Input to Orepass Design — A Numerical Modeling Study

Jonny Sjöberg

Axel Bolin

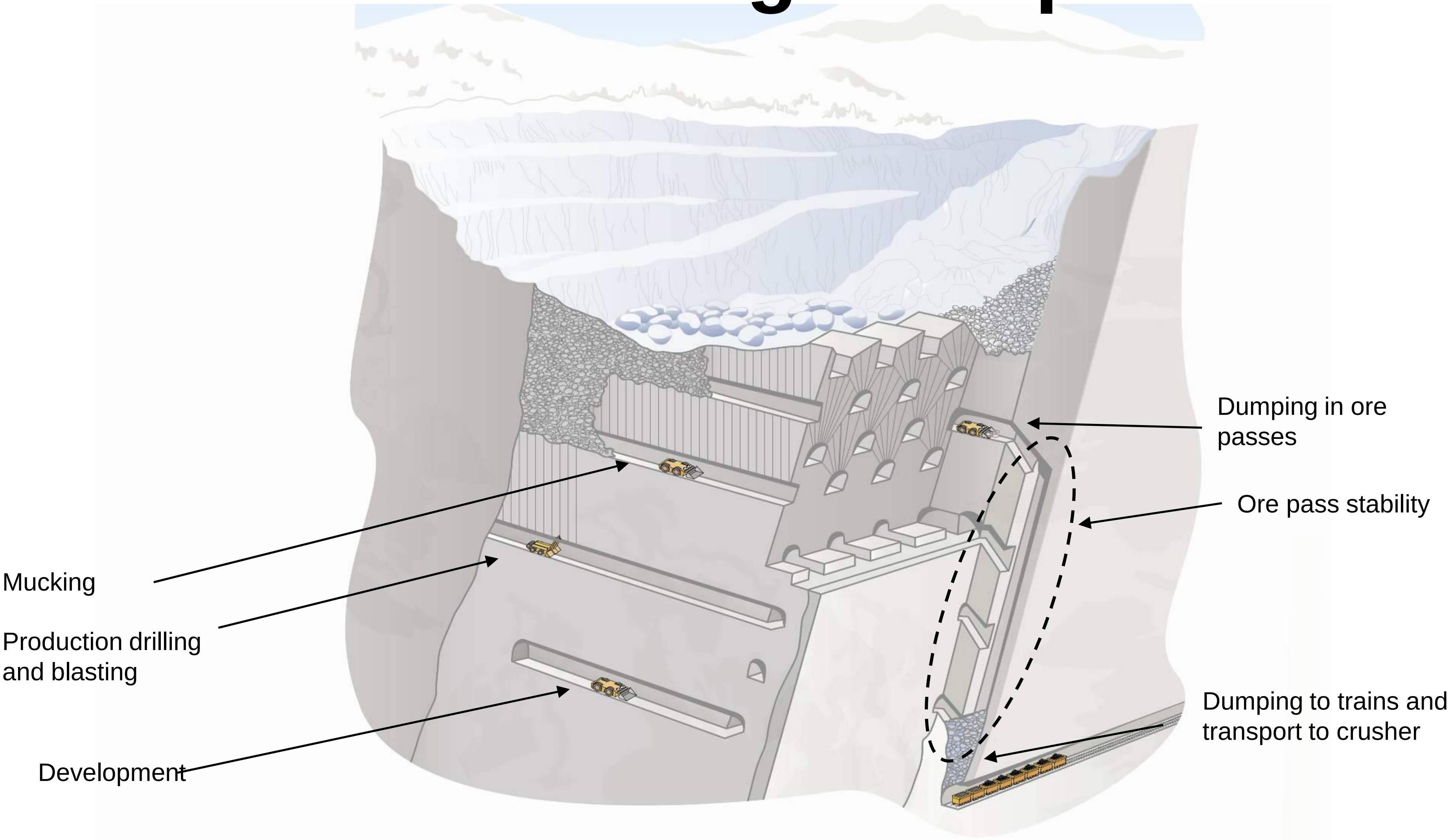
Abel Sánchez Juncal

Thomas Wettainen

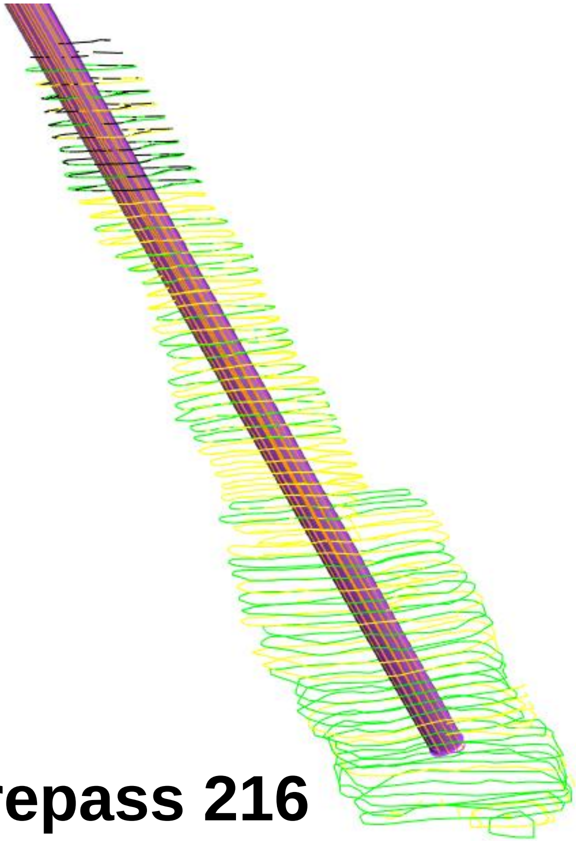
Diego Mas Ivars

Fredrik Perman

Sublevel caving & orepasses



Fall-outs in orepasses



Orepass 216

Commissioned april 2011

Closed for renovation

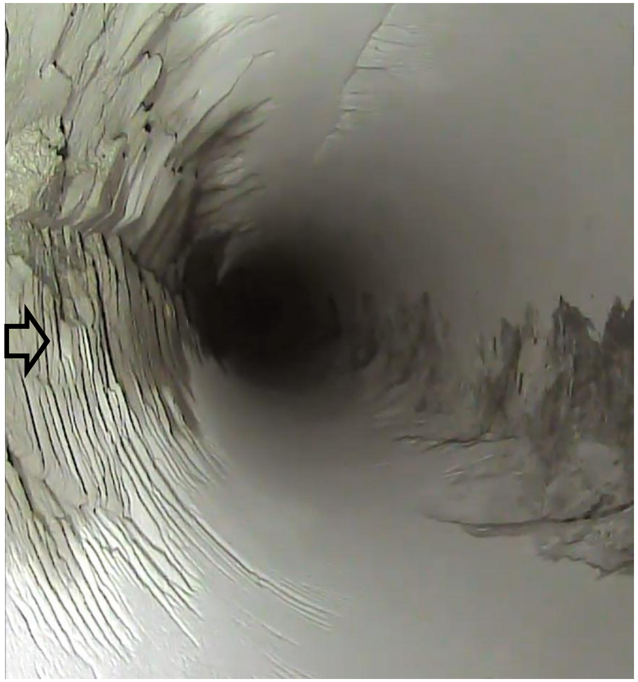
Orepass 225

Commissioned Oct 2012

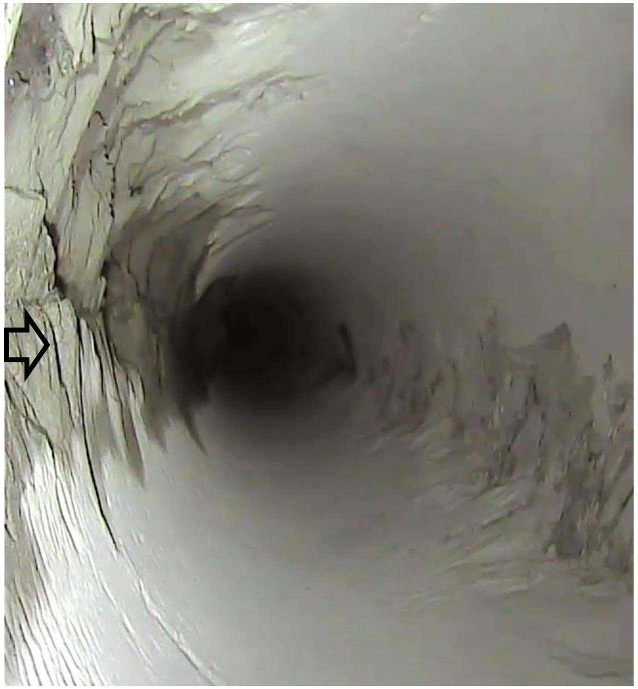
Permanent closure April 2013

ITASCA Consultants AB

Spalling failure in ventilation shaft



1044 m Level



1079 m Level

ITASCA
Consultants AB

Problems & Opportunities

- Orepass ***design guidelines required*** for potentially continued mining at depth
- Observations → validation → design:
  - Stress-induced failure
  - Validate strength and stress values
  - Investigate influence of nearby large-scale structures
  - Design options (location, orientation, shape)

