Utveckling av dynamisk injektering Etapp 2
Development of dynamic grouting Stage 2

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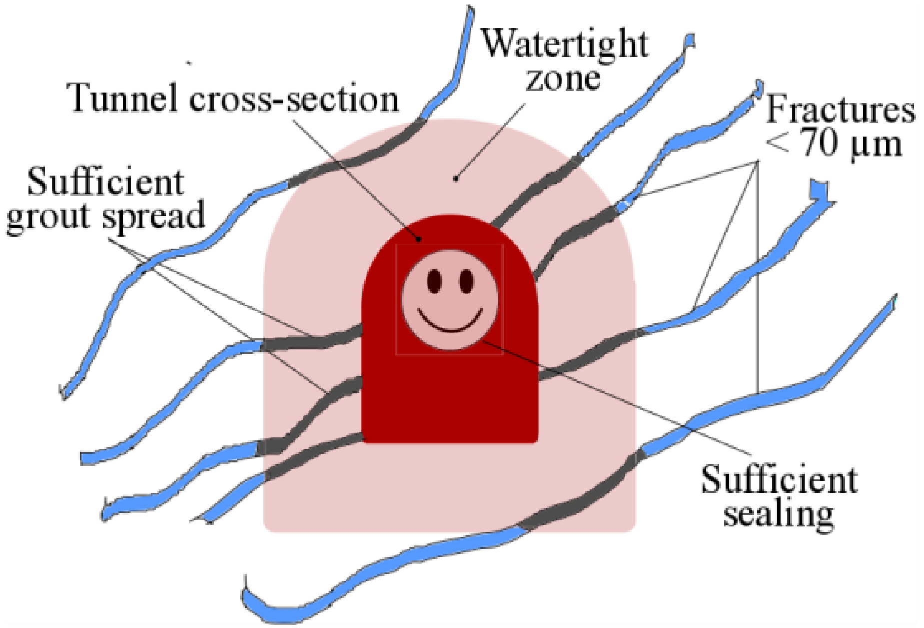
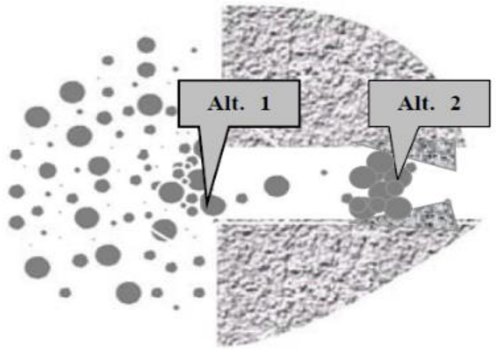
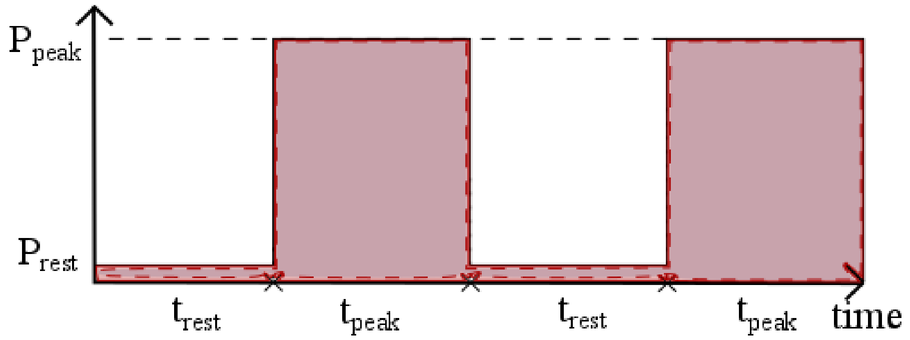
Background



Effective grouting in tunnel



Dynamic injection



Low-frequency pressure impulse of rectangular shape

Mechanism of action

Erosion of the filter cakes due to continuous change of flow pattern.

Expected outcome

- Less dissipation of the pressure impulses along the fractures.
- Effective improvement of grout spread in fractures ≤ 70 µm

Goals

Verification of the efficiency of the method in controlled condition in the lab.

Stage 1: Design, production, and pilot test of the dynamic injection prototype unit and testing the dynamic injection effect on grout penetrability using VALS

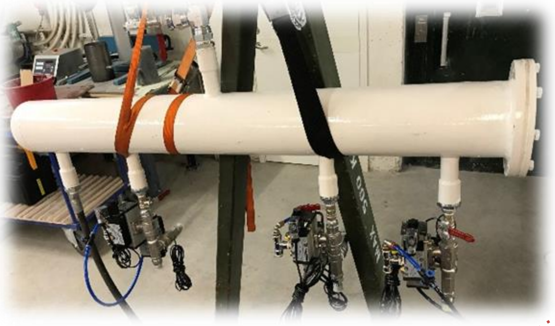
Demonstration of the effectiveness of the method in the field.

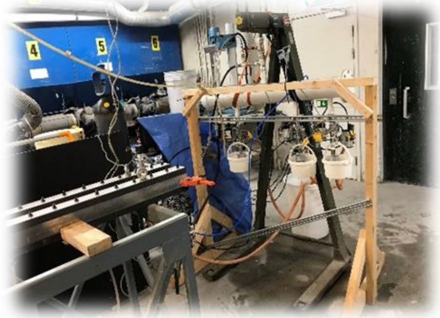
Stage 2: Field-scale experiments in Äspö HRL

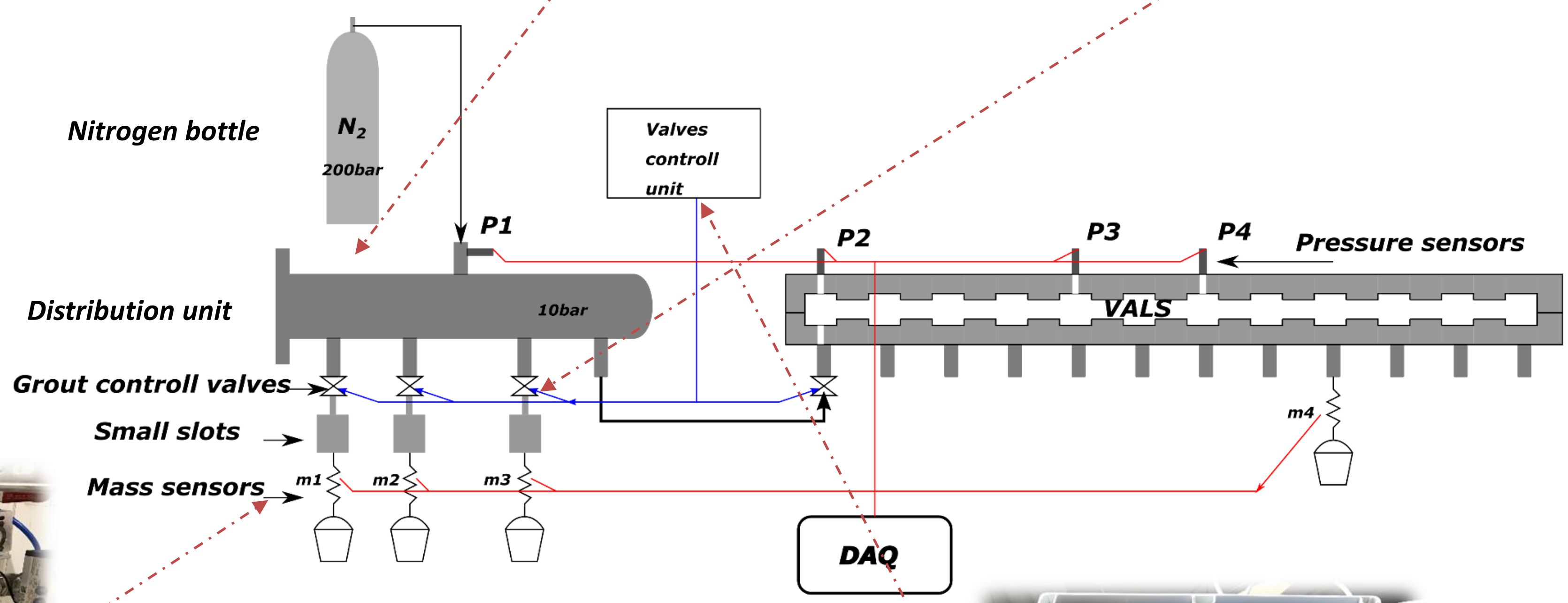
Variable Aperture Long Slot (VALS) and dynamic injection unit at laboratory

