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Training Workshop 2015

Case Example of POPLU Experiment

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D4 4.1.2

Outline of the Lecture

- **POPLU Project Objectives and Expectations**
- **Design of the POPLU Experiment**
  - **Rock Suitability Classification of Demonstrations Tunnels and Plug Location**
  - **Plug Design and Concrete Development**
  - **Instrumentation and Test Planning**
- **Implementation of the POPLU Experiment**
  - **Tunnel Excavation and Plug Slot Production**
  - **Plug Construction and Concrete Method Tests**
  - **Instrumentation Installation**
- **Forthcoming Activities**

POPLU Project Objectives

Addressing YJH-2012:

- **Construction of full-scale deposition tunnel end plug (demonstration, workmanship, quality control)**
- **Detailed structural design, including concrete recipe development for plug**
- **Tunnel excavation development, *(wire-sawing technique)***
- **Producing quality manual for quality control practices and risk mitigation for plug**
- **Instrumentation and performance monitoring (mechanical load transfer, concrete shrinkage, water tightness), including models**

POPLU is linked to SKB's full-scale dome plug test (DOMPLU)

Plug Performance Expectations (VAHA)

- **The plugs shall isolate the deposition tunnels hydraulically during the operational phase of the repository. (L3-BAC-9)**
- **The chemical composition of the backfill and plugs shall not jeopardise the performance of the buffer, canister or bedrock. (L3-BAC-13)**
- **The plugs shall keep the backfill in place during the operational phase. (L3-BAC-18)**
- **The plugs shall consist of materials that have a good hydraulic isolation capacity and that will not undergo large volume changes in the long term. (L4-BAC-2)**
- **The plugs shall be designed to maintain their hydraulic isolation capacity at least as long as the central tunnels are open. (L4-BAC-6)**
- **The plug shall be designed to withstand the sum of the swelling pressure of the backfill and the hydrostatic pressure of the groundwater at the repository depth. (L4-BAC-13)**
- **The plugs must be designed to maintain a backfilling function even after their hydraulic isolation capacity has been lost. (L4-BAC-14)**
- **Backfill and plug materials shall be selected so as to limit the contents of harmful substances (organics, oxidising compounds, sulphur and nitrogen compounds) and microbial activity. (L4-BAC-18)**

Additional Initial Plug Expectations

- **Plug should endure 7.5 MPa total pressure (4.5 MPa water pressure, 3 MPa expected swelling pressure)**
- **Design working life for the plug is 100 years**
- **The plug has a high water tightness (comparable to DOMPLU)**
- **Hydraulically conductive fractures shall not intersect the entire length of the plug**
- **Smooth/flat excavated rock surfaces at plug abutment (requirements to be determined), discontinuous excavation damage zone (EDZ)**
- **Low pH-concrete to be used**
- **May use steel and/or fibre reinforcement in concrete**
- **Filter and seal layers can be incorporated if necessary**
- **All material shall be checked and approved by the safety analysis team**

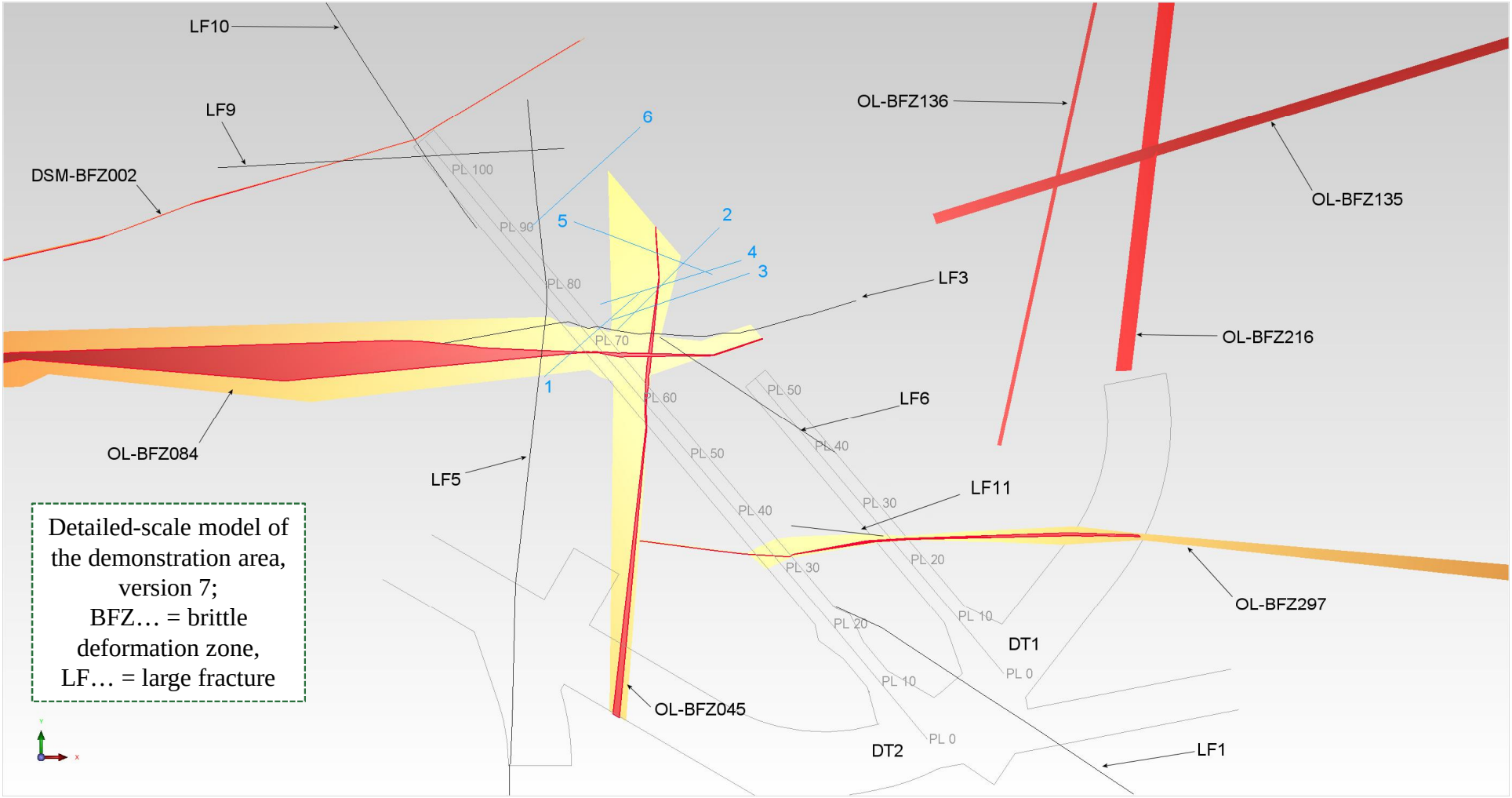
(green = applicable to POPLU test, red = not applicable to POPLU test)

Design of the POPLU Experiment – Tunnel and Plug Slot Location Planning

- **The Rock Suitability Classification (RSC) -system was used to select the locations of the two demonstrations tunnels needed for the POPLU experiment and the location of the plug within the tunnels**
- **The RSC-system has been developed by Posiva to evaluate natural properties of the repository host rock for the purpose of locating suitable rock volumes for the various parts of the repository e.g. hosting a deposition tunnel**
- **The criteria are based on requirements stemming from aspects of long-term safety, related to the functioning of the bedrock as a natural barrier as well as to ensuring proper conditions for the functioning of the EBS-system**
- **The criteria mostly deal with**
  - **Chemical composition of the groundwater**
  - **Groundwater flow**
  - **Mechanical stability of the host rock**