Objective & Scope

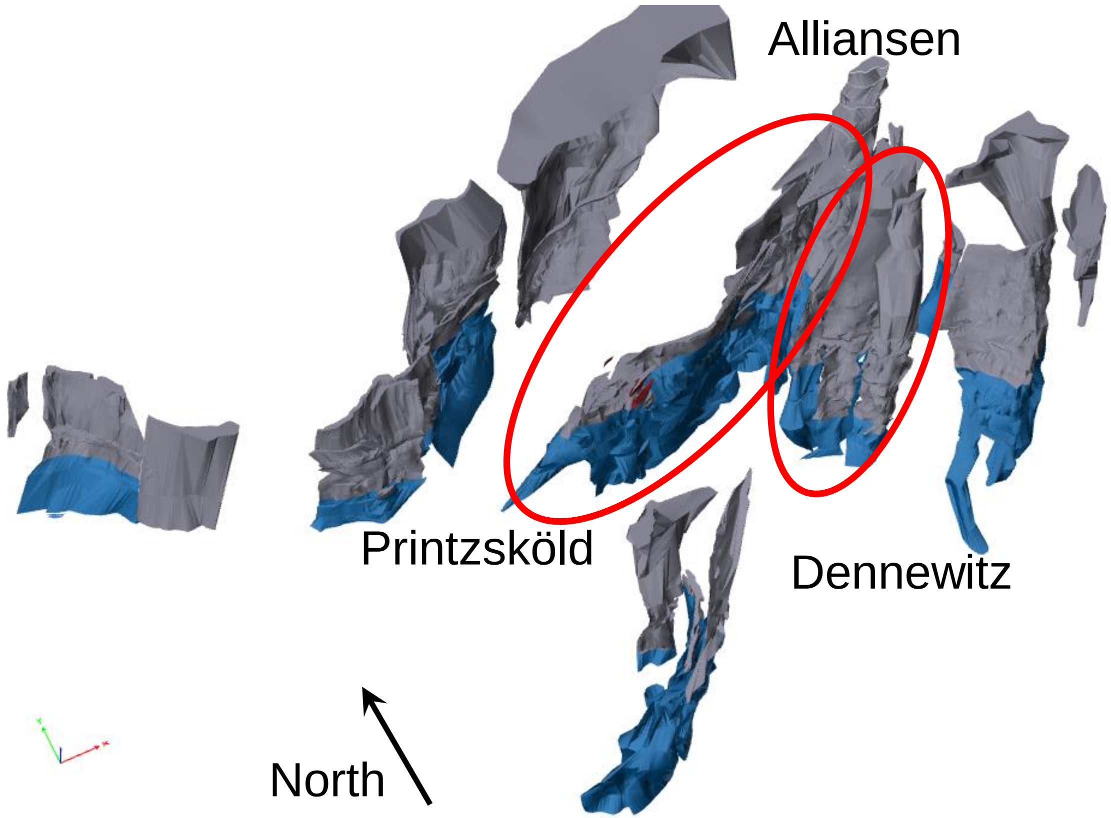
- Validate rock strength and stress state through comparison with observed fallouts in orepasses and shafts
- Determine the optimal orientation and location of orepasses for future mining
- Effects of wear only accounted for implicitly by simulating a change in orepass geometry

The LKAB Mining Company

- Iron ore producer
- Two underground mines in operation
  - Kiruna
    - 1 orebody (Kiirunavaara)
    - Annual production ≈ 29 Mton
  - Malmberget
    - 10 actively mined orebodies
    - Annual production ≈ 16 Mton
- Mining only with sublevel caving method

The LKAB Malmberget Mine

- Many orebodies of varying size and shape (8 km^2 area)
- Mining currently at 550–850 m depth
- Mineralization to 1300 m depth (?)
- Hard, strong rock mixed with weak, soft rock + some large-scale structures
- Several non-daylighting orebodies



