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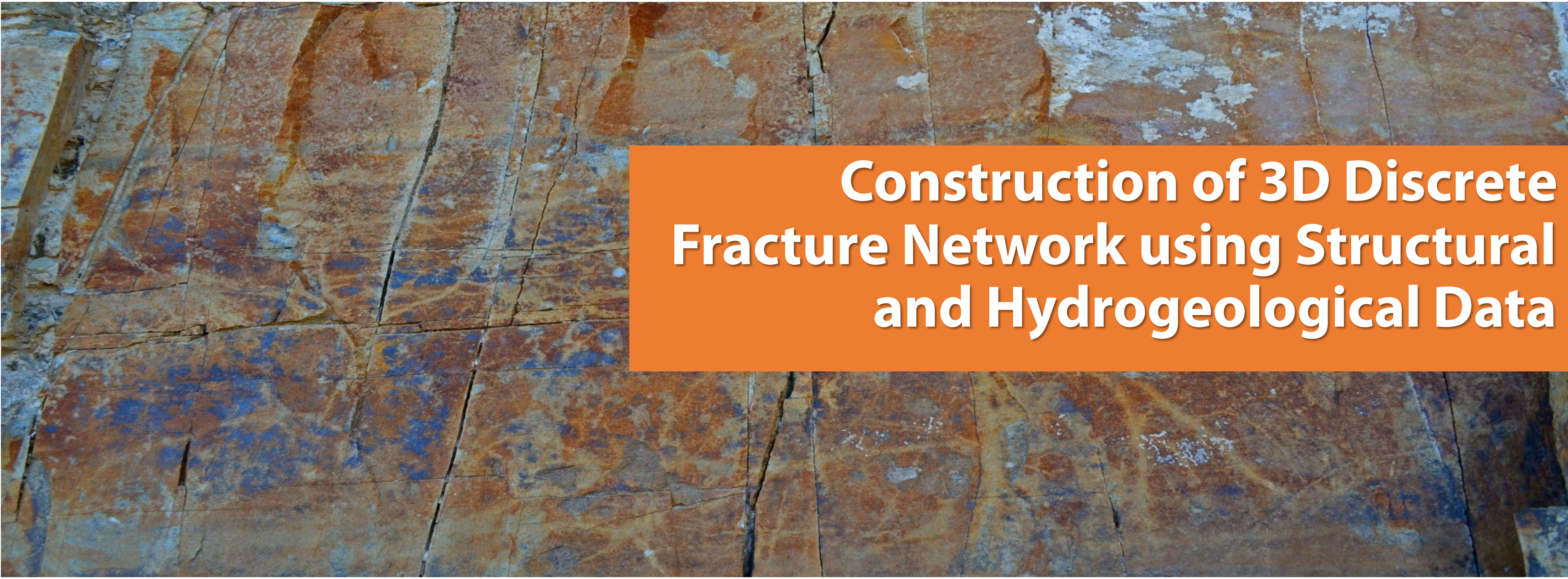

Construction of 3D Discrete Fracture Network using Structural and Hydrogeological Data

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Abstract

The presence of fractures and discontinuities in the intact rock affects the hydraulic, thermal, chemical and mechanical behavior of the underground activities. Various techniques have been developed to provide information about the spatial distribution of these complex features. LIDAR could provide a 3D fracture network model of the outcrop, Geolophysical borehole logs such as OPTV and ATV can be used to investigate 1D geometrical data (such as dip and dip direction) of the intersected fractures, and seismic survey can mainly offer a large structure distribution of the deep structures. An effort to combine all the existing data collected from various resources and different scales is inevitable to construct a 3D discrete fracture network (DFN) model of the rock mass that could adequately represent the physical behavior of the interested subsurface structure.

In this study, an effort on the construction of such a DFN model is carried out via combination of various structural and hydrogeological data in fractured crystalline rock. During the pre-characterization phase of the In-situ Stimulation and Circulation (ISC) experiment [Amann et al., 2018] at the Grimsel Test Site (GTS) in central Switzerland, a comprehensive characterization campaign was carried out to better understand the hydromechanical characteristics of the existing structures. The collected multiscale and multidisciplinary data such as OPTV, ATV, hydraulic packer testing and solute tracer tests [Jalali et al., 2018; Krietsch et al., 2018] are combined, analyzed and interpreted to form a stochastic-deterministic DFN model using the FracMan code. For further validation of the model, additional hydraulic tests are considered and comparison between the simulated and measured hydraulic responses allowed to justify if the simulated model could reasonably represent the considered fracture network in the ISC experiment.

