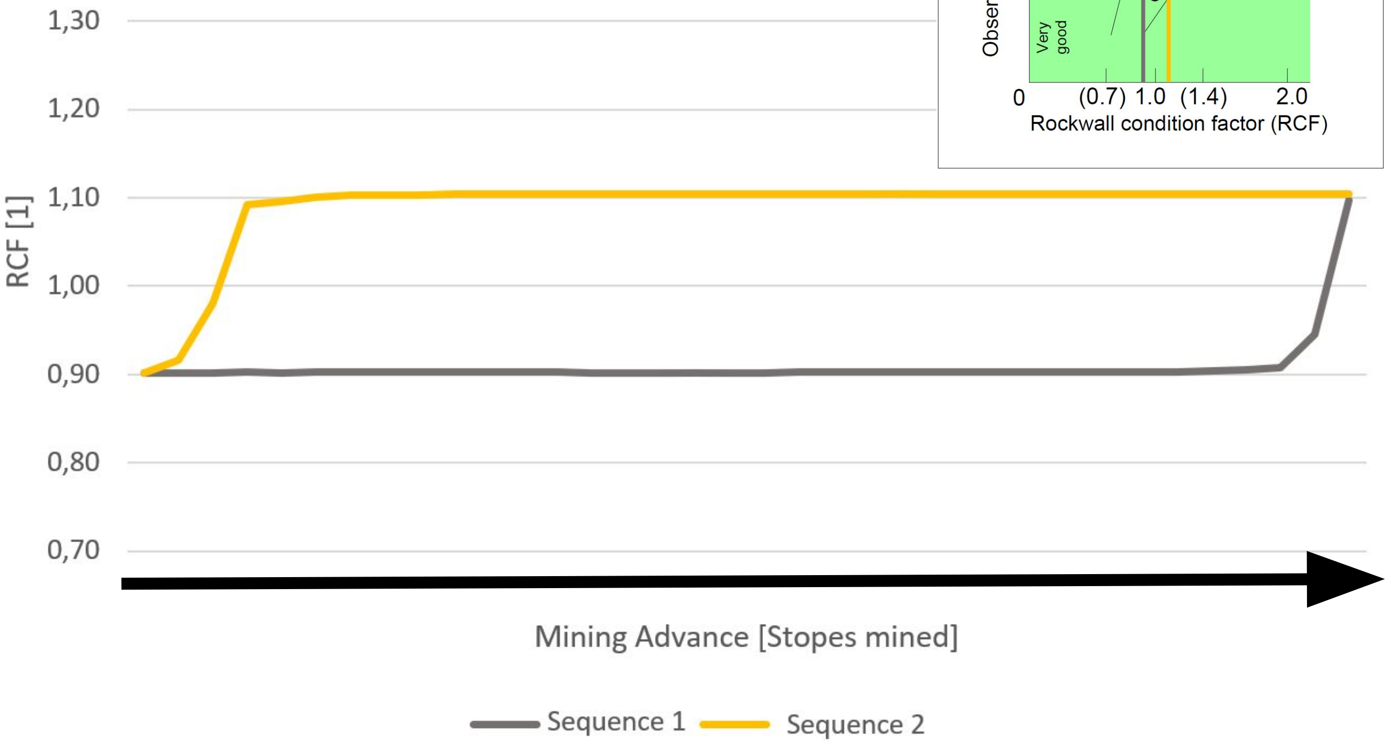


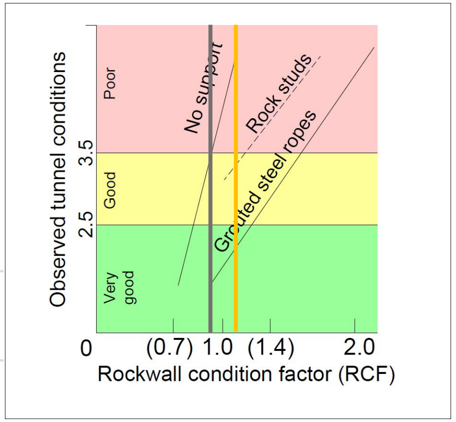


Forward Analysis – Results

- Prediction of:
  - Tunnel conditions







Forward Analysis – Results

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- Additional findings:
  - Mine design based on easy to understand criteria is accepted by mine personnel
  - Involvement of mining personnel in the planning process contributes to the development of ownership and encourages active involvement in the planning and implementation process.

Forward Analysis – Results

- Additional findings:
  - Comparison of numerical results with actual excavation behavior can be used to develop a better understanding of performance of structural elements. For example the slender panel pillars perform like crush pillars providing local support to the stopes whereas regional stability is provided by barrier pillars and abutment areas.

Conclusion

- This paper shows the applicability of design criteria in mine planning **based on field observations and numerical models.**

- The rating of tunnel conditions is a suitable tool to assess rock pressure conditions and should be done routinely to obtain a more accurate model.

- It is proposed to model of the whole mine and to update and calibrate it on a regular basis. In this way confidence can be developed in the value of numerical rock engineering design tools based on design criteria which can be applied readily and are understood by the miners.

THANK YOU

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