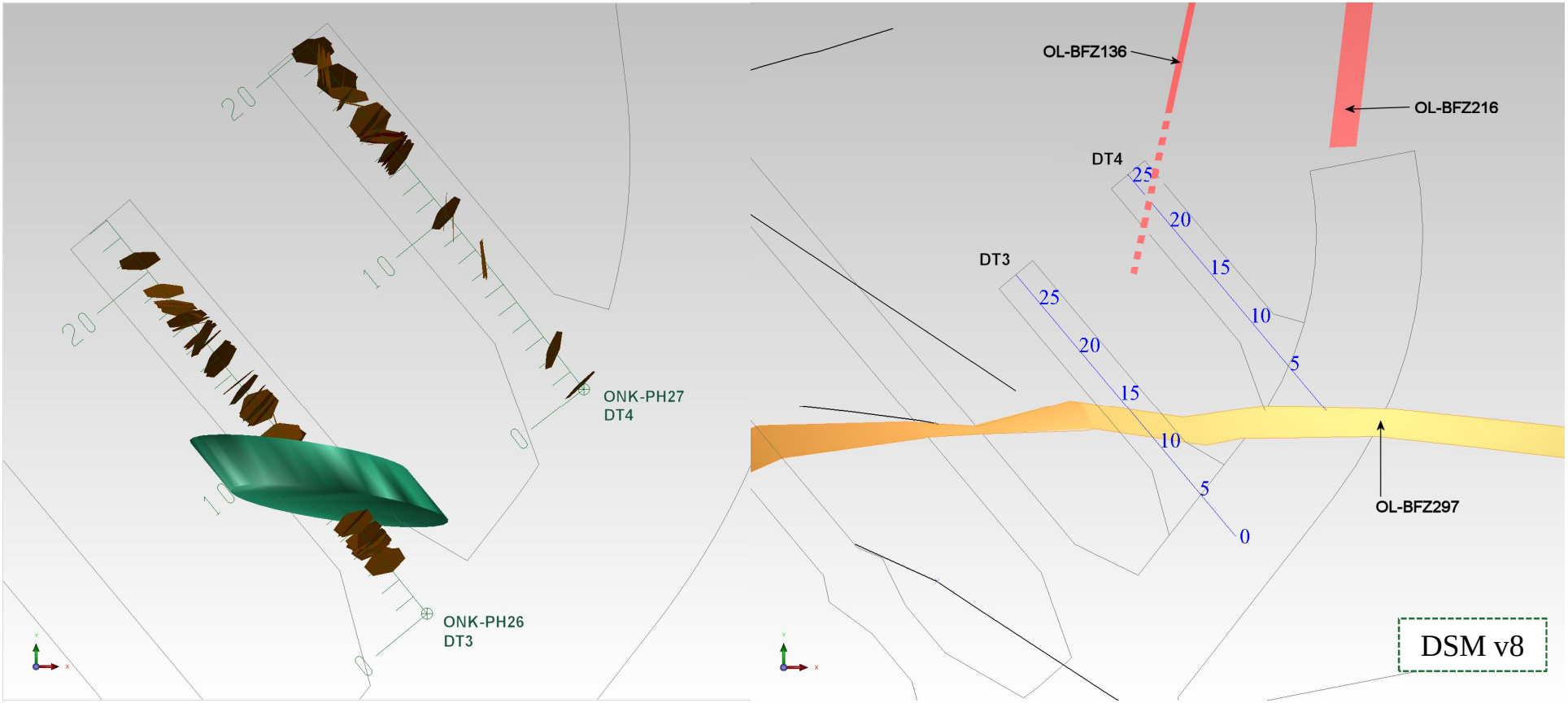
Rock Suitability Classification for POPLU – The Starting Situation

The area immediately northeast of the existing demonstration tunnels 1 and 2 was considered a possible location for the POPLU experiment on the basis of investigations and detailed-scale modelling of bedrock structures carried out earlier, during the construction of the two demonstration tunnels.



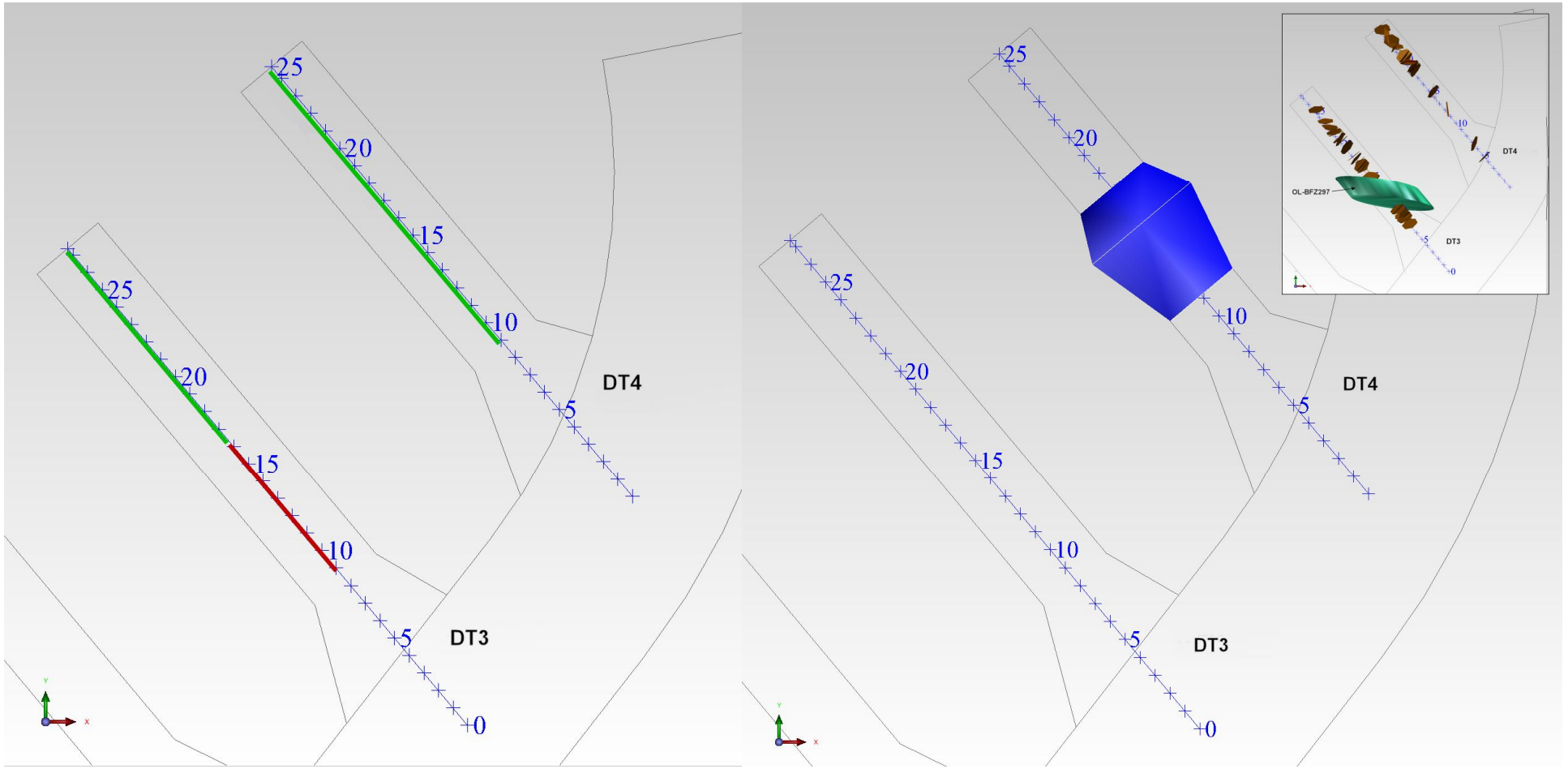
Rock Suitability Classification for POPLU – Pilot Hole Investigations

- To further verify the suitability of the selected location, a pilot hole was drilled within the profile of each planned tunnel
- The pilot hole drilling was done at the end of November 2012
- Posiva's standard set of drill hole investigations was carried out in the holes



Rock Suitability Classification for POPLU – 1st Suitability Classification (”deposition tunnel”)

- **The first suitability classification was carried out in February 2013**
- **Chainage 9.00 - 16.20 m of the demonstration tunnel 3 was classified unsuitable for a plug**
- **In all other locations the criteria set for bedrock hosting a plug were determined to be fulfilled**
- **It was suggested, that chainage 11 - 17 m in DT4 would preliminarily be chosen for the location of the POPLU plug, as the tunnel section in question would likely be the best in rock quality**

