Moglicë HPP - Albania

Jorge Terron

DEVOLL MOGLICË PROJECT

SWECO

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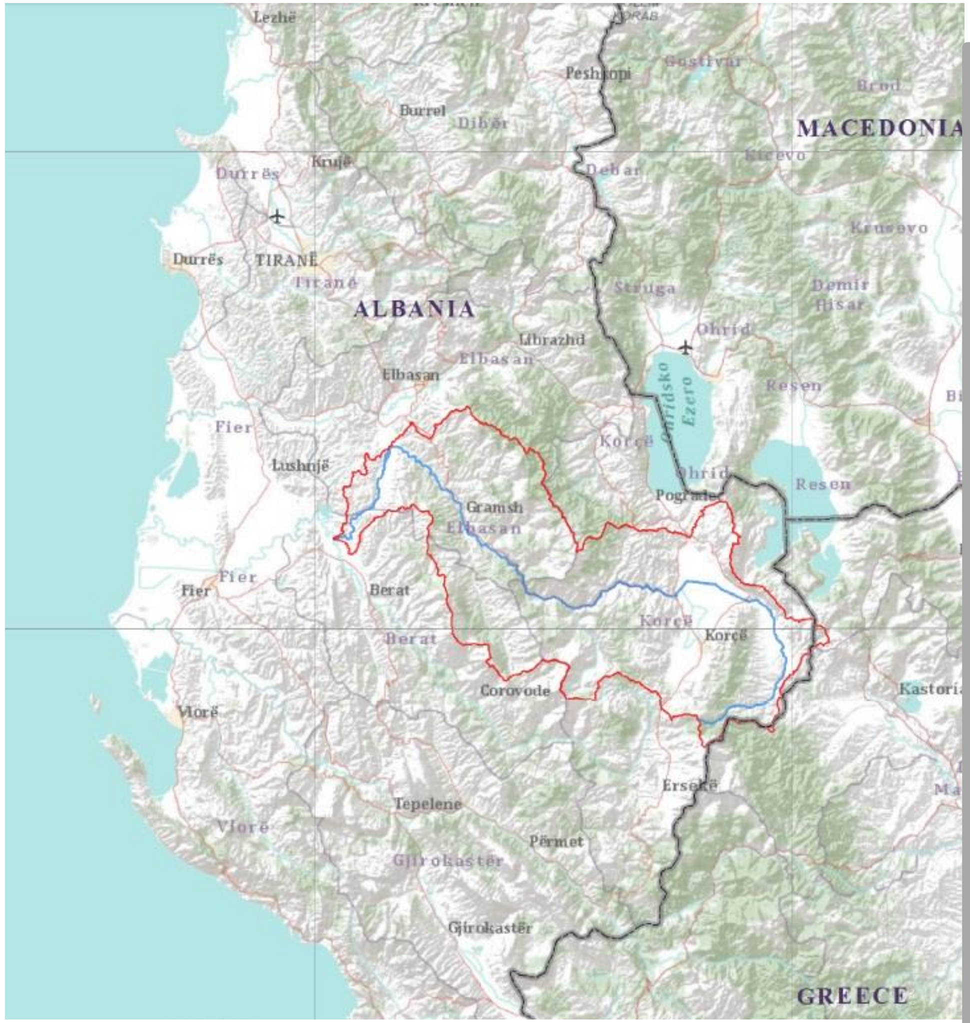
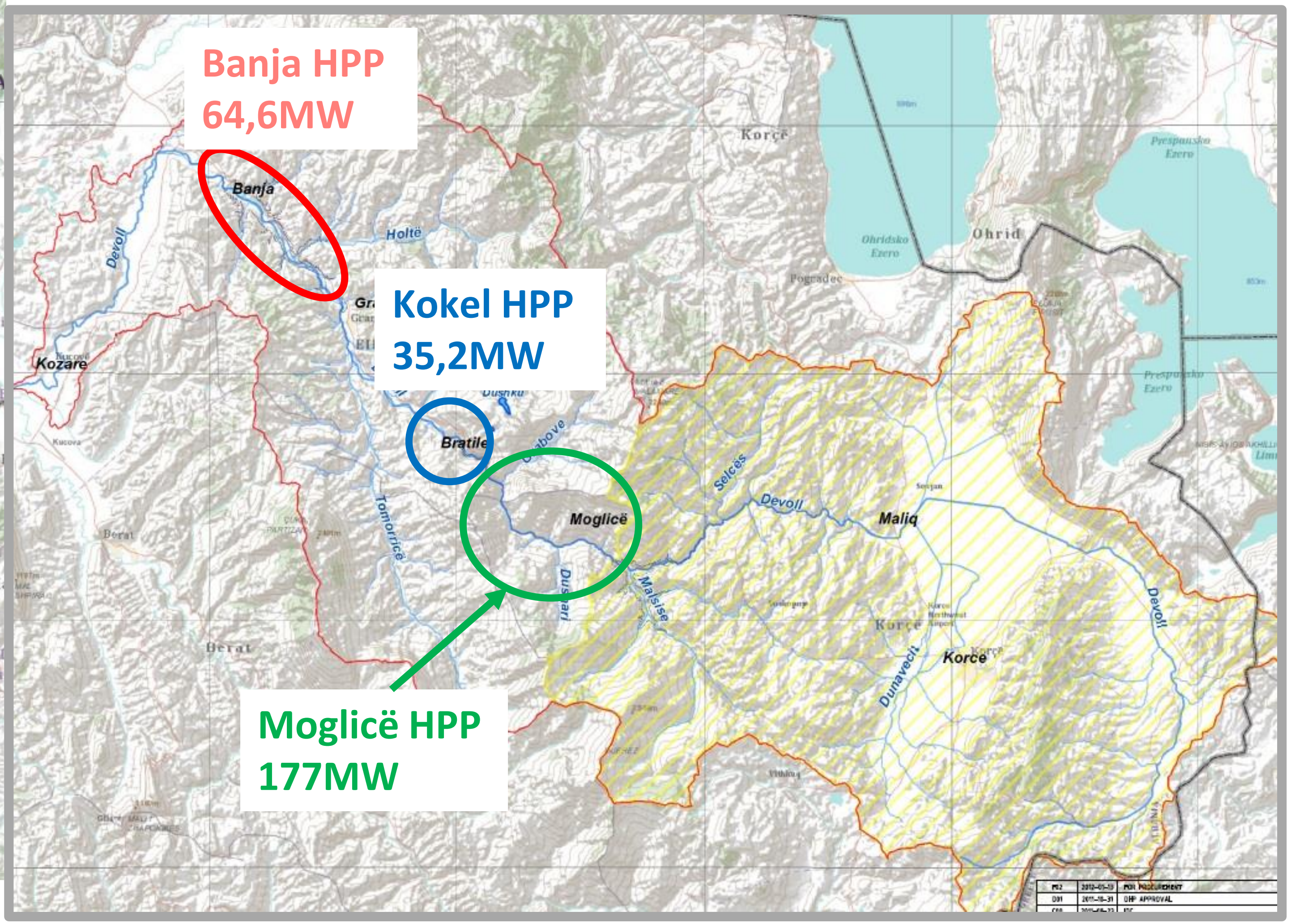




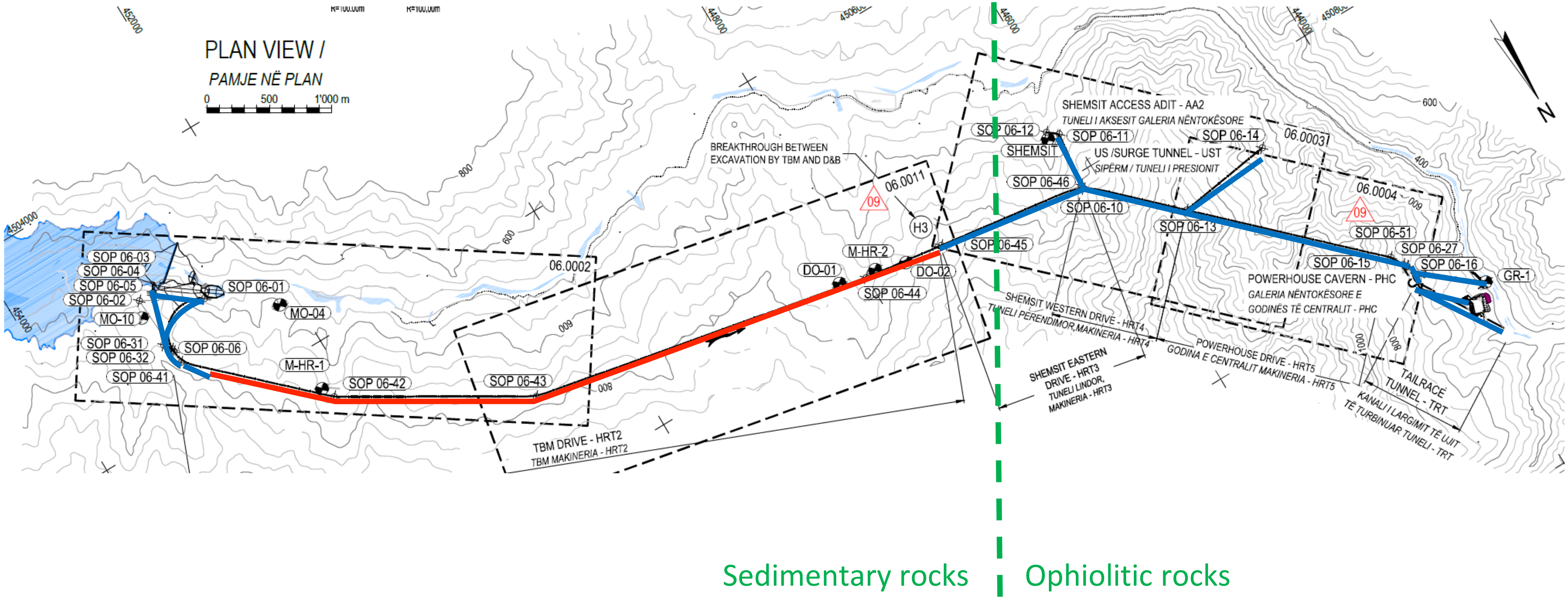
Project Summary

- Owner: Statkraft
- Contractor: Limak-AJE JV (Turkey)
- Head: 300 m
- Two Francis units, total combined capacity 177 MW
- 150 m high asphalt core dam
- 17 km rock tunnels (6 km TBM + 11 km D&B)
- 2 caverns
- 4 vertical shafts
- Difficult ground conditions
- Permanent rock support designer Contract: Sweco
- Basic Design: Norconsult
- Owners designer: AFConsult

General overview

TBM part 6 km

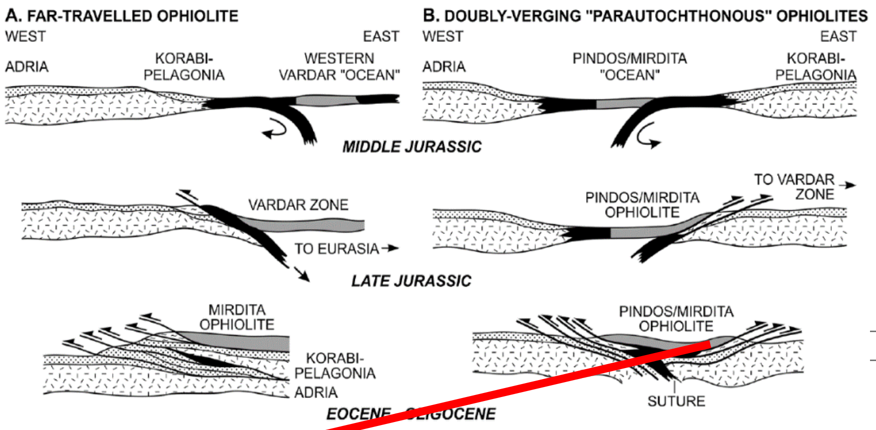
Drill and Blast ca. 11 km + shafts and caverns

