

WP2 – CIVIL ENGINEERING – FAR DETECTOR (FD)

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Lulea University of Technology (LTU)

WP2 - FD Concept Study Work Flow

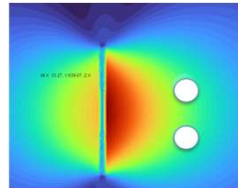
SNOLAB



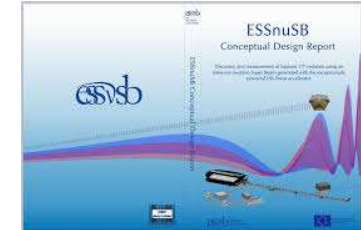
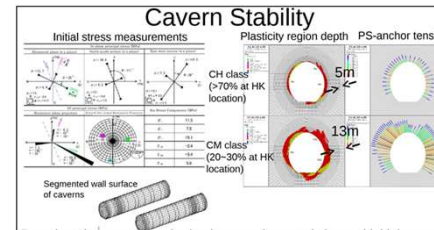
Hyper-K



Conceptual studies



Advanced studies



2023

2024

2025

2026

- Visits to SNOLAB, Hyper-K & Super-K
- **Meetings and MoU's with Zinkgruvan**
- 2 funding proposals – unsuccessful
- Held discussion with IDEON muon technology

- Craig Griffiths retires
- Preliminary studies, geology and engineering parameters
- Cavern stability studies
- 1 MSc Thesis
- **Visit of EC to Zinkgruvan**

- Policy & environmental assessments
- **Infra-Dev application**
- Advanced large cavern studies
- 3 conference papers (ARMA, EUROCK, BEFO)

- Report compilation
- **Final Deliverable M46**
- Contribution to ESSnUSB Design Study Report
- **Infra-Dev application answer – Oct 2026**
- (BeFo/Trafikverket – 2027)

Horizon-Infra Application 2026

(Submitted: 16-June-2026)
(Response: xx-October-2026)

ESSnuSB-FD INFRADEV

Part B

HORIZON-INFRA-2025-01-DEV-03: Consolidation of the Research Infrastructure landscape – Individual support for evolution, long term sustainability and emerging needs of pan-European research infrastructures

Design Study

Title of Proposal: Design study of the ESSnuSB Far Detector infrastructure for fundamental neutrino oscillation research with additional benefits of their use for geological exploration and other uses

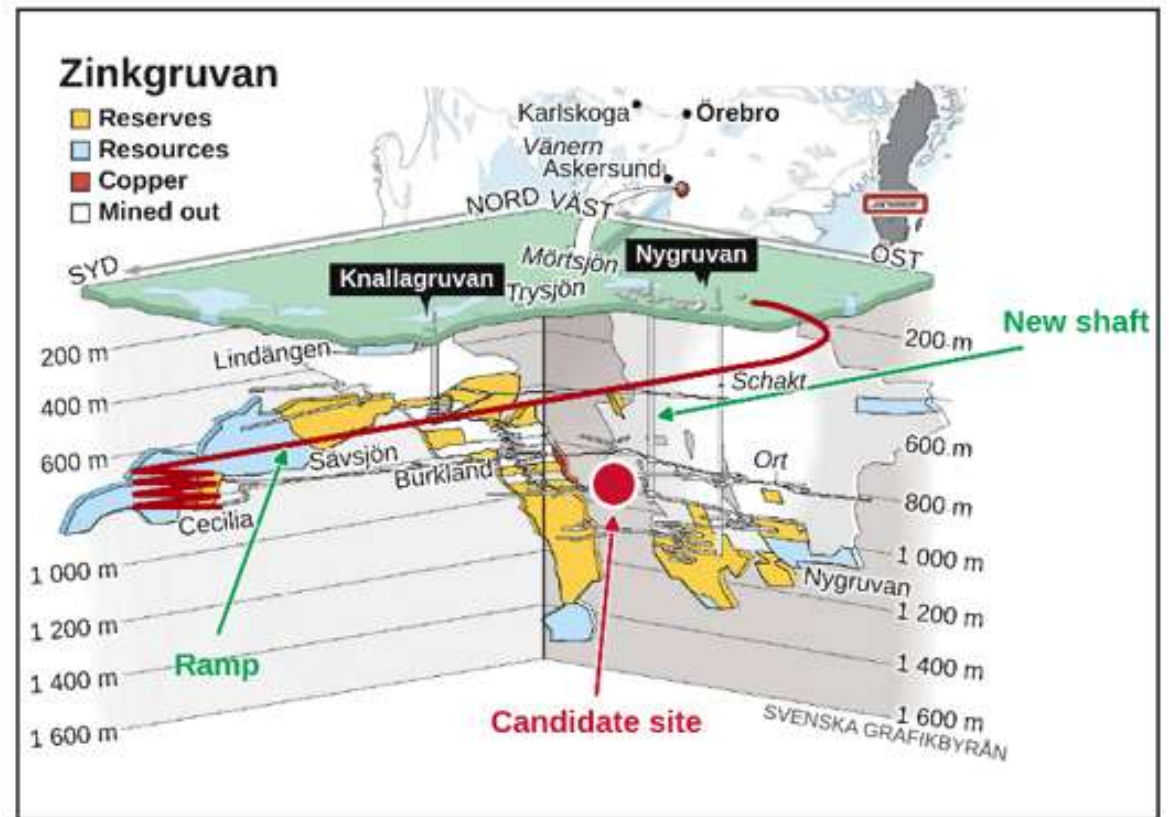
Acronym of Proposal: ESSnuSB-FD

Participant no.	Participant organisation name	Part. short name	Country
1 (Coordinator)	Lulea Tekniska Universitet	LTU	Sweden
2	Uppsala Universitet	UU	Sweden
3	University of Oulu	UO	Finland
4	Kungliga Tekniska Hogskolan	KTH	Sweden
5	Lunds Universitet	ULUND	Sweden
6	European Spallation Source ERIC	ESS	Sweden
7	Cuprum Research & Development Centre	CRD	Poland
8	Universität Hamburg	UHAM	Germany
9	Aachen University	RWTH	Germany
10	Ruder Boskovic Institute	RBI	Croatia
11	Centre National de la Recherche Scientifique	CNRS	France
12	National Center for Scientific Research "Demokritos"	NCSR	Greece
13	Universita degli Studi Roma Tre	UNIROMA3	Italy
14	Université de Strasbourg	UNISTRA ¹	France
15	Aristotelio Panepistimio Thessalonikis	AUTH	Greece
16	Consorcio Para la Construcción, Equipamiento y Explotación de la Sede Española de la Fuente Europea de Neutrones por Espalación (ESS Bilbao)	ESSB	Spain
17	University of Oslo	UIO	Norway
18	University of Bergen	UIB	Norway
19	European Organisation for Nuclear Research	CERN ²	IEIO
20	Hellenic Open University	HOU	Greece
21	Boliden Zinkgruvan	BZ ³	Sweden

