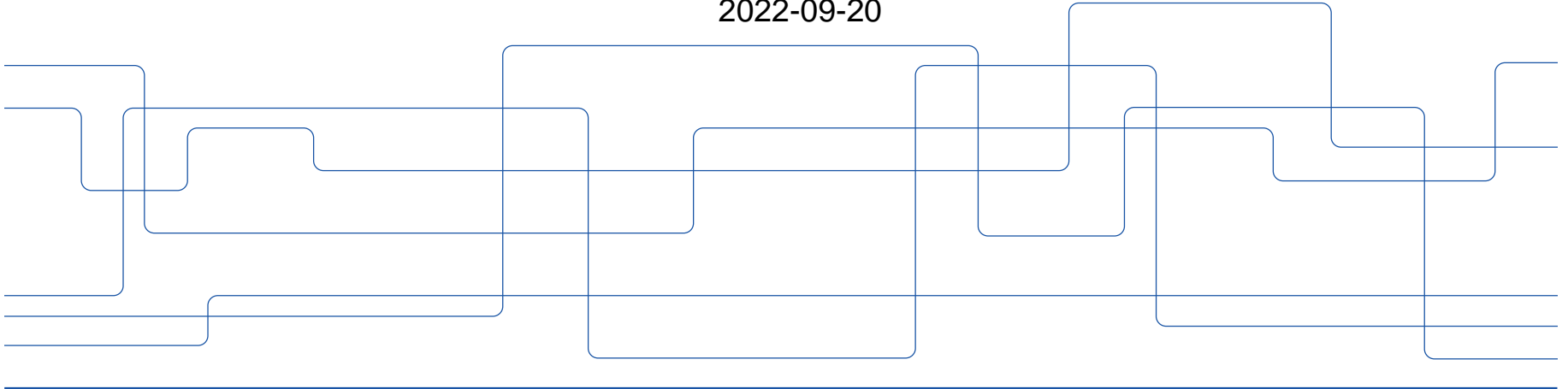




Remedial grouting in rock foundations under dams

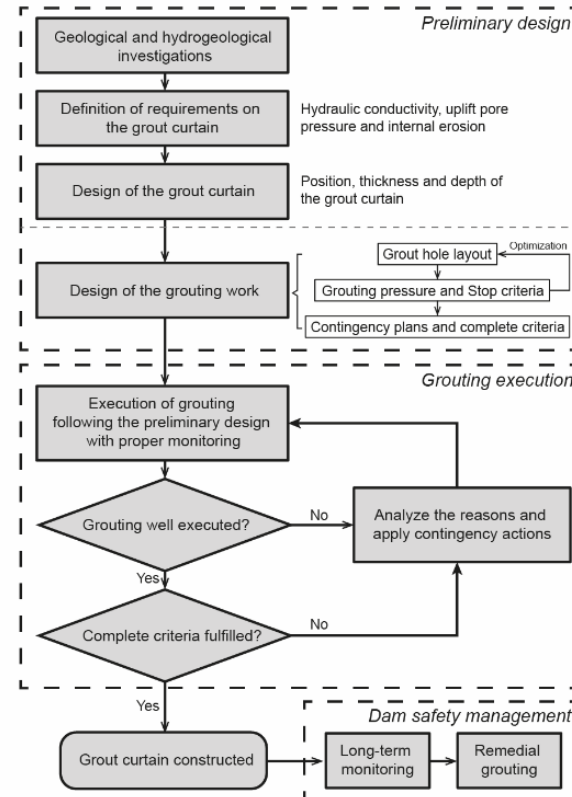
Suihan Zhang, Fredrik Johansson
2022-09-20