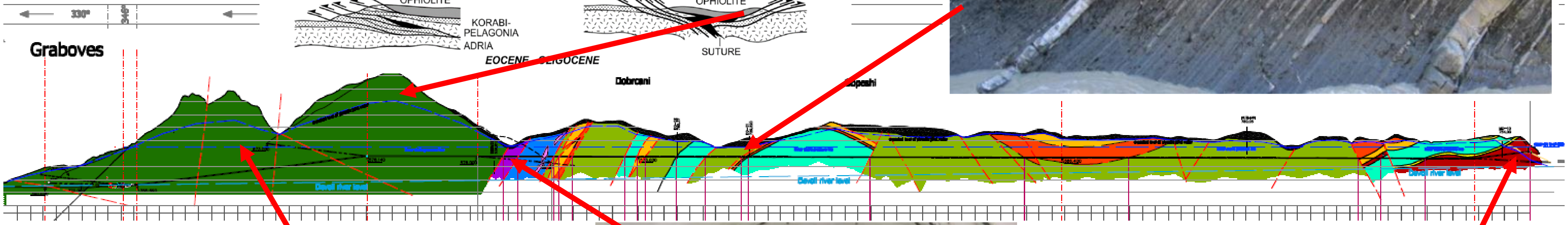


Sedimentary rocks

Ophiolitic rocks

Geology


A. FAR-TRAVELLED OPHIOLITE
WEST
EAST
ADRIA
KORABI-PELAGONIA
WESTERN VARDAR "OCEAN"
B. DOUBLY-VERGING "PARAUTOCHTHONOUS" OPHIOLITES
WEST
EAST
ADRIA
PINDOS/MIRDITA "OCEAN"
KORABI-PELAGONIA
MIDDLE JURASSIC
VARDAR ZONE
TO EURASIA
PINDOS/MIRDITA OPHIOLITE
TO VARDAR ZONE
LATE JURASSIC
MIRDITA OPHIOLITE
KORABI-PELAGONIA
ADRIA
PINDOS/MIRDITA OPHIOLITE
SUTURE
EOCENE - OLIGOCENE


Graboves
Dobrcani


01 08 2015

Dam area

Overview - Abutments

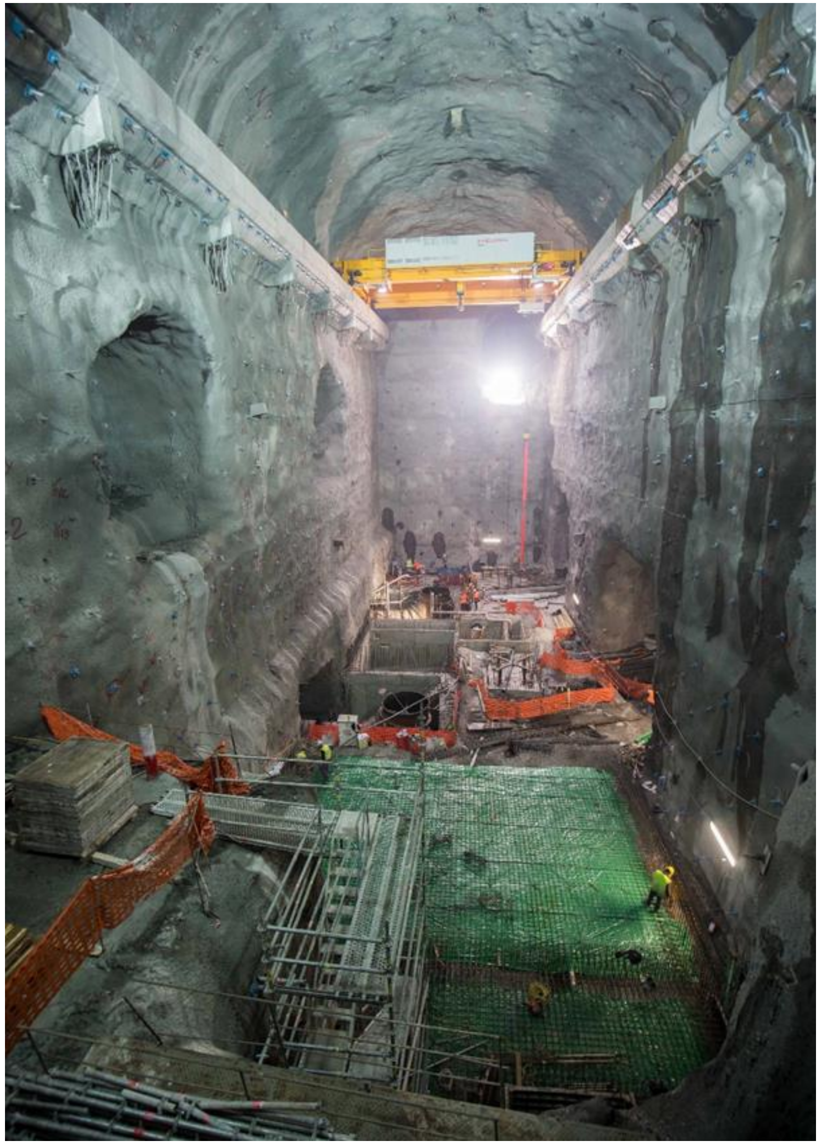
Overview – Intake open cut

Overview - Intake

Overview - Spillway

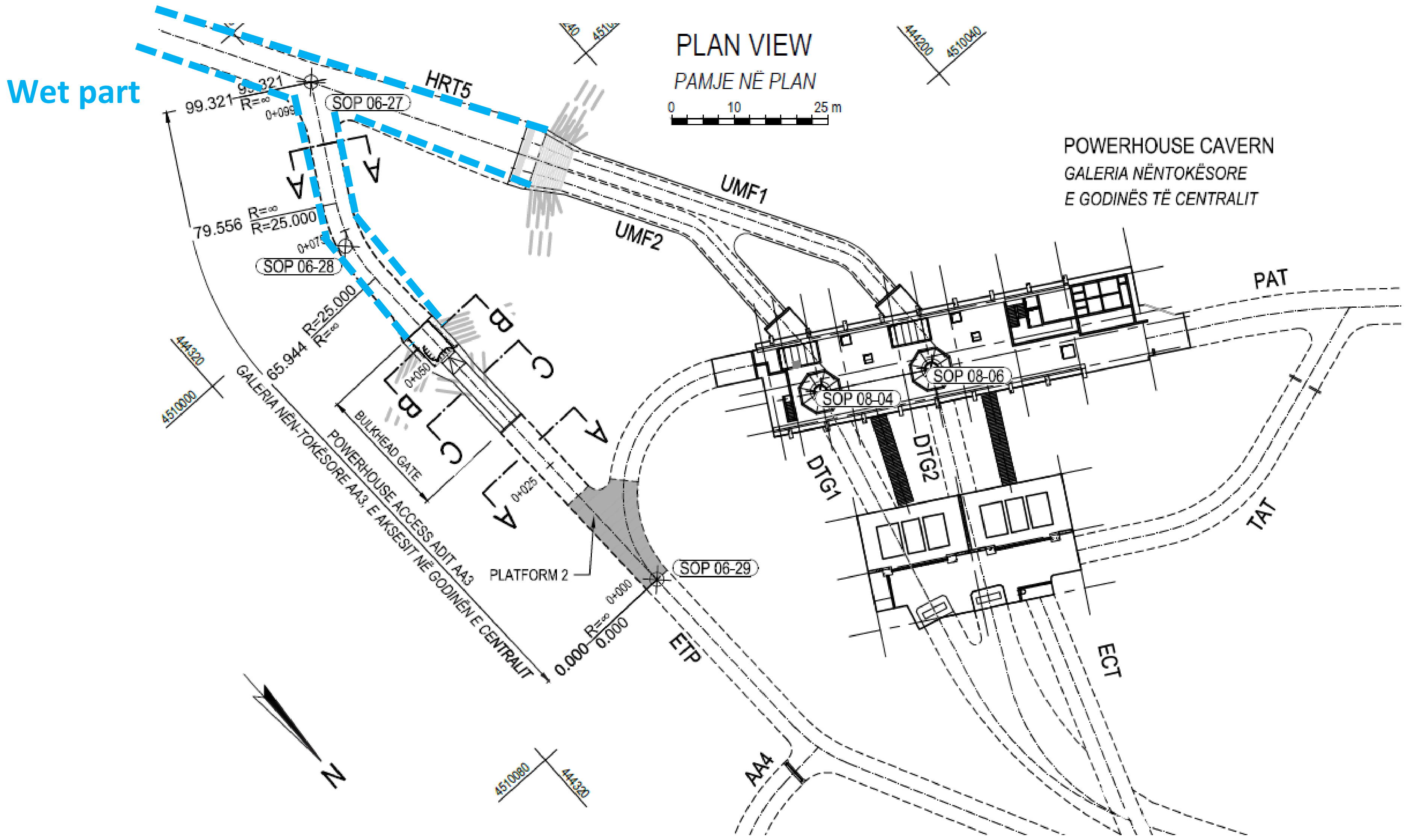
Overview - TBM

Cavern complex - Moglicë



- Site investigations: Nov 2015 to Feb 2016
- Excavation starts: Jan 2016
- Excavation and final support ends: Feb 2017

Plan view cavern complex



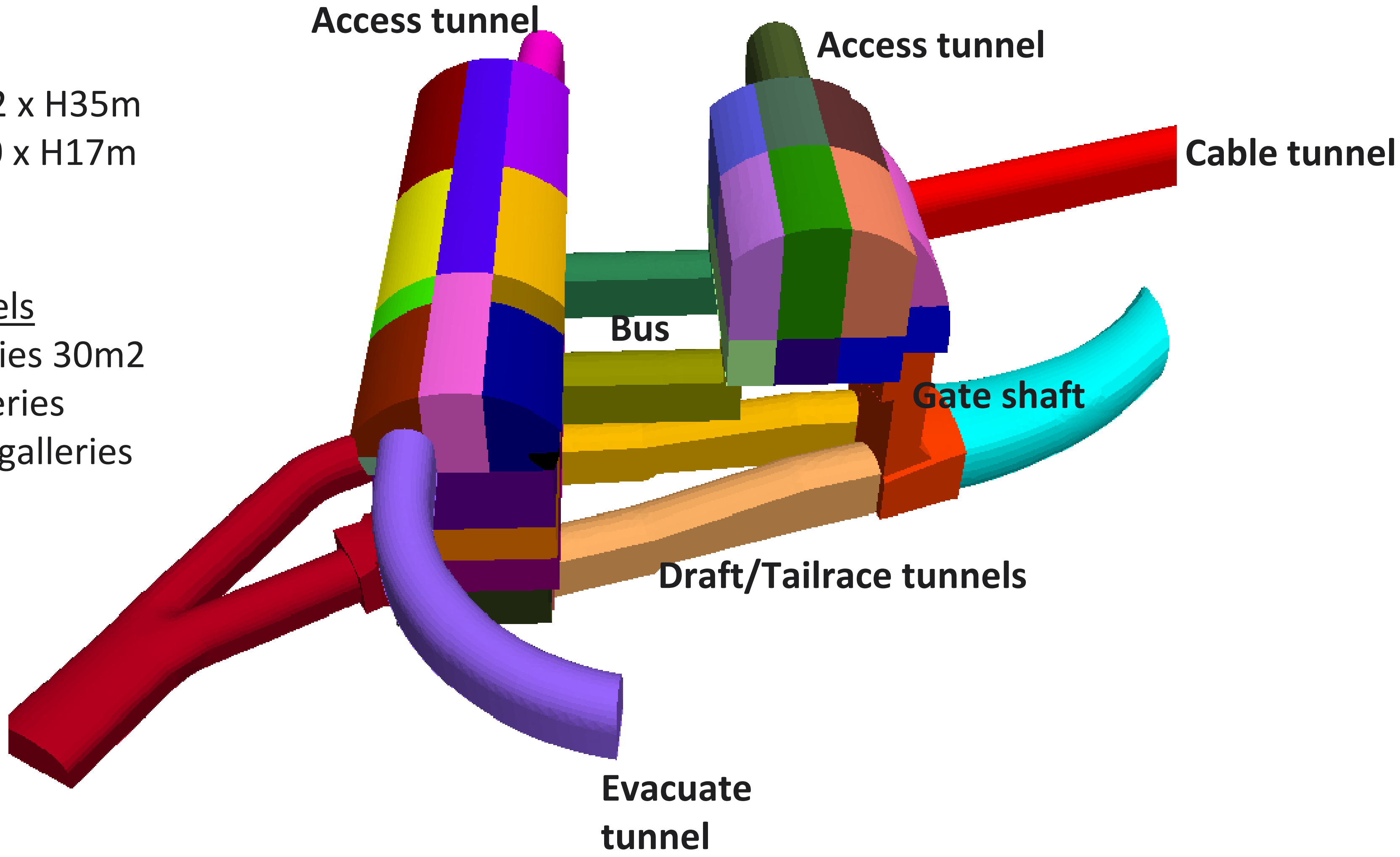
- 300m water head
- 60m long penstocks
- Jointed rock