References

Amann, F., Gischig, V., Evans, K., Doetsch, J., Jalali, M., Valley, B., Krietsch, H., Dutler, N., Villiger, L., Brixel, B., Klepikova, M., Kittilä, A., Madonna, C., Wiemer, S., Saar, M.O., Loew, S., Driesner, T., Maurer, H., Giardini, D., 2018. The seismo-hydromechanical behavior during deep geothermal reservoir stimulations: open questions tackled in a decameter-scale in situ stimulation experiment. Solid Earth 9, 115–137. https://doi.org/10.5194/se-9-115-2018

Jalali, M., Klepikova, M., Doetsch, J., Krietsch, H., Brixel, B., Dutler, N., Gischig, V., Amann, F., 2018. A Multi-Scale Approach to Identify and Characterize the Preferential Flow Paths of a Fractured Crystalline Rock. Presented at the 2nd International Discrete Fracture Network Engineering Conference, American Rock Mechanics Association.

Krietsch, H., Doetsch, J., Dutler, N., Jalali, M., Gischig, V., Loew, S., Amann, F., 2018. Comprehensive geological dataset describing a crystalline rock mass for hydraulic stimulation experiments. Scientific Data 5, 180269. https://doi.org/10.1038/sdata.2018.269

Key Points

- The main objective of this work is to **build a 3D discrete fractute network (DFN) model** using **deterministic** shear zones (S1 & S3) and **stochastically generated fractures** using the FracMan® software.

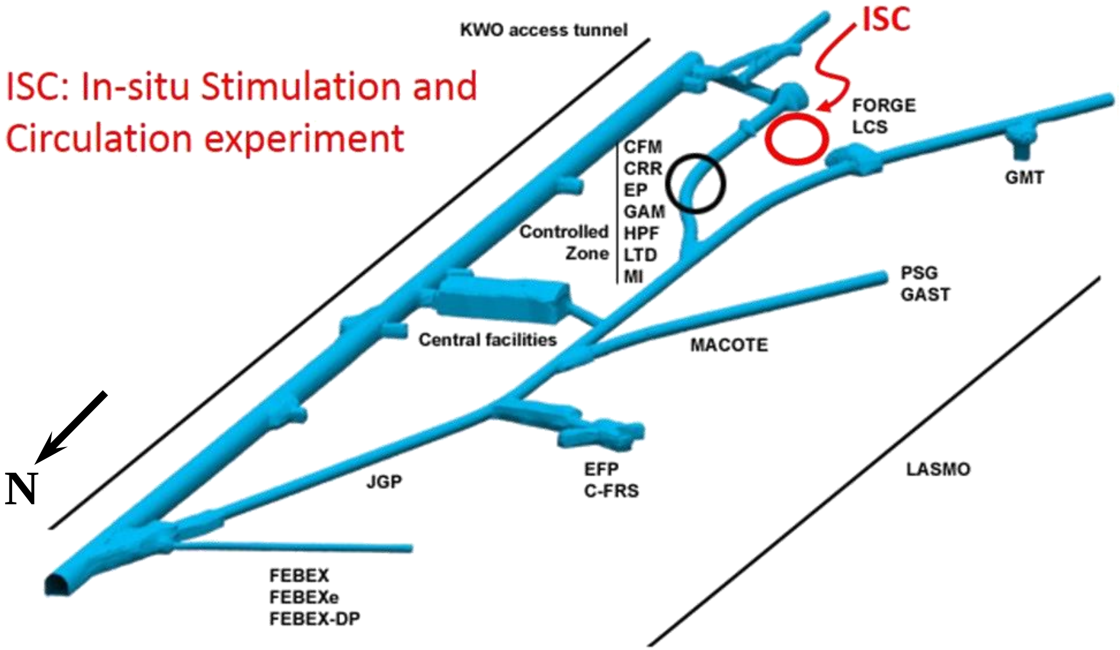
- The geological properties of the generated fractures are constrained using borehole logging data such as borehole optical televiewer (OPTV) from two boreholes (INJ1 & INJ2).