Zinkgruvan-Wiks-ESS Lund

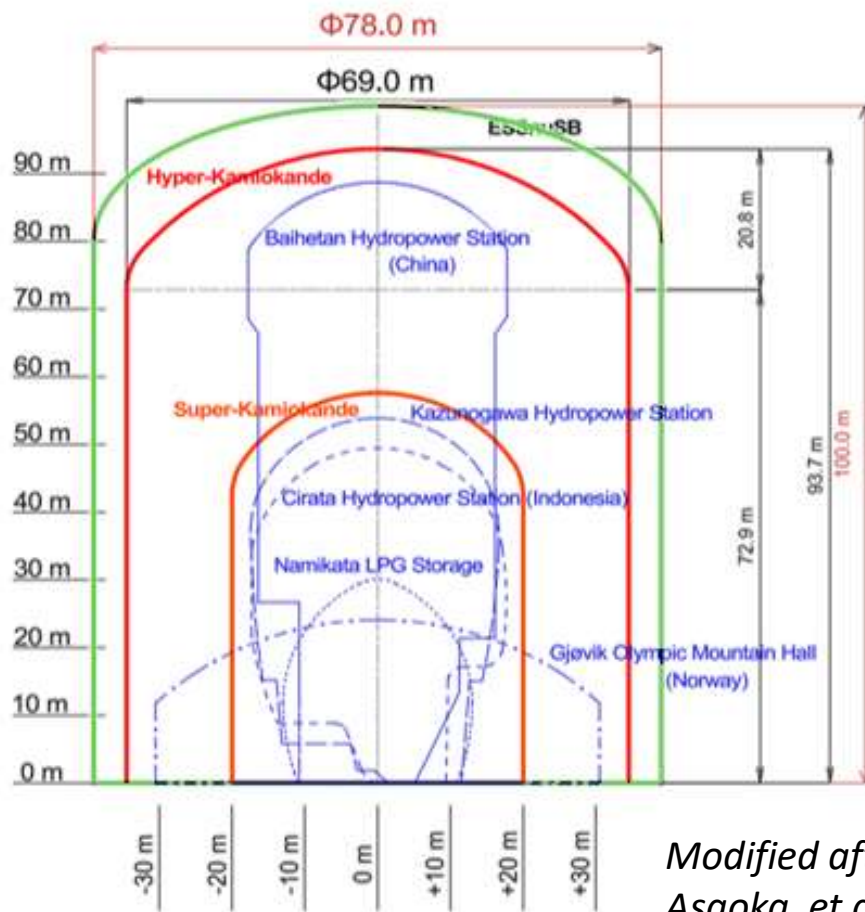


(a)

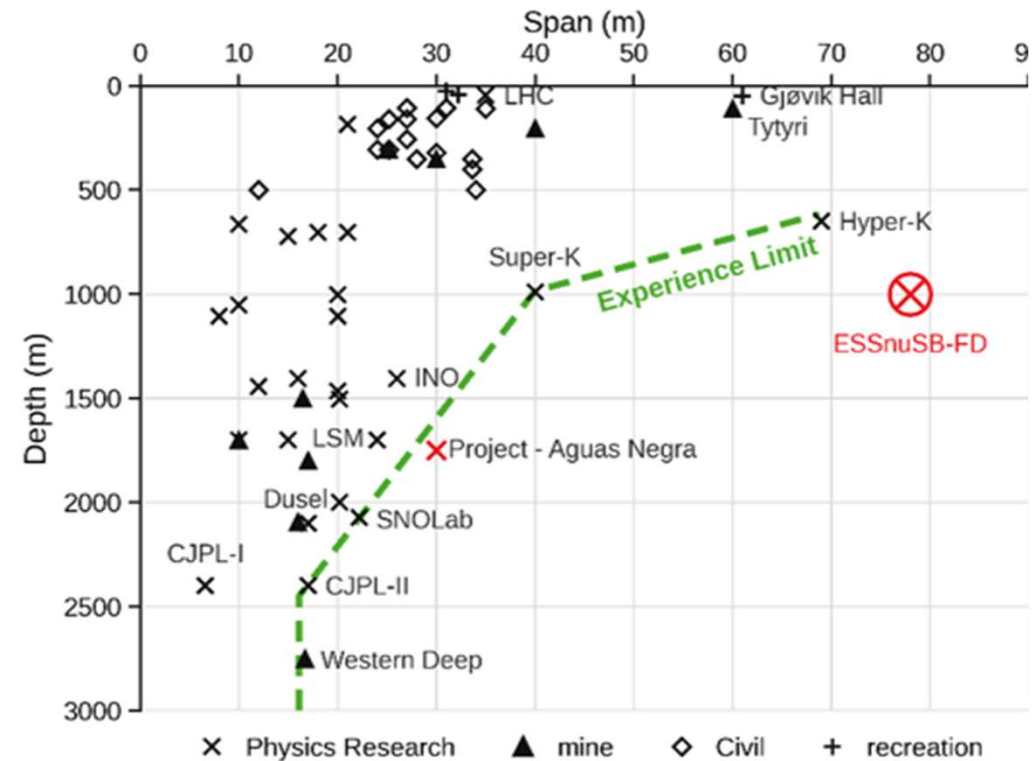


(b)

Rock Engineering Challenge



Modified after
Asaoka, et al, 2026

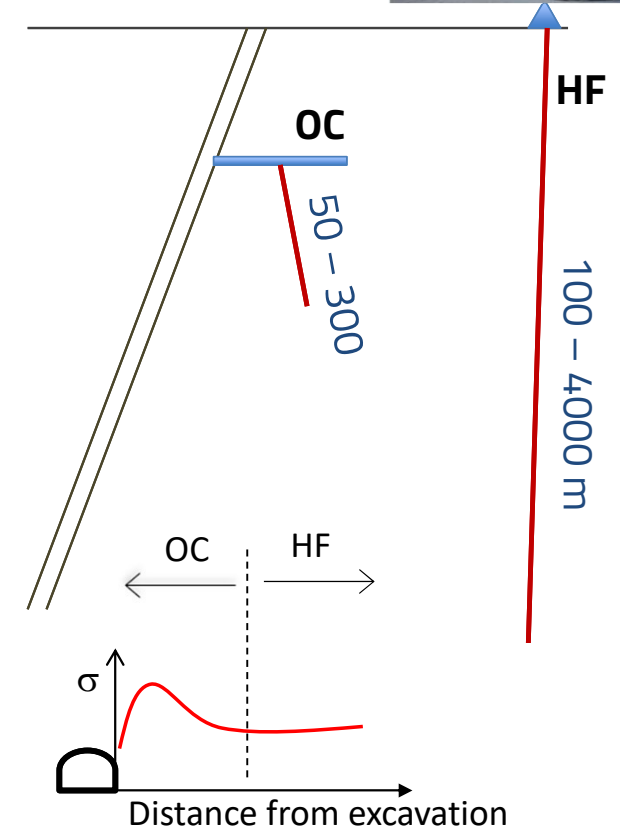
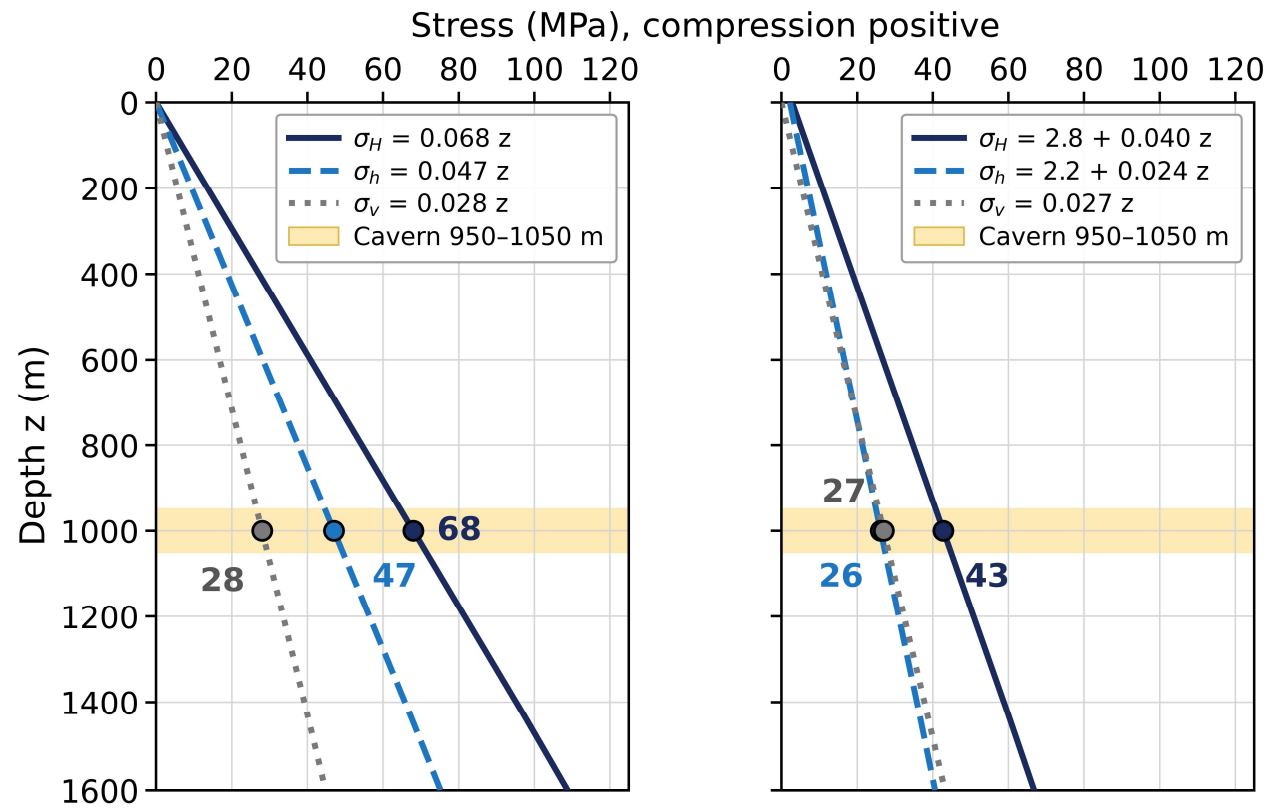