3 dimentional view cavern complex

- PHC W16 x L62 x H35m
- TRC W21 x L30 x H17m
- Pillar: 17m

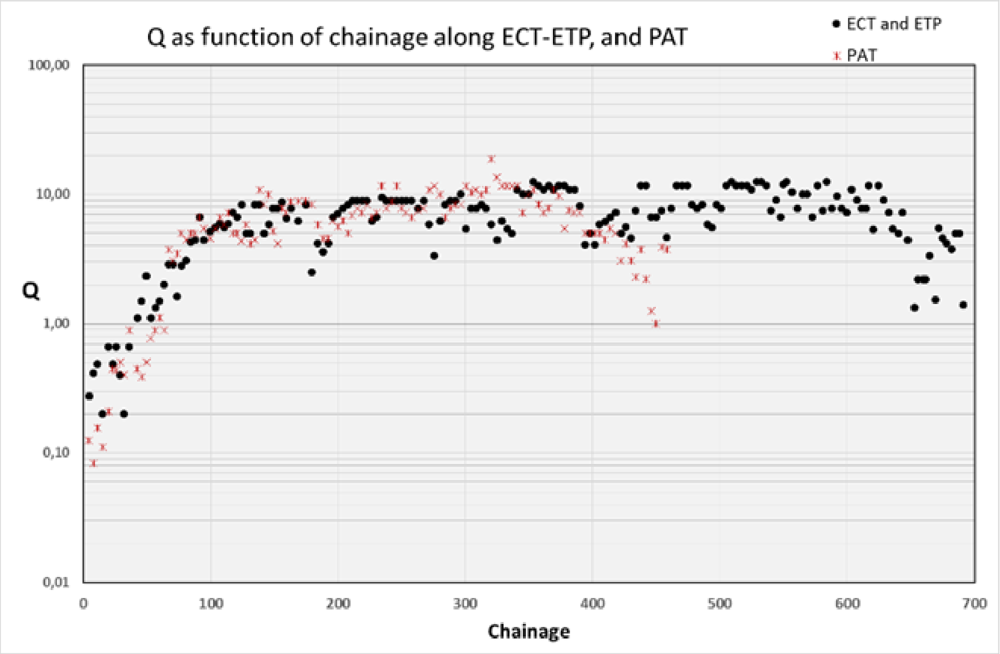
<u>Junction tunnels</u>

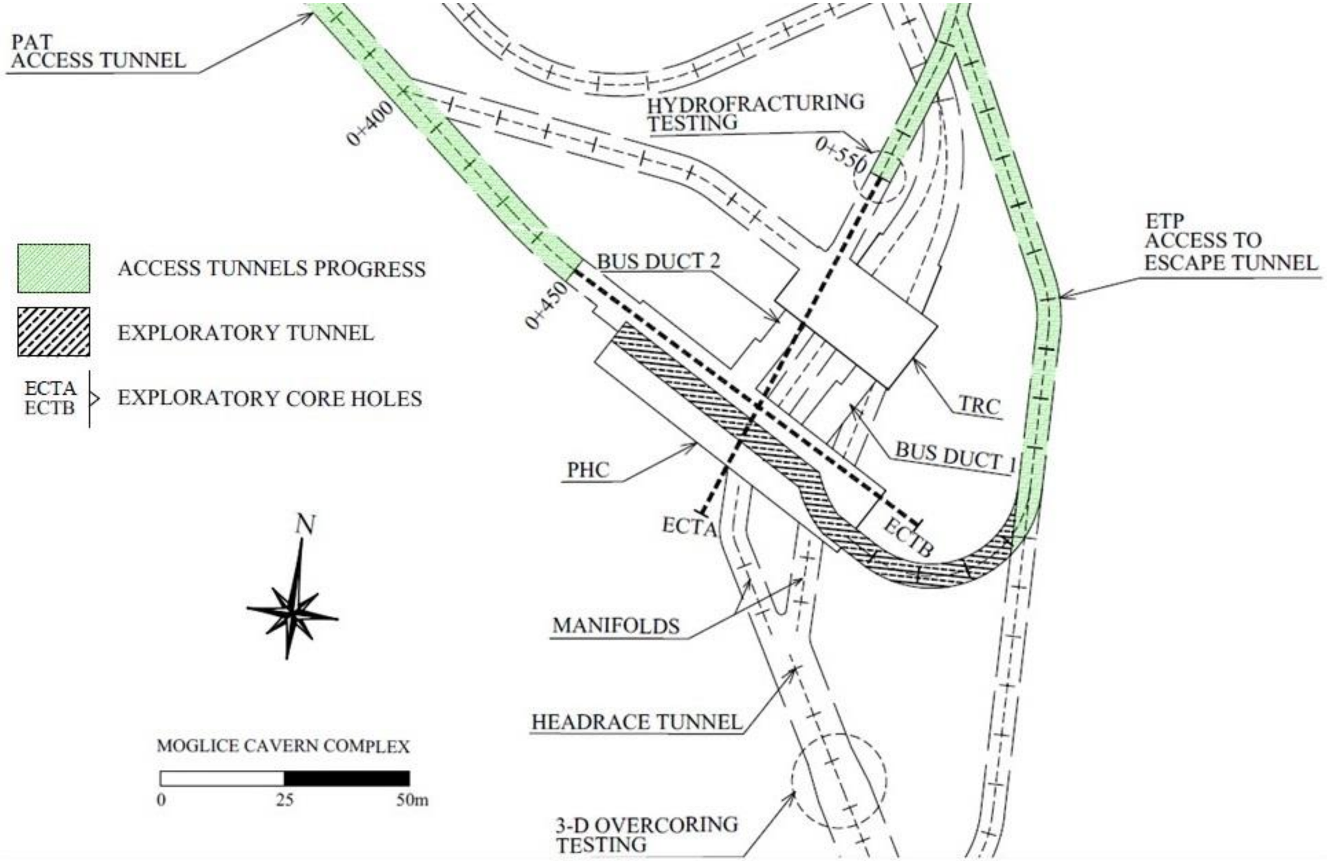
- Two bus galleries 30m2
- Two draft galleries
- Two penstock galleries



Cavern complex- Site investigations

- Limited amount of geo-information from Basic design
- Decreasing rock mas quality when approaching the cavern complex
- Sweco to decide on final location and design rock support





Cavern complex- Site investigation strategy

- Evaluation of rock mass quality and rock mass conditions from access tunnels
- Two exploration core holes from access tunnels
- Water loss tests
- Stress measurements
- Rock testing
- Face mapping

Interpretation + monitoring

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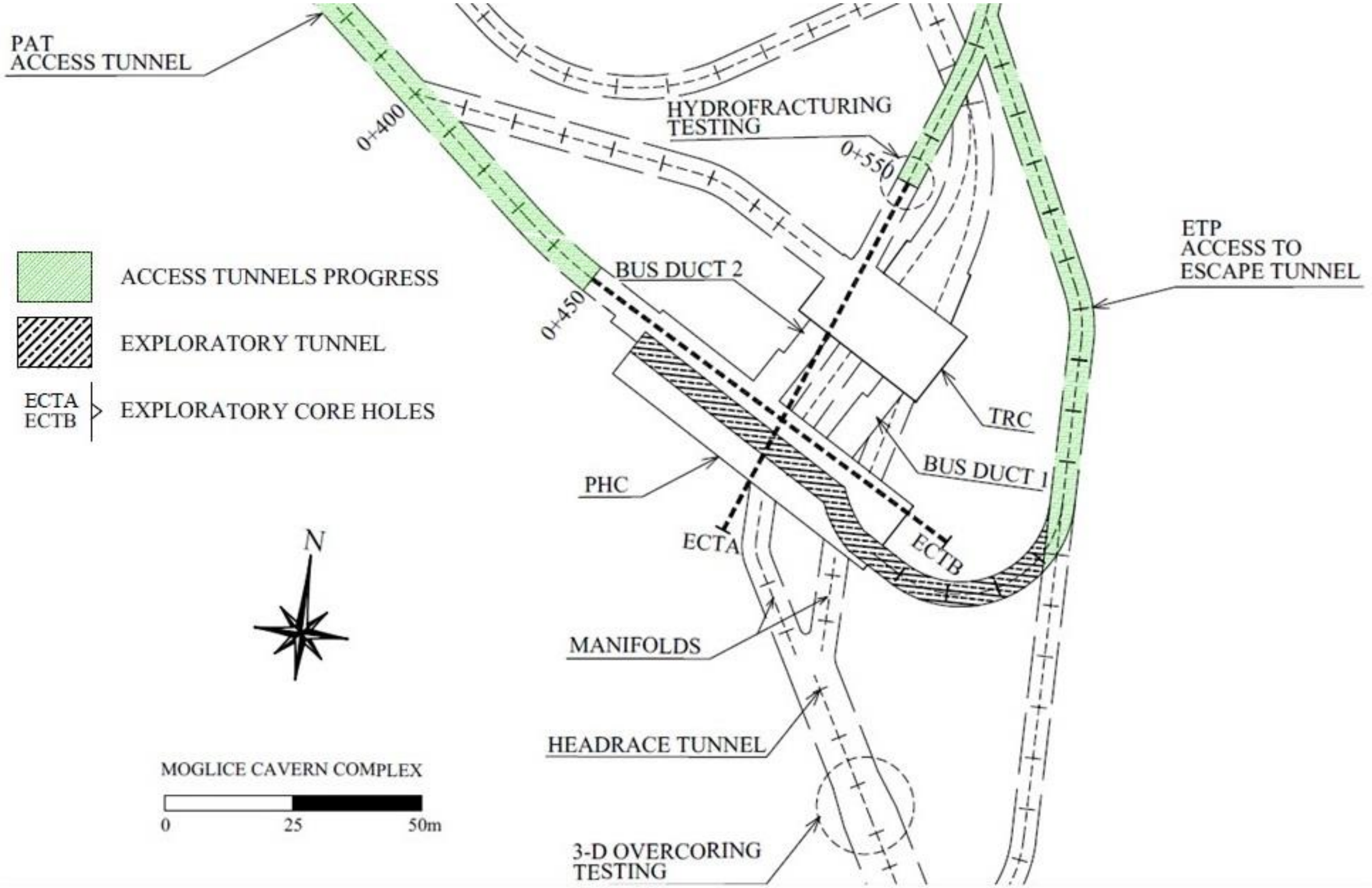
Geomodel