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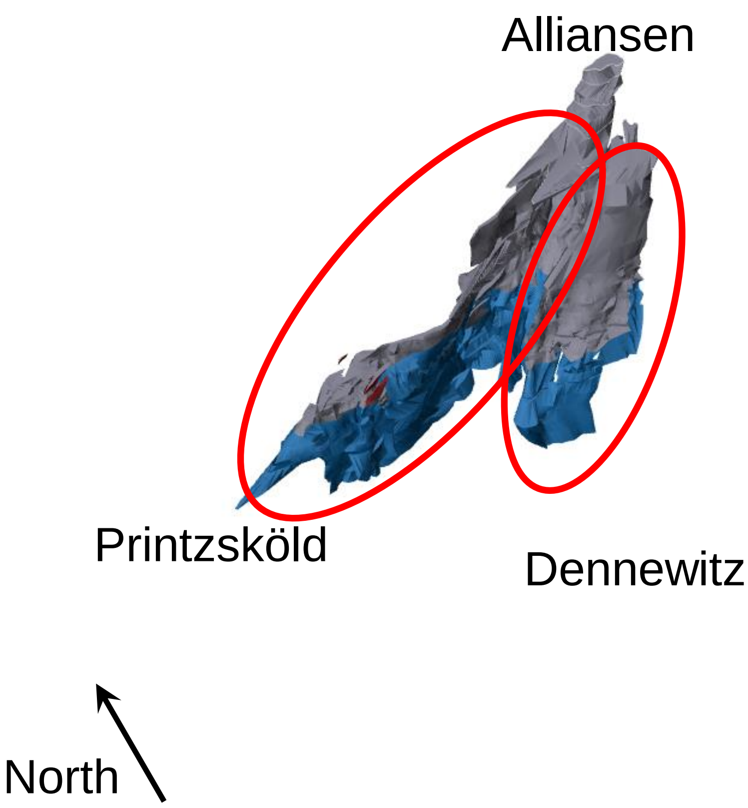
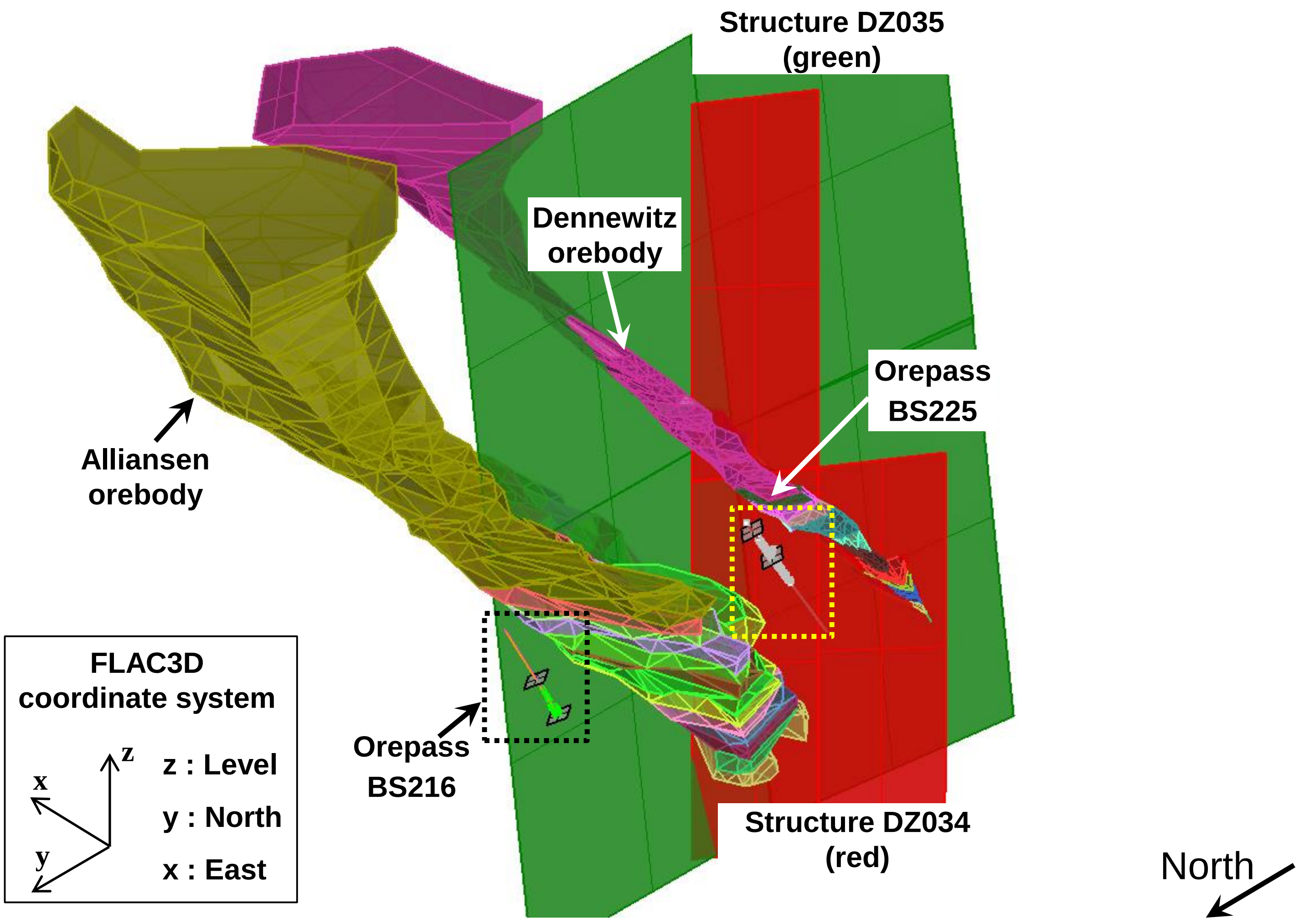
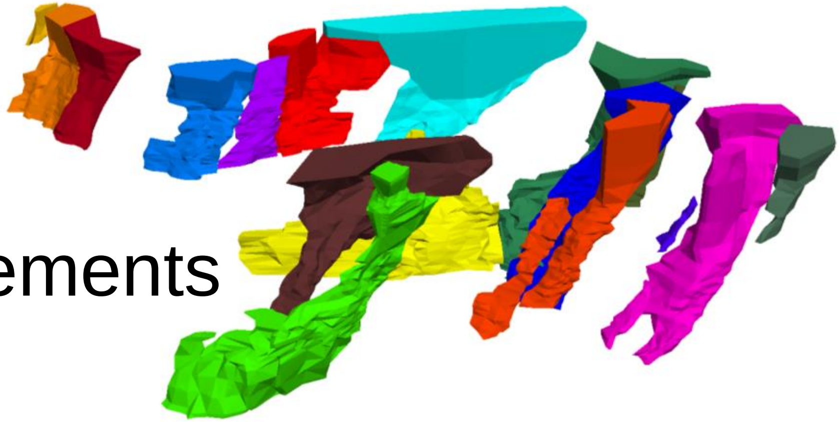


Problem Description – Ore Pass Fall-Out



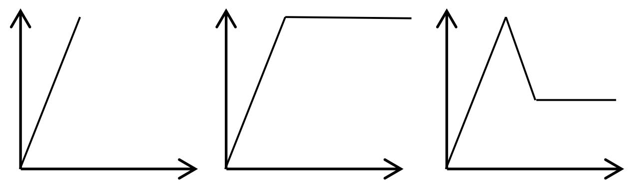
Modeling Approach

- Local model:
  - 2D-section perpendicular to orepass axis
  - Boundary stresses from mine-scale model
- Mine-scale model
  - 3D model, calibrated against stress measurements



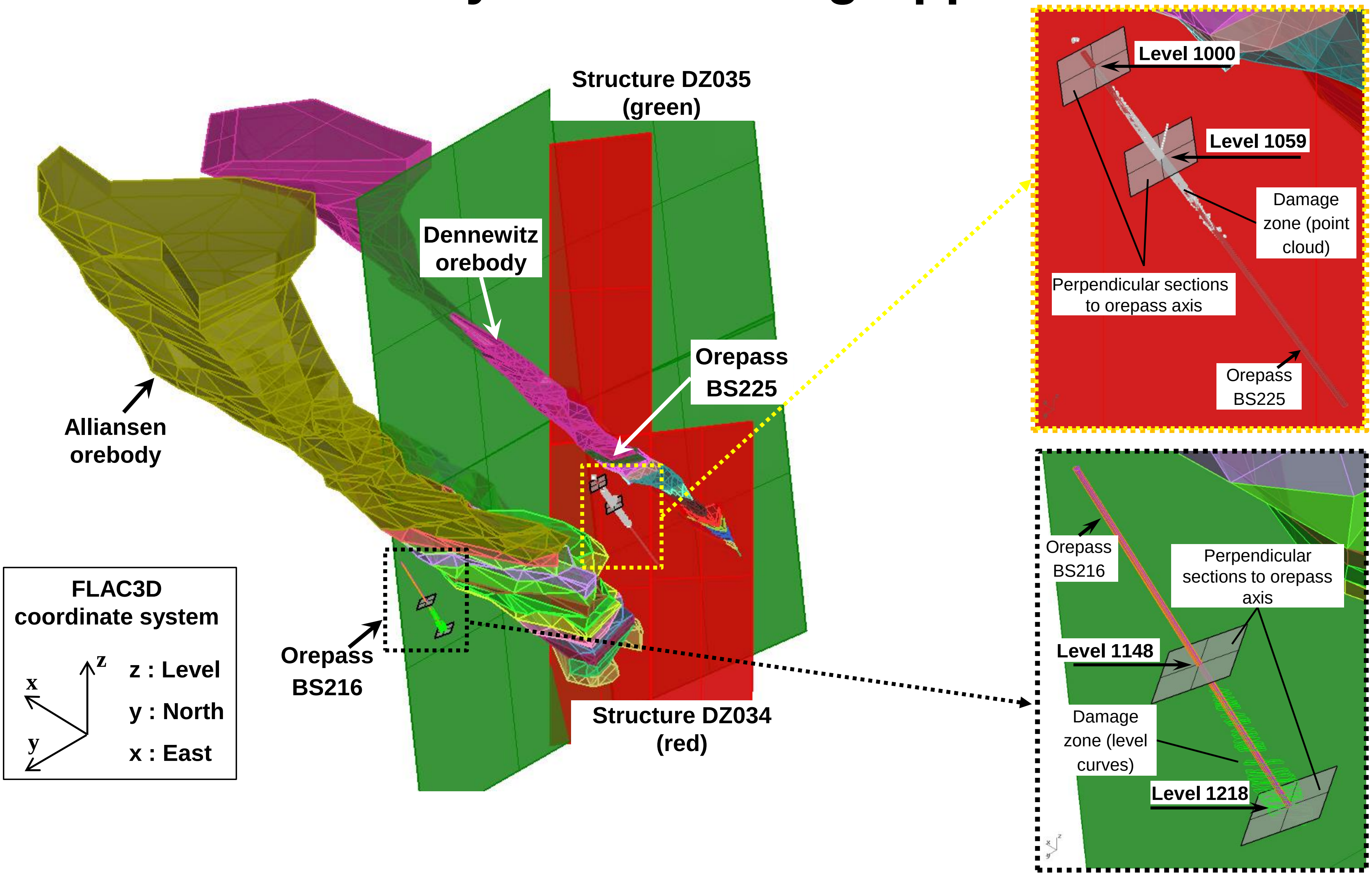
Modeling Approach

- Analysis of two levels in each orepass:
  - Upper portion (no fall-outs)
  - Lower portion (extensive fall-outs)
- Parametric studies:
  - Material models