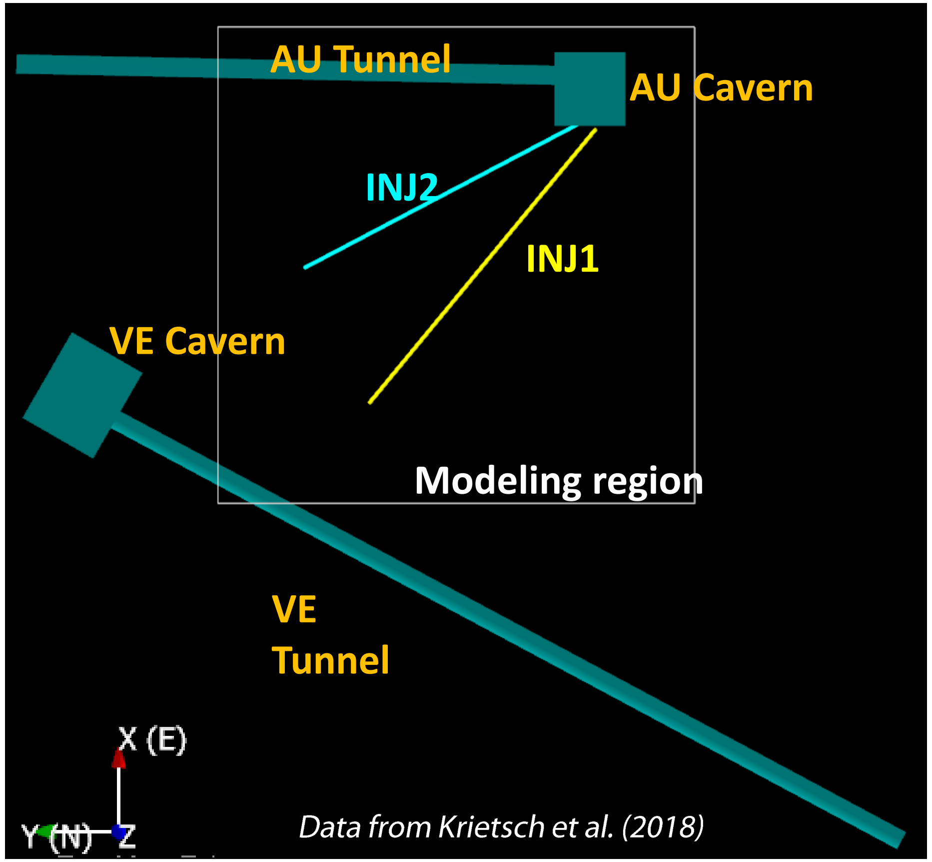
- The hydraulic properties of the fractures are retrained using the results of in-situ packer tests such as pulse, constant rate and head injection tests which were conducted in various intervals in the two boreholes.

- The model shows not only **geometric fracture distribution** but also **hydraulic properties** of the fractures and possible **hydraulic connectivity** between different intervals.

ISC Experiment - Grimsel Test Site

ISC: In-situ Stimulation and Circulation experiment

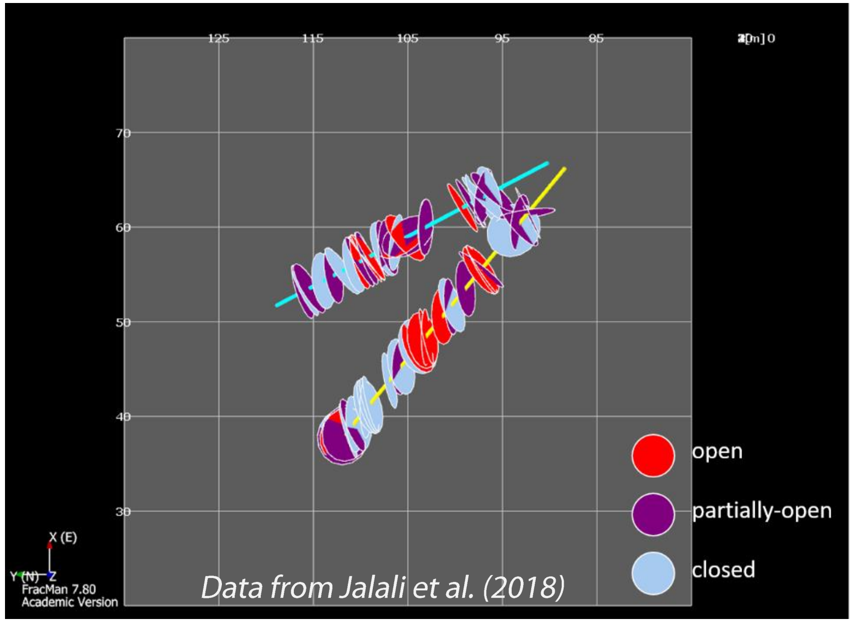




Data from Krietsch et al. (2018)