Cavern complex- Rock mass conditions interpreted from tunnels

- Mainly fair rock in tunnels, but poor in caverns

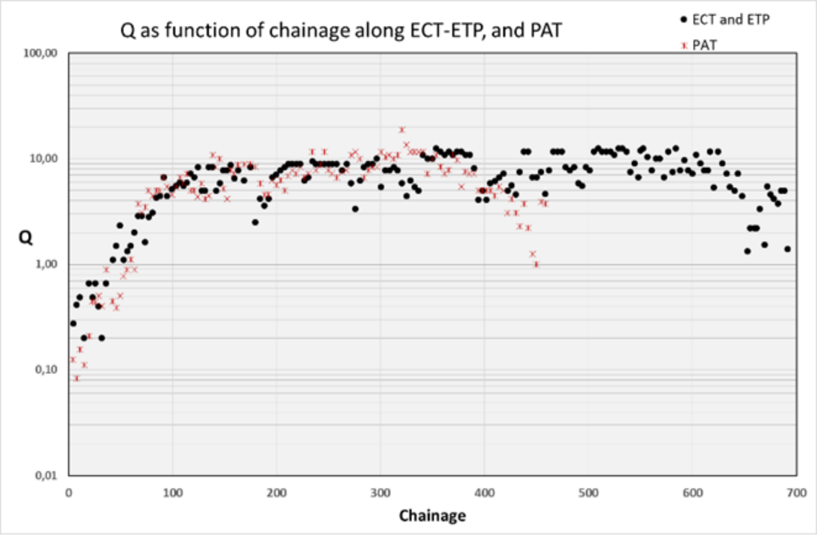
- Continuity of zones of 35-40m

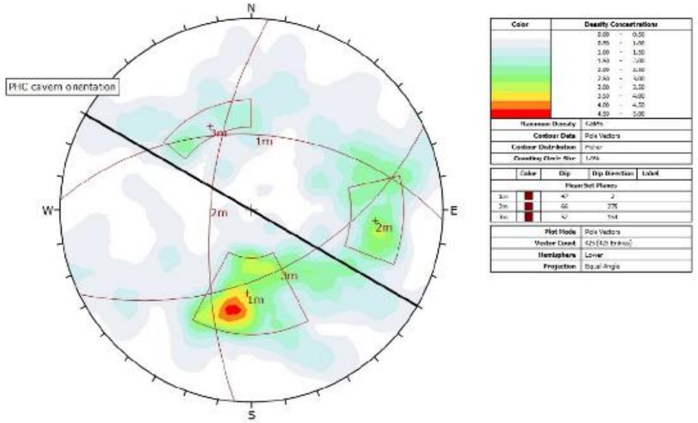
- Lensed and undulated shapes

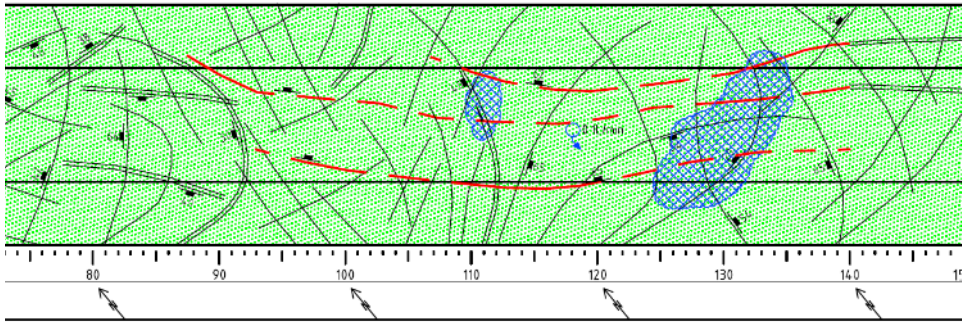
- Orientation of Long axis of caverns deemed favourable compared to main joint sets

- Stress measurements in Tender design => SH = 20 MPa, Sh = 9.5 MPa ,Sv= 9.5MPa. SH oriented NE-SW

- Convergence measurements wall-to-wall in tunnels showing closure of 12mm in fair rock



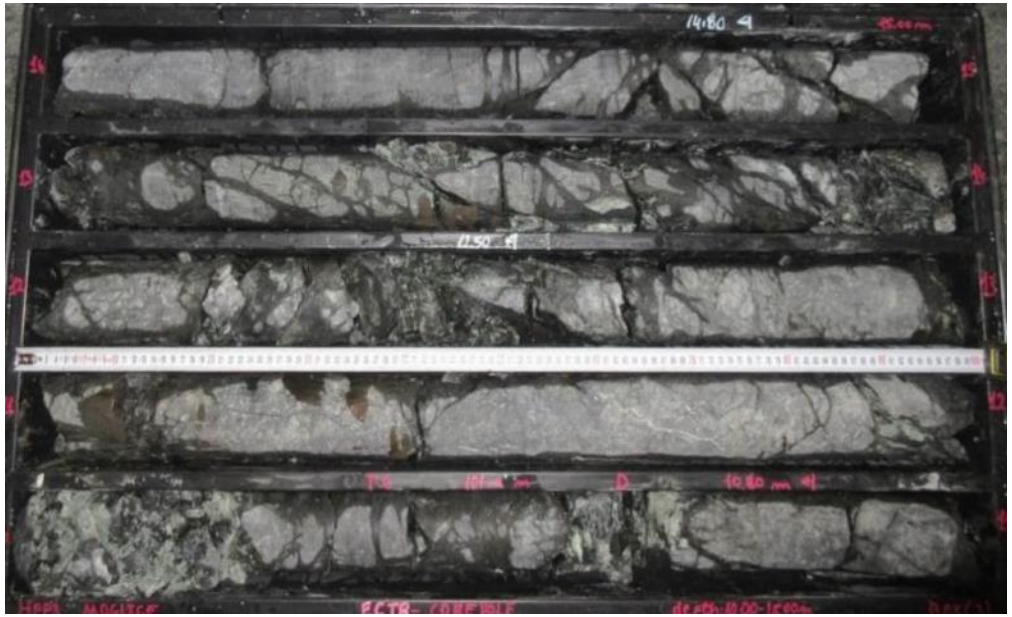




Cavern complex - Core drillings

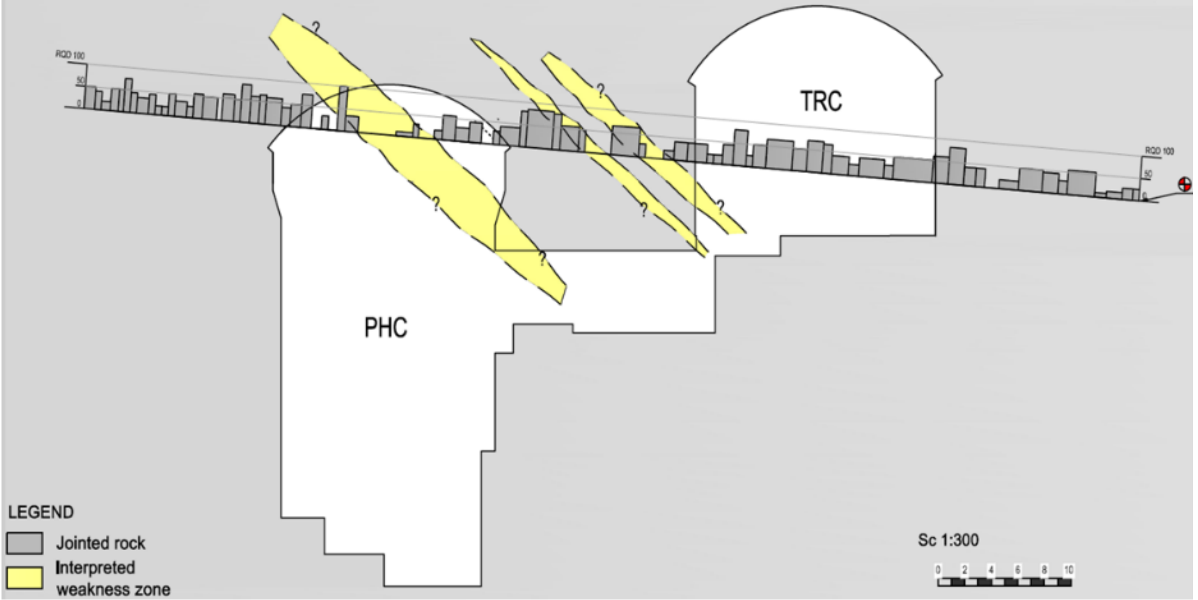
SWECO

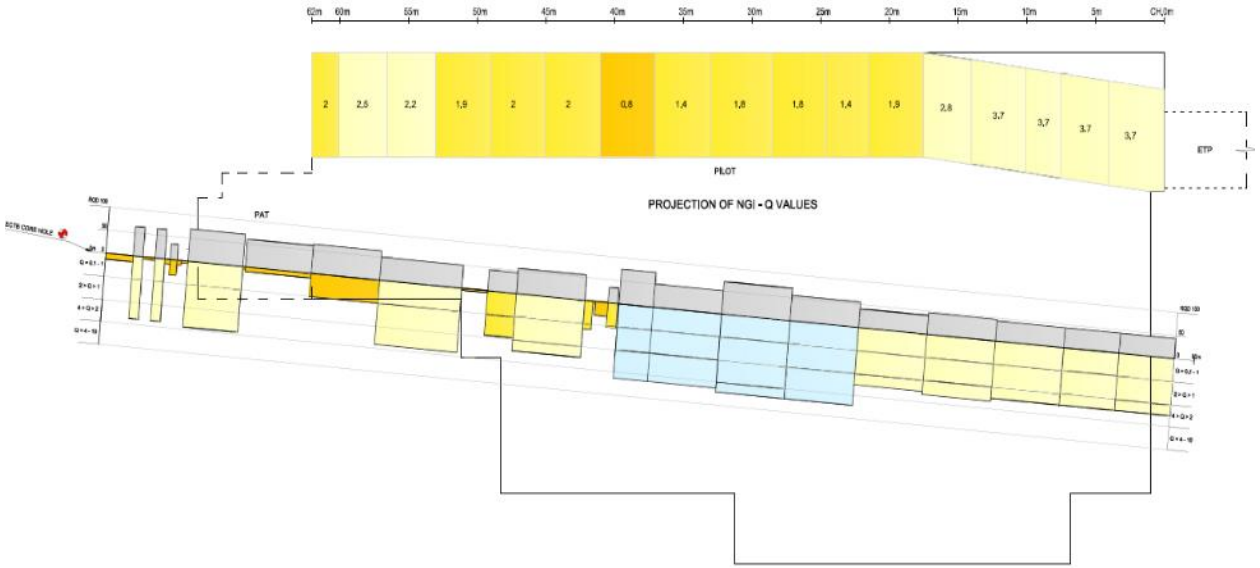
- Jointed harzburgites with presence of zones
- High and rapid variability o rock mass quality
- Sampling for testing
- Brittle rock and many incipient joints
- Often serpentinized, tight and smooth joints
- Average rock mass quality Q=3
- Intact rock strength 40-75 MPa
- Dry conditions in the drill holes. Only moisture at the zones