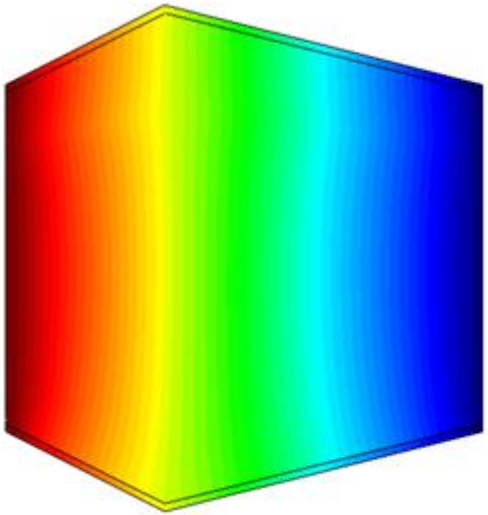


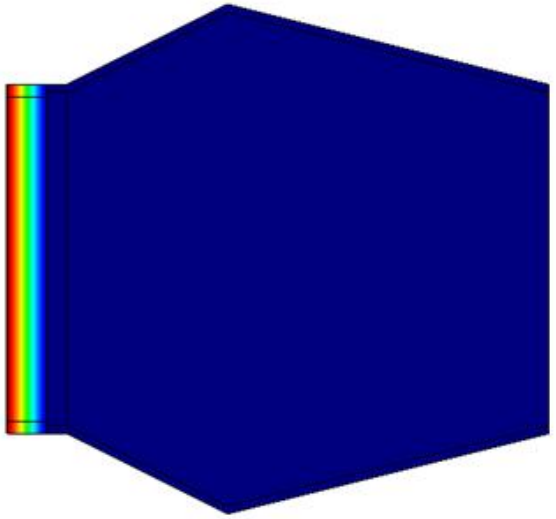
Structural Design of POPLU Experiment

- **The structural analysis and detailed design of the POPLU experiment commenced in Autumn 2012**
- **In addition to the concrete plug component and stainless steel reinforcement it contained the design of**
  - **Backwall**
  - **Filter layer**
  - **Tunnel-to-tunnel and plug lead-through pipes**
- **The basis of the structural design were**
  - **100 years design service life; material requirements, crack control**
  - **7.5 MPa pressure behind the plug; leak tightness, structural strength**
  - **Temperature differences**
- **Leak tightness of the concrete plug component is ensured by**
  - **3 strips of bentonite tape around the plug circumference**
  - **6 injection loops around the plug circumference**

Structural Design of POPLU Experiment

- **Water tightness of the POPLU design was modelled with different seal layer material options and configurations**
- **The modelling showed that adding a clay component to the plug design increases the water tightness of the design (learned also from the previous full-scale experiments and DOMPLU)**
- **No clay component was added to the POPLU design as the idea of the POPLU experiment is to demonstrate the performance and water tightness of a plug design with no additional component layers**





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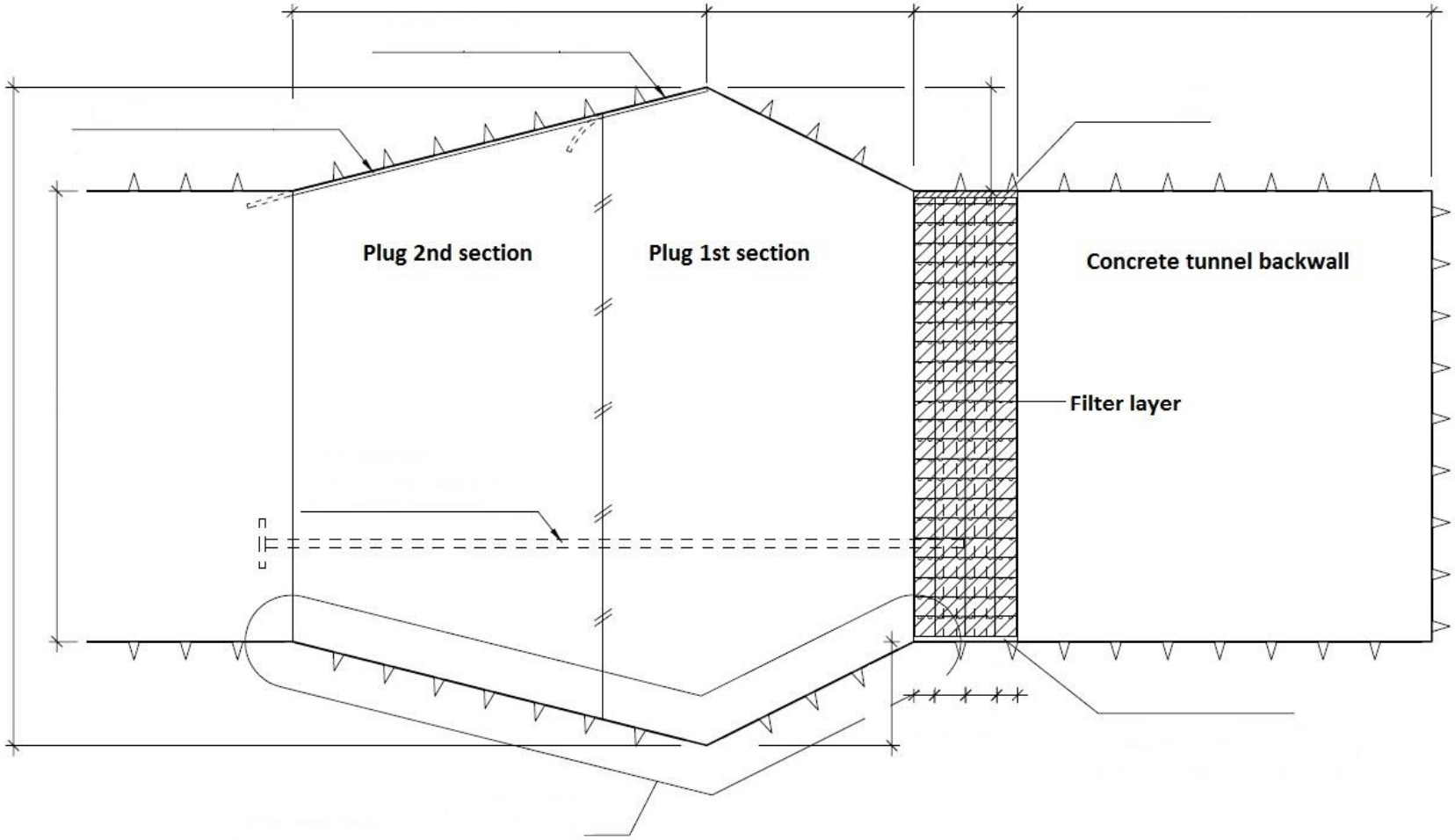
Structural Design of POPLU Experiment



Concrete plug component: length 6 m, width 6 m, height 7 m
Filter layer: length 1 m, width 4 m, height 5 m
Backwall: length 3 m, width 4 m, height 5 m