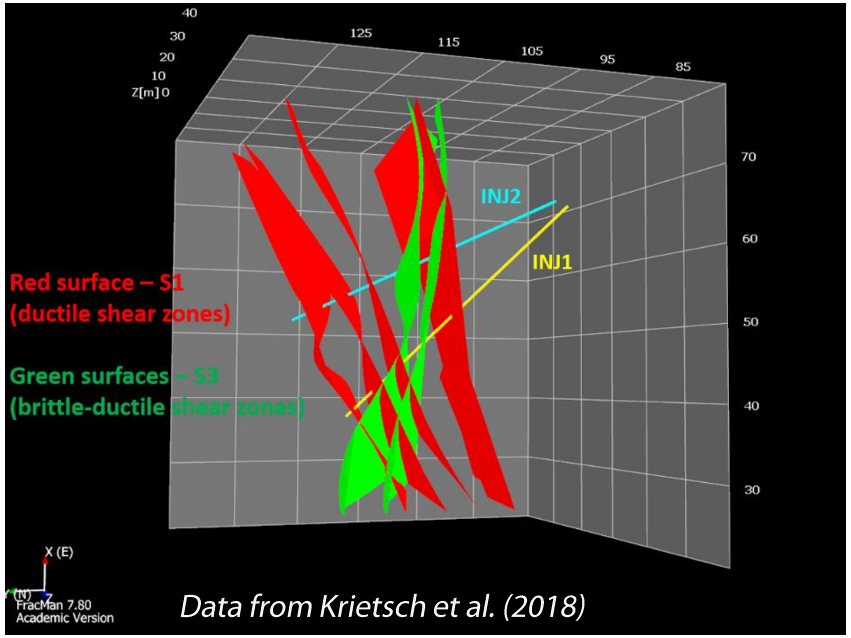
Geological Data Construction

OPTV Data from two boreholes



Data from Jalali et al. (2018)

S1 & S3 shear zones



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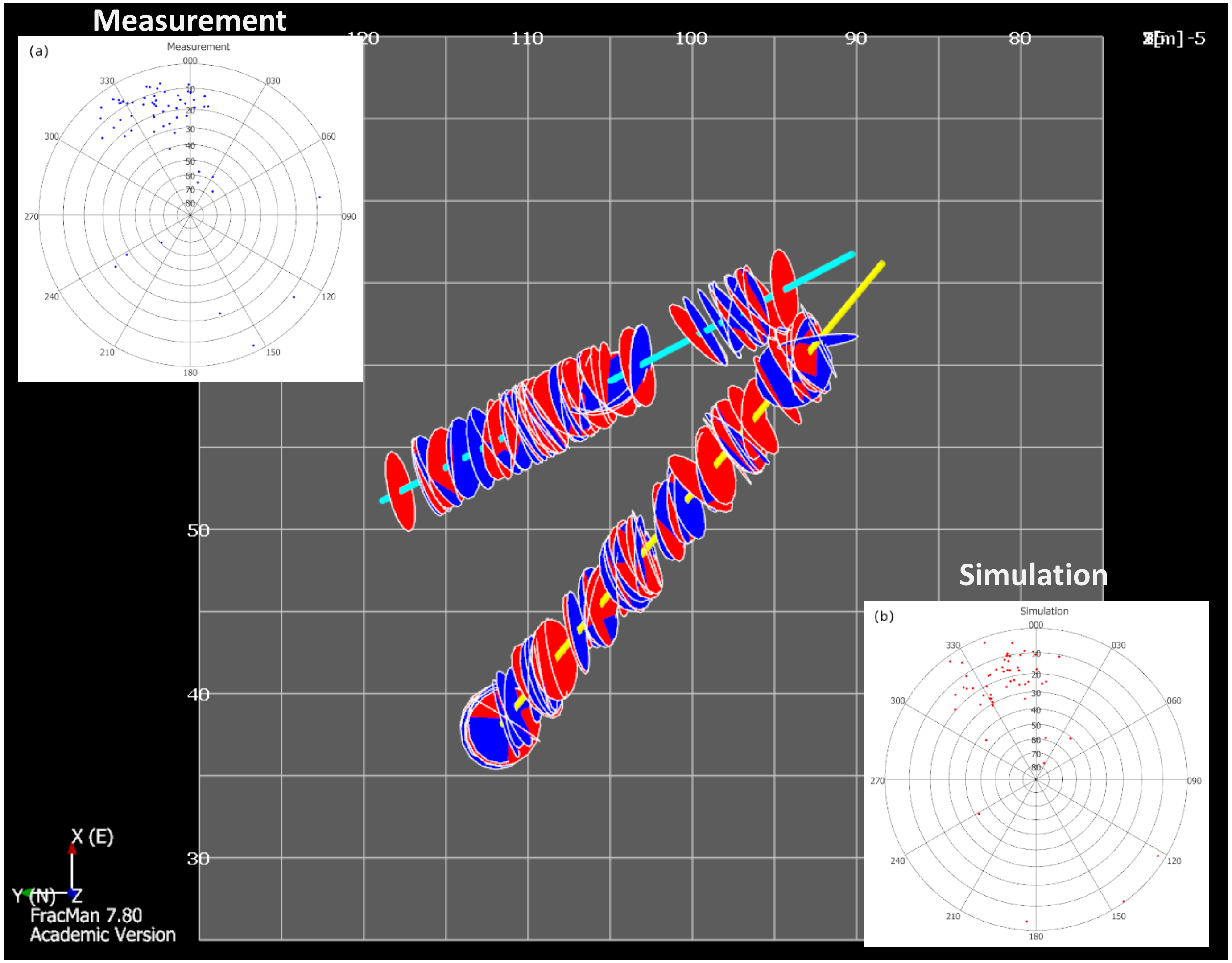
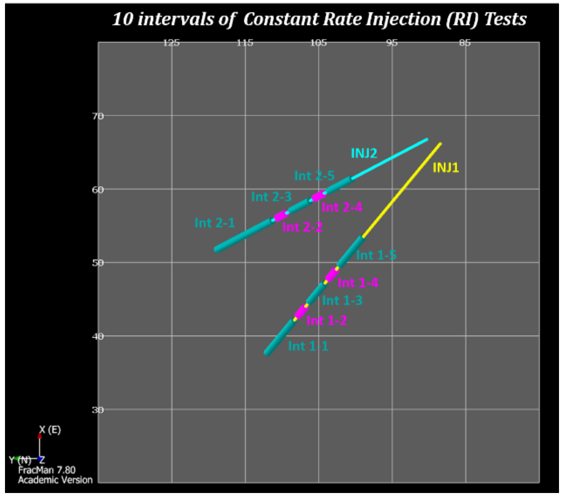