Cavern complex- Core drillings interpretation

- Jointed harzburgites with presence of zones
- High and rapid variability of fracturation
- West and upper part of the complex placed in a rock mass of poorer quality (Q1-3) and more serpentinized
- Eastern and mid-lower part of the complex placed in rock mass of quality Q 2-4
- Reasonably tight rock mass K 1x10-8 m/s
- Medium-strong rock 40-75 MPa (intact rock strength)
- Brittle rock and many incipient joints





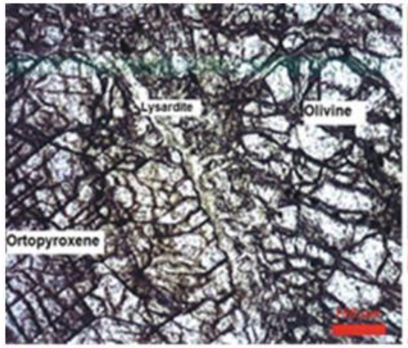
SWECO

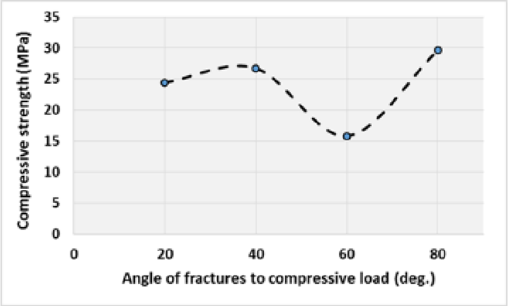
Cavern complex- Rock testing

- Jointed harzburgites with presence of zones from macro to microscale, mylonitised structure

- Intact rock strength difficult to determine

- Strength anysotropy





- Swelling pressure 0.02MPa for serpentinite infillings

Photo Tunnel HRT2, Chainage 0+681 (Left Side) After Testing

- In general, brittle rock. Reasonably strong rock compared to the low tensile strength.

Compressive strength (MPa)	Schmidt hammer	PLT Diametrical	PLT Axial	PLT lumps	UCS lab	UCS cubic sample
Max	94	51	76	46	75.7	-
Min	45	30	51	26	8.9	-
Mean	66.9	40.7	64	35	33.1	53.6
St. Deviation %	18.2	8	9	10	37	-

Cavern complex- Stay or move?

- Generally poor rock mass quality is interpreted with presence of zones
- Favorable stress confinement
- Favorable results for hydraulic conductivity

Analysis risks and costs of both choices Stay and move

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STAY

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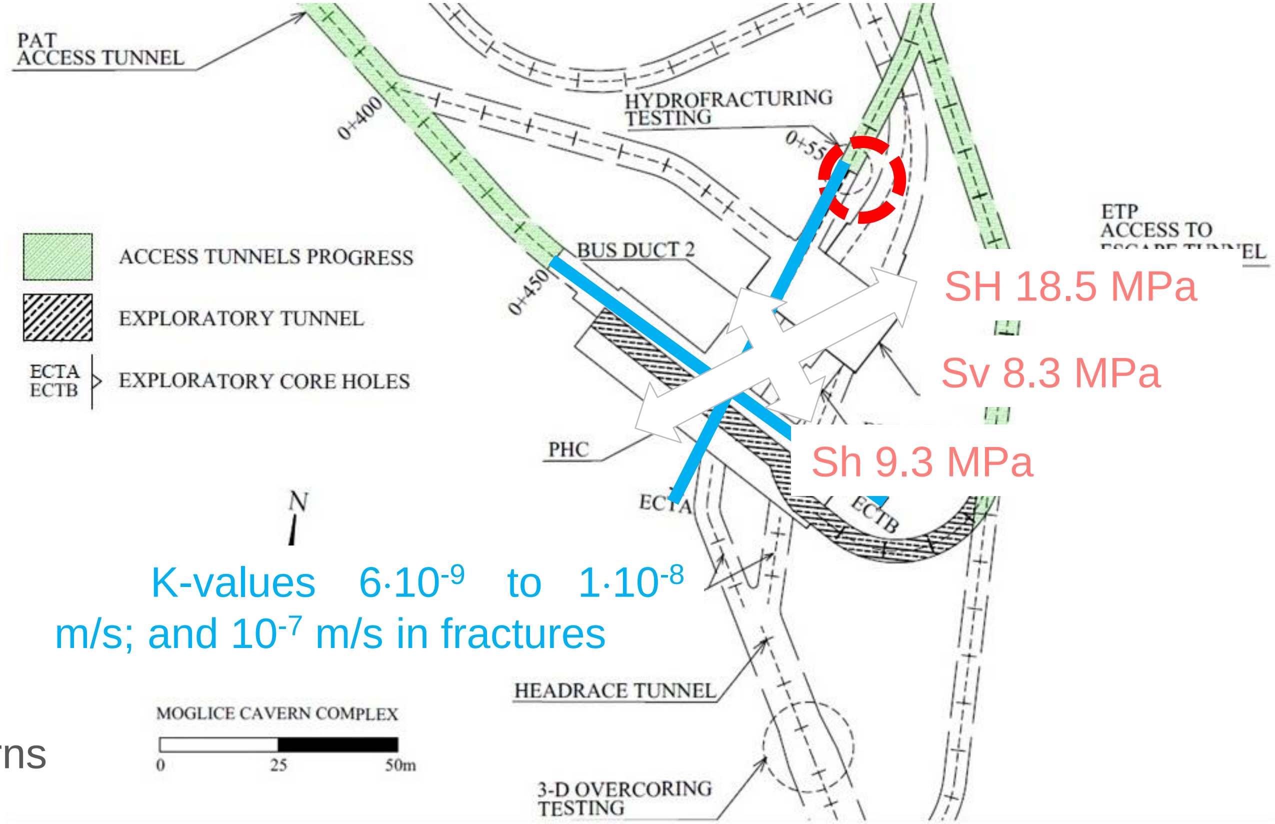


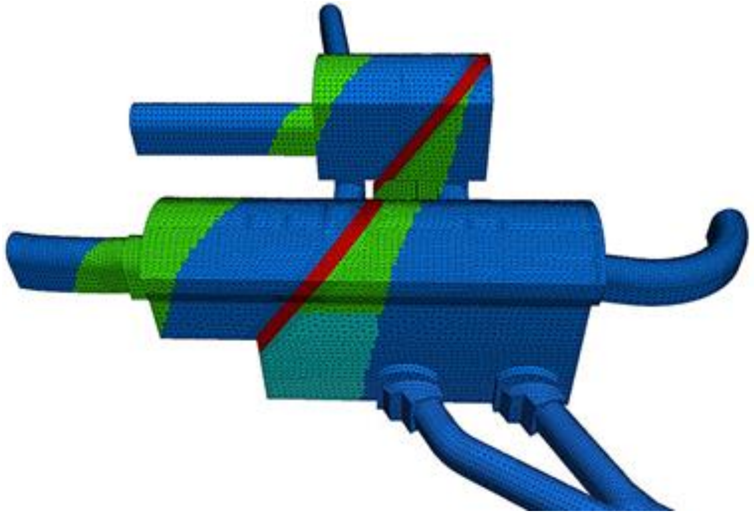
1. The calculated rock mass behaviour in preliminary FEM models showed that properly excavated and supported caverns could ensure stability

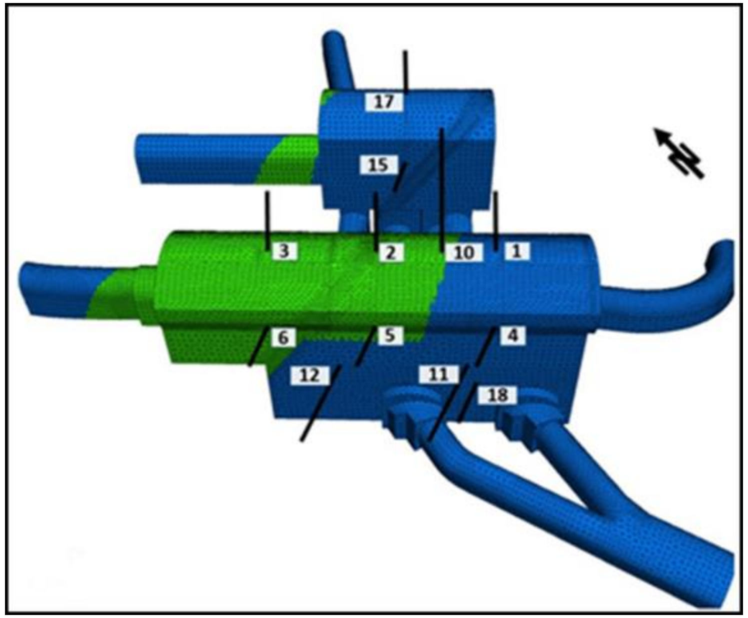
2. Locked cavern. Only possible a shifting towards upstream: ++$$ and ++Time for A) additional site investigations, B) redesign C) Head loss. And there would be still a risk that the new location was not suitable

3. The measured stresses and rock mass conductivity showed favorable conditions for cavern stability and penstock location

Cavern complex- Geomodel

- Geomodel interpretation based on site investigations (rock mass quality distribution)
- Update of geomodel with the observations done in pilot gallery
- Rock mass characterization based on mapping and measured deformations in the pilot gallery
- Strategy based on a continuous measuring of the system behaviour and update of rock mass properties

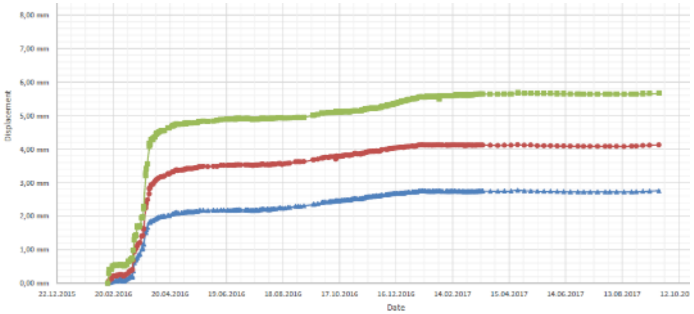


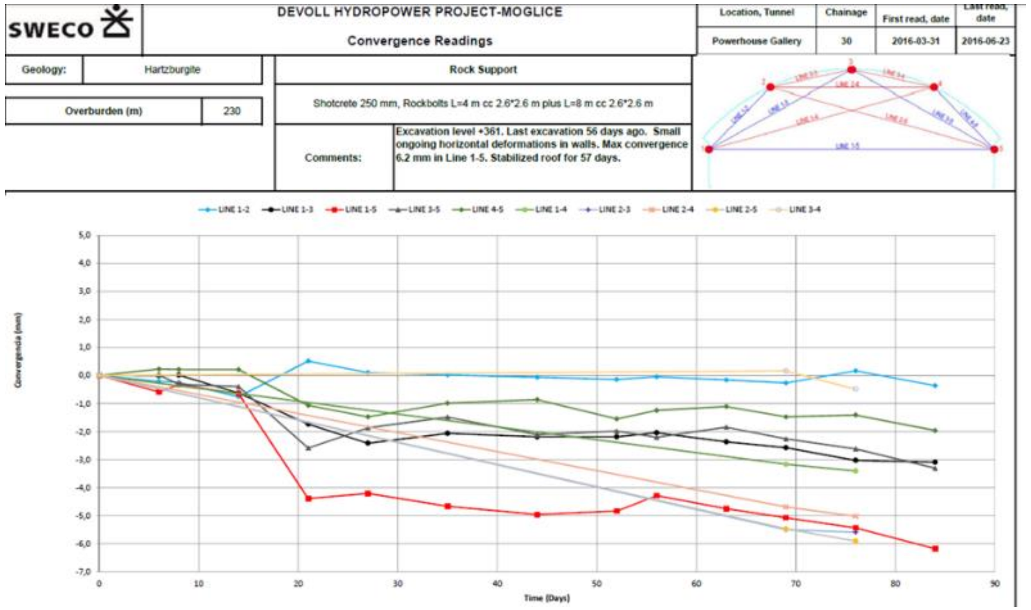


Rock class	**NGI-Q**	Max Q	Min Q	Mean Q	St. Dev	% Distr.
II	**10-40**	-	-	-	-	-
III	**4-10**	5.8	4.1	5.4	0.7	7.4
IV A-1	**4>Q>2**	3.8	2.1	2.9	0.5	47
IV A-2	**2≥Q≥1**	1.9	1.1	1.7	0.2	39.1
IV B	**0.1-1**	0.9	0.3	0.7	0.2	6.4