Design of grout curtain for new dams

Licentiate thesis June 2021

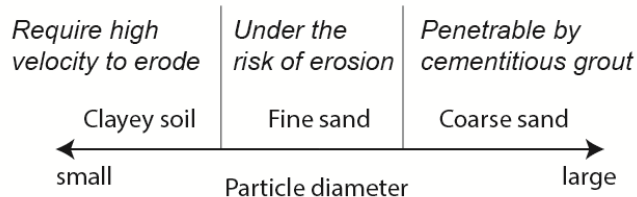
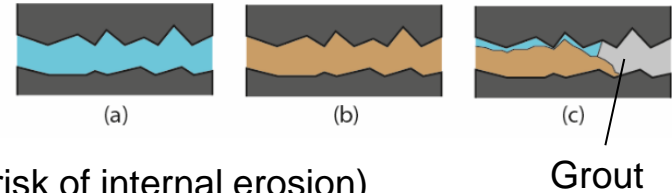
- Design of grout curtains for new dams
- To deal with the limitations of current empirical design methodology, a theory-based design methodology was proposed based on new and existing theories on rock grouting, including:
 - A distinction between design of the grout curtain and design of the grouting work
 - Analytical design of the thickness of the grout curtain
 - Iterative design of the grouting work



Design of grout curtain for new dams

Erosion of fracture infillings - a branch issue from the design methodology

- Three scenarios after flushing the borehole:
 - (a) infilling materials completely flushed away
 - (b) fracture fully filled by the infilling materials
 - (c) fracture partly filled by the infilling materials (risk of internal erosion)
- Fine sand: under the risk of erosion

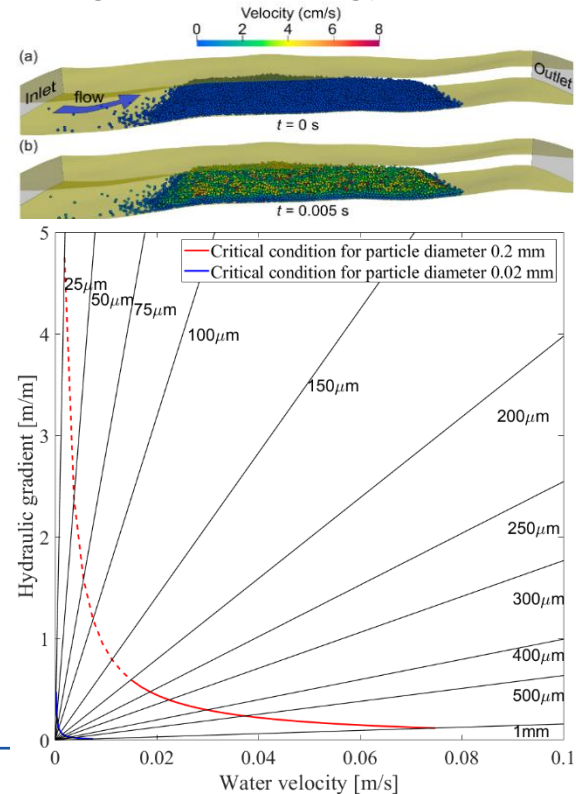


Design of grout curtain for new dams

Erosion of fracture infillings- a branch from the design methodology

- Coupled Computational Fluid Dynamics (CFD)-Discrete Element Model (DEM) analyses under a series of velocities (2-7 cm/s)
- Conclusions:
 - For ungrouted fracture partly filled by fine sand, the erosion is difficult to prevent in a grout curtain.
 - The White's equation could potentially provide better estimation compared to the classic criteria from Shields equation and Hjulström's equation.

$$\tau_{wc} = 0.18(\rho_s - \rho_w)gD\tan\theta$$



Current publications

Published articles

- Zhang, S., Johansson, F. and Stille, H. (2021) Design Methodology for Grout Curtains Under Dams Founded on Rock. *Geotech Geol Eng.* <https://doi.org/10.1007/s10706-021-02019-z>
- Teng, P., Zhang, S. and Johansson, F (2021). Numerical modelling of incipient motion of fracture infillings. *International Journal of Rock Mechanics and Mining Sciences* 48 (December 2021); 104960. <https://doi.org/10.1016/j.ijrmms.2021.104960>