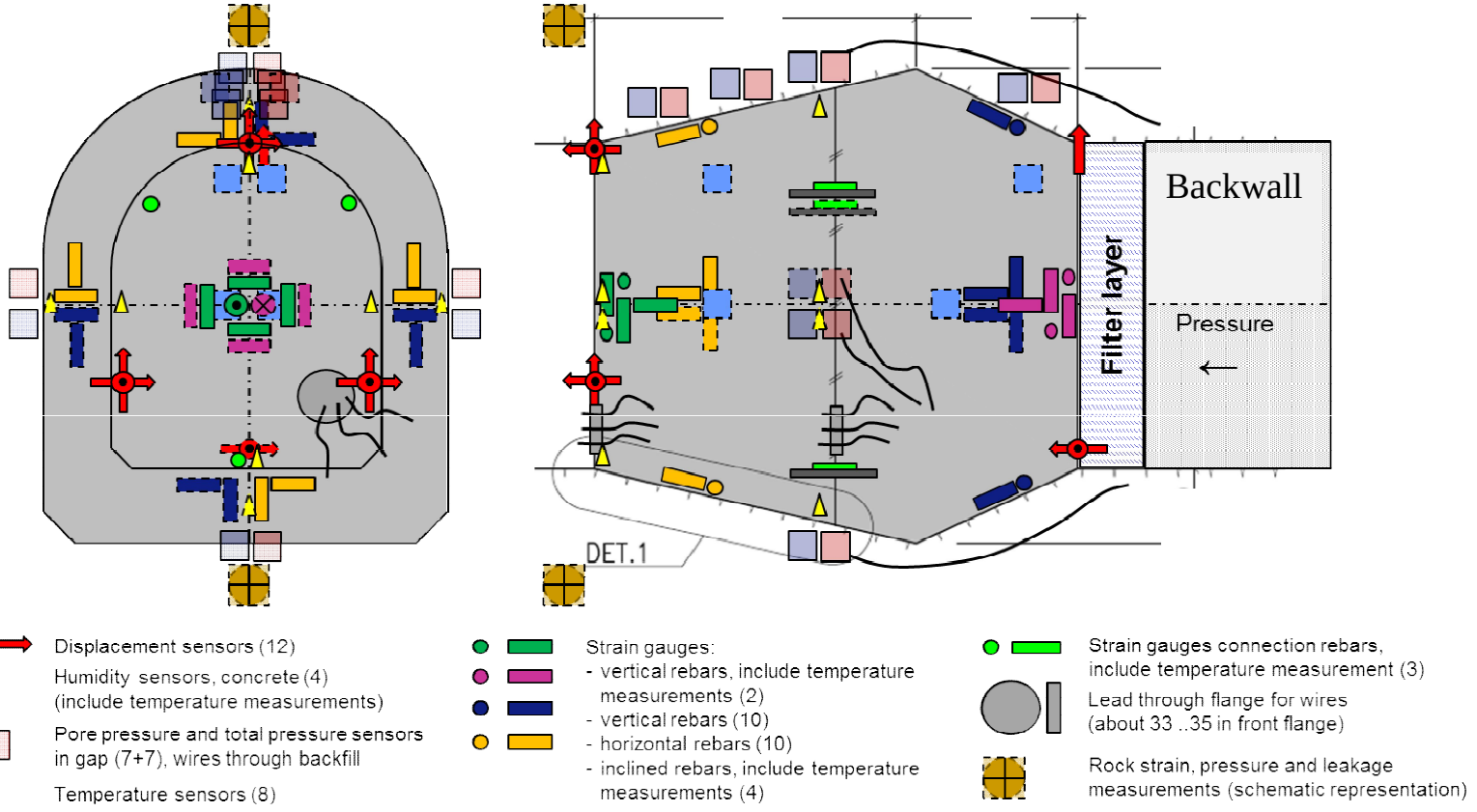
Low-pH Concrete Recipe Development

- The concrete recipe development for the POPLU experiment commenced in Autumn 2012
- Objectives set for the concrete development
  - Low amounts of cement for low PH
  - Minimal shrinkage
  - Workability: Self compacting concrete (SCC)
  - Low permeability
- Three different concrete mix designs were developed
- Mix designs were modified versions of Swedish plug concrete and Canadian plug concrete (from previous full-scale experiments)
- Two concrete mix designs were chosen to large scale (factory) testing
- The concrete mix for POPLU was selected based on the results of the factory testing and recommendation from foreign materials approval
- Cement based low-pH injection grout is under development for contact grouting

Low-pH Concrete Recipe Development

	POPLU Target		POPLU Concrete		"Normal concrete"
Compressive strength, MPa	> 50		79.5		50
Split tensile strength, MPa	3.2		4.5		3.2
Modulus of elasticity, GPa	34		34.2		34
Autogenous shrinkage, mm/m	(min)		0.15		0.1
Drying shrinkage, mm/m	(min)		0.22		0.6
Water tightness, mm	max 50		5.0		25
Chloride diffusivity, m^2/s	(min)		$2.8*10^{-12}$		$10-20*10^{-12}$
pH of leachate at 90 days (reference/Groundwater)	< 11		11.4 / 10.3		>12,5

POPLU Instrumentation Planning

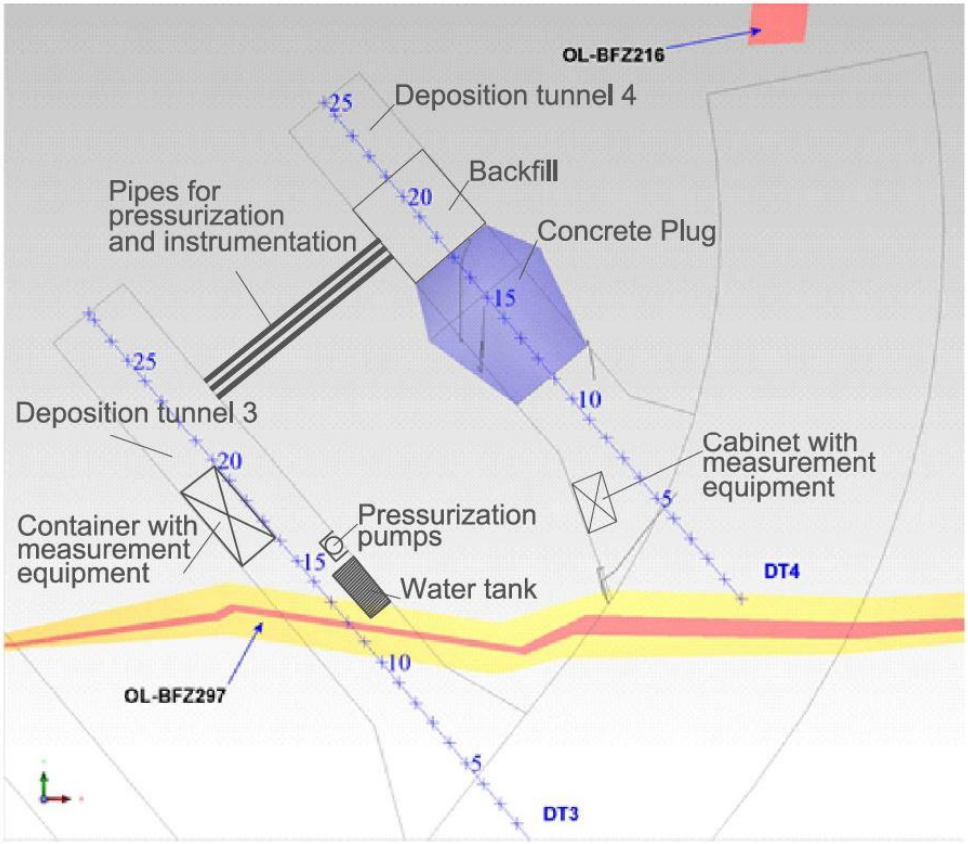


Values to be measured: temperature, humidity, strain, displacement, pressure, and water leakage.

POPLU Instrumentation – Sensors

	Code	Front part FP	Seam SE	Back part BP	Filter layer FL	Back wall BW	*Total*
Strain gauges	SG	16	3	13			*32*
Thermocouples (single)	TCI	6		2		(4)	*8 (12)*
Total pressure sensors	TP	2		5	4		*11*
Pore pressure sensors	PP	2		5	4		*11*
Rel. Humidity sensor (Fuktcom)	RHF	2		2		(1)	*4 (5)*
Rel. Humidity sensor (Aitemin)	RHA	2		1		(2)	*3 (5)*
Displacement sensors (LVDT)	DS				3		*3*
Displacement sensors (Omega)	DSO	9					*9*
	Total	**39**	**3**	**28**	**11**	**(7)**	**81 (88)**