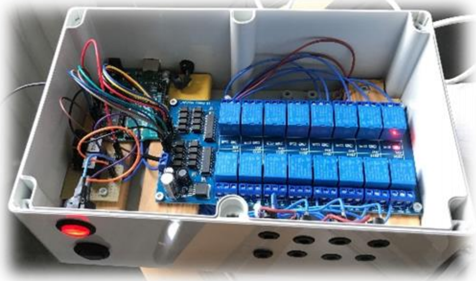
Distribution unit at Äspö HRL

Stage 1 R&D and pilot test of the dynamic injection unit and laboratory test



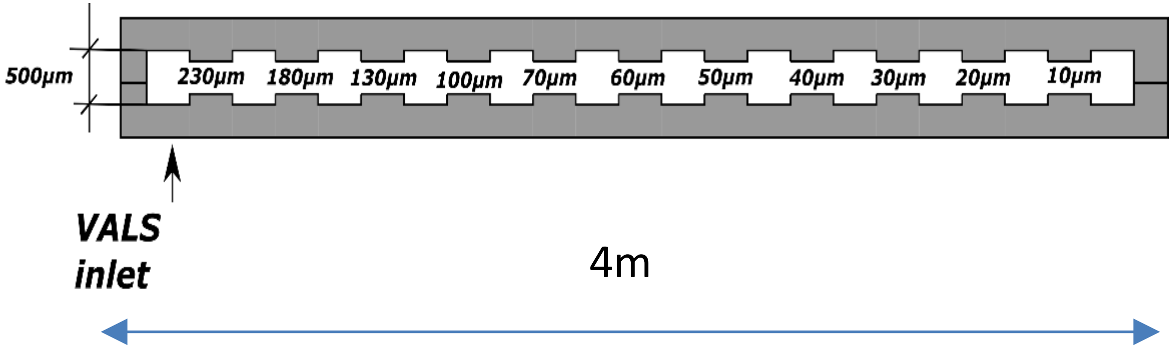




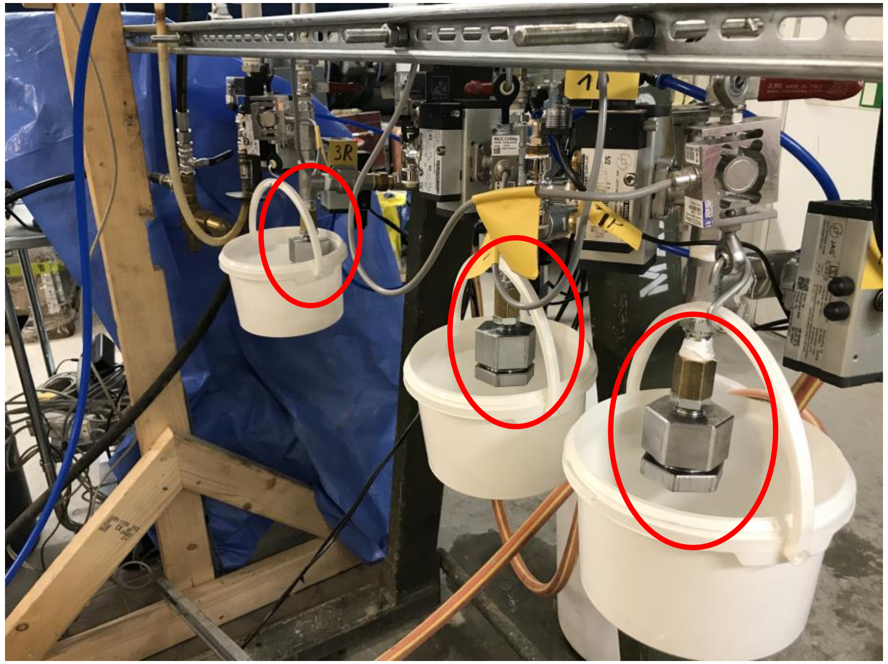


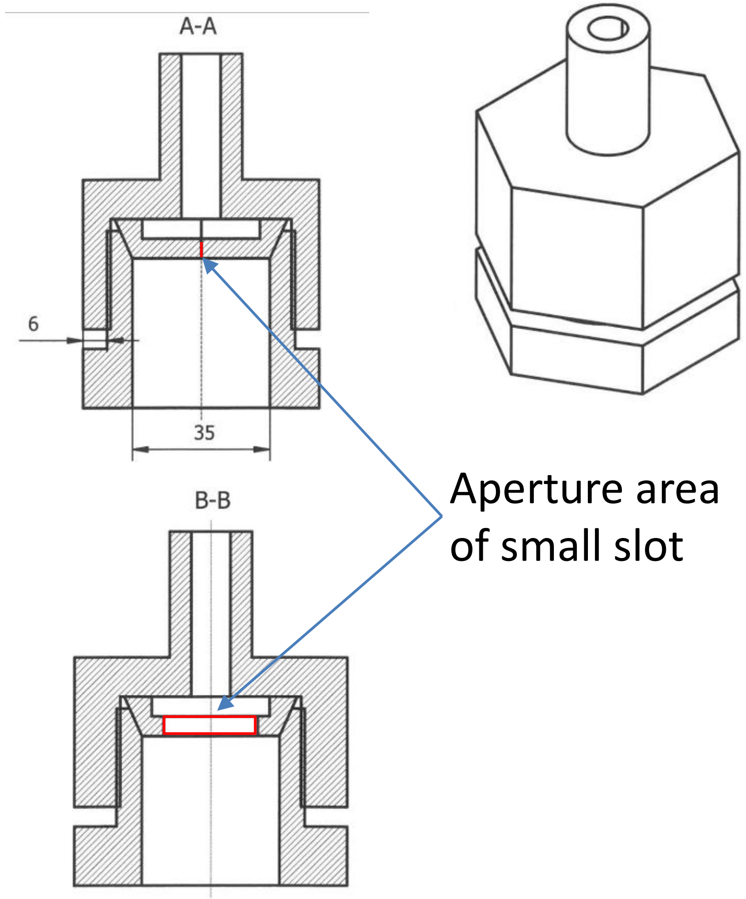
Variable Aperture Long Slot - VALS

Stage 1 R&D and pilot test of the dynamic injection unit and laboratory test



Small slots

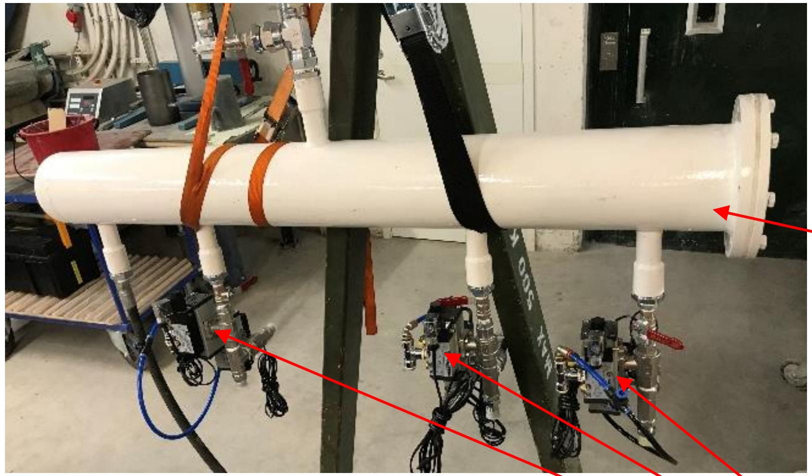




- Small slots had apertures of 70µm, 60µm and 50µm size
- They were used to test the small size testing rig concept for dynamic injection effect

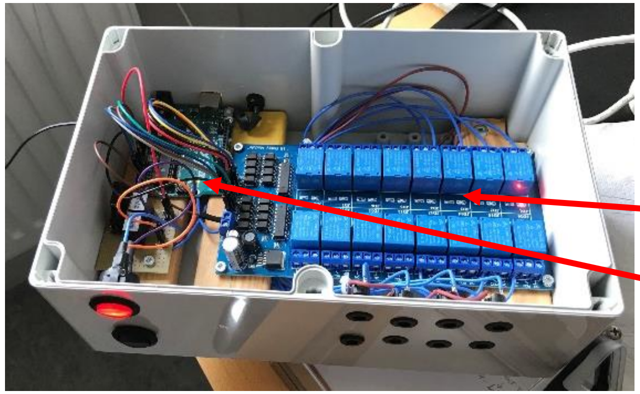
Stage 1 R&D and pilot test of the dynamic injection unit and laboratory test