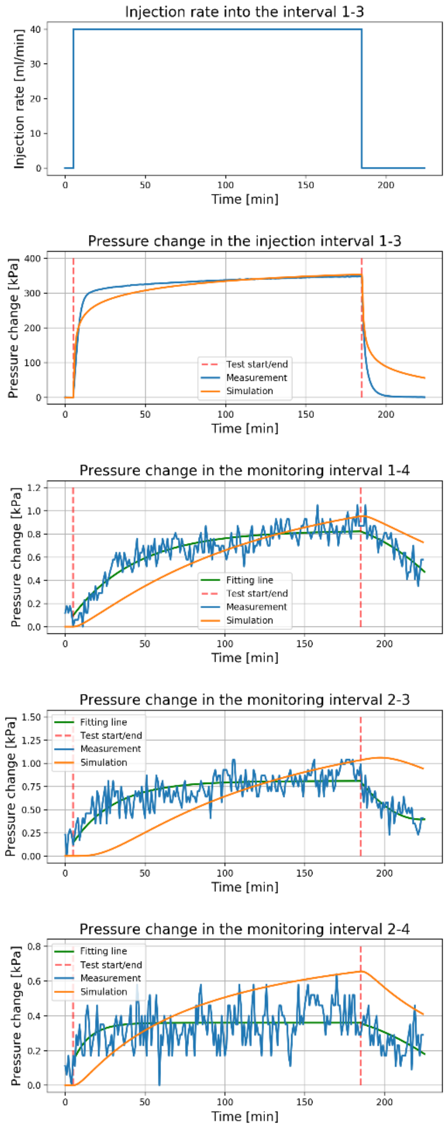
Hydrogeological Data Construction

Constant Rate Injection

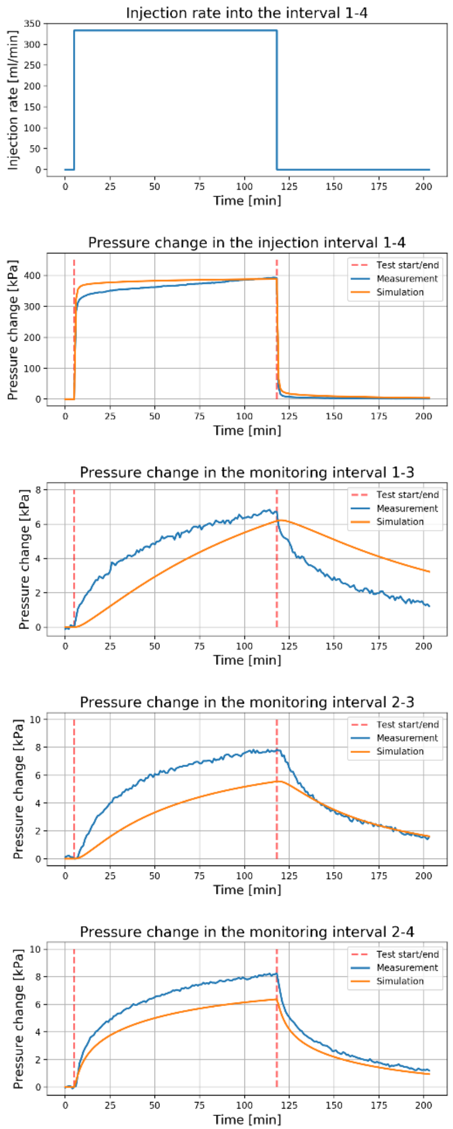


Injection interval	Measured depth [m]
Int 1-1	37.58-44.6
Int 1-2	34.66-36.68
Int 1-3	29.74-33.76
Int 1-4	26.82-28.84
Int 1-5	19.90-25.92
It 2-1	33-45
Int 2-2	30-32
Int 2-3	25-29
Int 2-4	22-24
Int 2-5	16-21