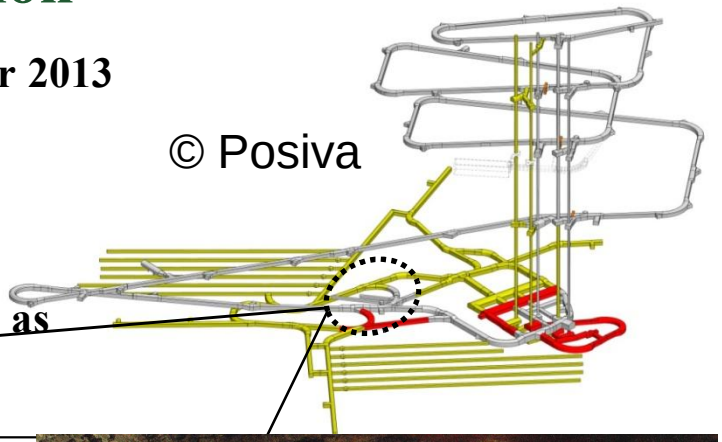
POPLU Pressurisation Test Planning

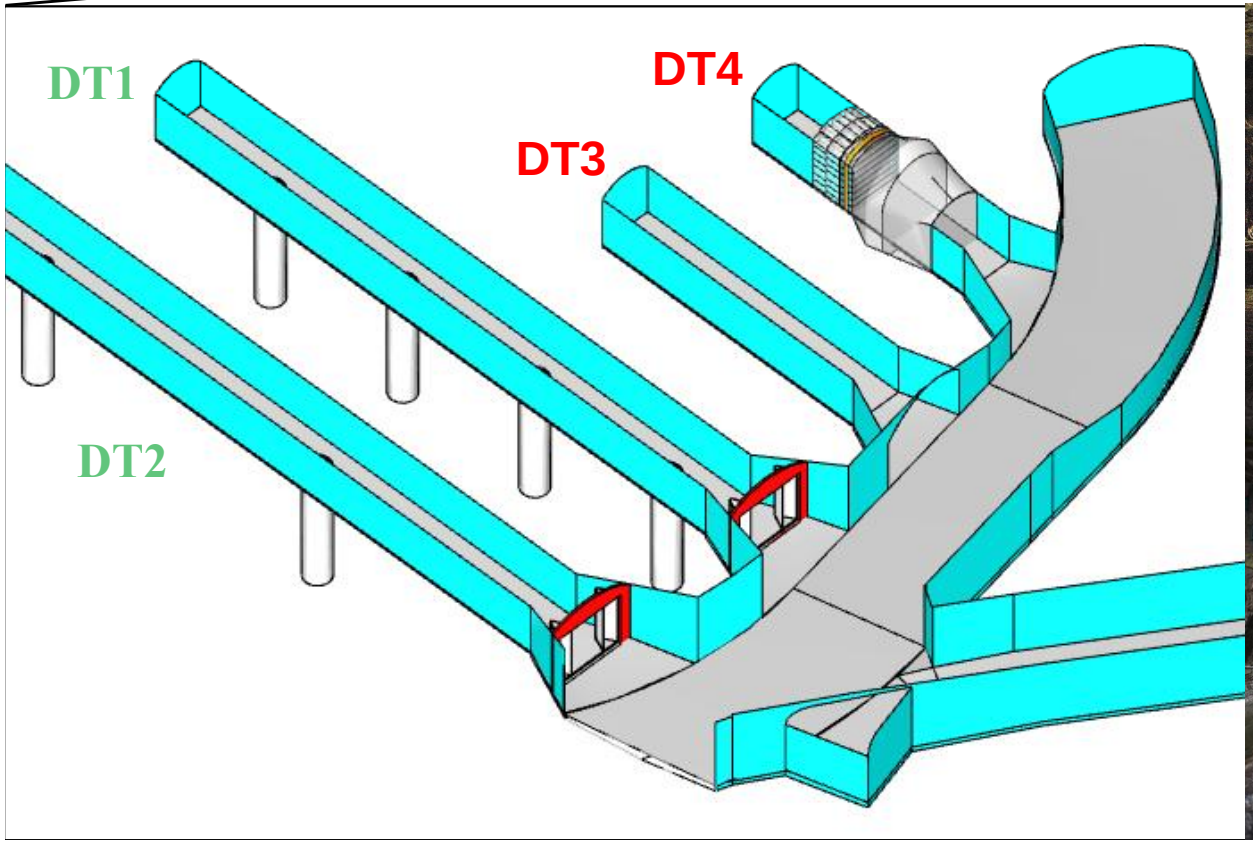


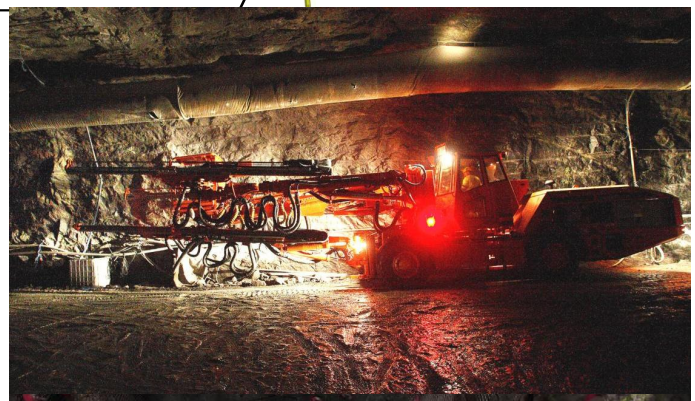
- **Primary test criteria of POPLU is water tightness (no leakage, measured on front face of the plug)**
- **Use of 70 sensors in concrete plug component to evaluate the changes in values during pressurisation**
- **Water pressurisation system to fill filter layer behind the plug and induce loading corresponding to groundwater pressure**
  - **pressurisation up to 4.2 MPa**
  - **pressurisation time of 11 weeks**
  - **pressurisation adjusted based on response from leakage and sensors**

Implementation of the POPLU Experiment – Tunnel Excavation and Plug Slot Production

- Tunnel excavation commenced at -420 m level in September 2013
- Excavation was finished in December 2013
  - DT4 was excavated first, then DT3
- The method used for excavation was drill and blast
- The tunnels were excavated to fulfil the same requirements as the previous demonstration tunnels (DT1 and DT2)

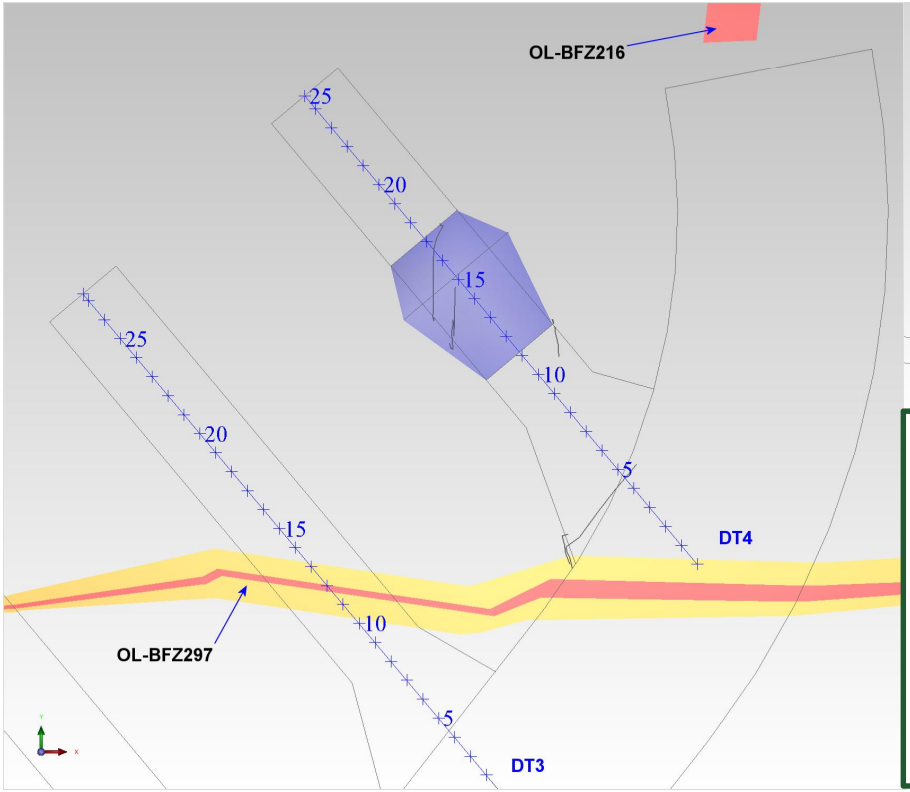


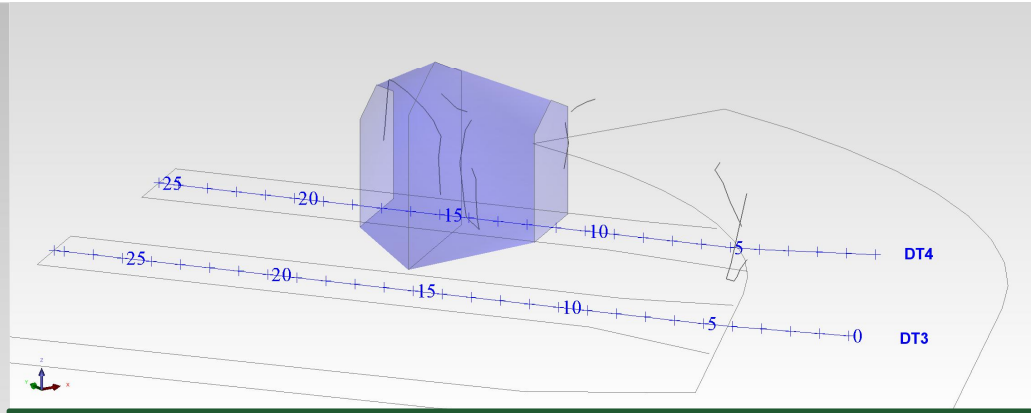




Rock Suitability Classification for POPLU – 2nd Suitability Classification ("deposition tunnel")

- The second suitability classification was carried out in October 2013
- Once the excavation had reached chainage 17.2 m (slightly past the end of the prospective plug location), the detailed-scale model was updated using the data obtained from the tunnel
- Based on the tunnel observations (and the detailed-scale model), no hydrogeological (L5-ROC-59) or brittle deformation (L5-ROC-60) zones are present in the assessed tunnel section or the suggested plug location
- Also, no fractures are present - hydraulically conductive (L5-ROC-80) or not - that would intersect the entire length of the plug