High ground pressure

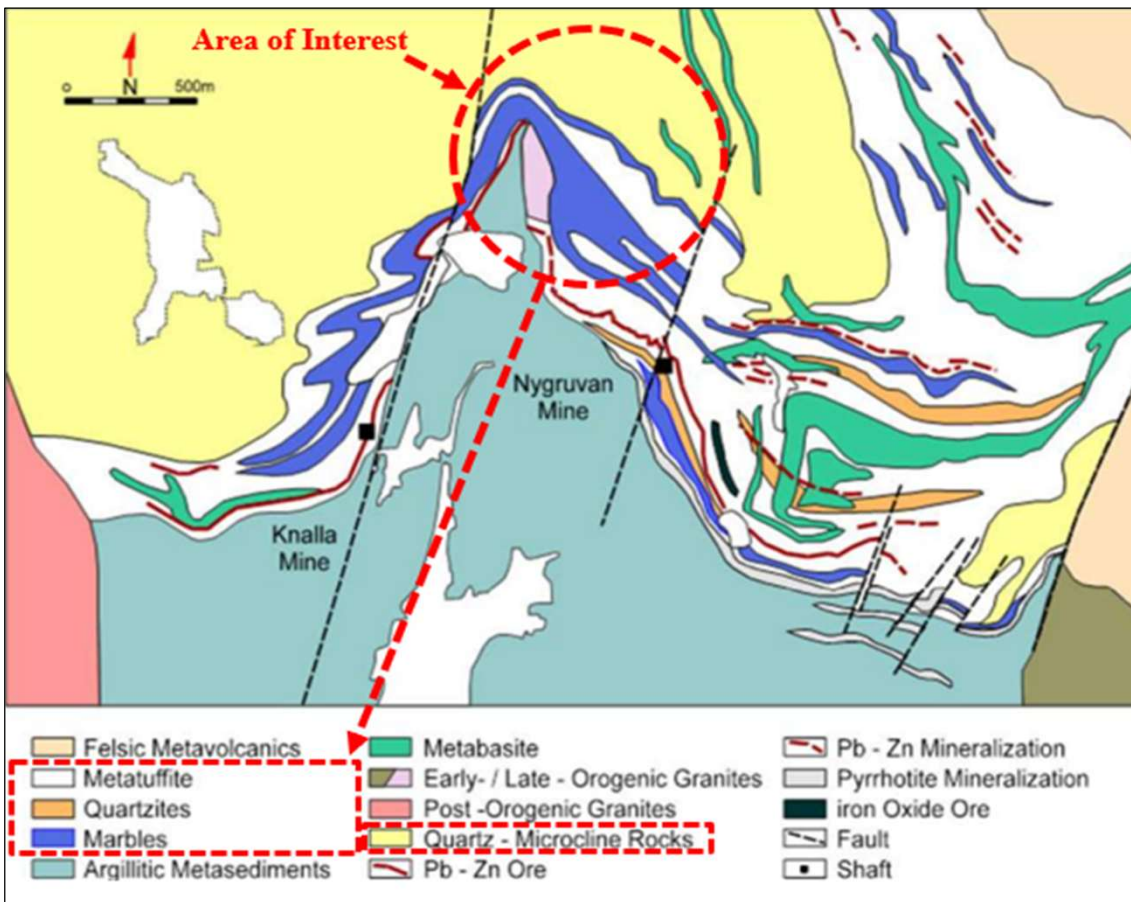


(a) Overcoring

(b) Hydraulic fracturing



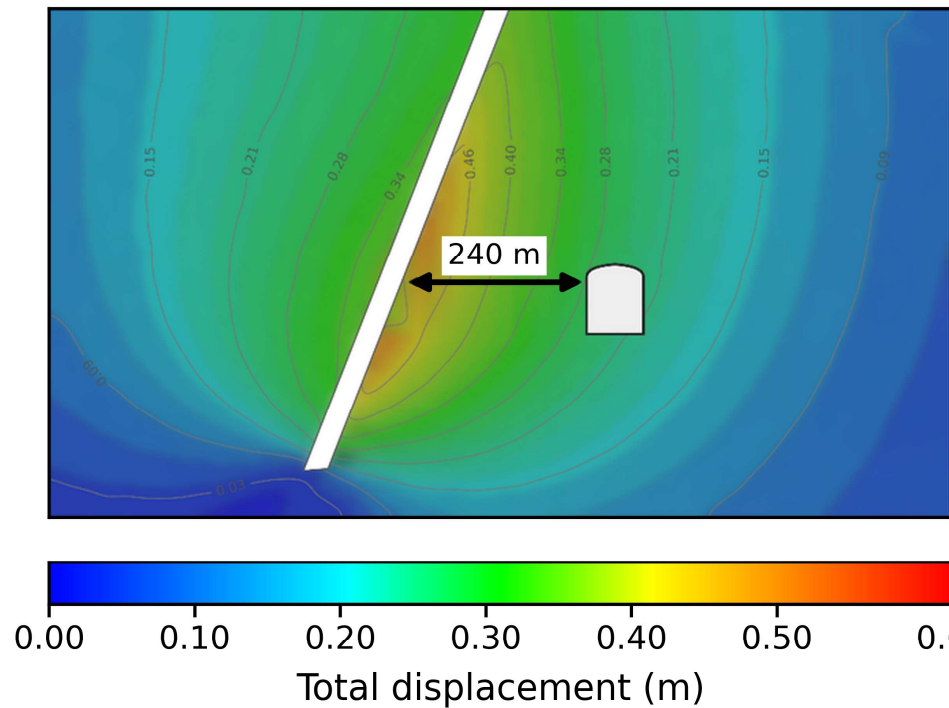
Engineering geology



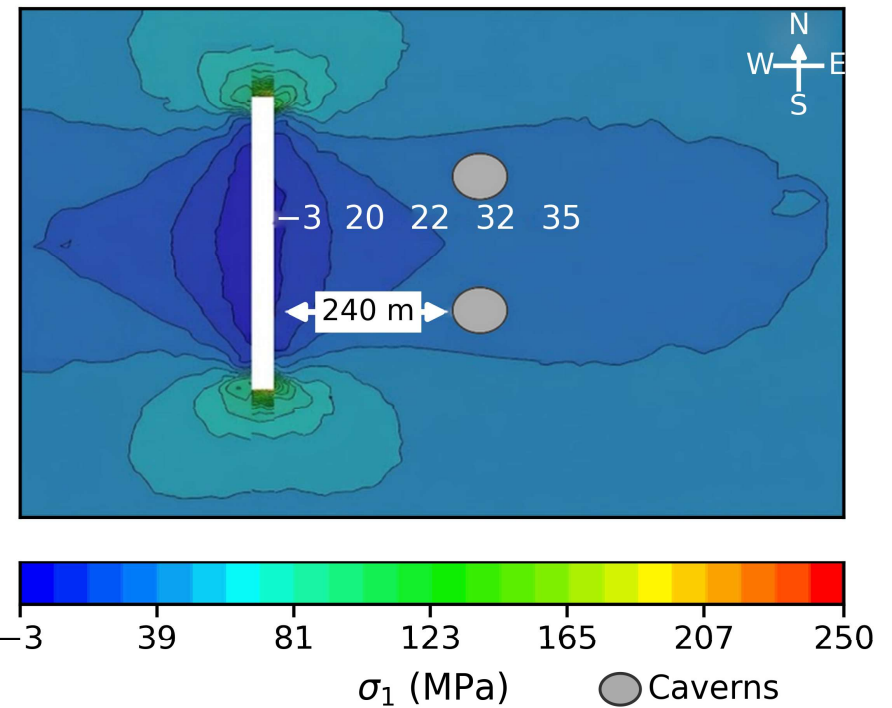
Stability Assessment

Stand-off distance

(a) Mine induced ground displacement

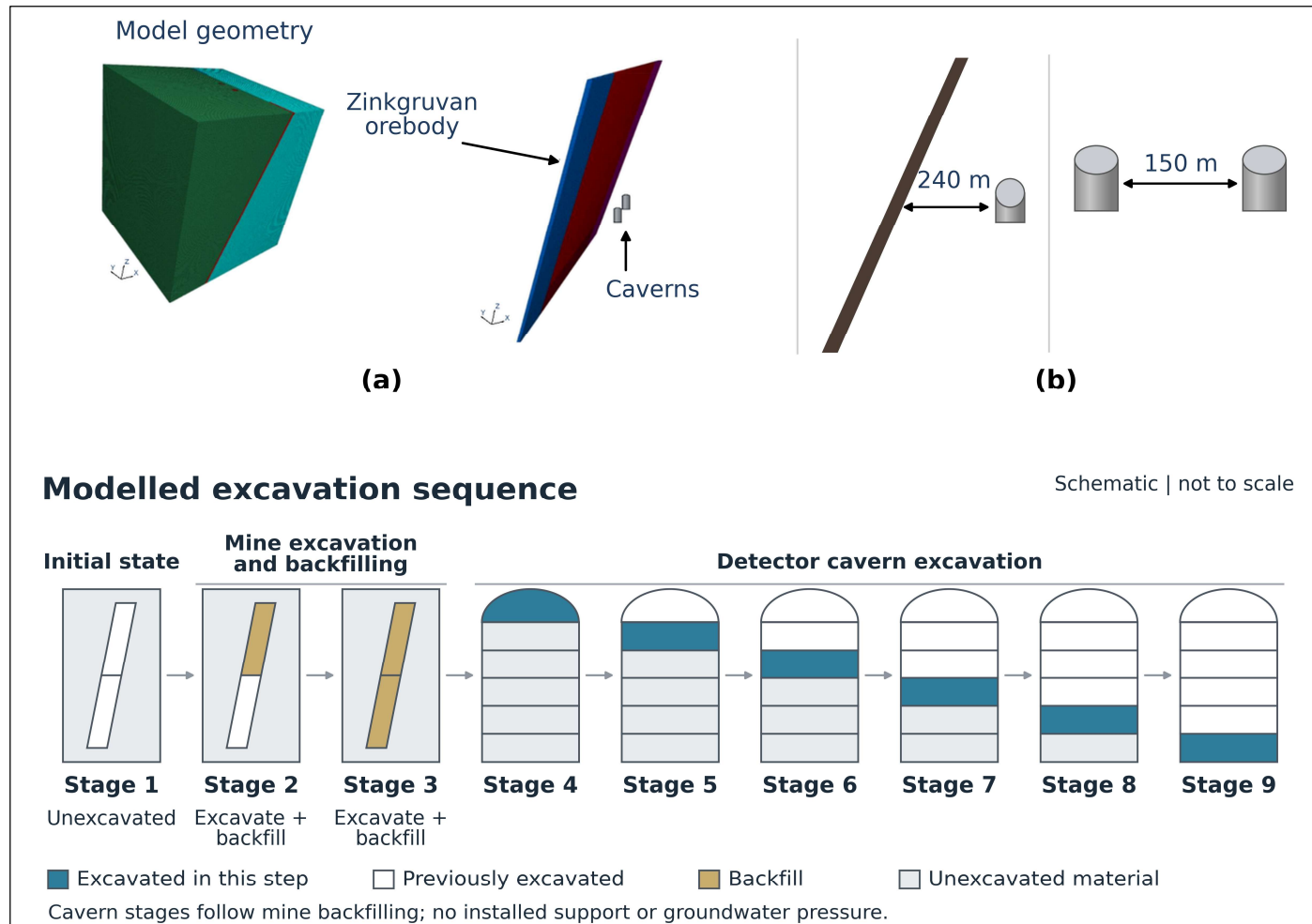


(b) Mine induced stress



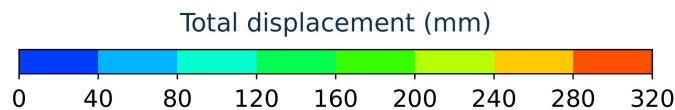
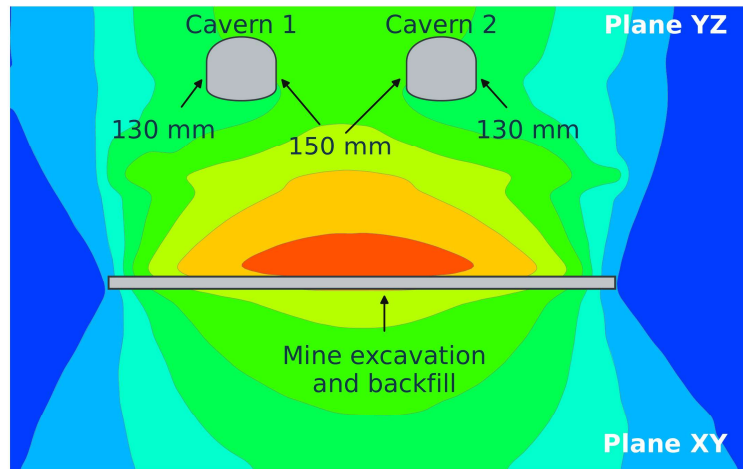
Cavern Stability

Continuum Analyses (FEM/FDM)



Stability assessment – continuum method