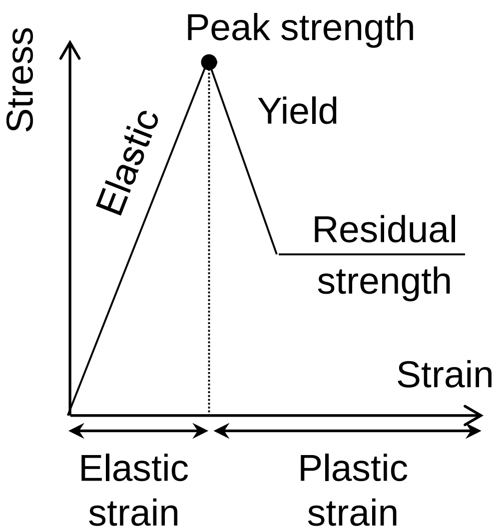
  - Strength values
  - Location of large-scale structures

Geometry and Modeling Approach

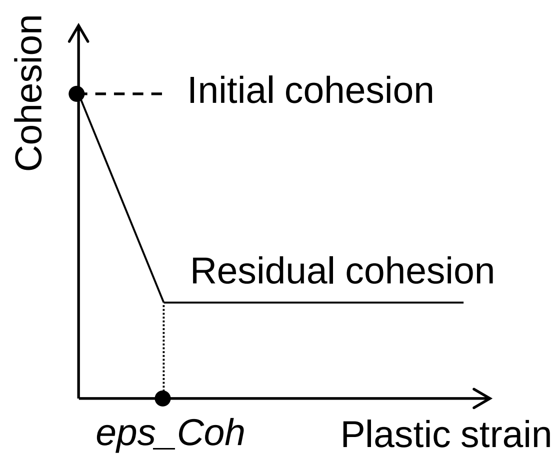


Brittle Material Model; *CWFS*

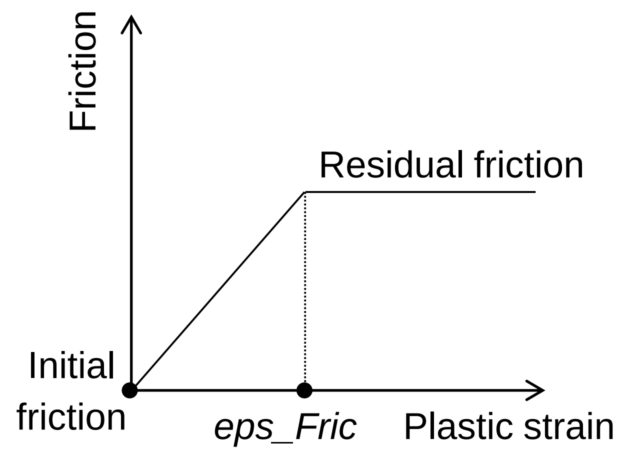
Cohesion-Weakening Friction-Strengthening



Strain-softening model



Variation of cohesion with plastic strain



Variation of friction with plastic strain

Material model for brittle failure

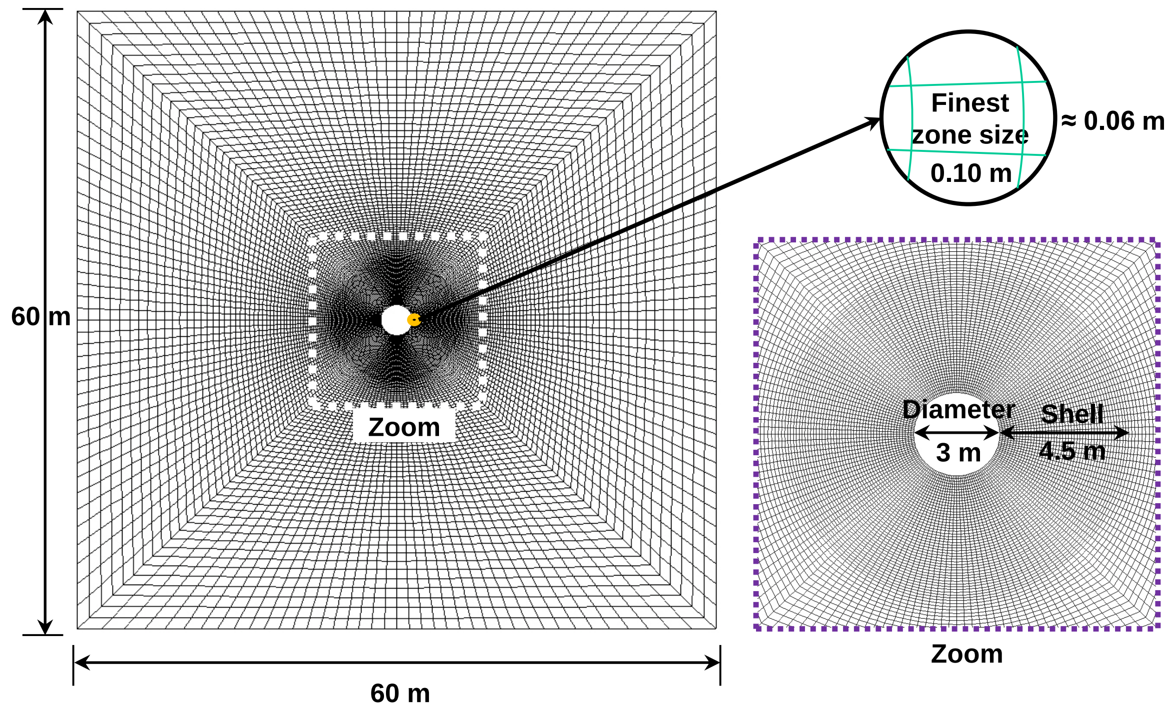
In other words:

"**c and then tan fi**"

~~not "**c plus tan fi**"~~

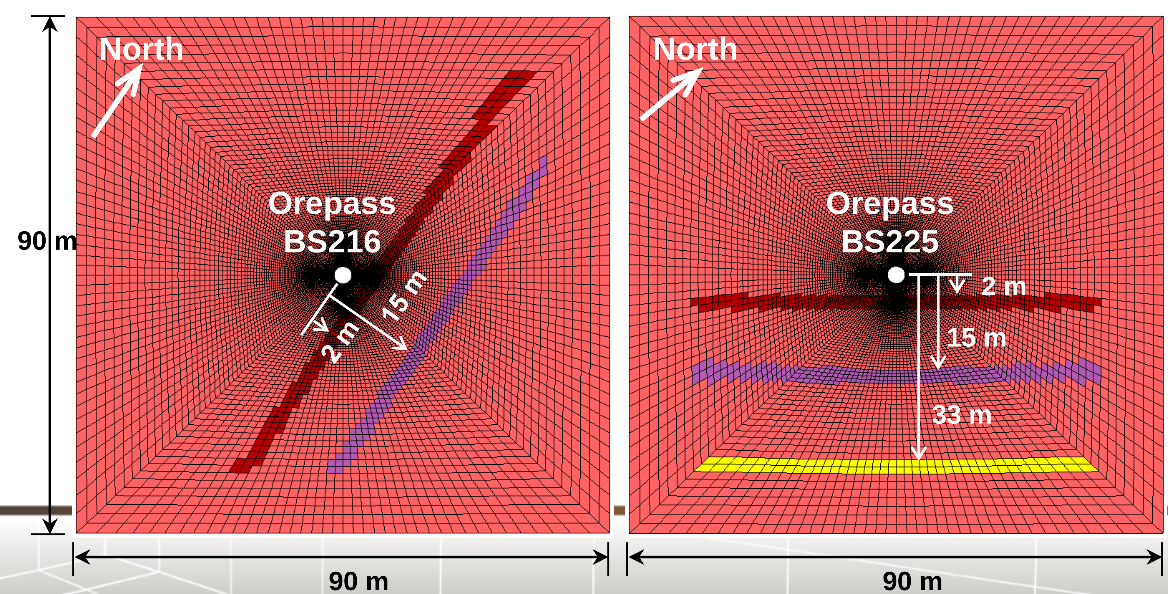
FLAC (2D) model

- Model section perpendicular to orepass axis
- High resolution (10 cm zone size)