Dynamic injection unit



Distribution unit acting as pressurised grout container

Pneumatic valves for grout flow control



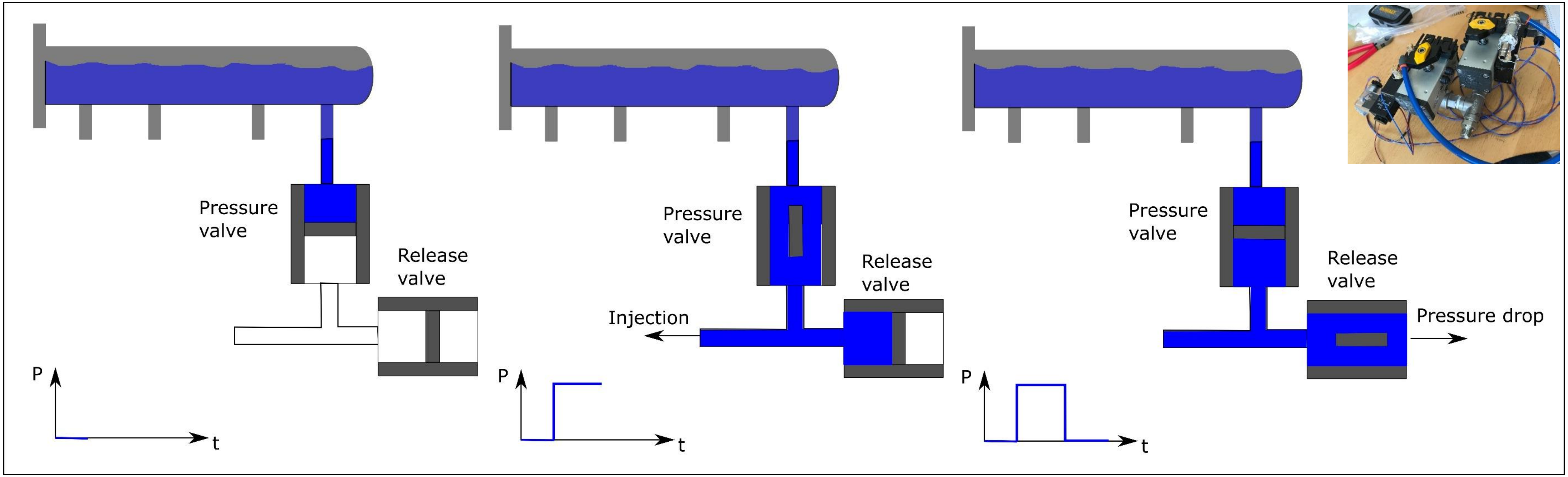
Relay board

Arduino board

Pneumatic valves controller

Forming of dynamic pressure

Stage 1 R&D and pilot test of the dynamic injection unit and laboratory test

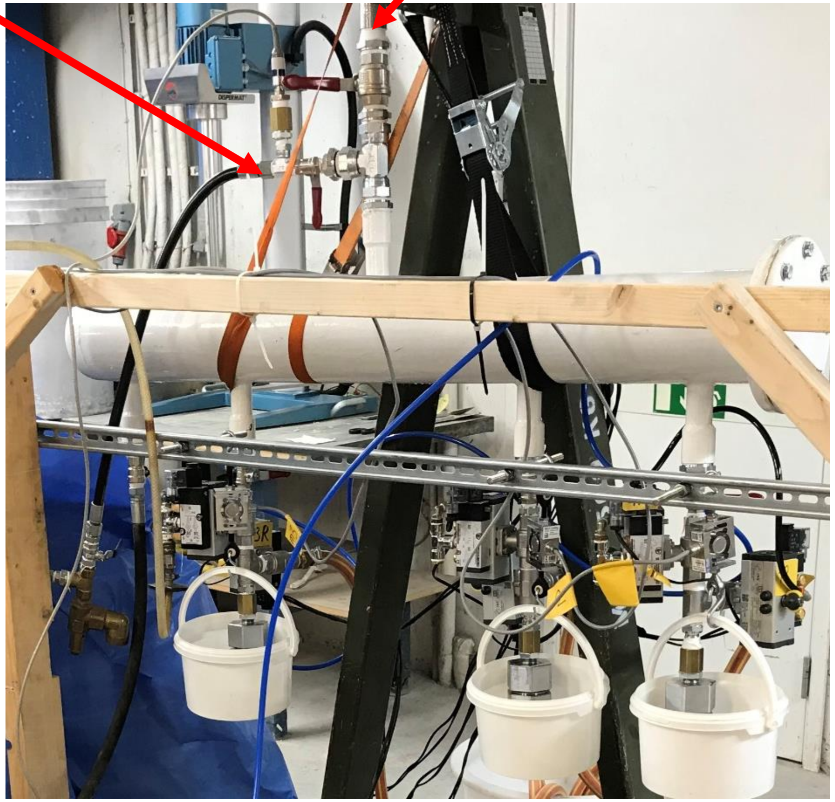


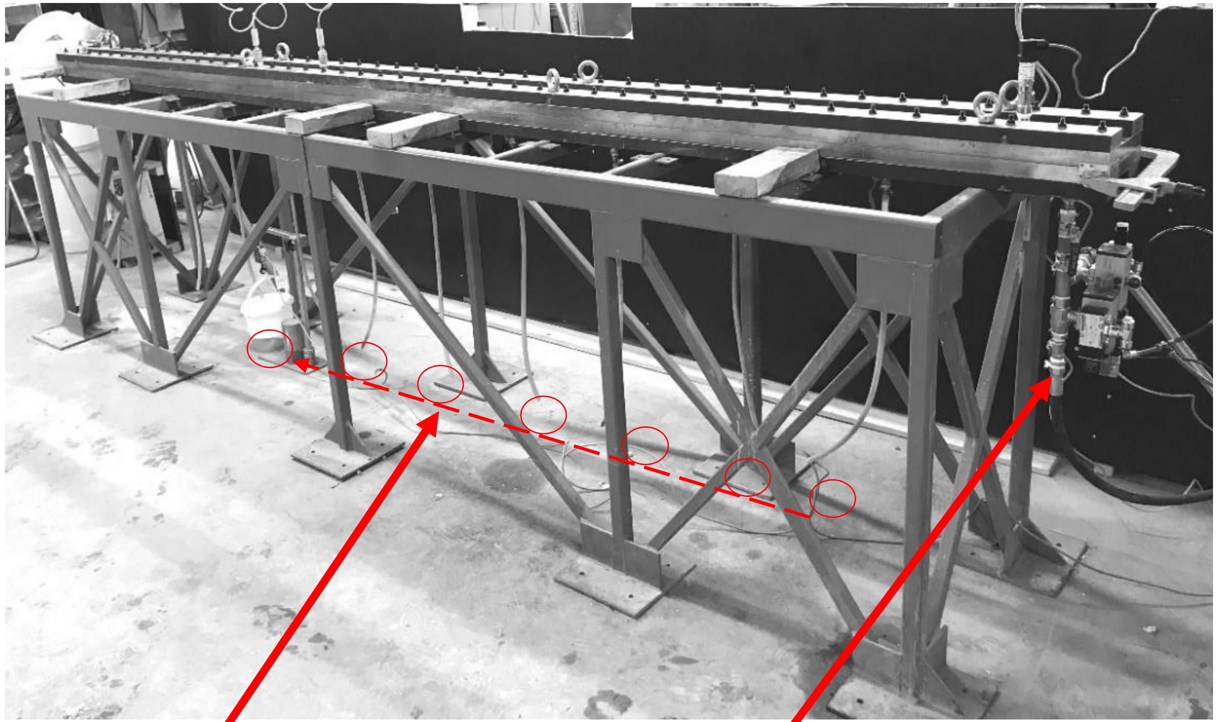
Stage 1 R&D and pilot test of the dynamic injection unit and laboratory test

The experiment routine

1 Filling in the grout (~11l)

2 Applying 12 bar pressure



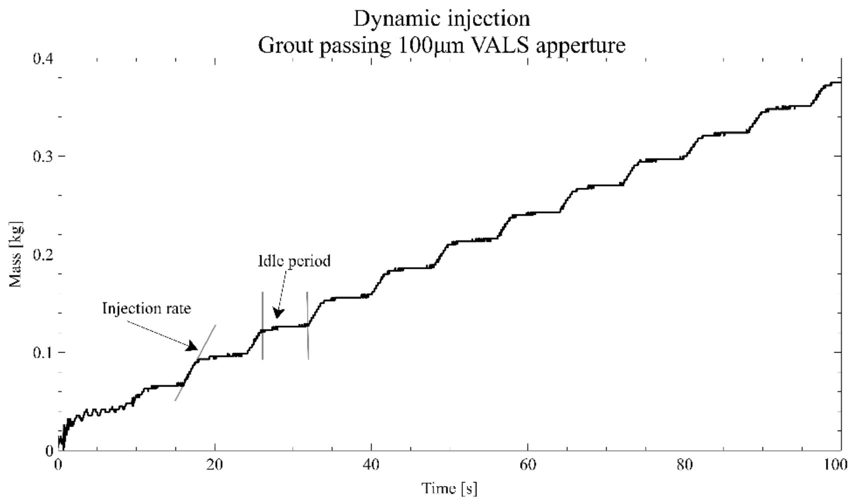


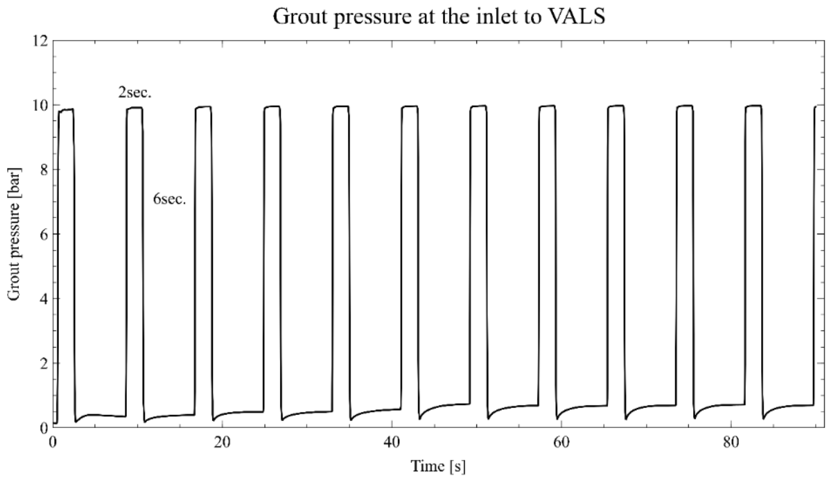
3 Injecting grout to VALS

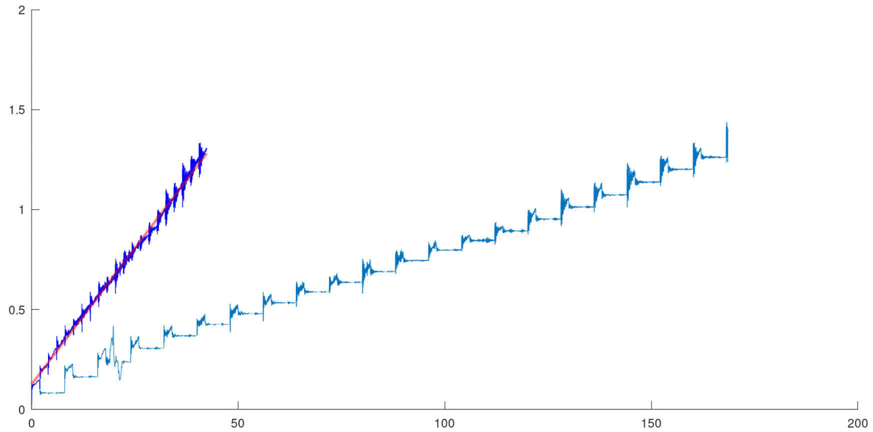
4 Measuring grout mass flow under each aperture valve. Measuring time 15-180s dependent on flow rate.