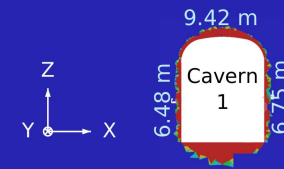
(a) Total displacement



(b) Yielded zones

Plane XZ

Maximum yielding depth
Roof = 10 m
Walls = 7 m
Floor ≈ 24 m
(estimated)



Plane YZ

Maximum yielding depth
Roof = 10 m
Walls = 12 m
Floor ≈ 24 m
(estimated)



Plane XY

Maximum yielding depth
around tunnel barrel
= 9-15 m



Yielded elements (%)



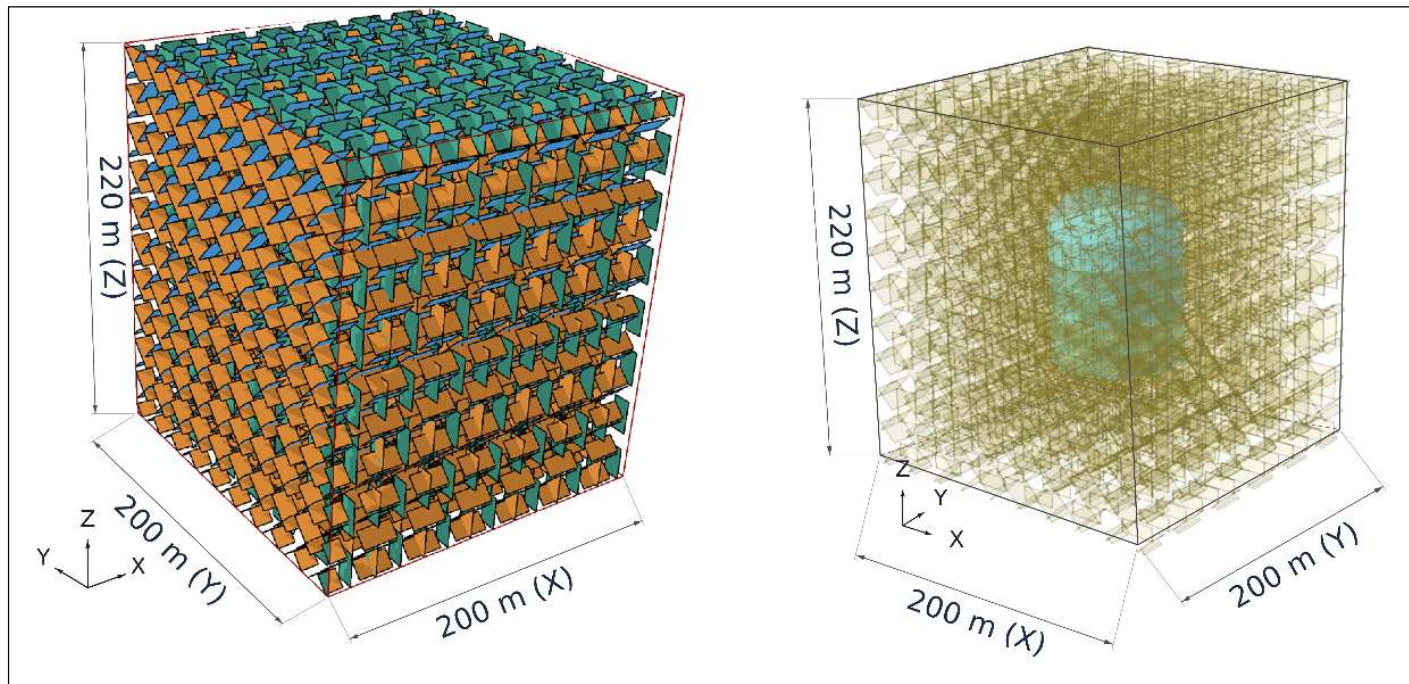
$$\text{average deformation gradient} \approx \frac{\text{relative displacement across the zone}}{\text{zone thickness}} = \frac{0.15}{15} = 0.01 = 1\%.$$