Design of grout curtains for existing dams

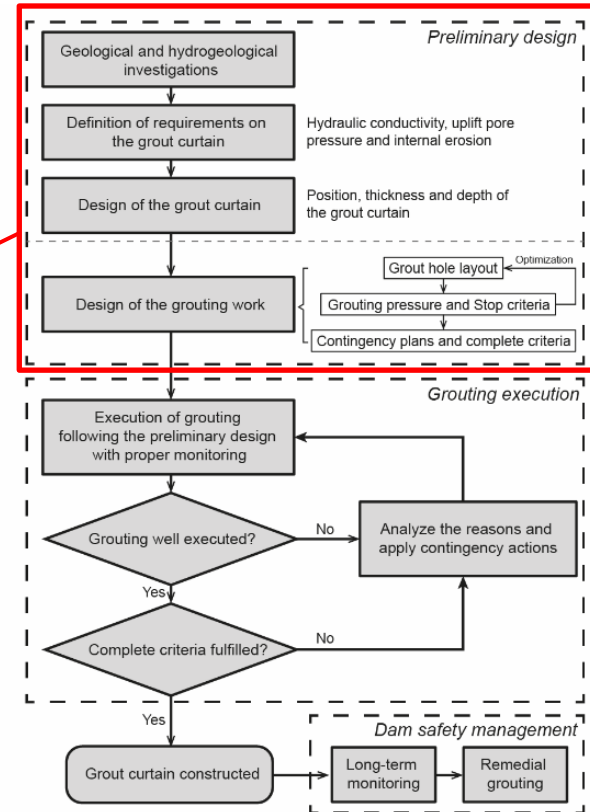
Licentiate

- Design of grout curtains for new dams

PhD

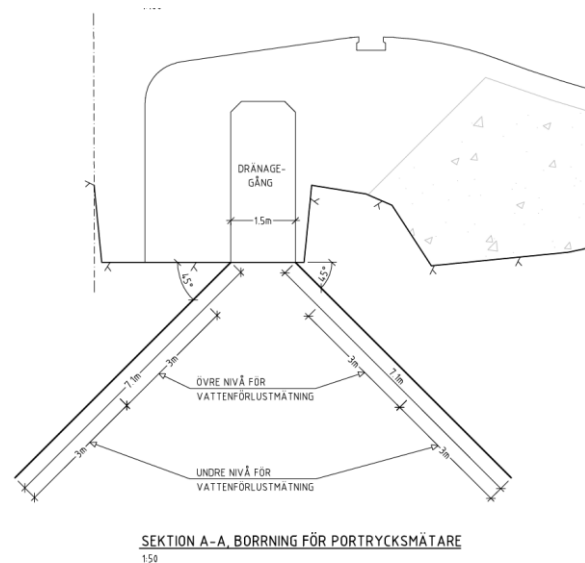
- Case study on Forshuvudforsen dam reconstruction project
- Design of remedial grouting under existing dams

Implementing the preliminary design methodology



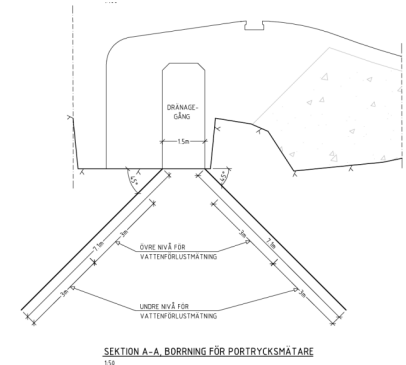
Forshuvudforsen case study

- Case studies to verify the applicability of the design methodology (Forshuvudforsen dam reconstruction)
- June 2022