Model with structures

- Larger model
- Same resolution



Material Properties

- Parameter values estimated from laboratory tests, logging & experience
- Properties defined for dominant rocks:
  - RL = Red leptite
  - GL = Grey leptite
  - BI = Biotite
- Properties weighted by rock type:

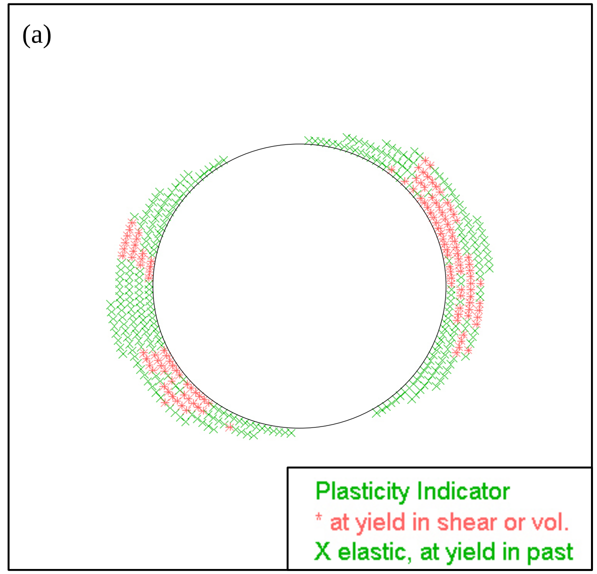
*FLAC_p = RL(%) * RL_p + GL(%) * GL_p + BI(%) * BI_p*