**Rock burst
potential**

Cavern Stability

Deterministic Discrete Fracture Network (DFN)

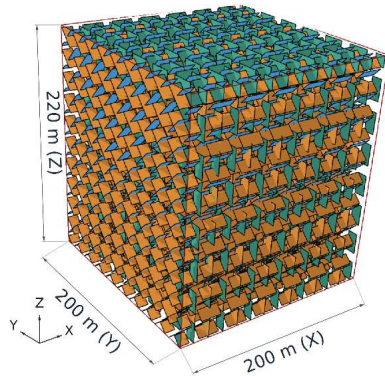
Testing the “blocky” to “very blocky” rock mass!



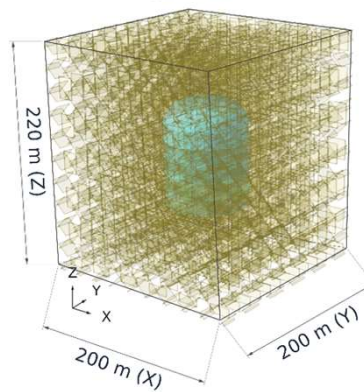
GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS (Hoek and Marinos, 2000)					
From the lithology, structure and surface condition of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI=35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surface in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.					
STRUCTURE	SURFACE CONDITIONS				
INTACT OR MASSIVE - intact rock specimens or massive in situ rock with few widely spaced discontinuities	VERY GOOD Very rough, fresh unweathered surfaces	GOOD Rough, slightly weathered, iron stained surfaces	FAIR Smooth, moderately weathered and altered surfaces	POOR Stickensided, highly weathered surfaces with compact coatings or fillings or angular fragments	VERY POOR Stickensided, highly weathered surfaces with soft clay coatings or fillings
DECREASING SURFACE QUALITY →					
DECREASING INTERLOCKING OF ROCK PIECES ↓	90			N/A	N/A
	80				
	70				
	60				
	50				
	40				
	30				
	20				
	10				
BLOCKY - well interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets					
VERY BLOCKY - interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets					
BLOCKY/DISTURBED/SEAMY - folded with angular blocks formed by many intersecting discontinuity set. Persistence of bedding planes or schistosity					
DISINTEGRATED - poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces					
LAMINATED/SHEARED - Lack of blockiness due to close spacing of weak schistosity or shear planes	N/A	N/A			

DFN modelling cases

Deterministic Joint Network (RS3 Parallel Network)



Three sets of 20 m × 20 m planes at constant spacing



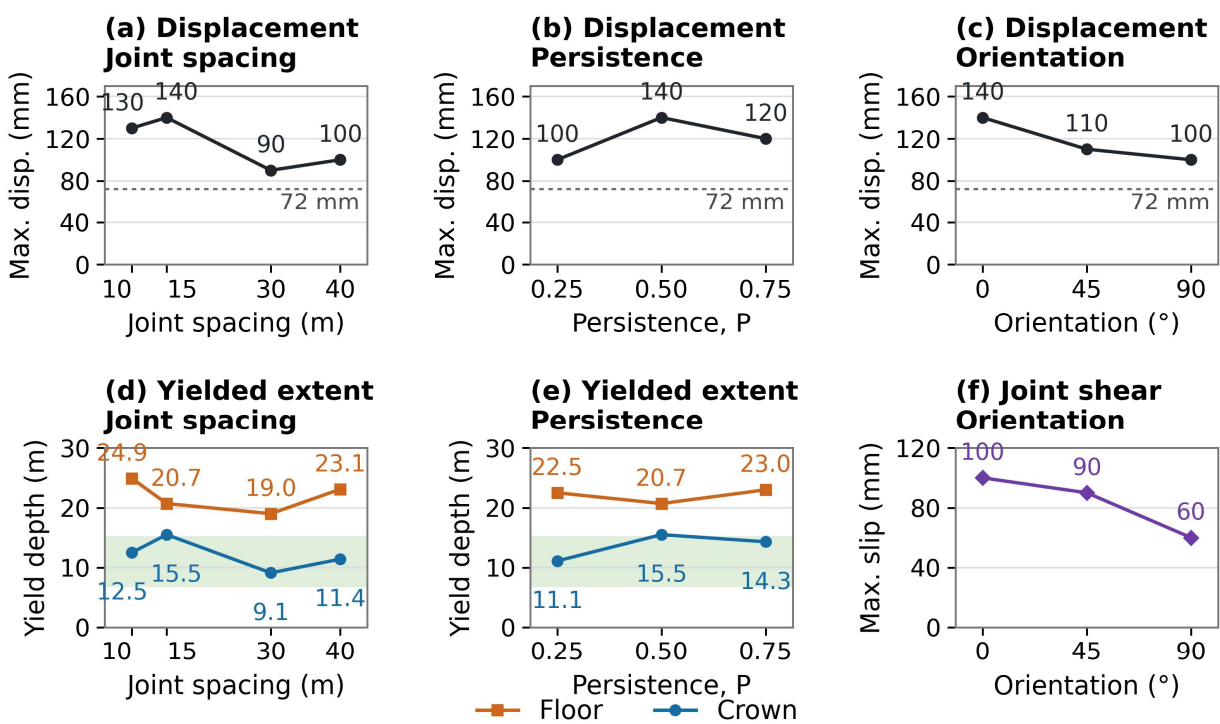
Network kept within 60 m of the half-cavern

Sensitivity	Cases	keep constant
Spacing	40, 30, 15, 10 m	P = 0.50; reference orientation
Persistence	0.25, 0.50, 0.75	Spacing = 15 m; reference orientation
Orientation	0°, 45°, 90°	Spacing = 15 m; P = 0.50

Joint Inputs

Input	Value adopted
Joint sets	J1 45°/90°, J2 45°/270°, J3 90°/0° (dip/dip direction): two conjugate sets and one vertical cross set
Joint Plane Size	20 m × 20 m quadrilaterals, about a quarter of the span; parallel planes at constant spacing
Persistence	Joint length divided by total length along the plane. Baseline P = 0.50: 20 m joint plane size, 20 m rock bridge
Joint strength	Mohr–Coulomb: $c_j = 0$, $\phi_j = 28^\circ$, no dilation, no tensile strength, residual = peak
Explicit zone	60 m around the cavern, about three joint lengths (Oda 1988); equivalent continuum outside
Placement	Fixed seed point and constant values: no random variables, deterministic

DFN Model Results



	Massive GSI > 75	Moderately fractured 50 < GSI < 75	Highly fractured GSI < 50	
Low in-situ stress $\sigma_1/\sigma_c < 0.15$	 Linear elastic response.	 Falling or sliding of blocks and wedges.	 Unravelling of blocks from the excavation surface.	$D_i < 0.4 (\pm 0.1)$
Intermediate stress $0.15 < \sigma_1/\sigma_c < 0.4$	 Brittle failure adjacent to the excavation boundary.	 Localized brittle failure of intact rock and movement of blocks.	 Localized brittle failure of intact rock and unravelling along discontinuities.	$0.4 (\pm 0.1) < D_i < 1.1 (\pm 0.1)$
High in-situ stress $\sigma_1/\sigma_c > 0.4$	 Failure zone Brittle failure around the excavation.	 Brittle failure of intact rock around the excavation and movement of blocks.	 Squeezing and swelling rocks. Elastic/plastic flow.	$D_i > 1.1 (\pm 0.1)$