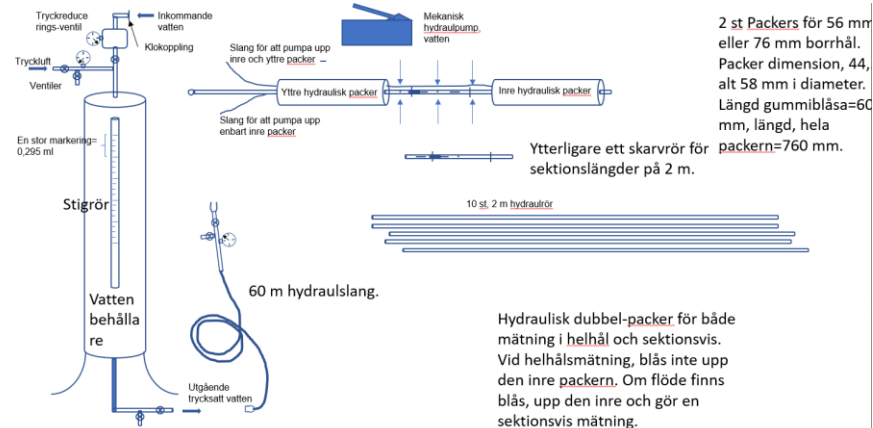
Forshuvudforsen case study

- Conducted water loss measurements on site.
- Two piezometers will be installed in the rock mass up-and downstream of the grout curtain.
- Use the water loss measurement results to perform a design following the proposed methodology.
- Compare this design vs original design
- Compare the predicted pore pressure reduction after grouting vs the real reduction recorded by the piezometers.



Forshuvudforsen case study

- The water loss measurements result will be used to:
 - To analyze the conductivity at different depths (sections divided by packers).
 - To analyze the correlation between the distribution of the fractures and the conductivity (by core mapping).
 - To evaluate the dimensionality of the flow (1D or 2D or a combination).
 - To provide indications to the grout, grout mix, grouting pressure and overall grouting strategy.



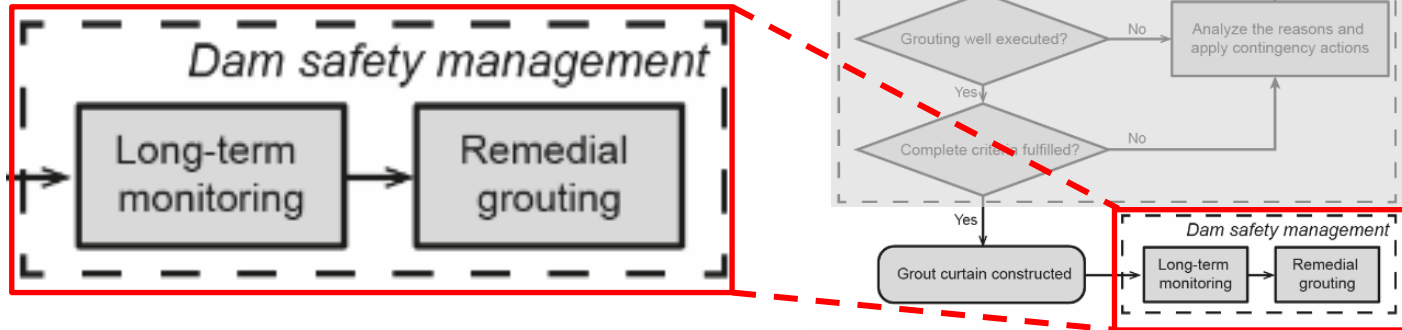
Design of grout curtains for existing dams

Licentiate

- Design of grout curtains for new dams

PhD

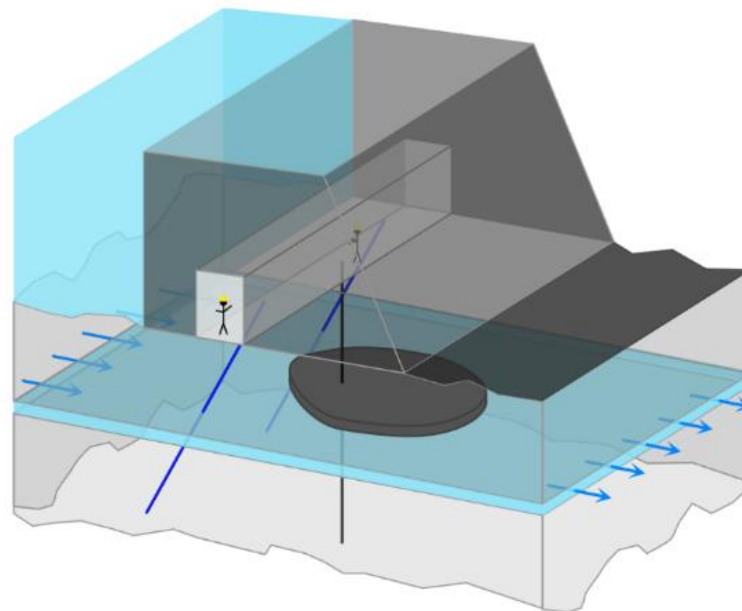
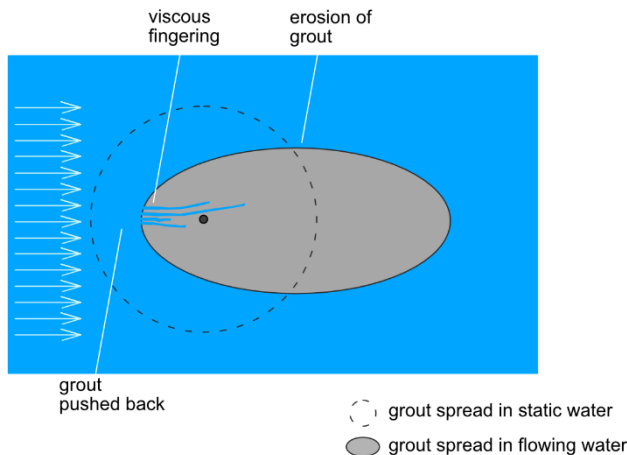
- Case study on Forshuvudforsen dam reconstruction project
- Design of remedial grouting under existing dams