Cavern complex- Geomodel

- Back calculation of rock mass properties based first on comparison of measurements in roof.
- Monitoring and back calculations of rock mass properties are done during the excavation of both caverns

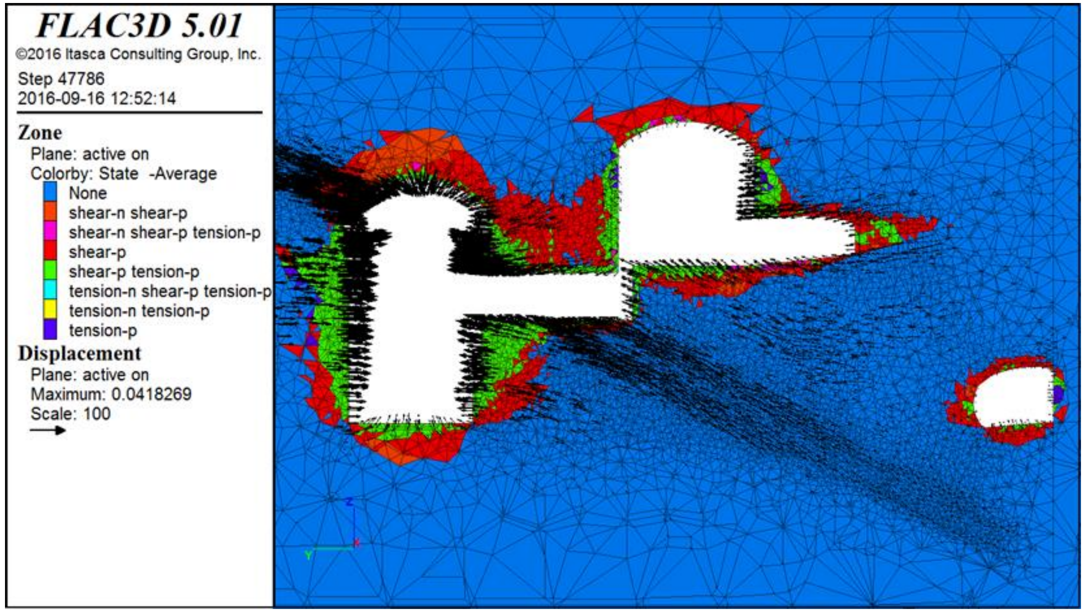


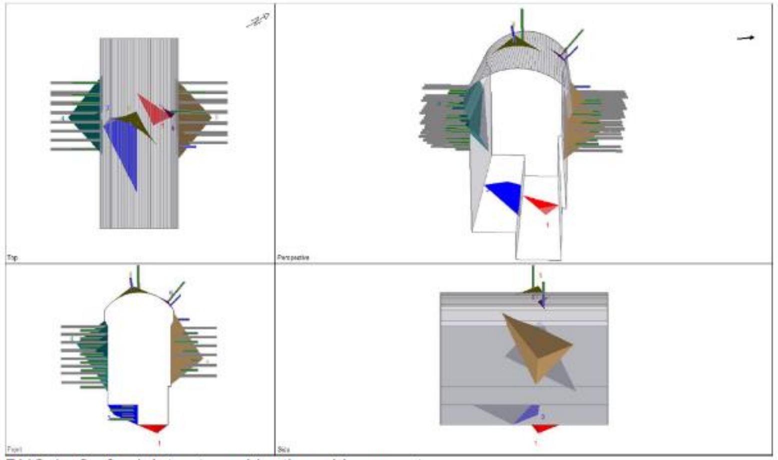


Rock mass properties	Rock units			
	III	IV A-1	IV A-2	IV B
Unit region	B	C	D	E
Mean Q	5	2.6	1.7	0.6
Mean GSI	48	43	38	31
UCS_{rm} (MPa)	3.5	2.3	1.5	0.9
Young's modulus, E_{rm} (GPa)	23.0	18	10.0	6.0
Poisson's ratio, ν_{rm}	0.2	0.2	0.2	0.2
Density, ρ (KN/m^3)	33	33	33	33
Cohesion, C_{rm} (MPa)	1.7	1.5	1.2	0.9
Tension, T_{rm} (MPa)	0	0	0	0
Friction angle, $Ø_{rm}$ (°)	49	47	42	37
Dilatation angle, δ (°)	5.0	5.0	5.0	5.0

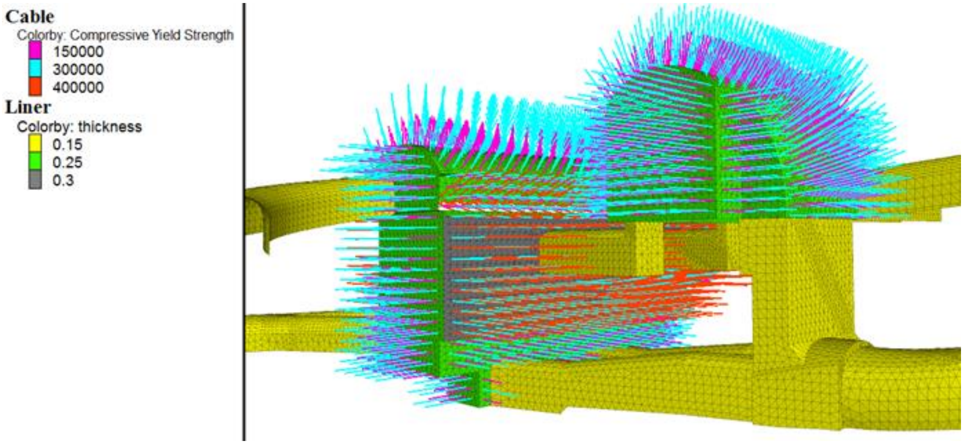
Cavern complex - Design

- Basic needs of rock support are estimated according to Q-system and checked with FEM modelling
- Rock support adjusted according to results of calculations: wedge stability and tenso-deformational analyses (FEM)
- Monitoring points have measured deformations in both caverns in the model and in the reality, allowing for support optimizations





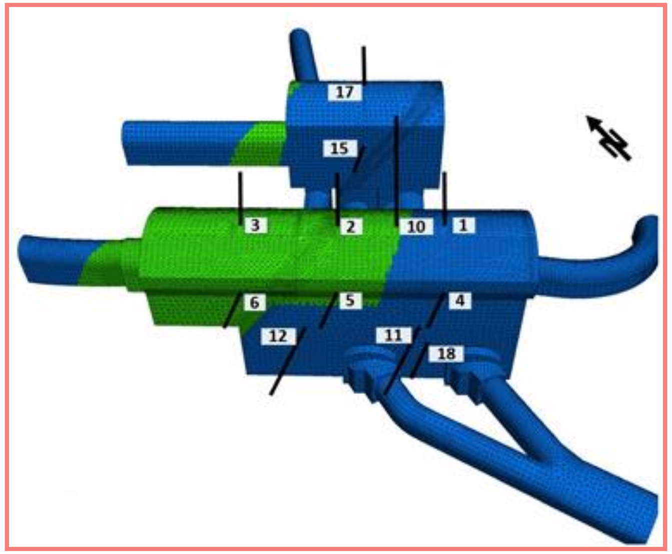
PHC 1m2m3m joint set combination with support

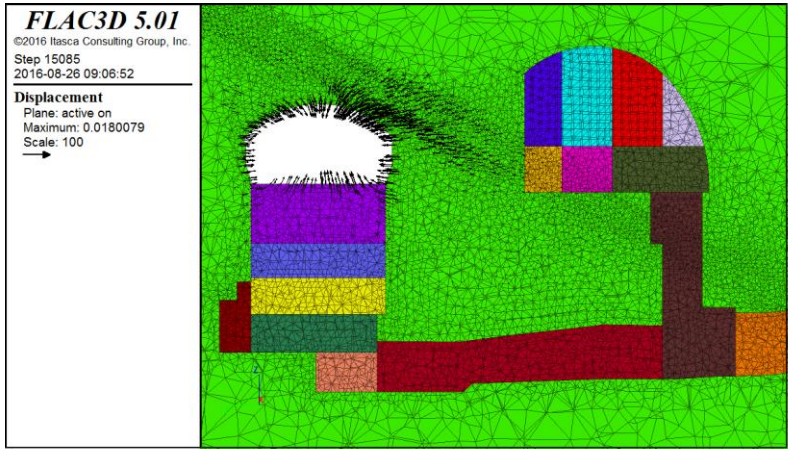


- Final design: Sfr 25-30cm, L4/7m Ø25/Ø32mm roof + L7/12Ø32mm walls

Cavern complex - Excavation

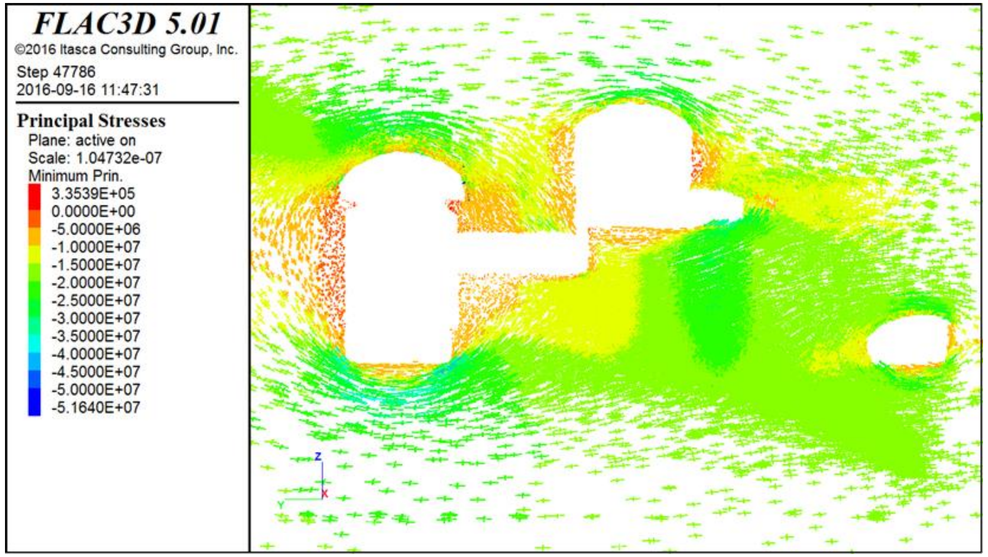
- Excavation from up to down in both caverns
- Excavation sequence adjusted to rock conditions in levels and benches
- Continuous monitoring after each excavation round
- Rock support installed at the face after each round
- Evidences of low tensile strength of rock when faces were unconfined
- FLAC analysis done with excavation steps
- Hold point inspections before any further benching