DFN Model Results

CASE SUMMARY

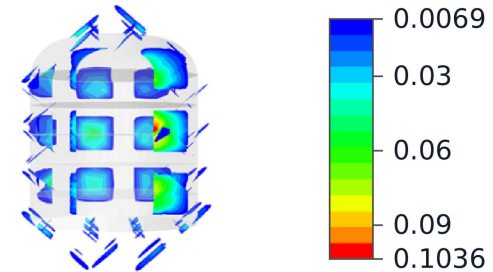
Case	Rotation	Max disp.	Joint shear
R0	0° / σ_1	0.14 m	0.10 m
R45	45°	0.11 m	0.09 m
R90	90° / σ_2	0.10 m	0.06 m

Phyton code

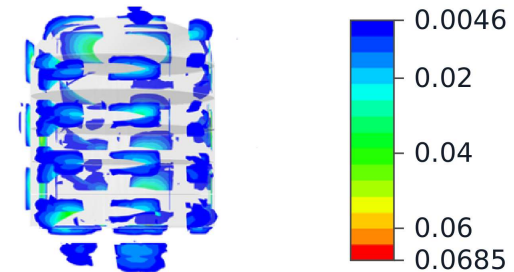
"Key Block Finder – Reinforcement Assistant "

Joint-Shear Pattern

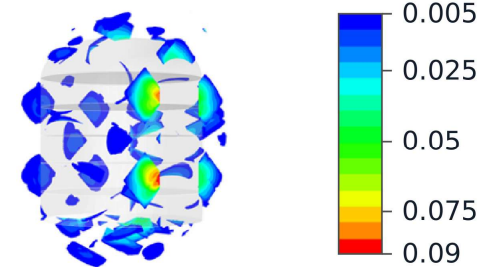
(a) DFN aligned with σ_1



(b) DFN aligned with σ_2



(c) DFN rotated 45°



Ground support

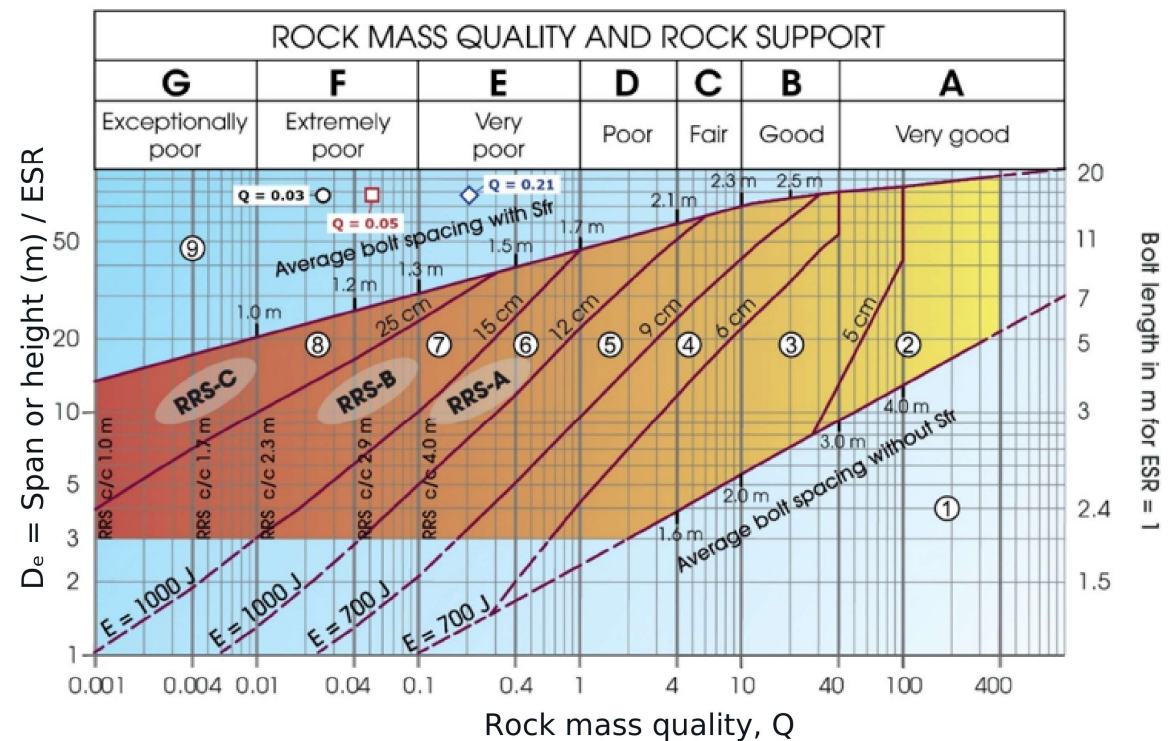
(a) Q-system assessment

GSI	Jw	SRF	Q	D _e (m)	Chart interpretation
65	1.0	50	0.21	78	Category 9: Special evaluation
65	1.0	200	0.05	78	Category 9: Special evaluation
65	1.0	400	0.03	78	Category 9: Special evaluation

GSI = Geological Strength Index
 Jw = Joint water reduction factor
 SRF = Stress reduction factor
 Q = Q rating
 D_e = Span or height (m) / ESR
 ESR = Excavation Support Ratio

For a 78 m span, D_e = 78 m
 assumes ESR = 1.

(b) Rock support chart

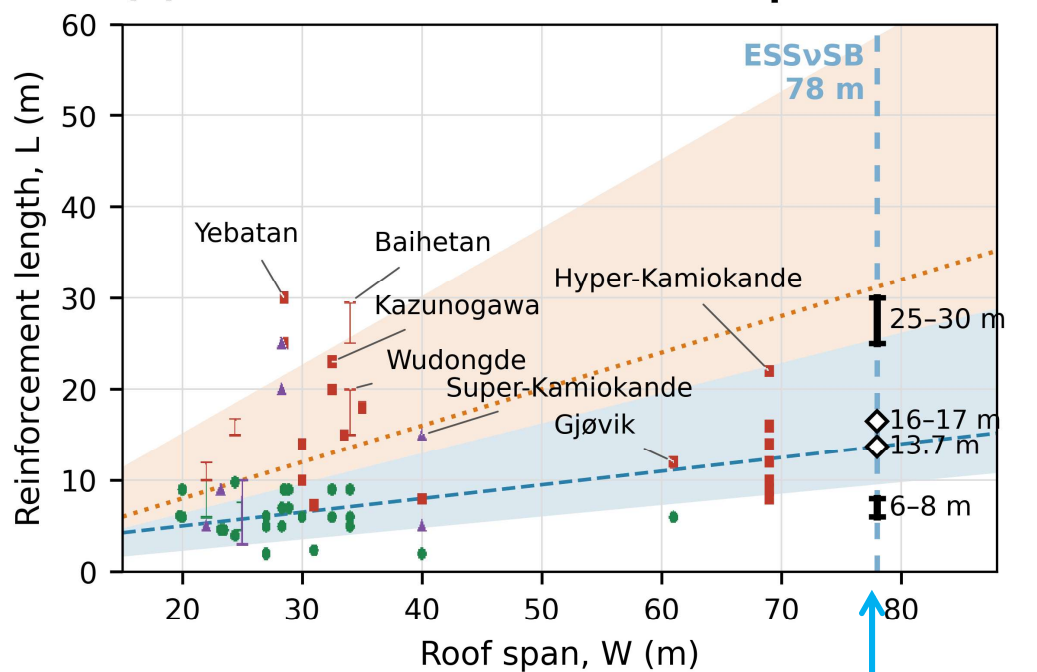


**ESSvSB: all three cases at D_e = 78 m plot in
 Support Category 9: "Special evaluation".**

NGI chart note: dashed-line areas have no empirical data.
 No bolt spacing or shotcrete thickness is assigned.