Experimental tests on remedial grouting

Problem formation:

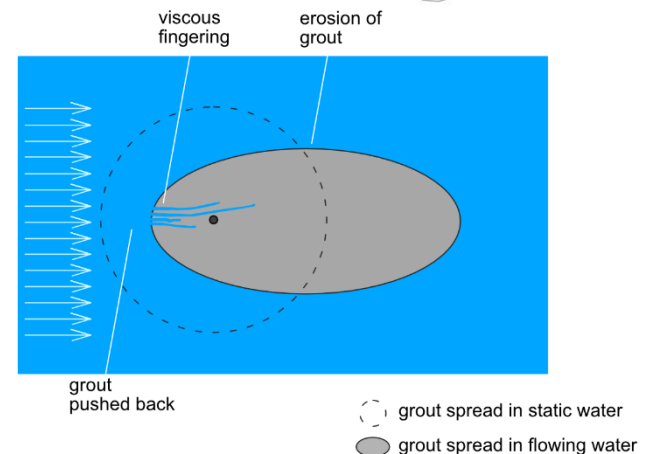
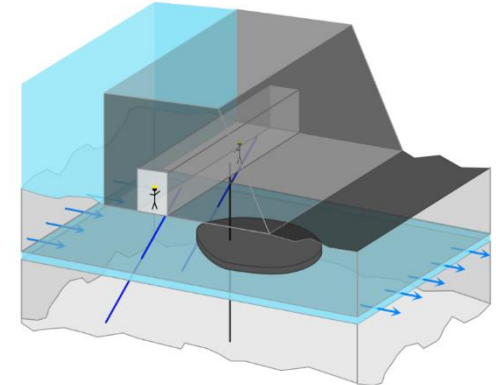
- Remedial grouting under existing dams
- Injection against high gradient/flow
- The injected grout is prone to erosion
- Grout spread is affected by the flow