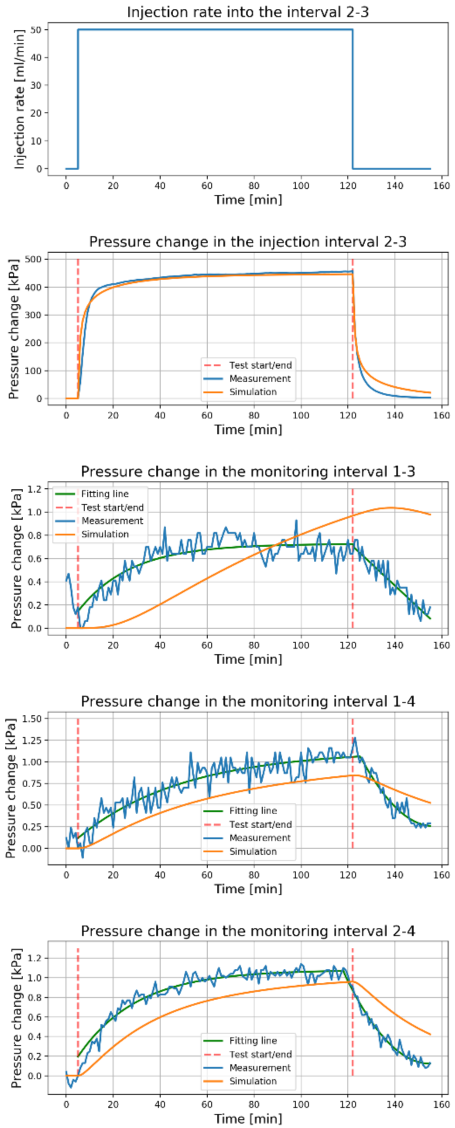
INT1-3



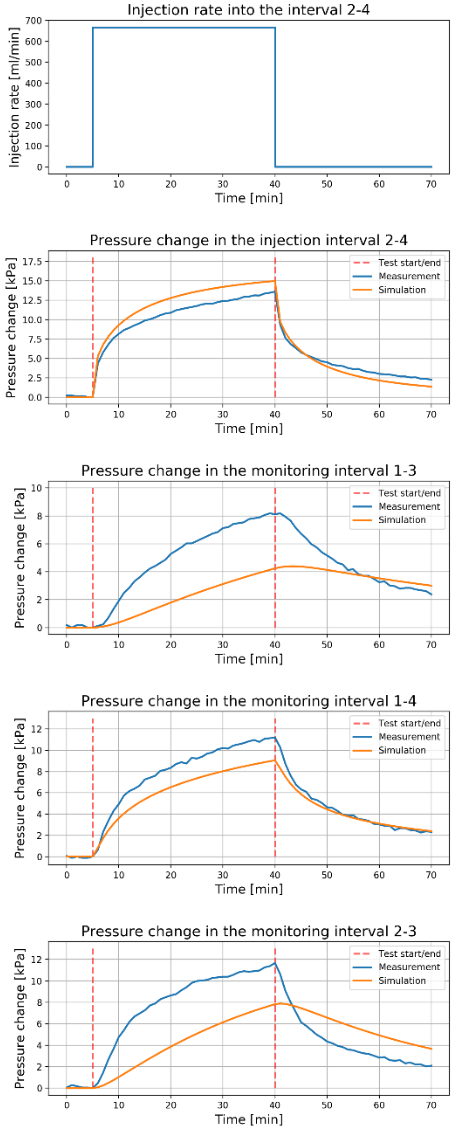
INT1-4



INT2-3

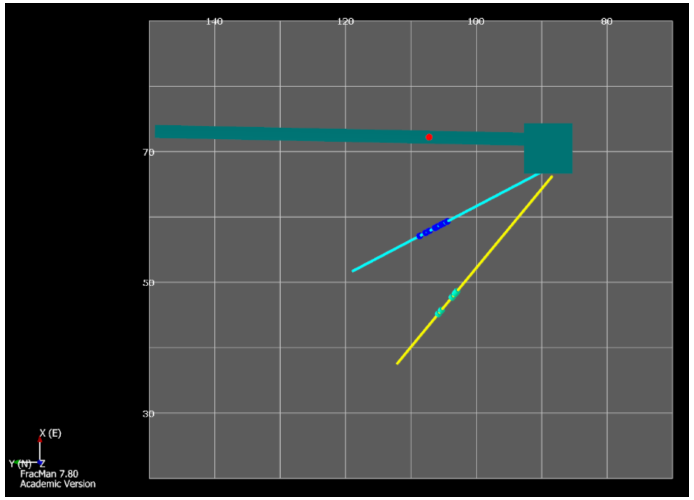


INT2-4



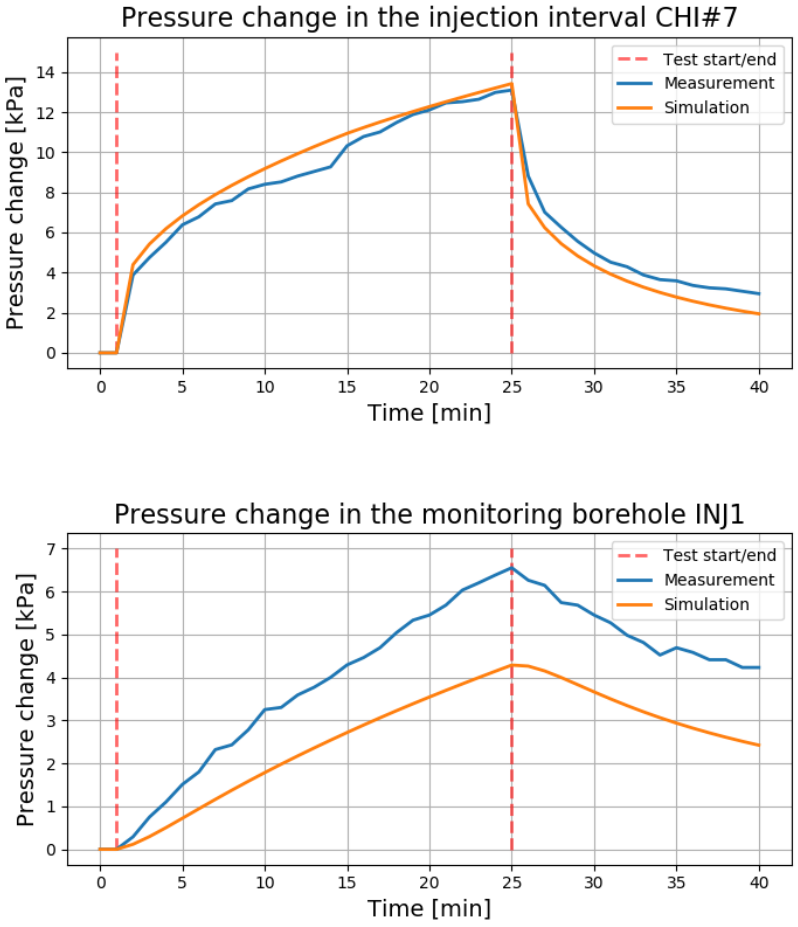
Hydrogeological Data Construction

Constant Head Injection

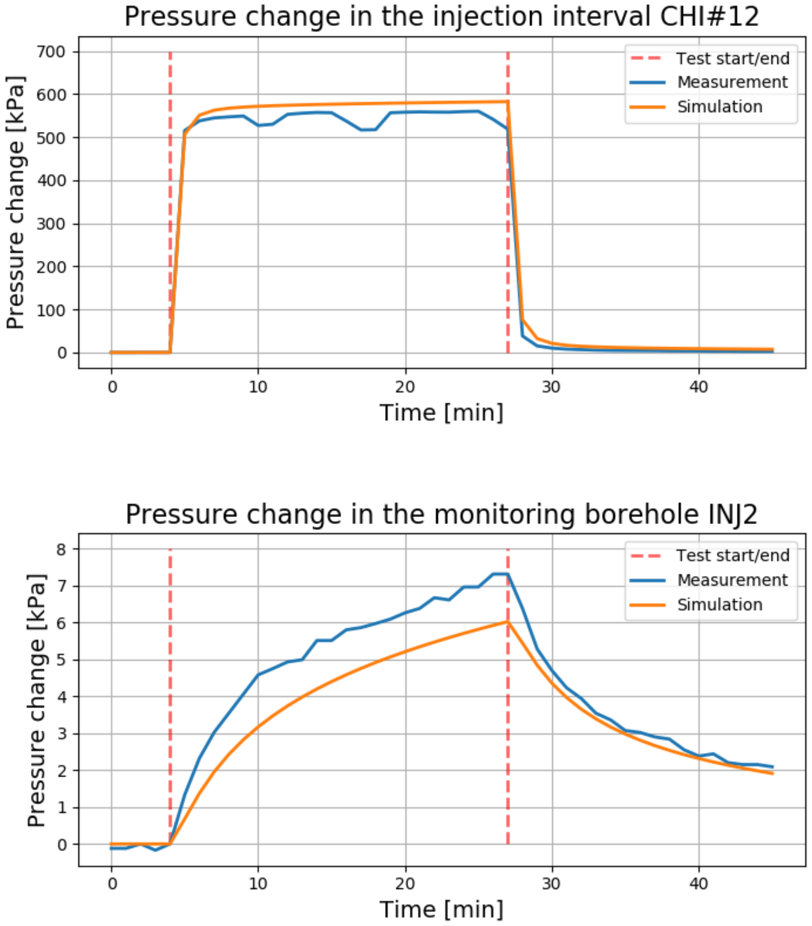


Injection interval	Measured depth [m]
CHI #1	28.53 – 29.05
CHI #2	27.11 – 27.63
CHI #3	26.25 – 26.77
CHI #4	24.83 – 25.35
CHI #5	24.31 – 24.83
CHI #6	23.38 – 23.90
CHI #7	22.89 – 23.41
CHI #8	21.96 – 22.48
CHI #9	32.53 – 33.05
CHI #10	31.64 – 32.16
CHI #11	28.58 – 29.10
CHI #12	27.67 – 28.19
CHI #13	27.16 – 27.68

CHI#7



CHI#12



Hydrogeological Data Construction

Computed pathway lengths [m]

	1-1	1-2	1-3	1-4	1-5	2-1	2-2	2-3	2-4	2-5
1-1		10.27	36.21	39.36	50.77	14.54	15.45	35.74	38.98	48.79
1-2	10.27		46.92	48.09	61.63	31.11	32.11	51.58	52.37	63.58
1-3	36.21	46.92		11.19	29.30	24.67	20.31	12.98	13.68	25.55
1-4	39.36	48.09	11.19		20.47	30.47	26.10	10.84	10.92	22.58