Results interpretation

Stage 1 R&D and pilot test of the dynamic injection unit and laboratory test



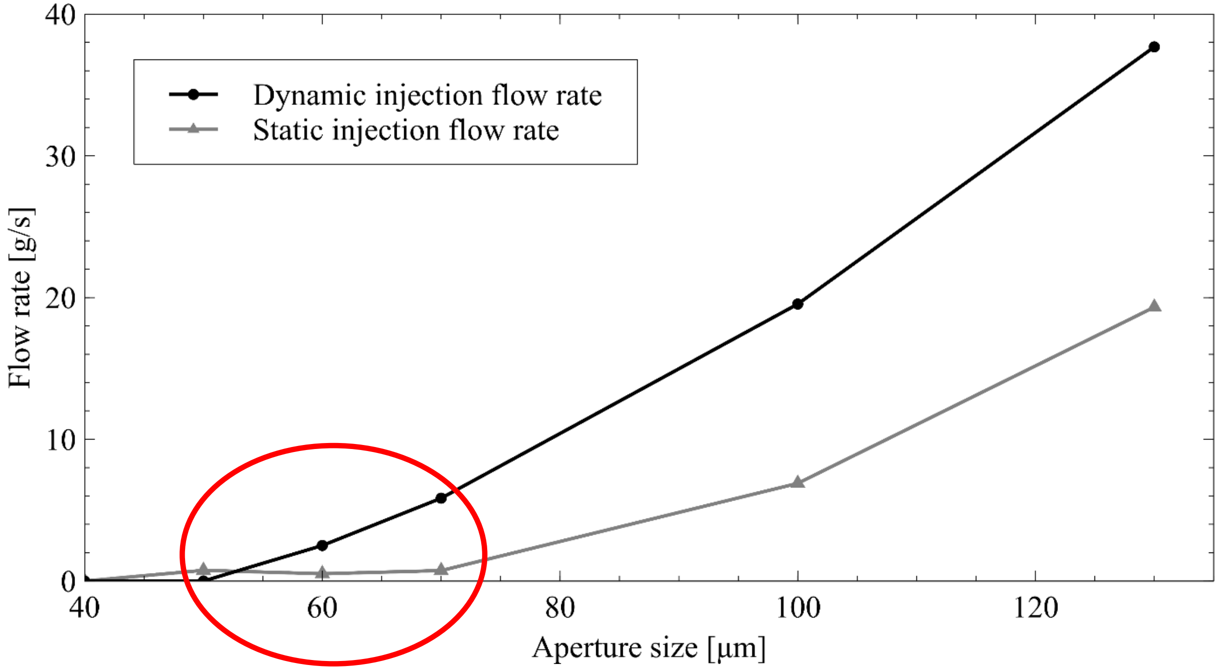




Idle period removed and the average flow rate calculated

Stage 1 Important results and conclusion

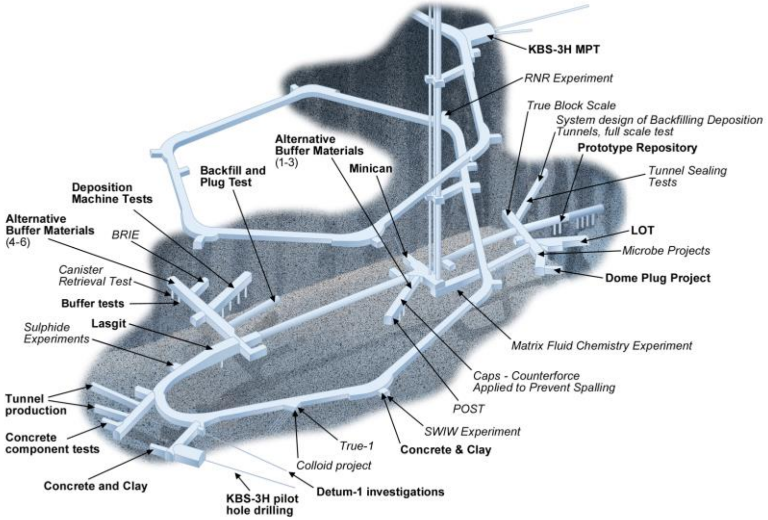
- The average flow-rate was higher for dynamic injection at all apertures.
- The grout penetrated up to 60 µm aperture for dynamic injection.
- The grout flow stopped at 70 µm aperture for static injection.
- The small slots test did not show consistent results. This might be because the slots were too close to pressure source.



Average grout flow rate for static and dynamic injection

Stage 2: Field-scale experiments in Äspö HRL

The field test was carried out at SKB's underground Hard Rock Laboratory (HRL) at Äspö on 5th of October 2022. The laboratory situated in the Misterhult Archipelago close to the Oskarshamn nuclear power plant.



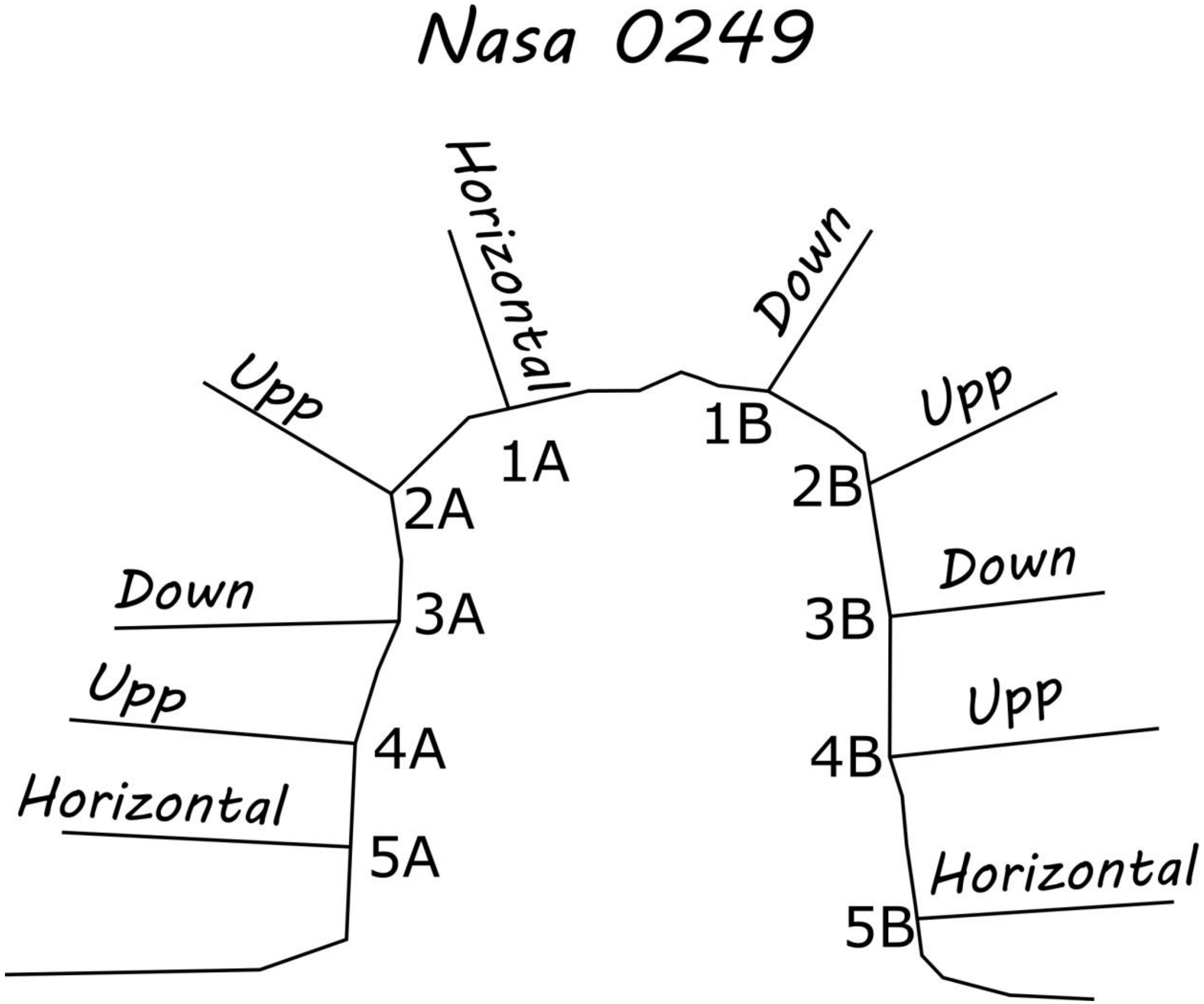
https://www.skb.com/research-and-technology/laboratories/the-aspo-hard-rock-laboratory/

The test site

- 8 possible sites were inspected at Äspö HRL.
- NASA 0249A was chosen for the field test.
- It was located ~200m from tunnel entrance and in ~50m depth

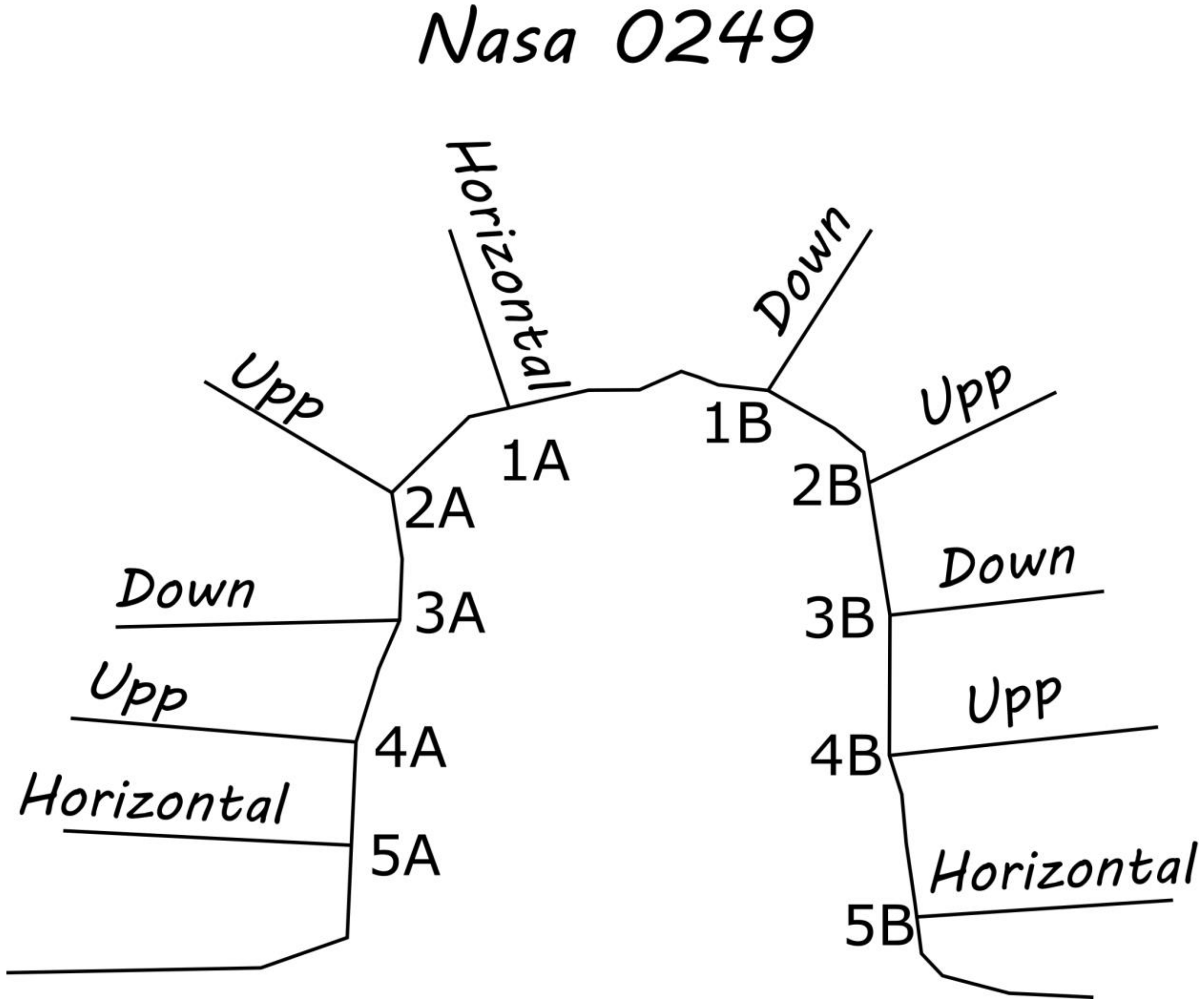
The boreholes drilling

- As next step 10 boreholes were drilled.
- The boreholes had following dimensions:
  - D=56mm
  - L= 10m



Hydrological tests

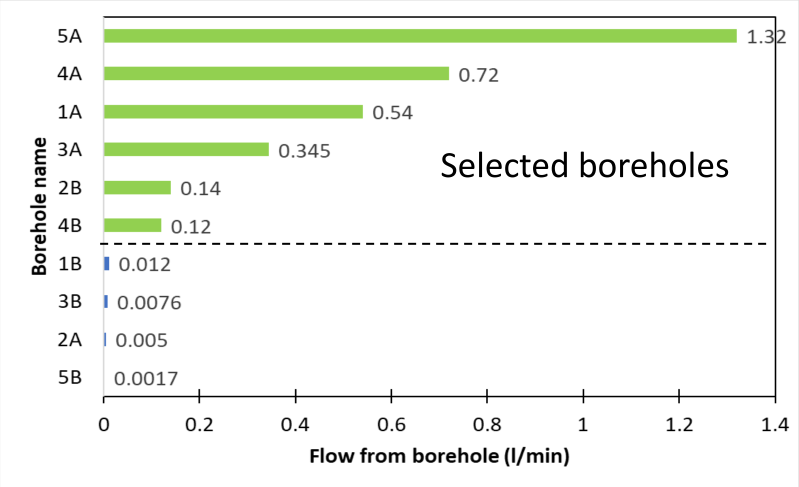
Two hydrological test were performed on boreholes to test the conductivity and possible interconnection.