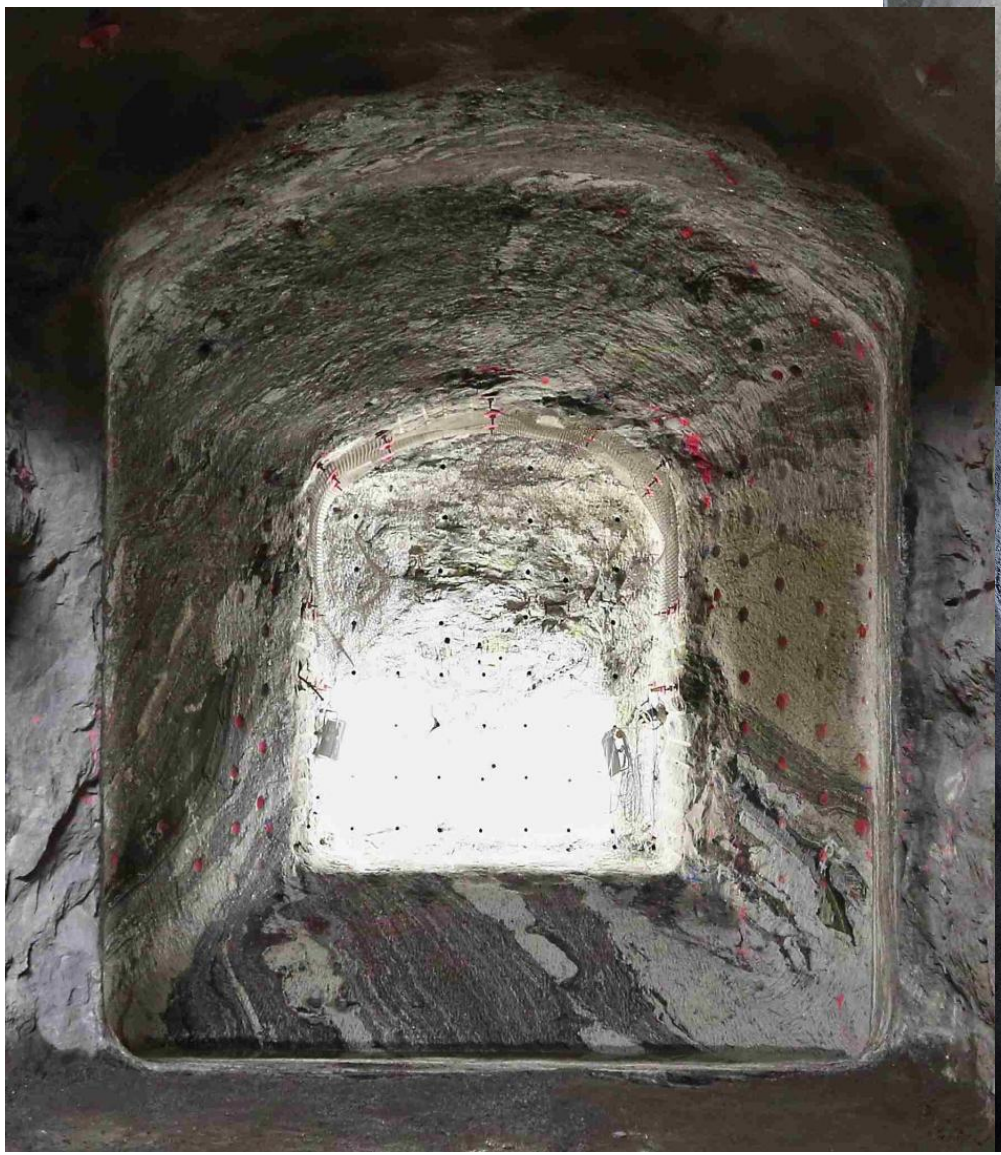




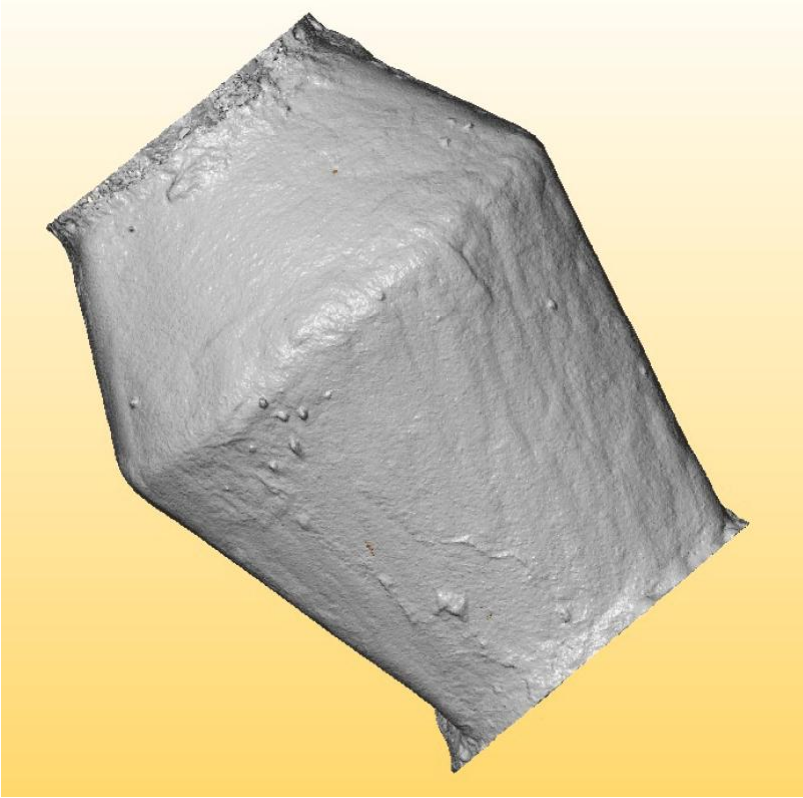
It was concluded that the criteria set for the plug location are fulfilled in the demonstration tunnel 4 in general and that the suggested chainage 11 - 17 m is suitable for the plug location.

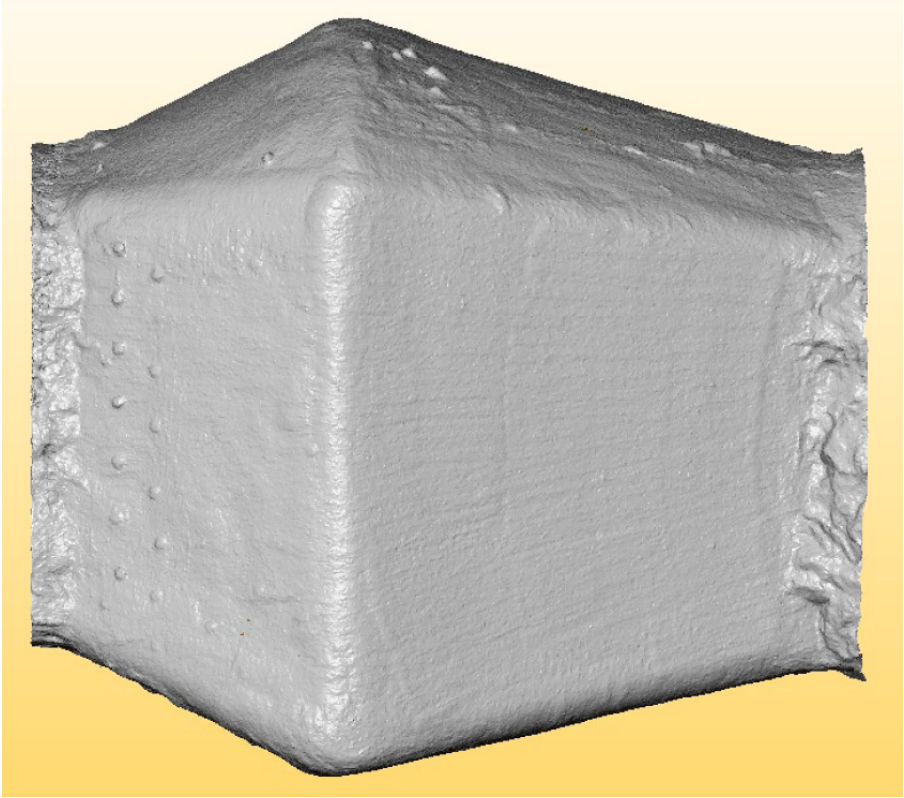
POPLU Slot Production – Drilling-Wedging-Grinding