Ground support

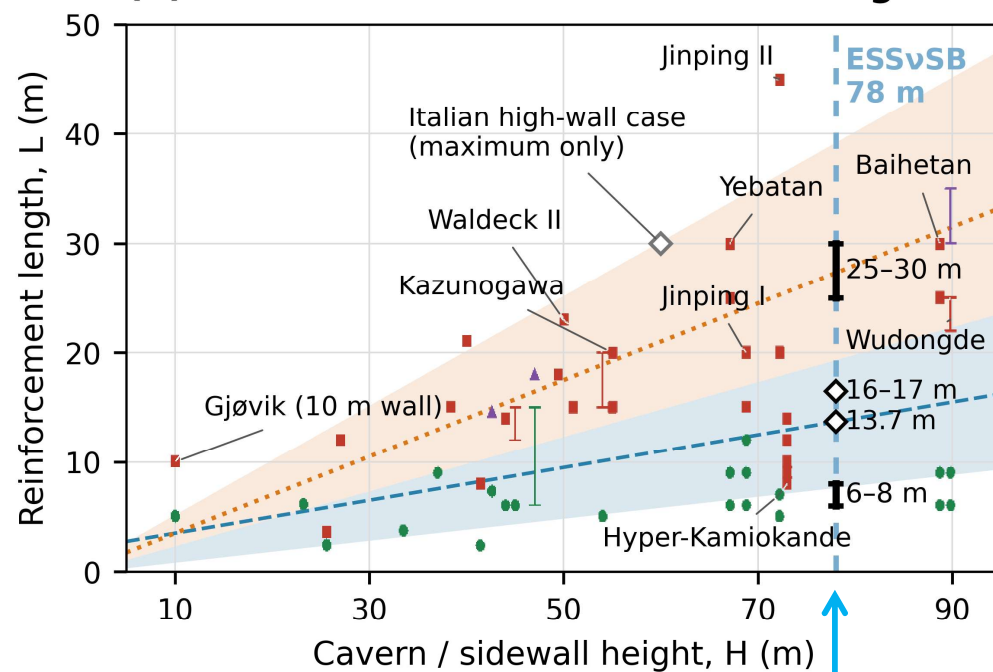
(a) Reinforcement versus roof span



- Cai rockbolts: $0.125-0.33W$; $0.10-0.33H$
- Cai anchors: $0.33-0.75W$; $0.25-0.50H$
- Historical bolts: $L = 2 + 0.15W$ (or H)
- Historical cables: $L = 0.40W$; $L = 0.35H$
- Systematic rockbolt / rebar

* Cable and prestressed-anchor lengths grouped for comparison only.

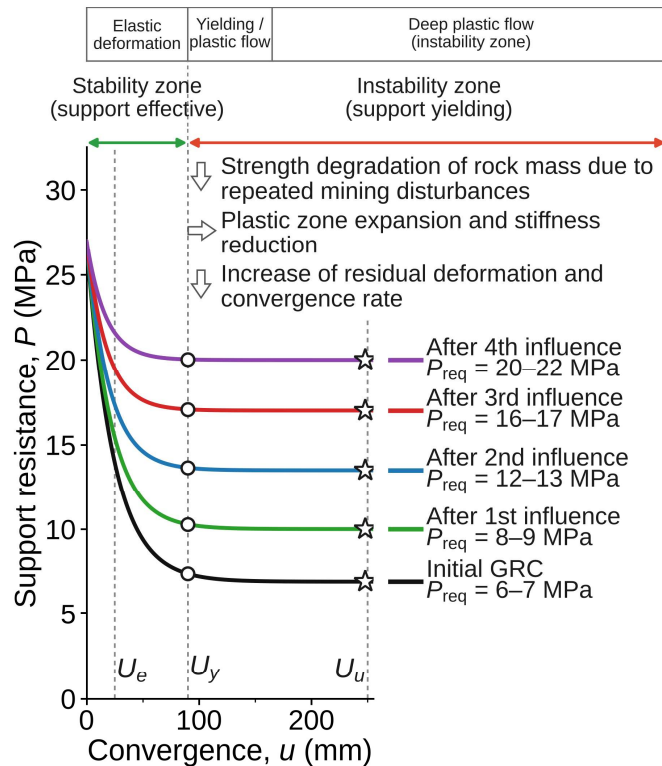
(b) Reinforcement versus cavern height



- Systematic cable / prestressed anchor*
- Local / supplementary reinforcement
- ESSvSB proposed ranges
- ESSvSB indicative bolt lengths
- Abstract-level candidate / maximum

Ground Reaction Curves (GRC) and Support Reaction Curves (SRC) - in cyclic disturbance

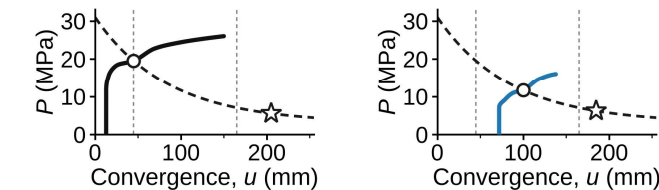
(a) GRC under staged excavations



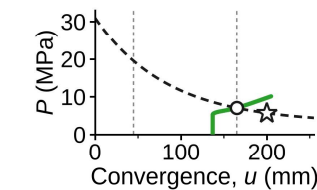
(b) SRC under staged excavations

Dashed vertical lines: zone limits as in (a).

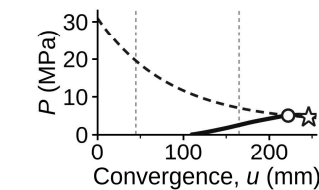
Case 1: Energy-absorbing support Case 2: Pre-stressed support



Case 3: Rigid support



Case 4: Arch support



(c) Interpretation of GRC evolution

1. GRC evolution

With each mining disturbance cycle, the bearing capacity and stiffness of the surrounding rock mass degrade significantly, resulting in an upward and rightward shift of the GRC and an expansion of the deep plastic flow zone.

2. SRC interaction

The intersection point between the support characteristic curve and the GRC represents the working state of the support system.

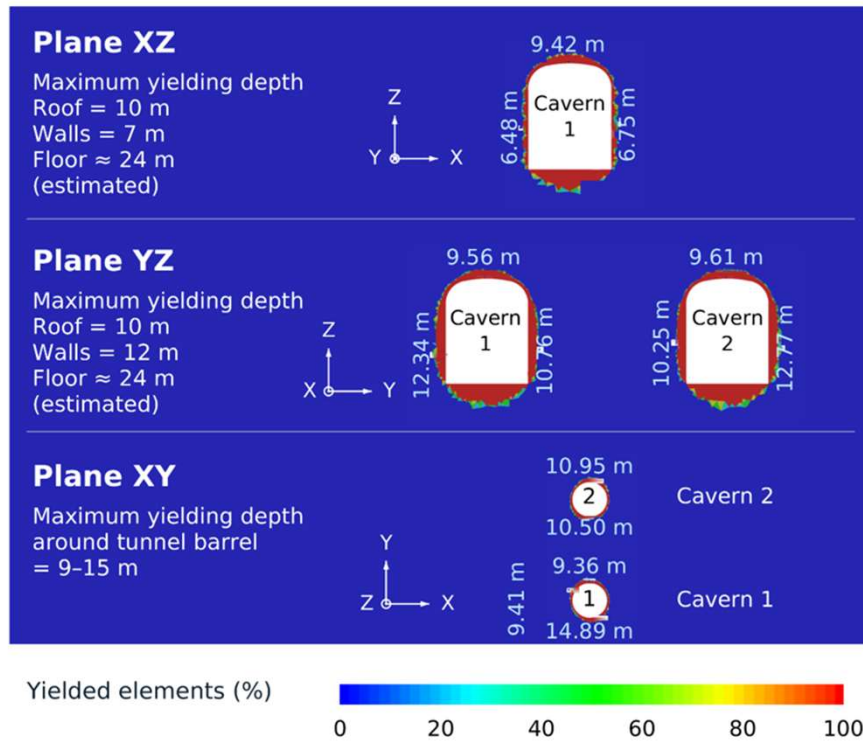
3. Failure mechanism

When the intersection point shifts into the deep plastic flow zone, the support system enters a state of excessive deformation, leading to instability and failure.