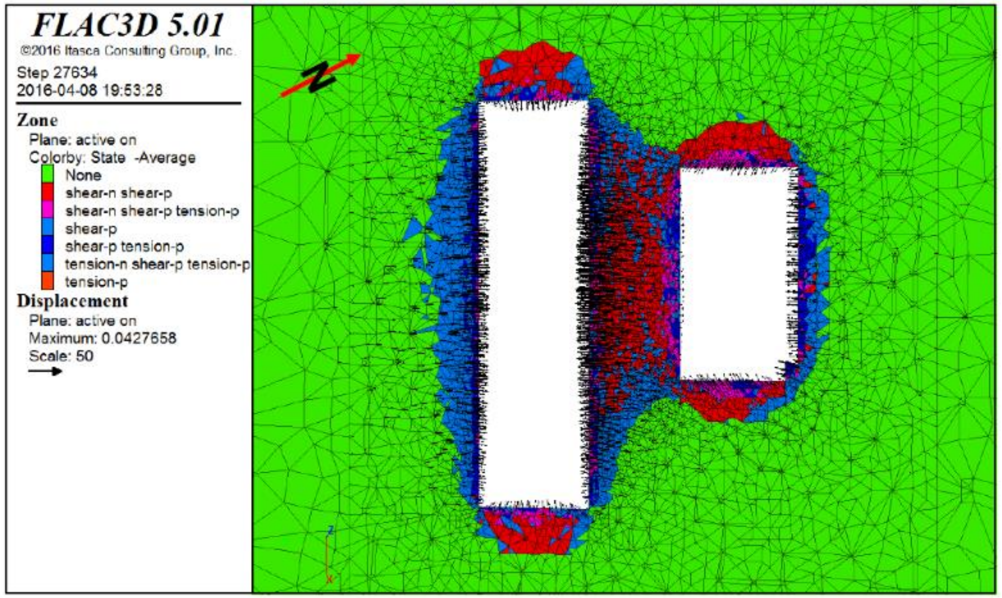


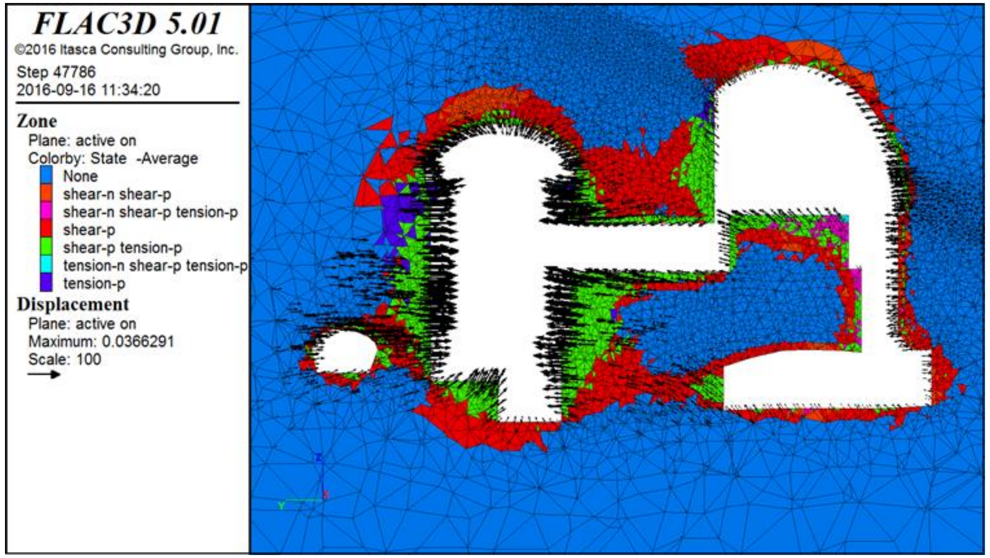


Cavern complex- Calculated response

- Calculations run in FLAC
- Stress state
    - Larger plasticisation in walls
    - Tensile failure in walls
    - Compression and arching in roofs
    - Shear and tensile failure in pillar
    - Shadow effect after both caverns excavated
- Displacements in crane beam level

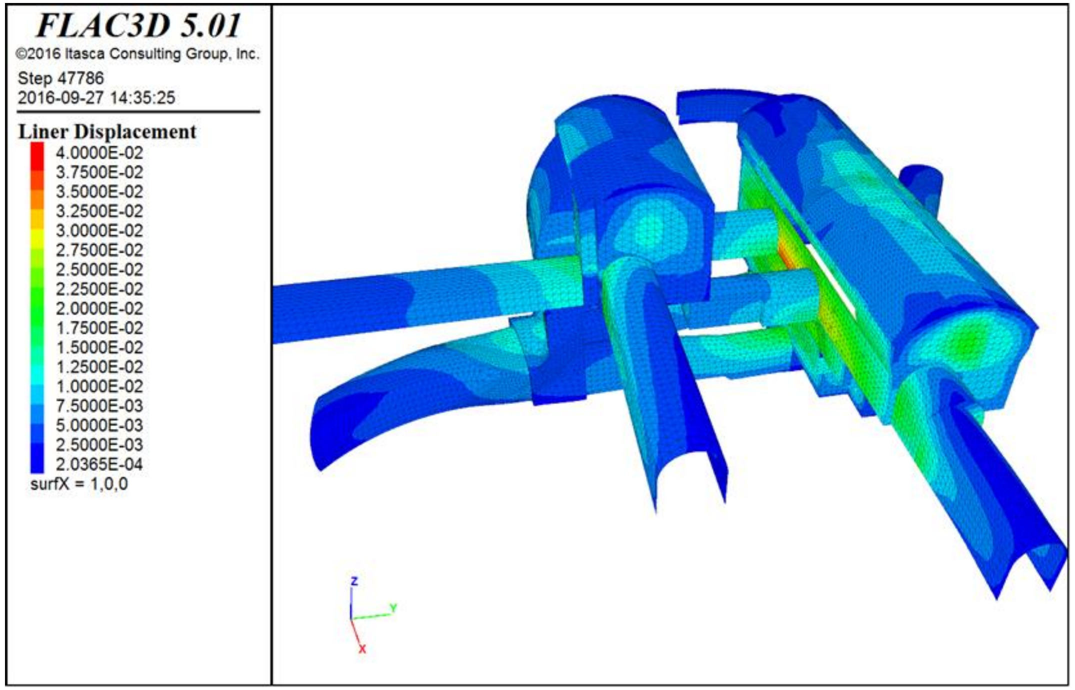


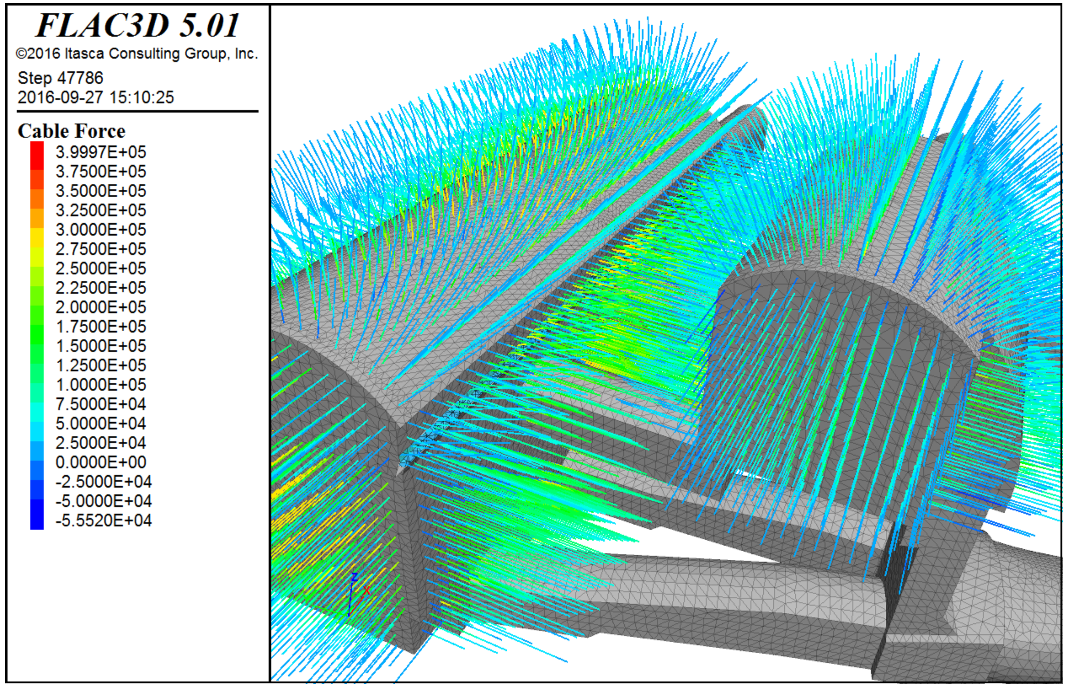




Cavern complex- Calculated response

- Up to 39mm maximum inward displacement at junction of bus duct and pillar
- Average 25-30mm displacement in high walls of the PHC
- Average 5-10mm displacement in roofs of both caverns





Cavern complex - Observed response

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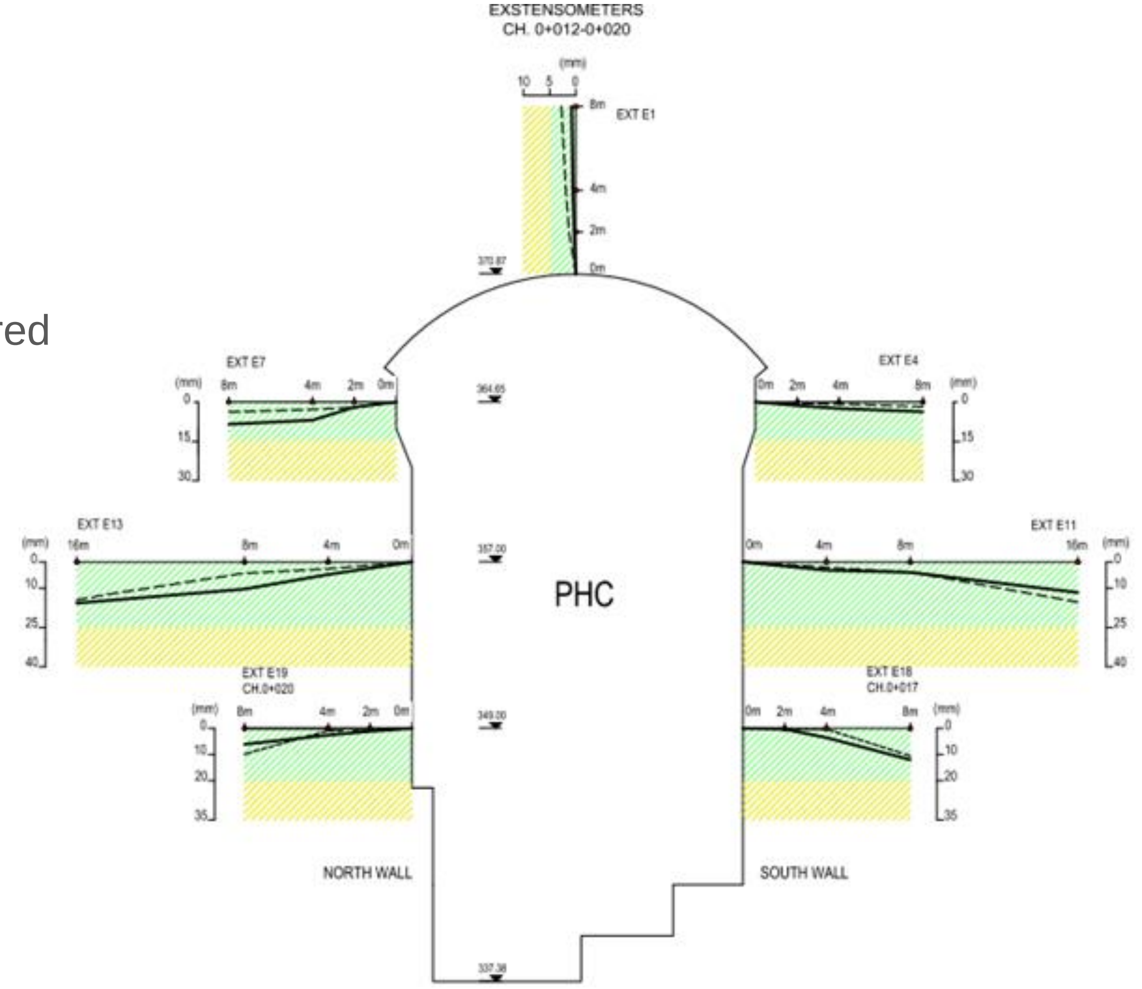
- Level of deformations within reasonable limits