June 2014 – February 2015



POPLU Slot Production – Laser Scan of the Ready Slot





POPLU Construction – Method Tests

- The transfer of the selected concrete mix design to construction was started in July 2014 by performing the 1st method test
- In total three method tests have been casted at ONKALO to test the concrete
  - aggregate size
  - temperature
  - chemical dosages
  - working methods
- Method test for contact grouting is under development

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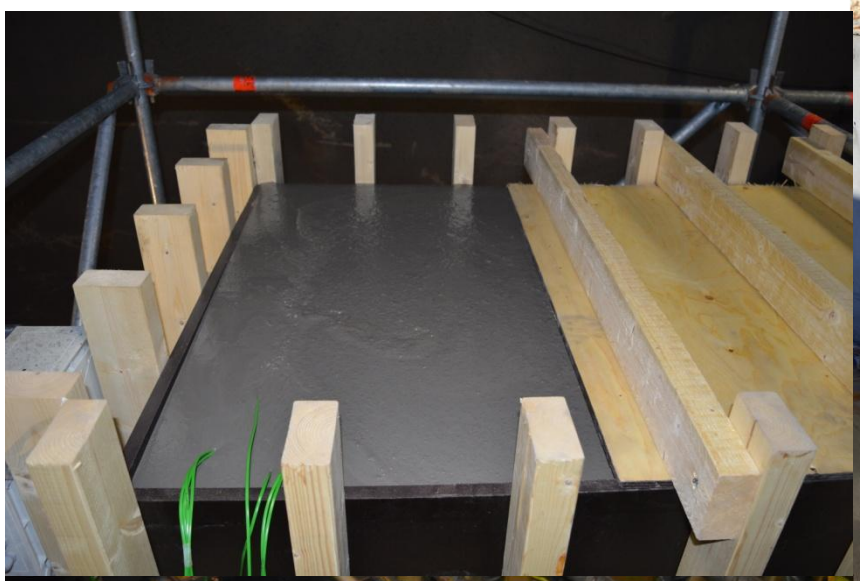
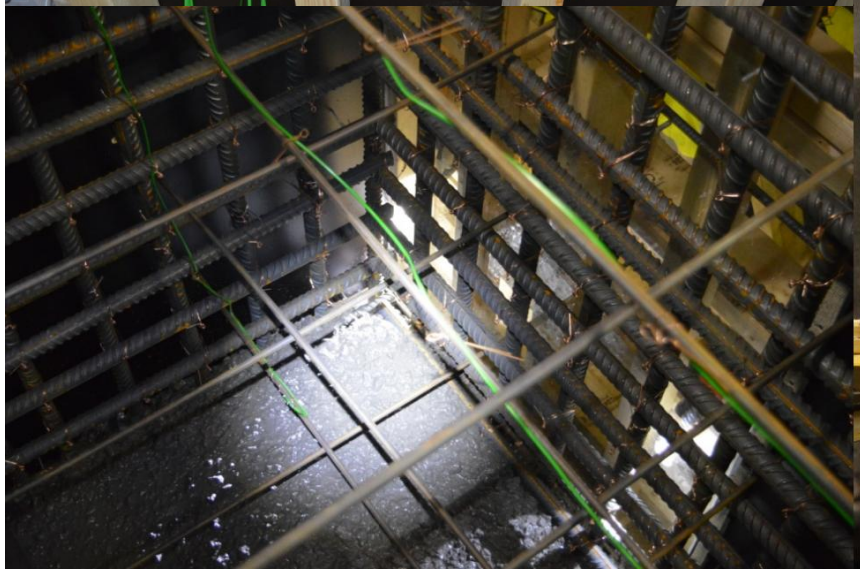
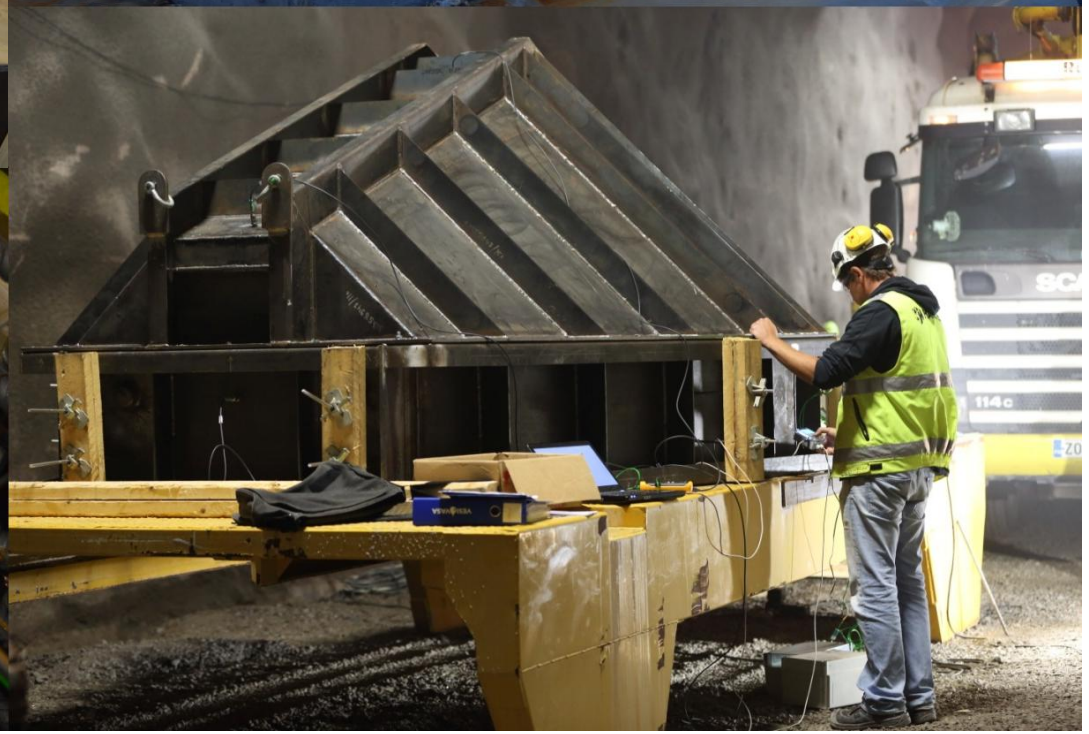
POPLU – Method Tests