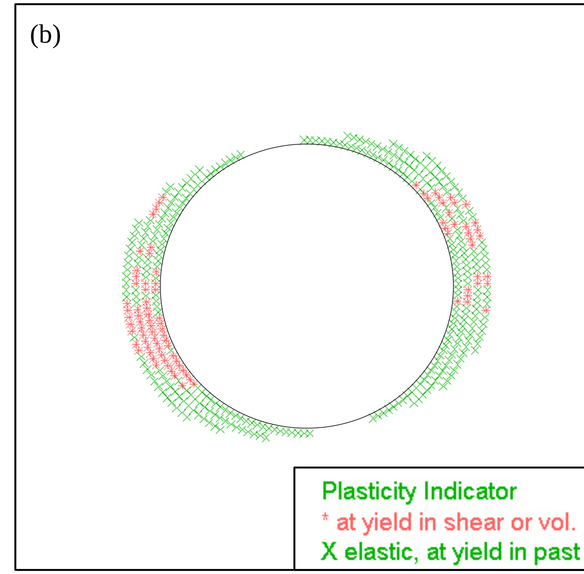
Representative Results

Orepass – Yielding

Mohr-Coulomb

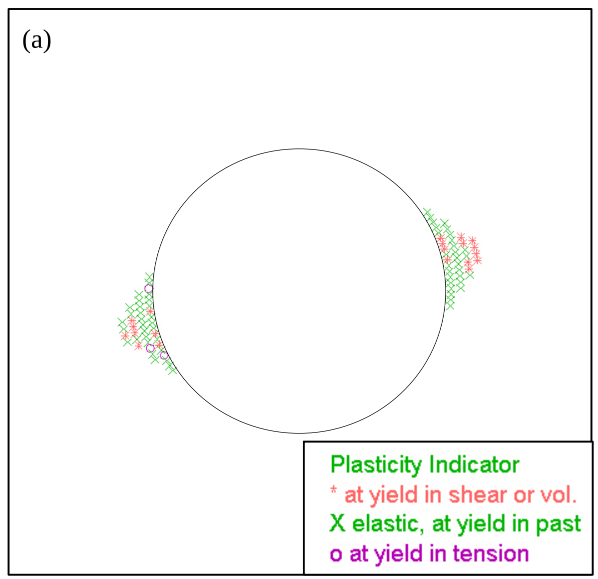
- Perfectly plastic
- 50% RL, 50% GL

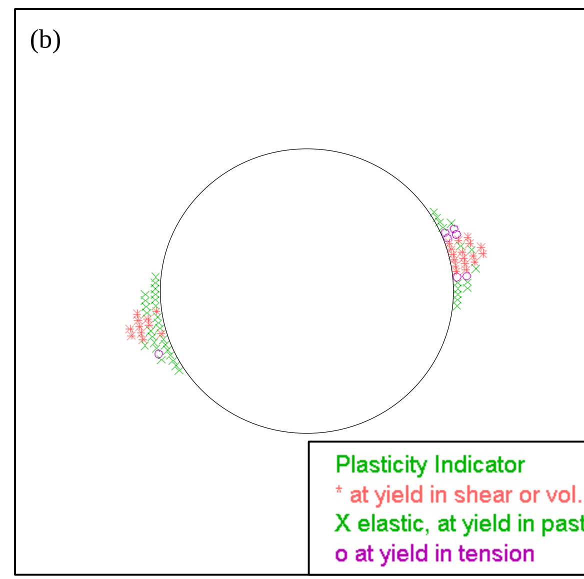




CWFS

- Cohesion weak-ening, frictional strengthening
- 50% RL, 50% GL

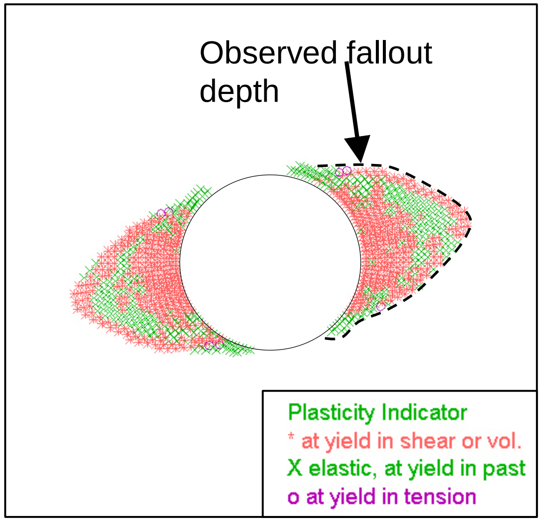




Orepass – Yielding

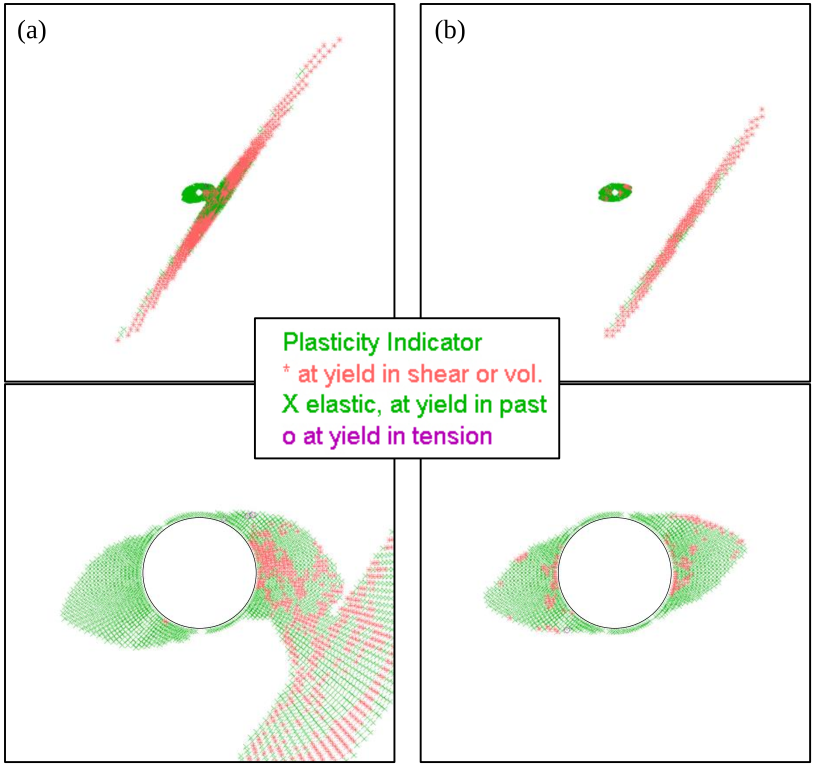
Comparison with fallouts

- CWFS
- 100% GL

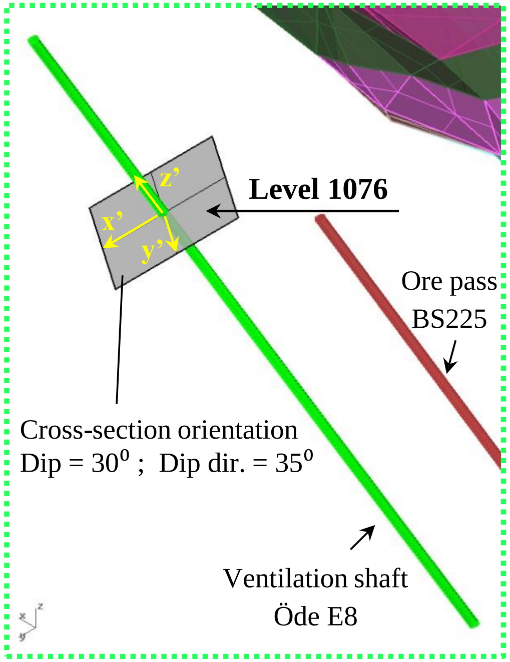


Influence of nearby structures

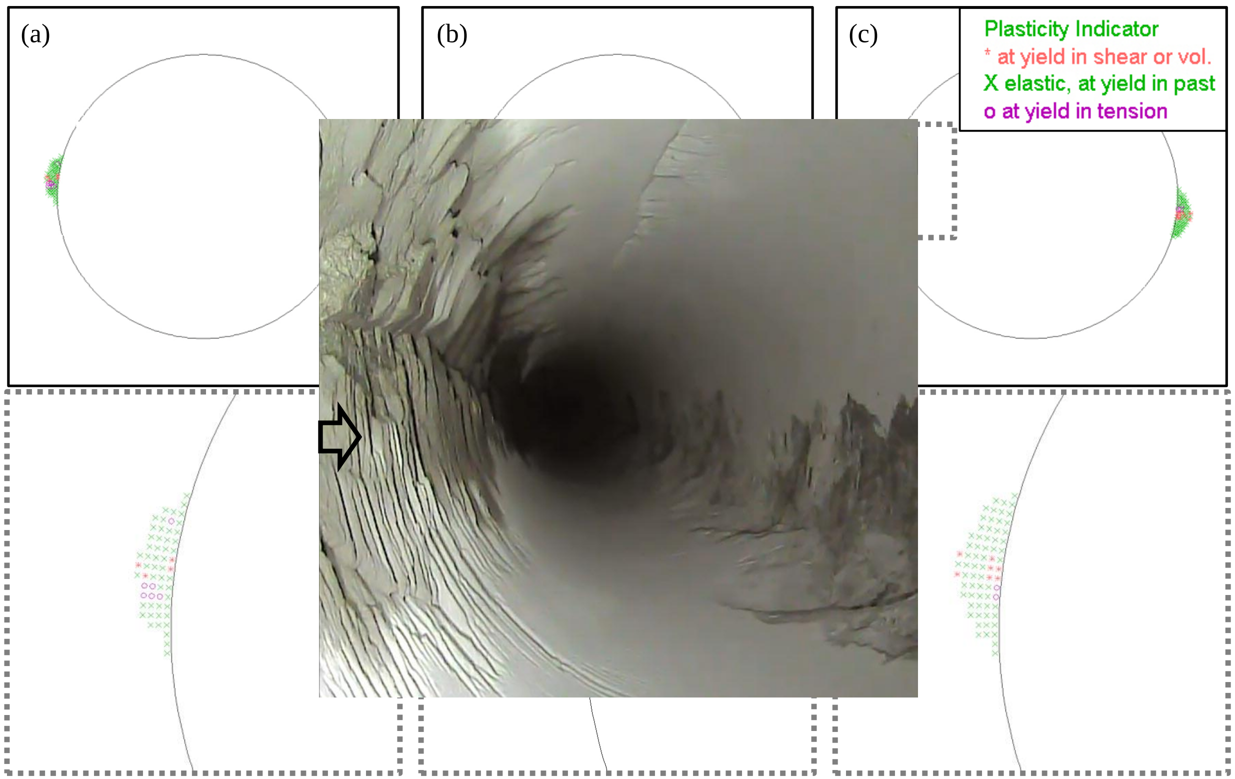
- CWFS, 100% GL
- Structure simulated as weak zone, *c*=0, ϕ=20° (Mohr-Coulomb)



Ventilation Shaft



- CWFS
- Fine-tuning of rock mass strength parameters



Validated Strengths (CWFS)

Rock mass	c [MPa]		ϕ [°]		Plastic strain limits [%]		I_{Beps}	σ_{tm} [MPa]
	Initial	Residual	Initial	Residual	*eps_Coh*	*eps_Fric*		
≈ 60% RL ≈ 40 % GL	55.0	6.2	0	46.2	0.2	0.4	1	0.95

Conclusions

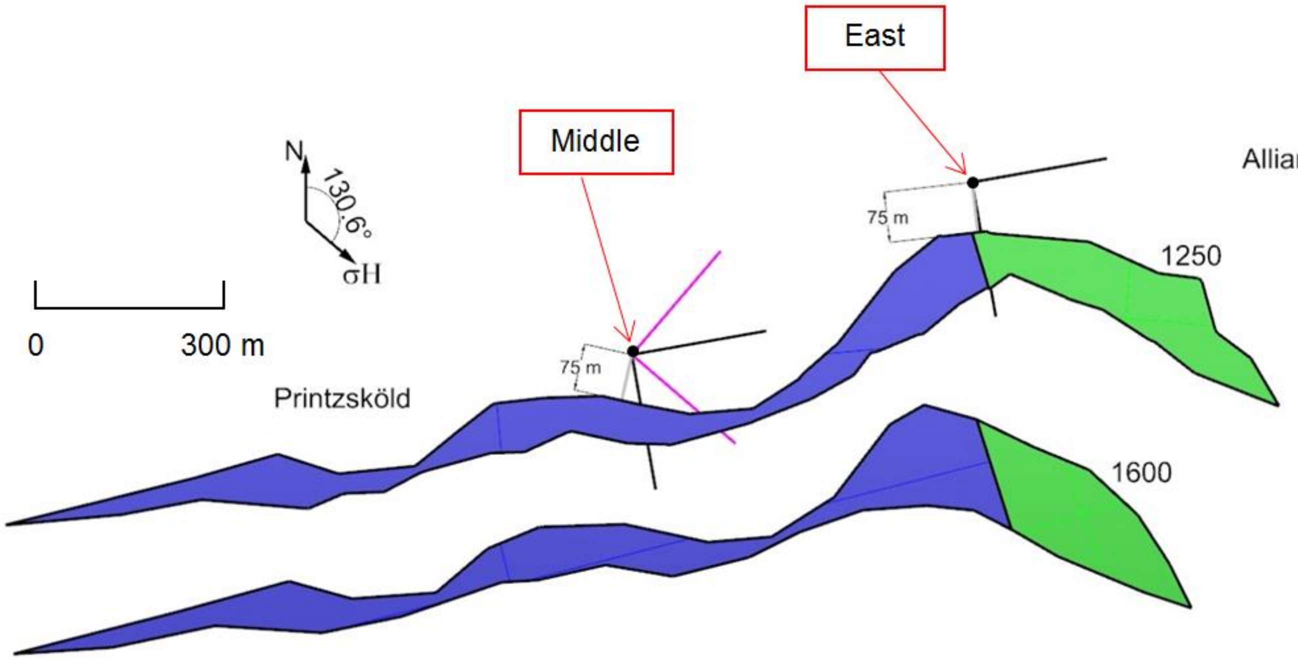
- Brittle material model (CWFS) required to replicated notch-shaped fallouts & spalling failure
- Strength values representative for stress-induced orepass failures
- Large-scale structures influence orepass stability – but only when in close proximity to the boundary (< 10 m).