- In general, recorded deformation in extensometers is than in optical prisms. Movements are not only local

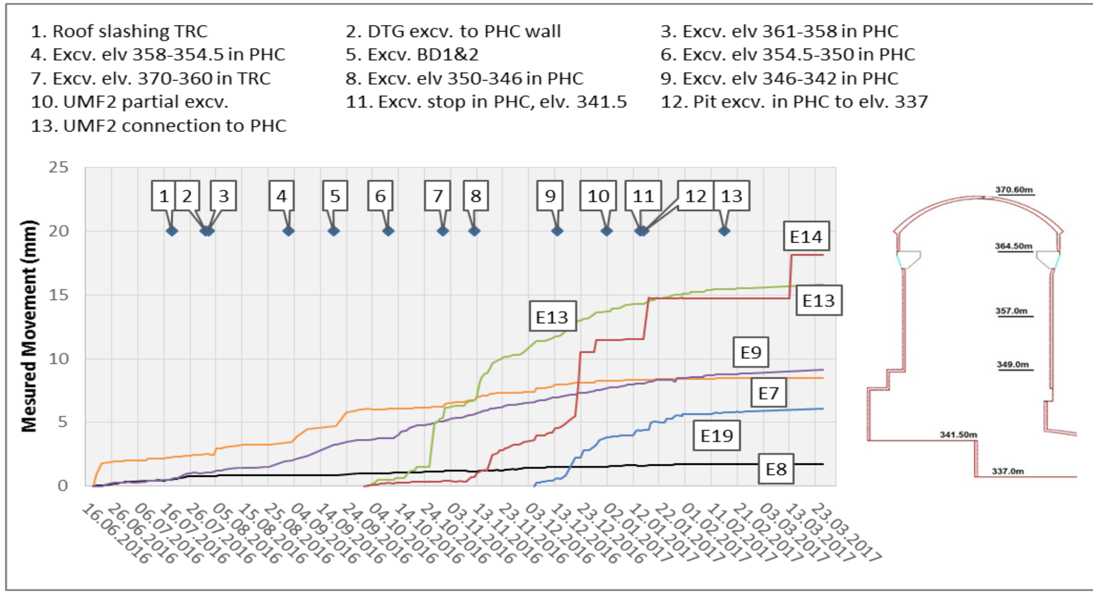
- General good agreement between expected and measured

Displacements (mm)		Ch. 15		Ch. 30		Ch. 45	
Location	Device	Calculated	Measured	Calculated	Measured	Calculated	Measured
Centre roof (Vert. displ.)	Prism	3.98	15	7.39	11	6.06	10
	Ext.	2.87	1.60	5.56	5.64	4.68	2.19
EL 364.5 North wall	Prism	11.48	12	12.44	12	10.85	11
	Ext.	3.84	8.50	8.65	1.75	4.33	9.1
EL 364.5 South wall	Prism	13.09	7	15.58	12	24.61	4
	Ext.	1.77	3.78	1.90	4.52	1.19	7.13
EL 357 North wall	Prism	13.30	14	14.95	19	11.92	9
	Ext.	14.58	15.82*	21.74	18.11	-	-
EL 357 South wall	Prism	14	14	14.69	17	12.80	17
	Ext.	15.47	11.70	15.63	19.60*	-	-
EL 349 North wall	Prism	16.12	10	16.83	10	15.22(ch38)	5(ch38)
	Ext.	9.87	6.1	-	-	-	-
EL 349 South wall	Prism	16.09	14	14.75	18	15.26(ch38)	13(ch38)
	Ext.	10.60	11.82	-	-	-	-

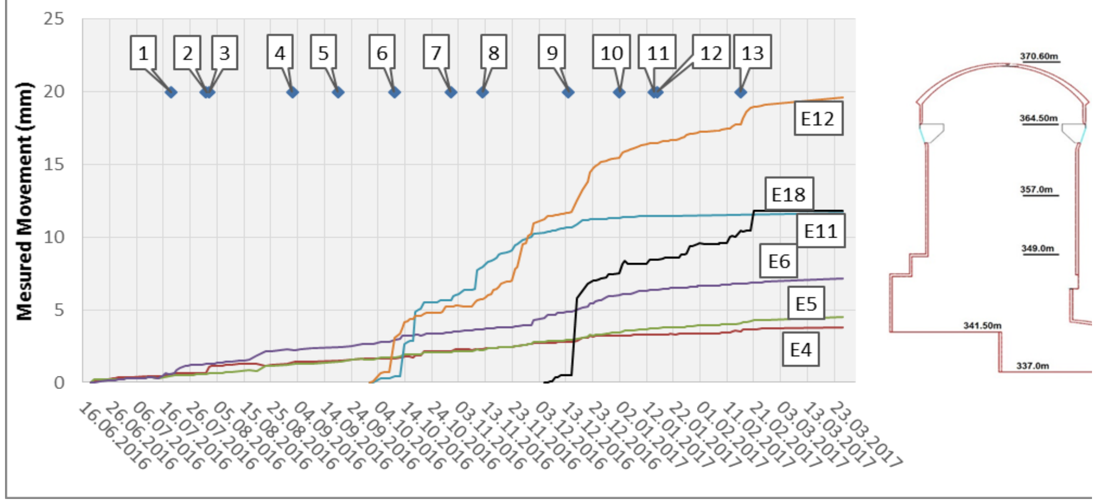


Cavern complex - Observed response

- Low level of deformations in roof and crane beam. Ext. 1 to 9. Smooth trends during benching.
- Certain independence of roof behaviour respect to walls
- Higher deformations in long walls as expected
- Certainly isotropic behaviour at the cavern scale: Similar magnitude of movements in a wall and within a level.
- Higher deformations, as expected, close to the pillar between bus ducts. Ext. 13 and 14.
- Independency of N and S walls.
- Marginal influence of TRC excavation on PHC



Measured deformations in extensometers (rod No 3). PHC North wall.



Measured deformations in extensometers (rod No 3). PHC Soutth wall.

Cavern complex - Conclusions

- The cavern complex has been possible to be constructed in poor rock. That has demanded heavy support, careful excavation and continuous monitoring. In turn, no risks derived from a relocation were taken.

- The decision to Stay has been beneficial. But a comparison of both choices Stay or Move a cavern complex can only be done in a reasonable way if enougth and reliable geological knowledge is available.

- Excavation of such cavern complex in poor rock does also demand a monitoring strategy that involves a combined and interactive deformation measurement program.

- Continuous monitoring from an early stage has been decisive to back-calculate rock properties and decide upon rock support. The monitoring strategy must be part of the design strategy.

- A combination of different of investigation techniques and rock testing have been needed to determine the ophiolite properties and reduce uncertainties due to the high variability in properties

- Sequential excavation and immediate rock support have helped to limit deformations

- Close supervision and inspection have helped on adjusting rock support and excavation

- Final good fit between calculated and measured movements, validiting the model

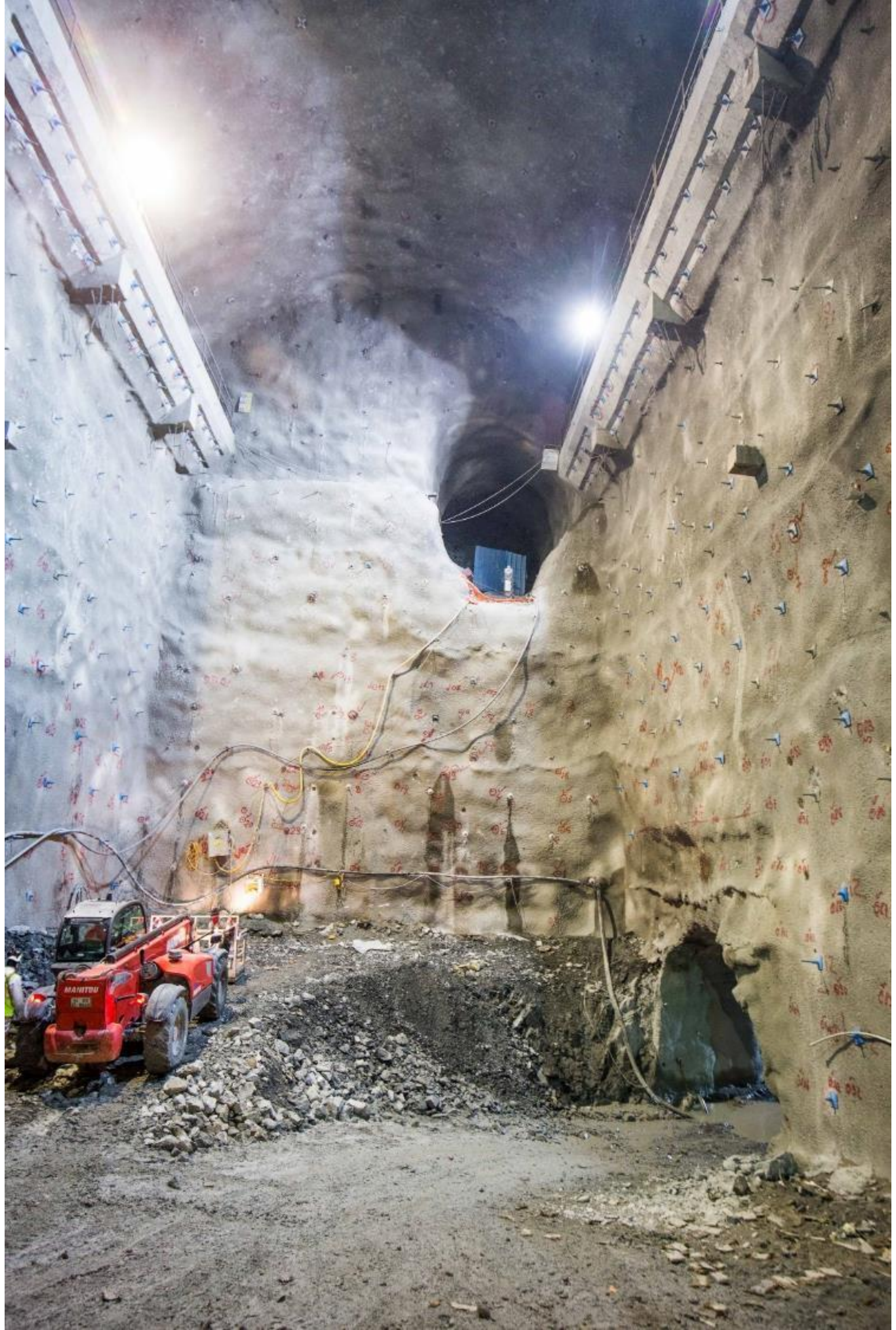
June 2016 crane beams casted

August 2016 Going below crane beams

November 2016 Bus duct galleries

Overview – Penstock tunnels

December 2016 Manifold tunnels level reached



January 2017 Transformer cavern excavated

February 2017
Both caverns excavated


SWECO
jorge.terron@sweco.no