Experimental tests on remedial grouting

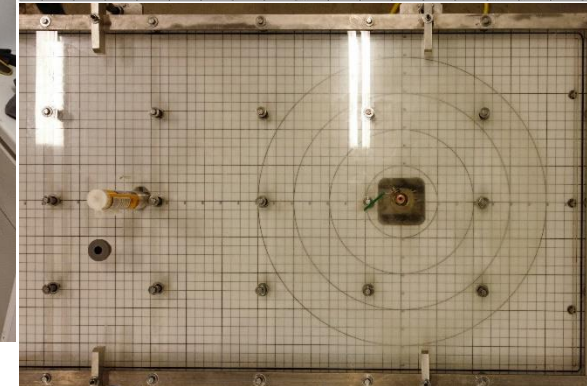
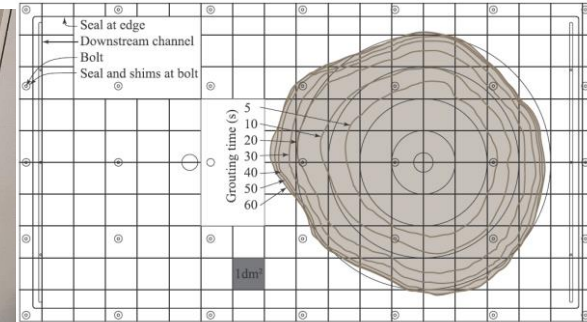
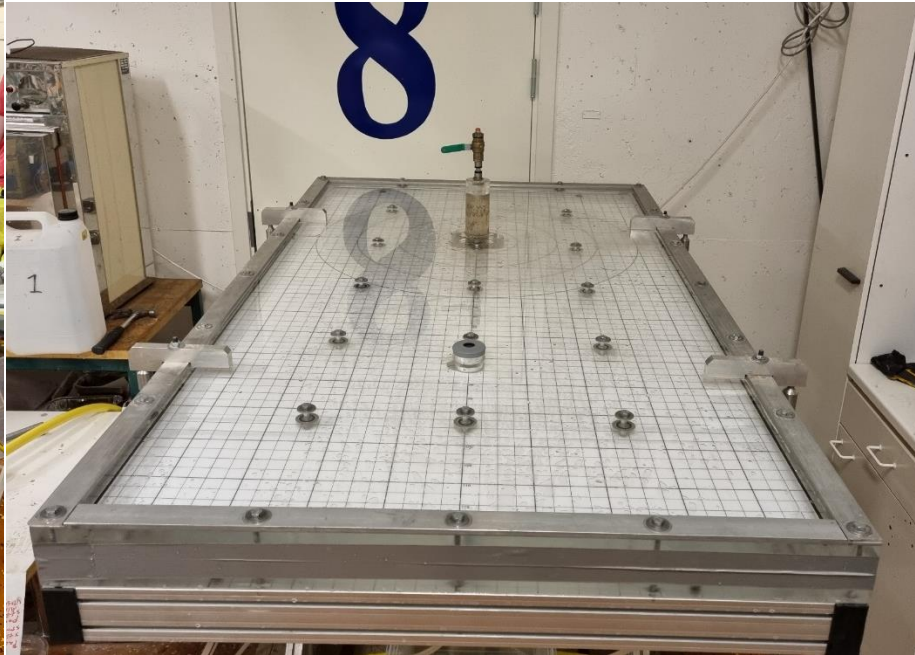
Research questions:

- 1) How is the grout spread affected by the water flow in the fractures? Is the analytical solution from Axelsson (2009) able to predict the spread in the upstream and downstream direction?
- 2) Is the use of relief holes effective for reducing the high hydraulic gradient and facilitate better remedial grouting outcome?
- 3) Does fingering occur when grouting in flowing water, what is the fundamental mechanism behind fingering?
- 4) How to incorporate the solutions and answers to questions 1) to 3) in the design of remedial grouting? What are the design strategies for remedial grouting?