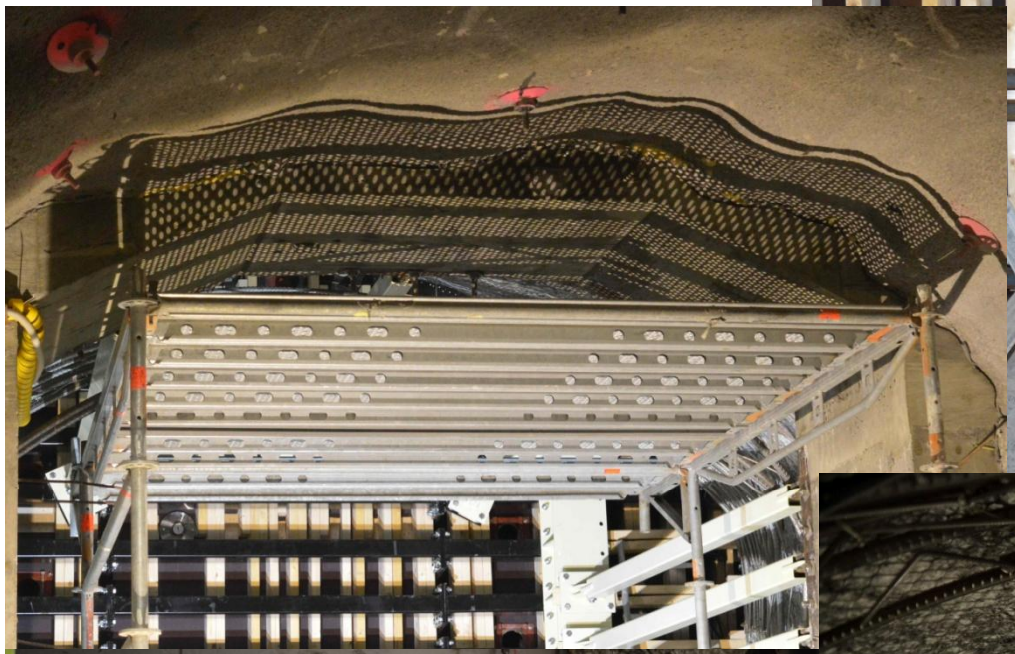






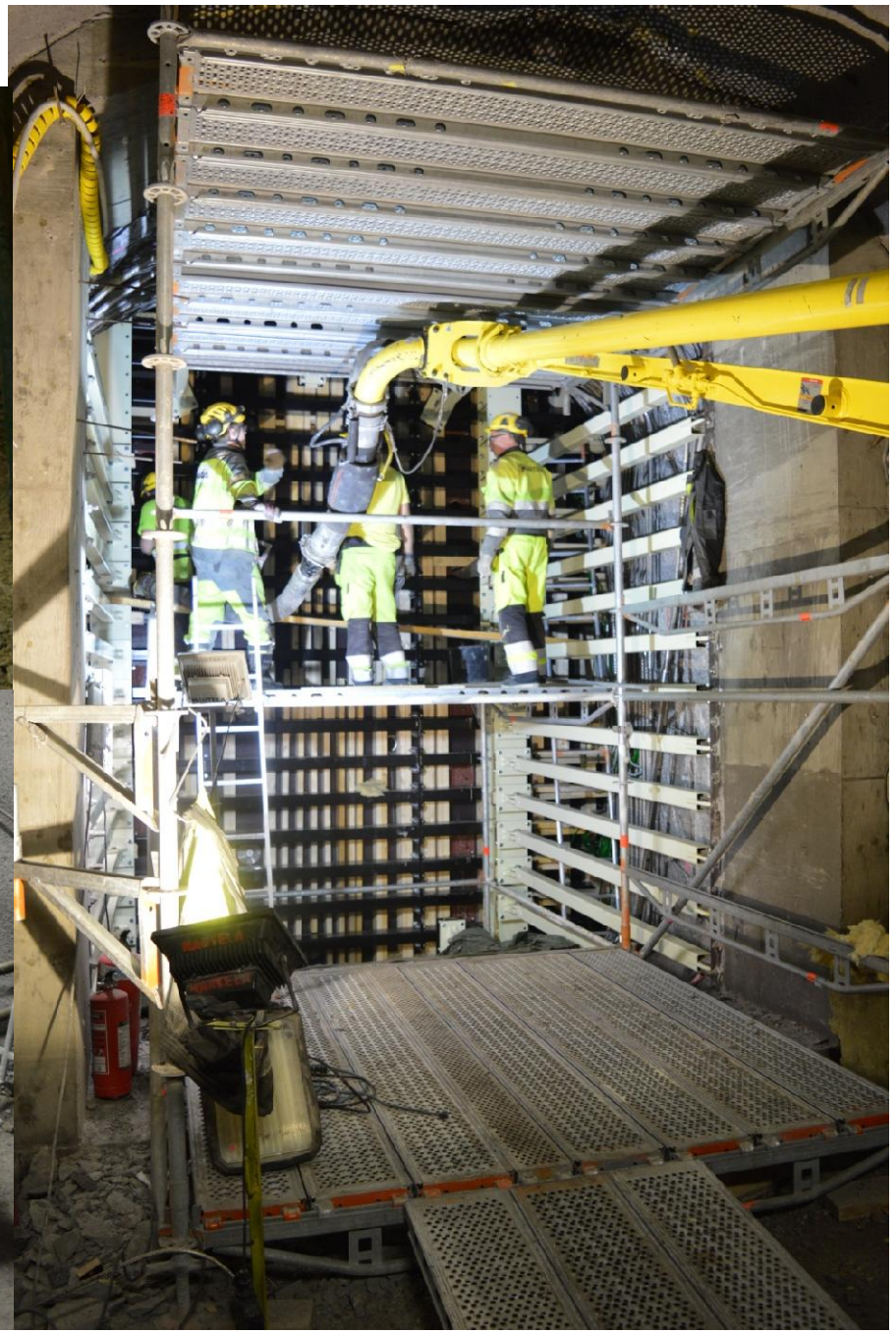
POPLU Construction

February 2015 – December 2015

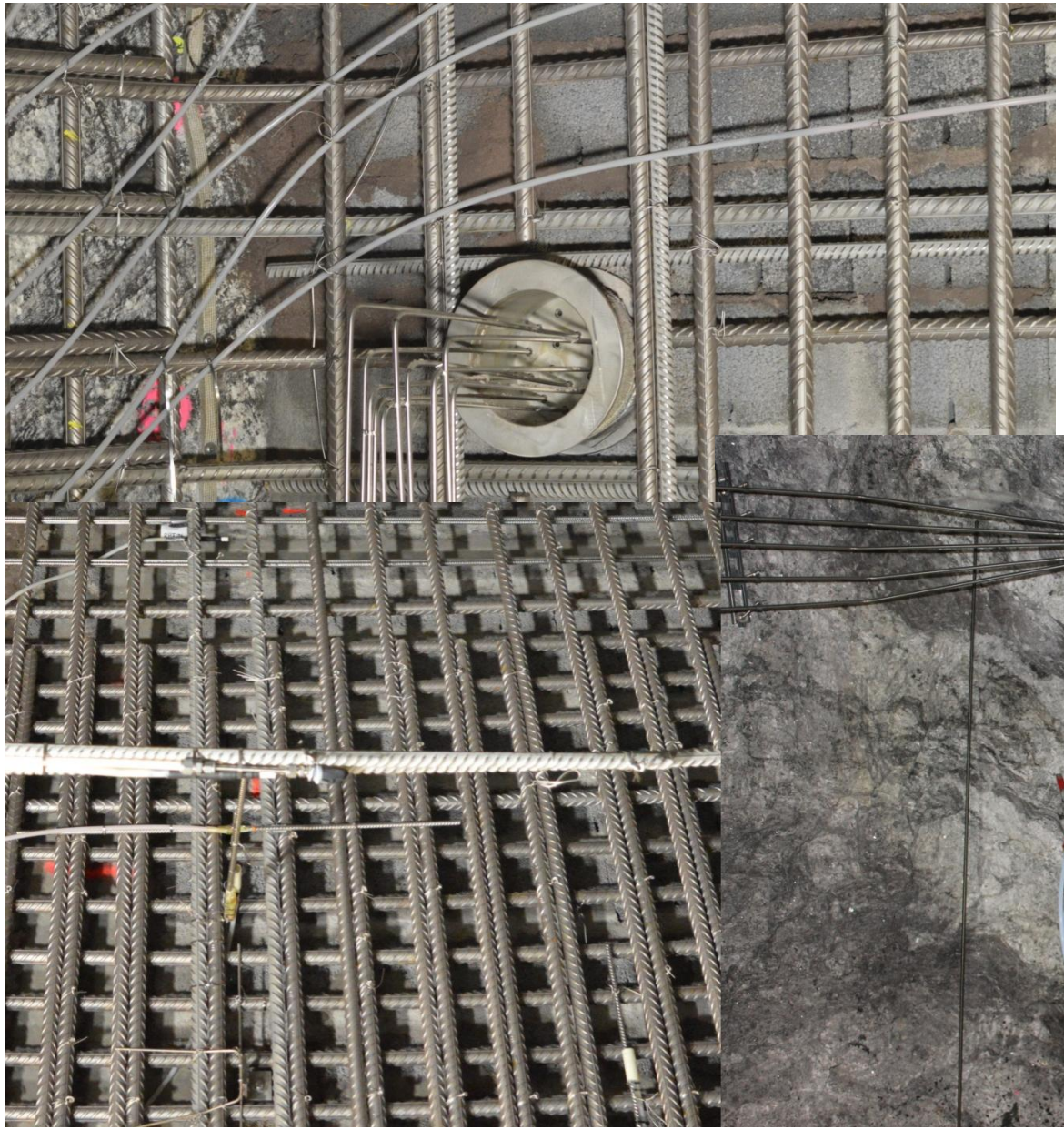


POPLU Construction

POPLU Construction



POPLU Instrumentation Installation



Forthcoming Activities

- **Reinforcement and instrumentation of 2nd plug part**
- **Casting of the 2nd plug part on September 16th 2015**
- **Contact grouting method test in October 2015**
- **Contact grouting of POPLU concrete plug component in December 2015**
- **Pressurisation of the experiment in January 2016**
- **Test programme for POPLU in long term under development**
- **Decommissioning / removal of POPLU experiment TBD – some future date in 2020's?**

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