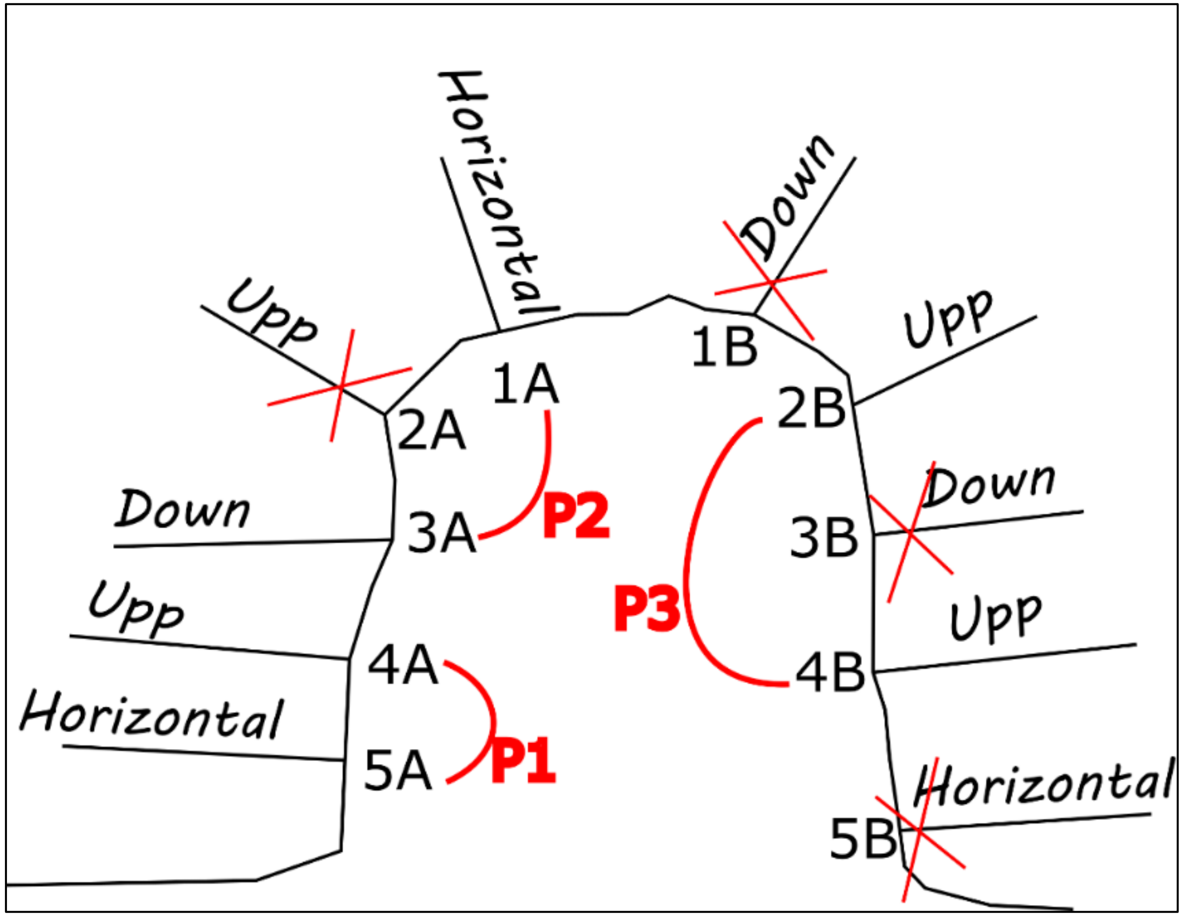
Hydrological tests
Test 1

Flow rate measurements of ground water for each boreholes:

- The flow was measured with flow-meter by opening packer wave.
- 4 boreholes were rejected doe to very low flow or no observed flow at all.
- The flow rate values were used to pair boreholes with similar characteristic for dynamic and static grout injection methods comparison in field test.



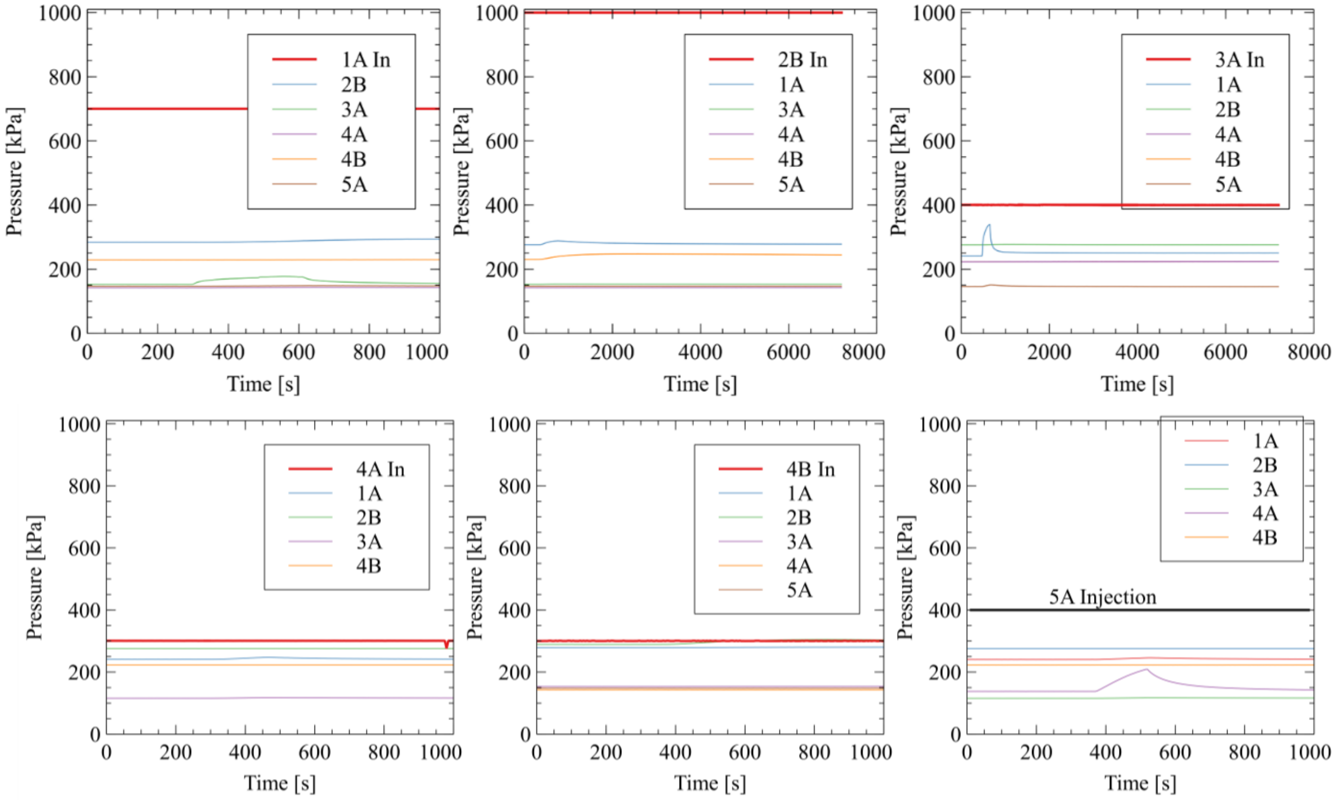
Hydrology tests



Hydrological tests
Test 2

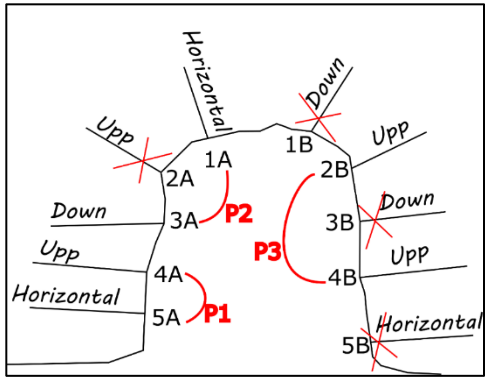
Remaining 6 boreholes were tested for connectivity:

- Water was injected into one borehole for ~15min while recording the pressure change in other 5 boreholes.
- The injection pressure was 10bars in the water vessel, but due to friction in the tubes it dropped to 4-5bars at the borehole.
- The test results indicated no major connectivity among boreholes.