Design Considerations

Future Orepass Design

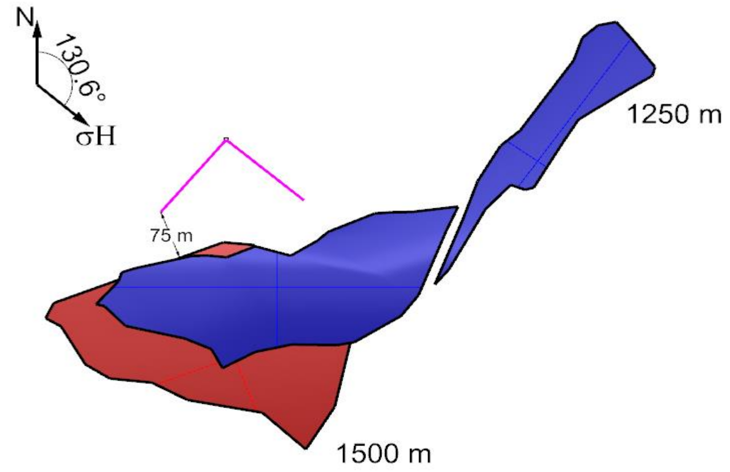
- Analysis of different orepass locations and orientations for potentially deeper mining
- Application the Alliansen-Printzsköld orebody and the Fabian orebody (two major future production areas)
- CWFS material model
- Orepass "groove" (wear effect)

Analysed Cases



Alliansen-Printzsköld

Fabian



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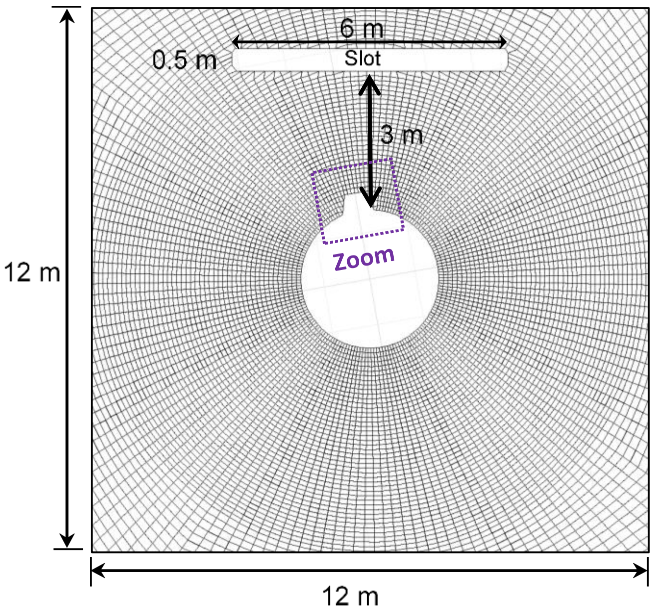
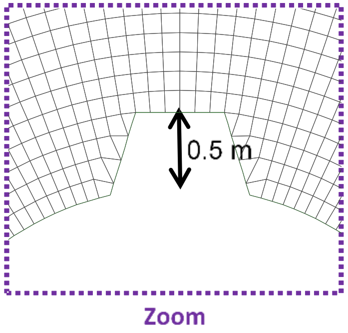
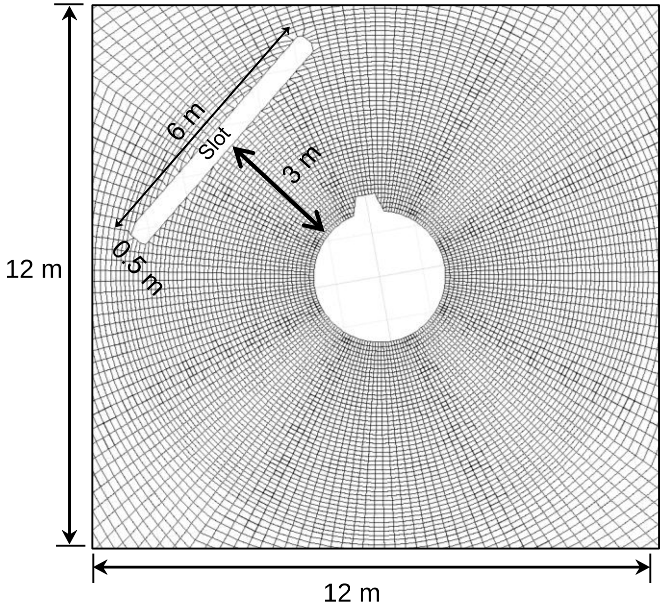