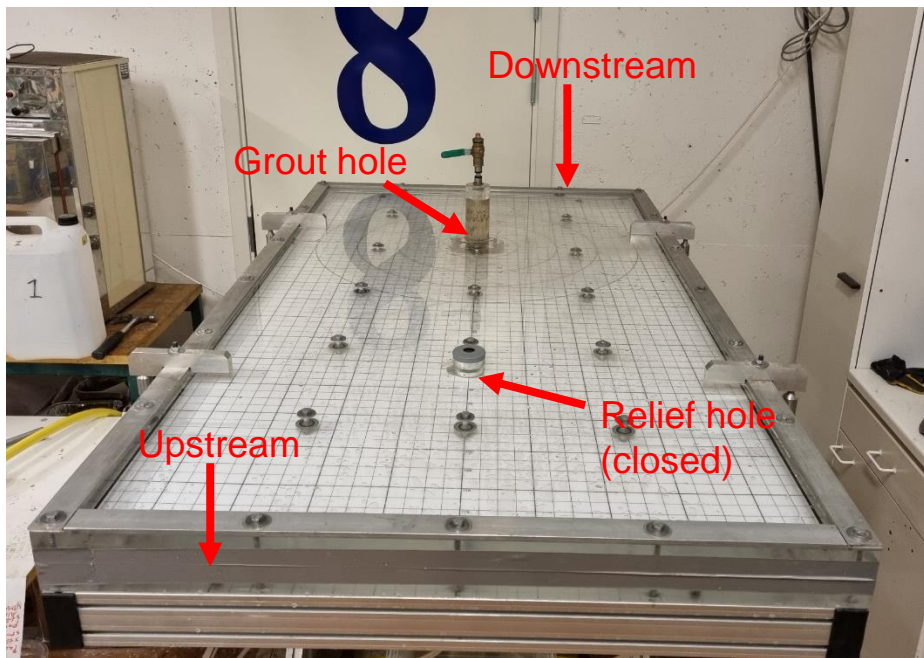
Experimental tests on remedial grouting

- The established setup in the lab at Luleå Technical University.



Experimental tests on remedial grouting

- Testing run using Ultrafine 20 grout against a hydraulic gradient ~ 1.6 , mean water velocity ~ 0.1 m/s
- Grout properties not measured





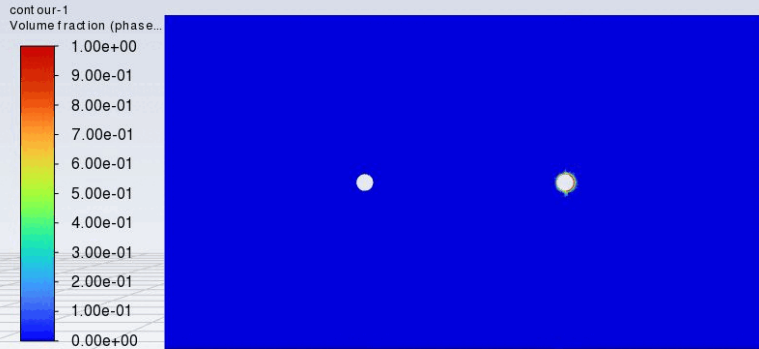
Experimental tests on remedial grouting

- Testing runs using Ultrafine 20 grout (video)

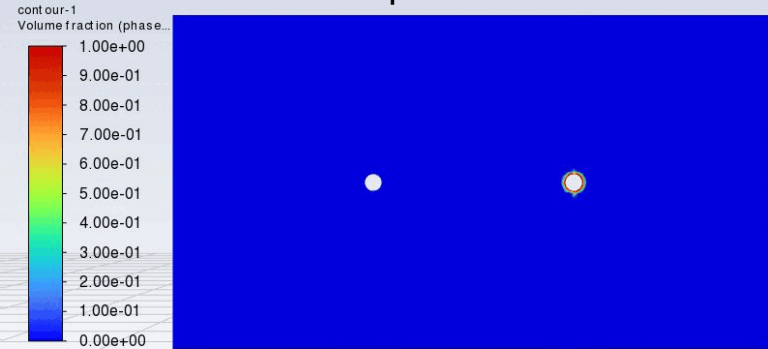
A numerical model for comparison

- CFD analysis using ANSYS Fluent module
- Example of results

Flow velocity (from left) 0.1m/s
Grouting pressure 0.3bar (30kPa)
Relief hole close



Flow velocity (from left) 0.1m/s
Grouting pressure 0.3bar (30kPa)
Relief hole open





Experimental tests on remedial grouting

- Future plan:
- October 2022: More tests with grout Injektering 30, with a series of different hydraulic gradients and open/closed relief holes, to systematically evaluate the grout spread under different conditions.
- Compare the results from numerical analysis with the results from the experimental tests.
- Answer the research questions.



Planned publications and disputation

Articles in PhD thesis

Paper D (conference)

On the use of pressure relief holes in remedial grouting of rock foundations under existing dams ([Abstract accepted by *Nordic Grouting Symposium 2023*, Full paper draft ready](#))

Paper E

Forshuvudforsen case study.

Paper F

Experimental tests on remedial grouting i.e. grouting in flowing water.

Disputation planned in Dec 2023.



Thank you!