1-5	50.77	61.63	29.30	20.47		48.38	44.63	24.07	22.89	13.47
2-1	14.54	31.11	24.67	30.47	48.38		6.23	24.02	27.25	37.07
2-2	15.45	32.11	20.31	26.10	44.63	6.23		20.27	23.50	33.32
2-3	35.74	51.58	12.98	10.84	24.07	24.02	20.27		3.23	12.76
2-4	38.98	52.37	13.68	10.92	22.89	27.25	23.50	3.23		11.58
2-5	48.79	63.58	25.55	22.58	13.47	37.07	33.32	12.76	11.58	

🟨 Pathway < 10 m

🟦 10 m < Pathway < 15 m

Pressure Changes in the Intervals [KPa]

Monitoring interval

Injection interval

	1-1	1-2	1-3	1-4	1-5	2-1	2-2	2-3	2-4	2-5
1-1	437.2 446.2 2%	2.7 1.5 44%								
1-2		326.7 342.7 5%								
1-3			348.4 354.2 2%	1.0 1.0 0%				1.0 1.1 10%	0.8 0.7 13%	
1-4			6.9 6.2 10%	394.7 388.8 1%				7.8 5.6 28%	8.3 6.4 23%	
1-5					59.4 61.2 3%					
2-1						266.1 272.9 3%	0 0.2			
2-2						2.2 1.2 45%	331.4 317.0 4%			
2-3			0.9 1.0 11%	1.2 0.8 33%			1.9 0	456.8 446.2 2%	1.0 1.0 0%	
2-4			8.2 4.4 46%	11.5 9.1 21%	4.8 0		2.1 0	11.6 7.9 32%	13.8 15.0 9%	
2-5										724.9 767.3 6%

1st row: measured pressure
2nd row: computed pressure
3rd row: absolute error

🟩 Injection interval

🟧 Absolute error ≤ 10%

🟦 10% < Absolute error ≤ 30%

🟪 30% < Absolute error ≤ 50%

▨ Absolute error > 50%

Discussion & Conclusion

- Large difference in fracture intensity (P10) indicating the distribution of fracture intersections along the borehole are variable. Higher density of the simulated fracture located near the six considered shear zones along the two boreholes is in a good agreement with the fracture distribution measured using OPTV logs.
- Strong conductivity and connectivity between two S3 shear zones and the boreholes (i.e. INT1-3, INT1-4, INT2-3, and INT2-4) were captured in both in-situ measurements and simulation data.
- Similar to the in-situ measurement, simulated results also show obvious asymmetry. Since the natural flow gradient toward the tunnels is neglected in the simulation procedure, the asymmetric pressure responses in various intervals mainly results from the heterogeneity of the fractures.