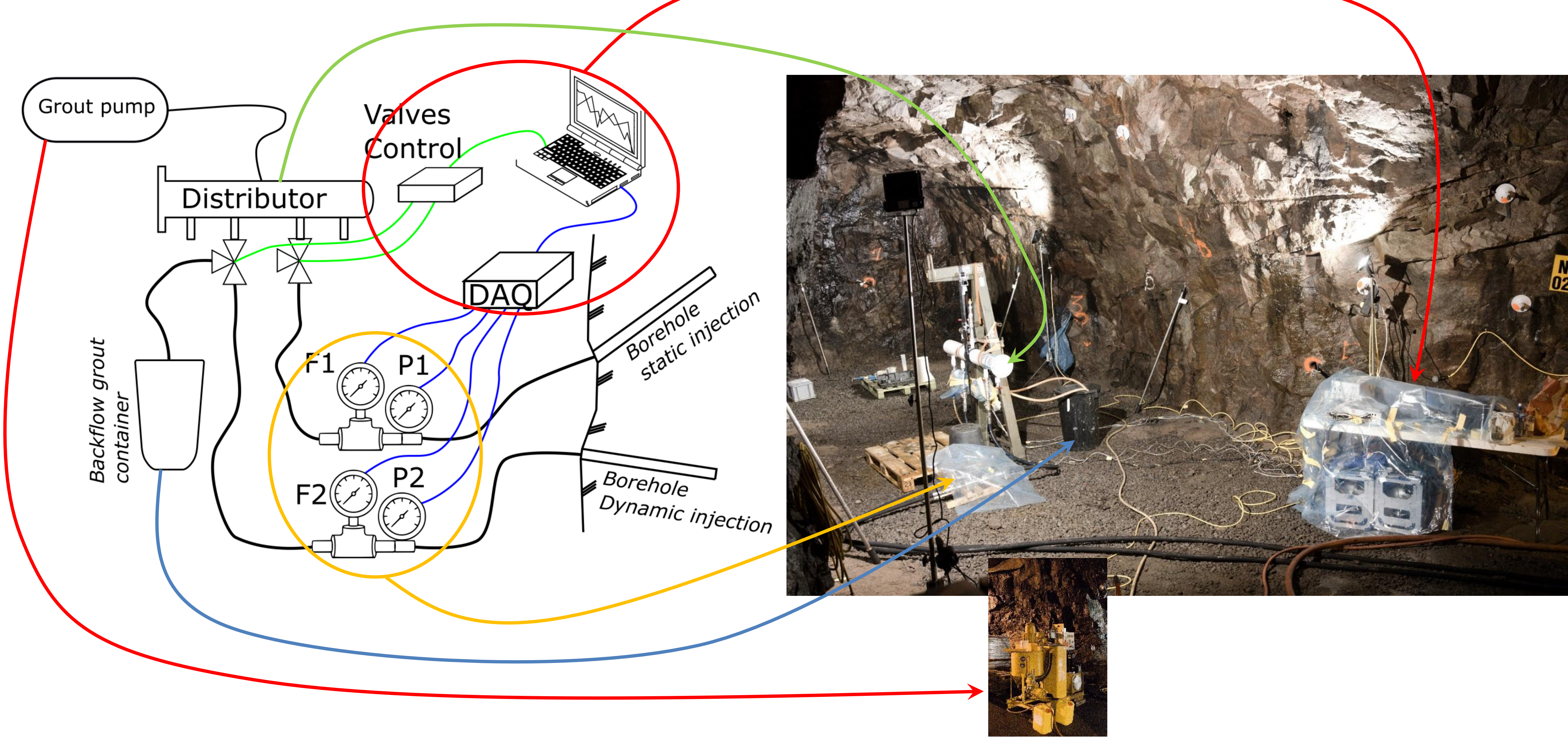


Pressure logger

Water container with Nitrogen bottle

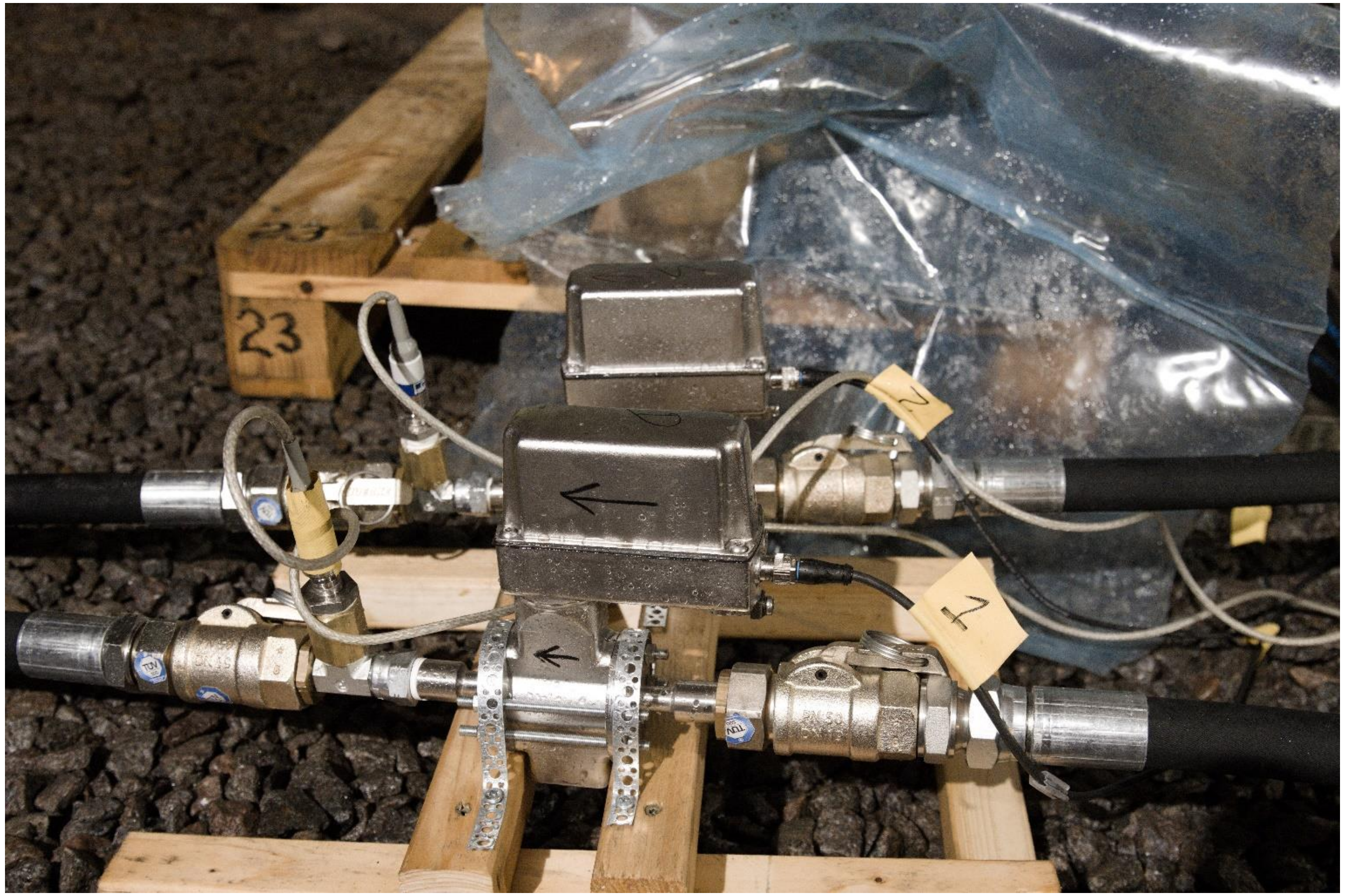


The field test test-setup



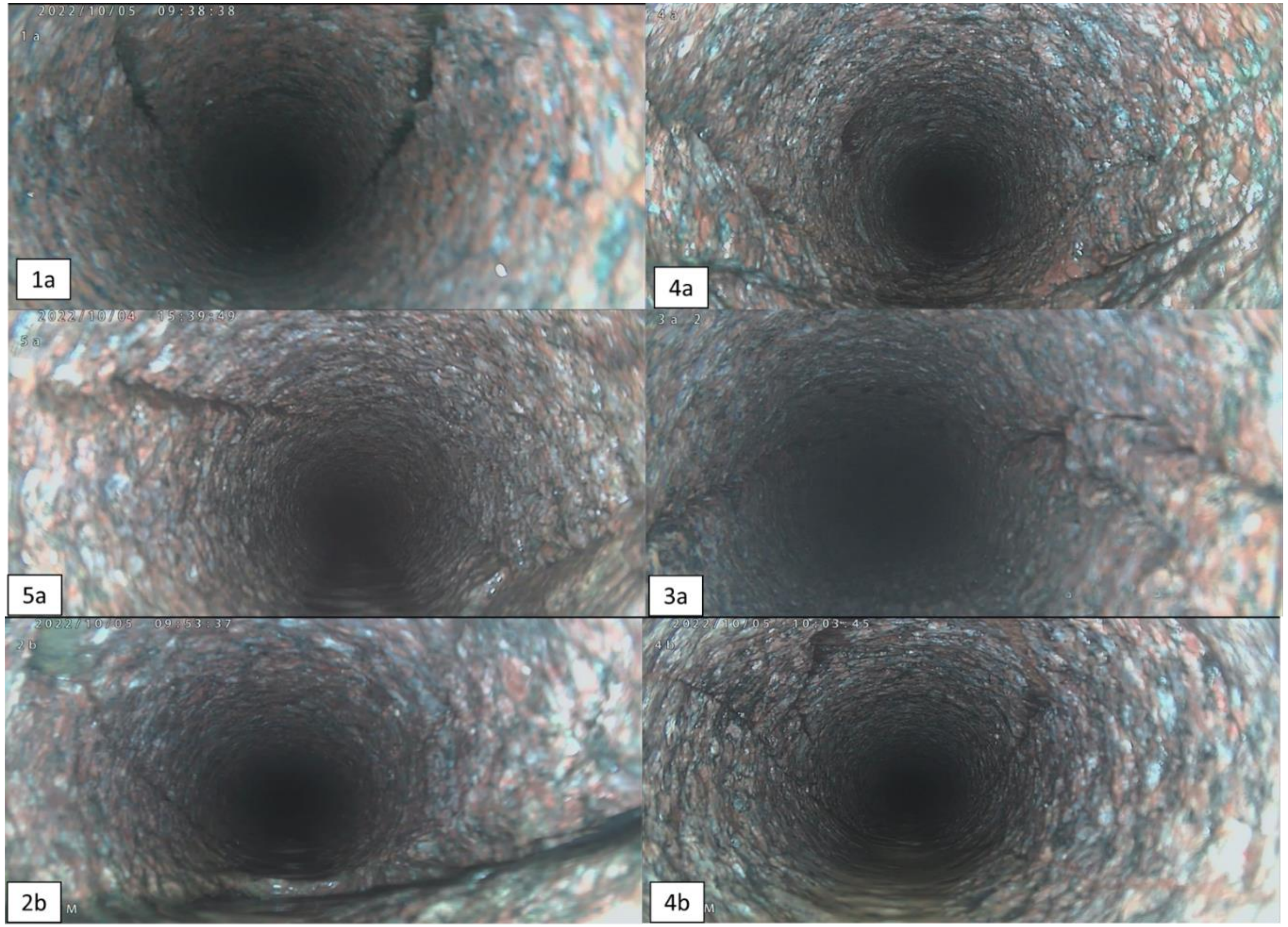
Data collection sensors

- Two flow meters with maximal flow range of 150 l/h.
- Two pressure sensors with range of 20 bars
- Injection pressure was 10-12 bars