Key quantitative indicators

- Elastic limit (u_e): ~30 mm
- Yielding limit (u_y): ~100 mm
- Residual stability limit (u_u): ~200 mm
- Residual strength reduction: ~65–70%
- Convergence at failure (Type A): >120 mm
- Convergence at failure (Type D): >200 mm (but stable in deep plastic flow zone)

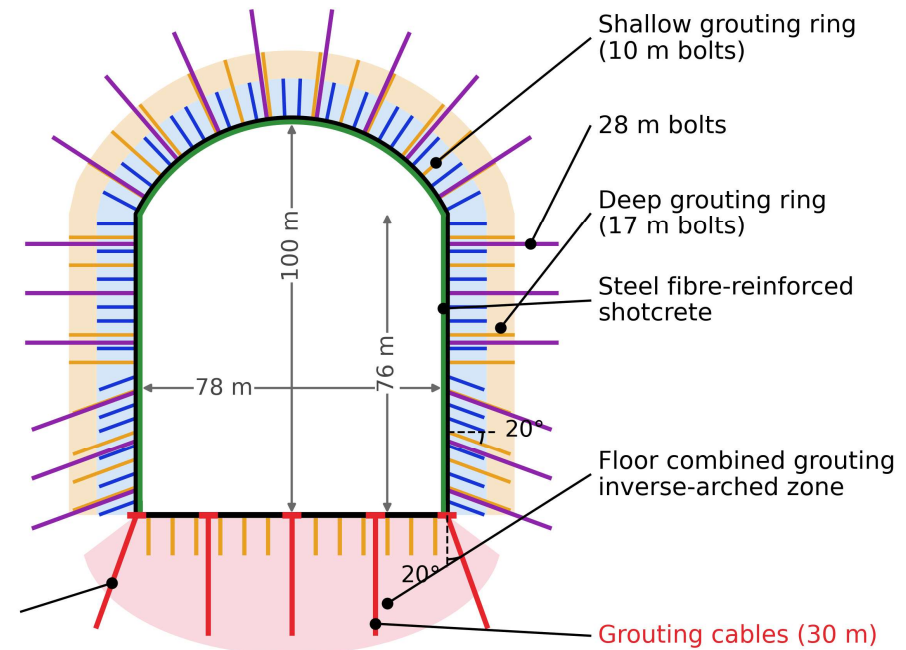
Conceptual support design



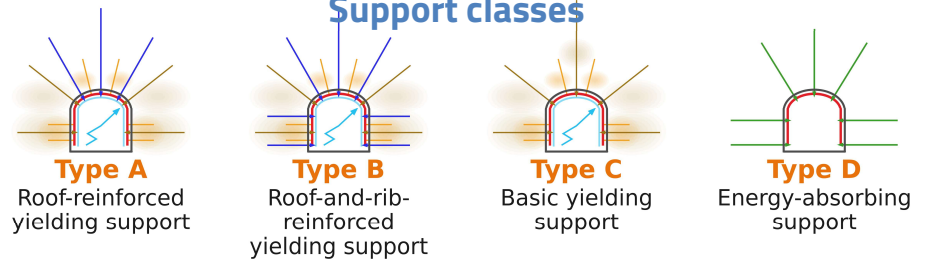
**90 bolts, equally spaced
around roof and walls**

- 10 m bolts (x 40)
- 17 m bolts (x 30)
- 28 m bolts (x 20)
- 10 m floor pipes
- 30 m floor pipes (x 2)
- 30 m floor cables (x 3)

Grouting pipes
(30 m, 20° from vertical)



Support classes



IAP – Finding #1

Finding: Far Detector

It is crucial to understand the long-term deformation of the rock for the Far Detector. These deformations can have a big impact on the design/costs of the underground cavern. Agree

Recommendations:

The IAP recommends obtaining historical deformation data from the mine as a matter of urgency to feed into these simulations.

Zinkgruvan Boliden is not a member of the ESSnuSB+ consortium and therefore cannot disclose mine data without a Non-Disclosure Agreement (NDA). LTU has therefore relied heavily on its many years of experience working with Boliden mines through joint research collaborations.

LTU's observations from the conceptual geotechnical studies of the caverns are consistent with its experience at Zinkgruvan.

IAP – Finding #2

General Remark: Far Detector

1. *Have the safety regulations to be adopted for the Far Detector facility design been clarified?*
2. *Would the facility be covered under the mining or civil engineering regulations?*

*This decision can obviously have a major impact on the overall design of the facility (e.g. ventilation, safety systems) and should be clarified. **Agree***

IAP – Finding #2

General Remark: Far Detector

1. *Have the safety regulations to be adopted for the Far Detector facility design been clarified?*
 - *Sweden does not regulate mine safety through a separate Mine Safety Act, like Australia or Canada for instance. Occupational safety in Swedish mines is governed by the Work Environment Act which applies generally to construction activities.*
 - *My visit to SnoLAB in 2023 in Sudbury, Canada, was specifically aimed at understanding the safety considerations. The state of Ontario has made concessions in the safety act to allow SnoLab to operate within the mine. However, SnoLAB maintains an insurance policy to compensate Creighton mine in the event where the safety mine is placed at risk and the mining operations must be must suspended.*
 - *Zinkgruvan has been very explicit that, any design study involving the mine must be supported by a detailed site investigation, including: (i) diamond drilling into the area of interest for geological investigation and (ii) Dedicated environmental assessment – Key part of Infra-Dev application submitted in June 2026.*
 - *Furthermore, Zinkgruvan has explicitly stated that all chemical elements that ESSnuSB wants to handle, including cadoliunium for water purification, must be discussed with Zinkgruvan in advance.*

IAP – Finding #2 - Regulatory

General Remark: Far Detector

1. *Have the safety regulations to be adopted for the Far Detector facility design been clarified?*
 2. *Would the facility be covered under the mining or civil engineering regulations?*
- Zinkgruvan currently operates under the Dalby K No. 1, Klara and Zinkgruvan exploitation concessions, together with environmental and water permits covering mining, mineral processing, tailings management and associated infrastructure. These approvals were granted for mineral extraction and should not be assumed to cover the construction and operation of a scientific facility. Under Swedish legislation, an exploitation concession establishes the right to extract concession minerals; it does not automatically authorise an unrelated use of the underground space.
 - USSnuSB detector will be located within Zinkgruvan's current exploitation concession

IAP – Finding #2 - Regulatory

Swedish authorities can mediate while considering:

- The national and international scientific value of the ESSnuSB Far Detector;
- The economic value of the mineral resource;
- The strategic importance of the mining operation; and
- Long-term land-use considerations.

A realistic assessment of potential conflicts requires detailed information on:

- The detector location and depth;
- The concession boundaries;
- Current mine plans;
- Long-term resource and reserve models;
- Planned mining horizons and future expansion areas; and
- Geotechnical exclusion zones associated with the detector.

IAP – Finding #2 - Regulatory

The ESSnuSB Far Detector itself would not be covered by mineral concession rights. Instead, it would most likely be regulated under the legal framework applicable to major research infrastructures, similar to ESS and MAX IV in Lund. The principal permitting and regulatory requirements are expected to include:

- Land access and property rights;
- Environmental permits;
- Building and construction permits;
- Workplace health and safety regulations;
- Radiation regulations, where applicable; and
- Governance and recognition as a national or international research infrastructure

Environmental Constraints

- Excavated rock deposition - a site 2.5 million cubic meters of excavated rock (this is equivalent to the amount of rock Zinkgruvan takes out in 4 years!)
- Disturbance to water table – eventhough Zinkgruvan mine, for environmental permitting this must verified or confirmed.
- Recycling of water – ESSnuSB huge amount of water, it must demonstrate how it will be recycle water

Cost estimation

- A preliminary excavation rate of €600–800/m³ was adopted based on mining experience. ESSnuSB will handle rough 1.2 – 1.5 million m³ of excavated rock.

Construction component	Estimated volume
Two detector caverns	960,000 m ³
Access tunnels and additional chambers	240,000 m ³
Fully-equipped material handling shaft (7 m dia. 1.05 km)	40,400 m ³
Allowance up to the rounded planning volume	39,600 m ³
Total	1,200,000 m³

Conclusion

- For the current study we have achieved our goal defined in the project milestone and deliverables. The final deliverable D2.3 will be submitted before October 30, 2026.
- Future work will focus detailed design study and will rely on detailed site investigation. An Infra-Dev application has been submitted in June 2026 for this purpose.



Thank you