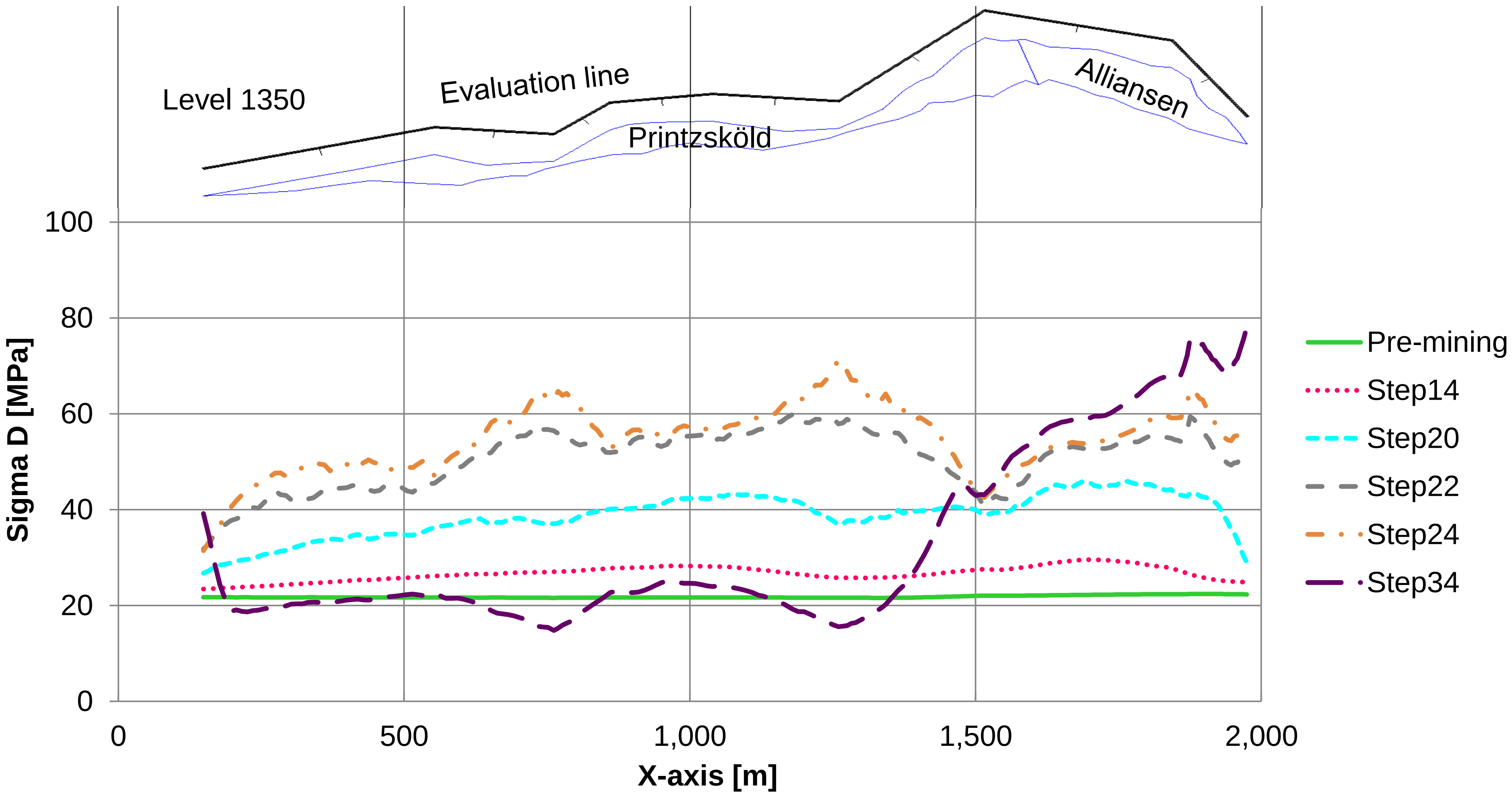


Orepass with "groove"

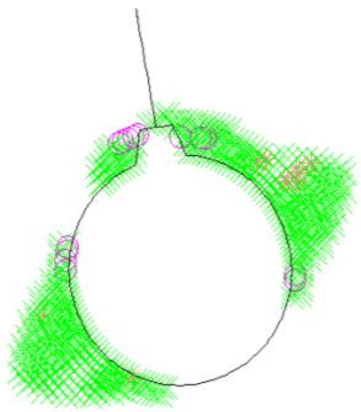
Destressing slot



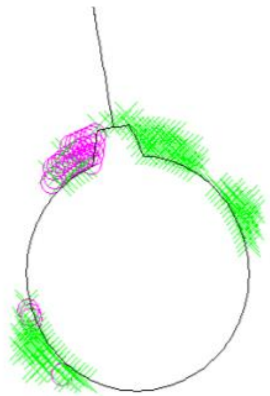
Stress at Orepass Location



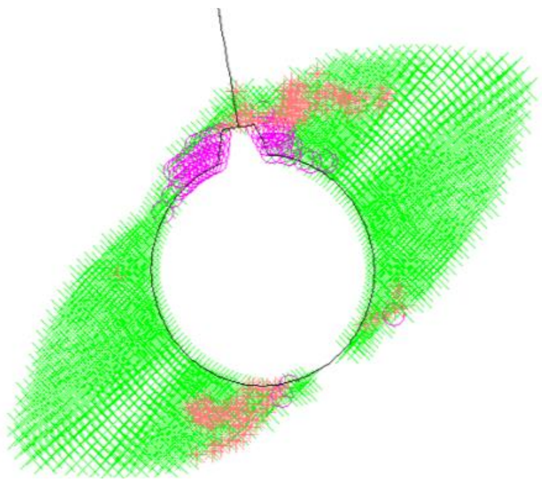
Effect of Orepass Location (& Strength)



Middle location

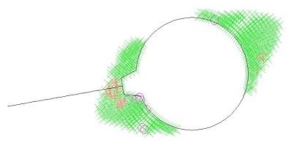
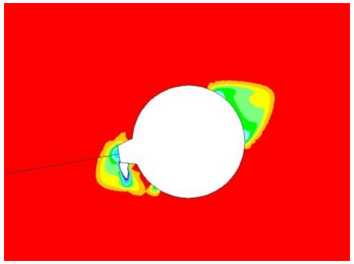
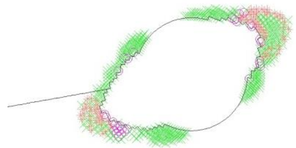
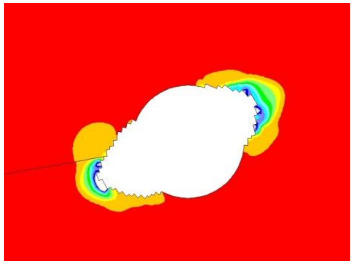
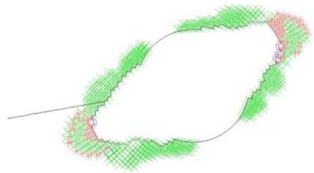
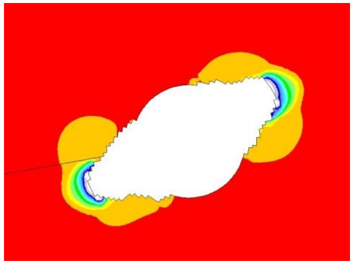
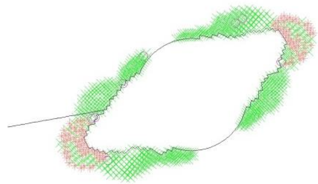
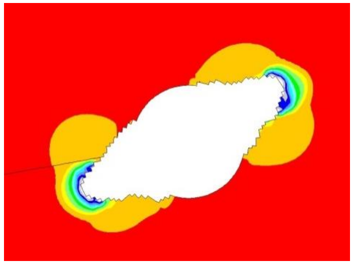


East location



East location & lower strength

Progressive Failure

Stage	Plasticity Indicator * at yield in shear or vol. X elastic, at yield in past o at yield in tension	Max. shear strain increment 0.00E+00 2.00E-03 4.00E-03 6.00E-03 8.00E-03 1.00E-02
C		
D		
E		
F		

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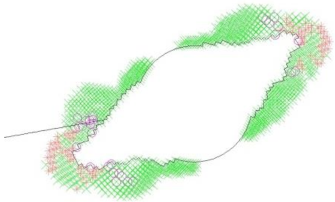
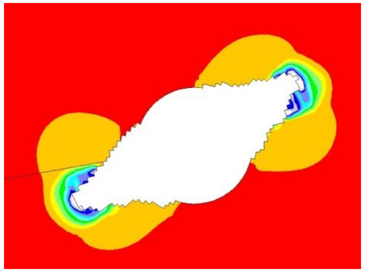
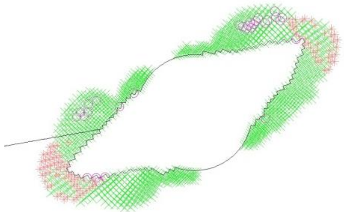
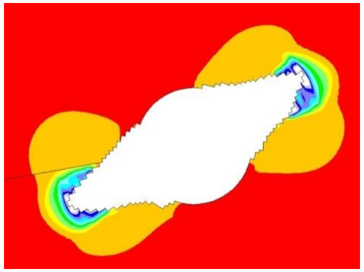
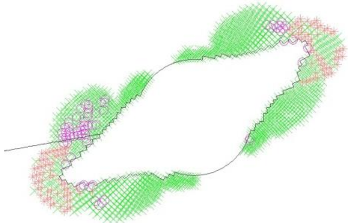
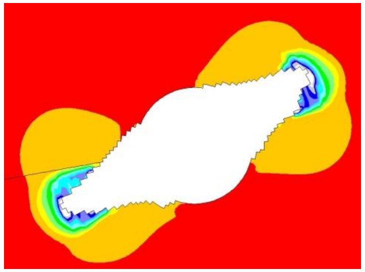
G		
H		
I		

Design Recommendations (I)

- Influencing factors:
  - Rock mass strength
  - Geographical location (stress state)
  - Orepass geometry
  - Orepass orientation

Decreasing importance

- East location (for Alliansen-Printzsköld) is more advantageous)
- Parallel orientation is (slightly) preferable

Design Recommendations (II)

- De-stressing slot not recommended; deconfinement leads to increased rock mass damage near the orepass
- Progressive geometrical changes due to wear may lead to more extensive spalling; must be considered in future work
- 3D stress model of the orepass should be considered


LKAB
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Special thanks to: Jimmy Töyrä (LKAB)