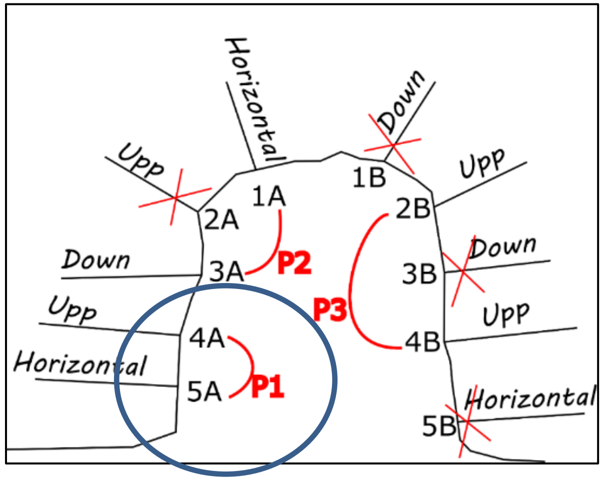
Data collection sensors

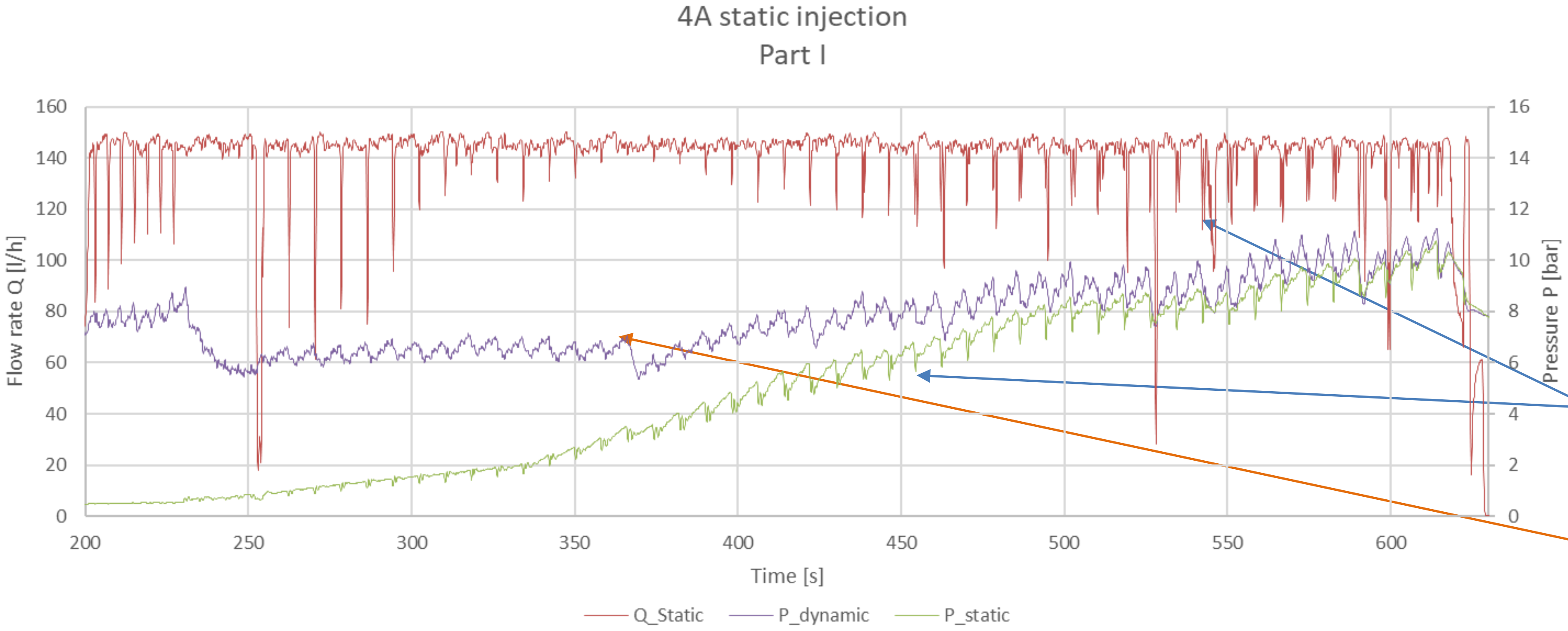
- Before the experiment boreholes were inspected with camera.
- Multiple fractions were observed.
- Most of them were located within 3m from borehole start.
- The fractions were mostly longitudinal.



The grout injection

- The injection started from pair P1 boreholes (BH).
- The injection was done at a same time for both boreholes.
- 5A BH was used for dynamic injection and 4A for static.
- The interference was observed in pressure graphs



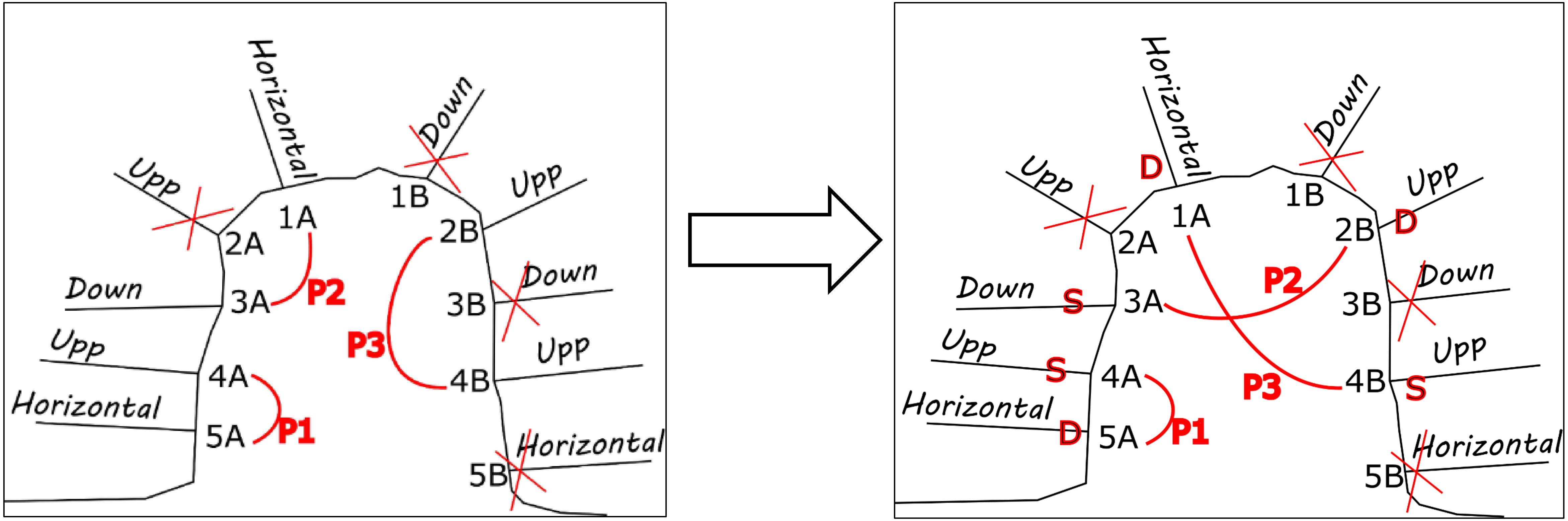


Unexpected spikes in static injection flow and pressure graphs

The static flow rate spikes are consistent with dynamic injection pressure pulses

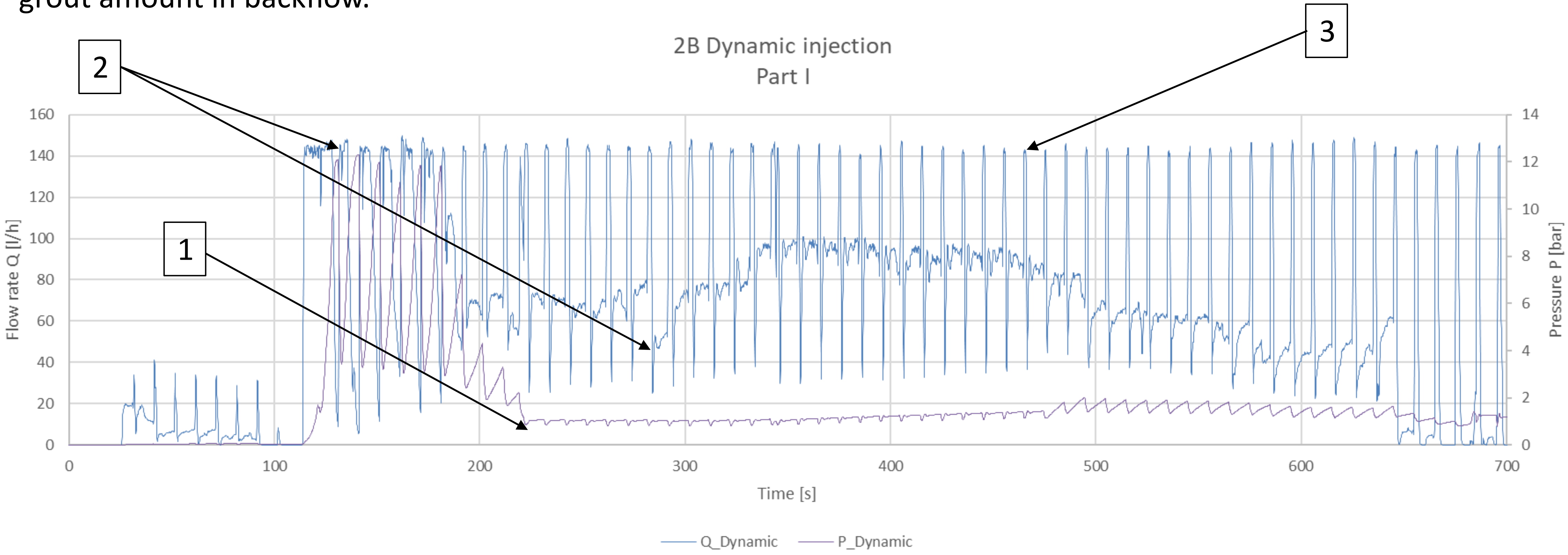
Rearranged injection plan

- After first grout injection test the borehole injection pairs were rearranged, so that the distance between boreholes would reduce chance of interference.
- Moreover, the boreholes were injected one at a time.



Unexpected challenges

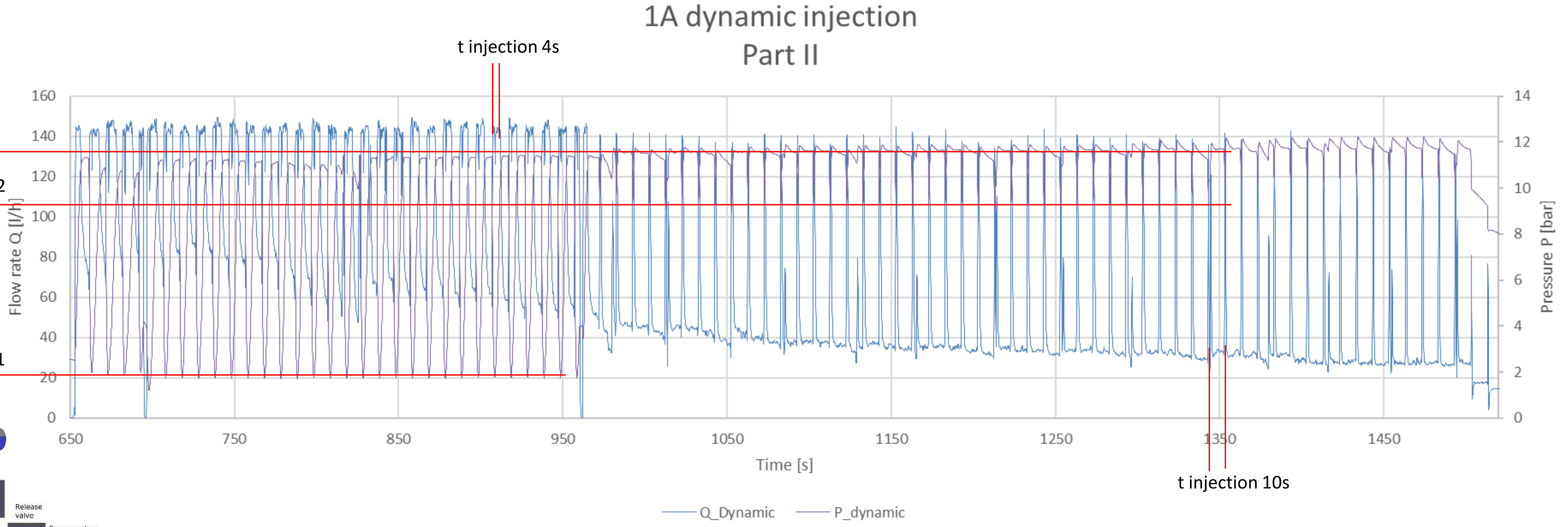
1. Despite the pressure sensors were cleaned after each test the clogging was observed for dynamic injection of 2B borehole.
2. Due to large size of rock fractions in the boreholes the grout flow reached measurement limits of the flow-meters and had to be reduced by regulating packer valves at the boreholes. Part of data was not possible to record.
3. The backflow of the grout during dynamic injection created unexpected overflow spikes. Was not possible to measure grout amount in backflow.

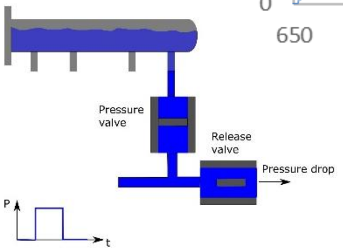


Test results

Dynamic injection

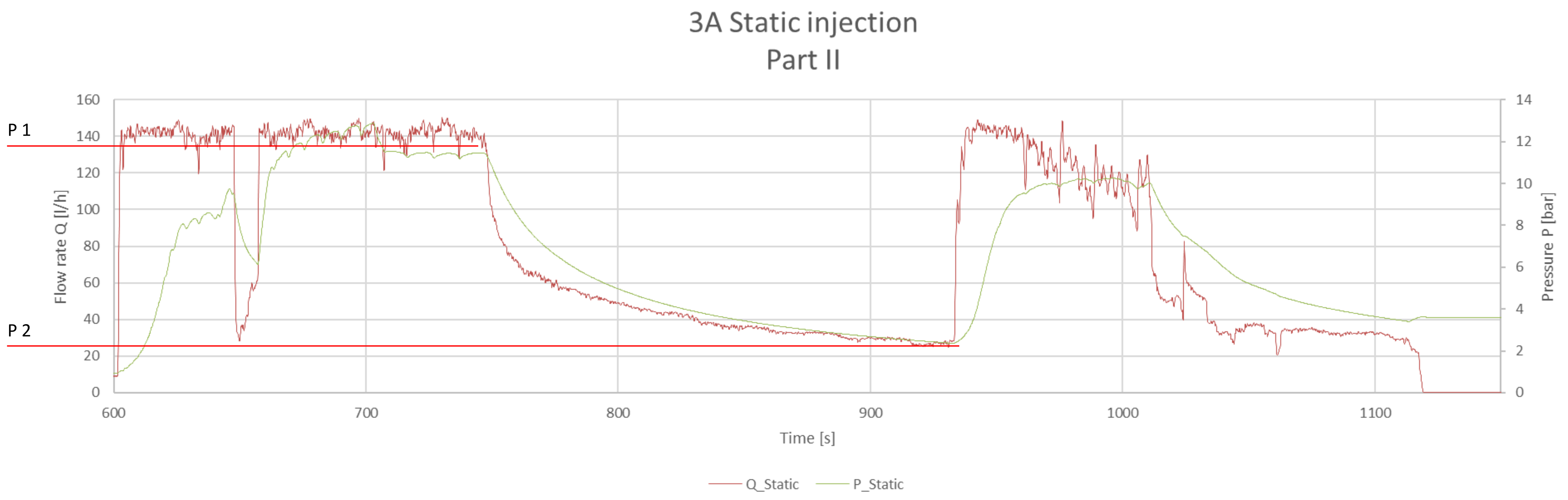
1. By changing the grout pressure release period (***t release***) was possible to regulate the minimal injection pressure in the borehole (***P min***).
2. The maximal injection pressure (***P max***) was not affected neighed by pressure release period (***t release***) nor by injection period (***t injection***) nor reduced grout flow rate (***Q***).





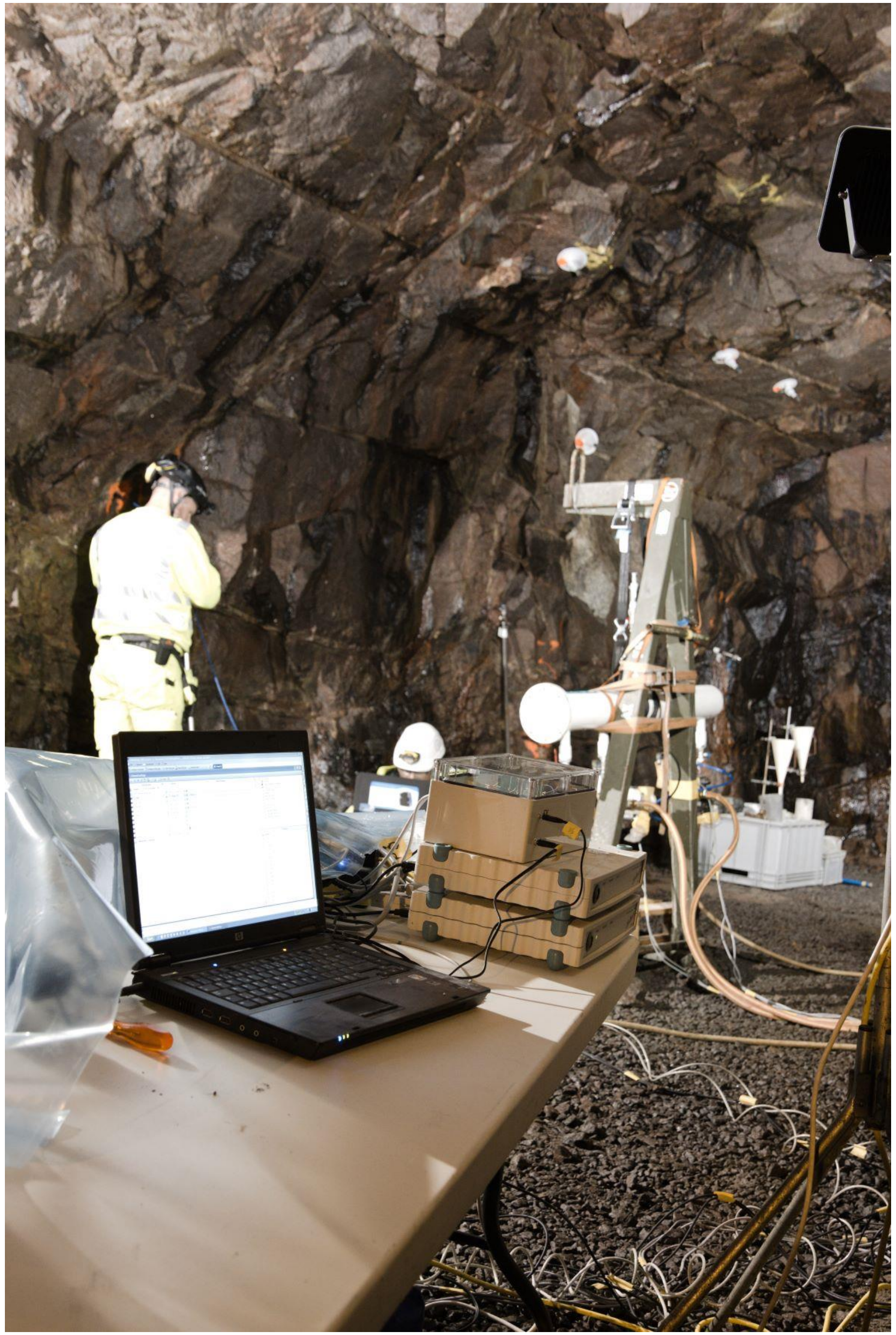
Test results
Static injection

1. When performing static injection it was observed that injection pressure in borehole (***P***) was related to grout flow-rate (***Q***), that is the pressure decreased when the flow rate decreased by regulating packer valves at the borehole.



Summary

- During this project dynamic injection approach was tested in laboratory and field conditions.
- At the laboratory tests the dynamic injection showed larger flow rate at all apertures with respect to static. Moreover, with dynamic injection grout passed 60 µm size aperture, while for static injection grout flow stopped at 70 µm aperture.
- In field test, the dynamic injection helped to maintain maximal injection pressure also at small flow rates. This was applicable for both types of boreholes: with high ground water inflow and low ground water inflow.
- In the field test, the unique experience was gathered by combining experimental apparatus, laboratory sensors with industrial injection system to perform successful dynamic injection grouting.



Thank you

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