TIGHT

True Improvement in Grouting High pressure Technology for tunnelling

TIGHT – A RESEARCH PROJECT ON MODERN ROCK MASS GROUTING TECHNIQUES

Nordic Grouting Symposium 2019 - Helsinki

Chief Scientist/Professor II Eivind Grøv, SINTEF/NTNU
Project manager TIGHT

TIGHT - What is it?

TIGHT = Acronym for:

True Improvement in Grouting High pressure Technology for tunneling

Which means:

- Development of high pressure rock mass grouting to seal off tunnels and caverns

→ High pressure grouting is in focus up to 100 bar pressure

TIGHT - What is it?

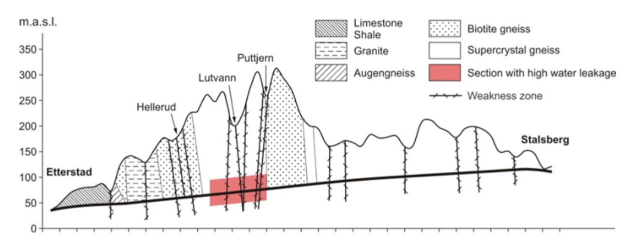
- Project with a budget of 17 mill NOK over 4 years
- Started in 2014 and completed in 2018
- Research Council 80% cash funding
- Industrial partners contributes with 20% cash fund
- A competence building project – make findings available for the industry
- Industrial partners benefit of getting access to new competence first, and involved in the work
- Innovations to take place by industrial partners based on their achieved new competence

TIGHT – Why is it?

Puttjern – photo Aftenposten

The thoughts behind the application:

- Norwegian tunnelling was hard hit following the Romeriks-porten tunnel in the nineties – public&political attention
- 'Miljø- og Samfunnstjenlige Tunneler' at the turn of Millenium
- A game changer to understand and handle water in Norwegian urban tunnels
- Norwegian tunnelling fell behind in scientific and well documented research on this topic
- Norway has an Empirical Approach



In 2004 'Active Grouting' was created

- Defined as continuous pressure build up
- As high pressure as possible as stop criteria
- Up to 100 bar if conditions allow (1000m H_2O)
- Gradual pressure increase balanced varying W/C-ratio
- As low W/C-ratio as practically possible
- Steady flow rate around 20 l/min
- Requires continuous monitoring and follow-up
- Low W/C-ratio to prevent long distance grout penetration damaging surroundings
- Drill many grout holes, also at tunnel face

But, is this the way it is performed and what if it is not?

In 2004 'Active Grouting' was created

Active Grouting requires understanding of:

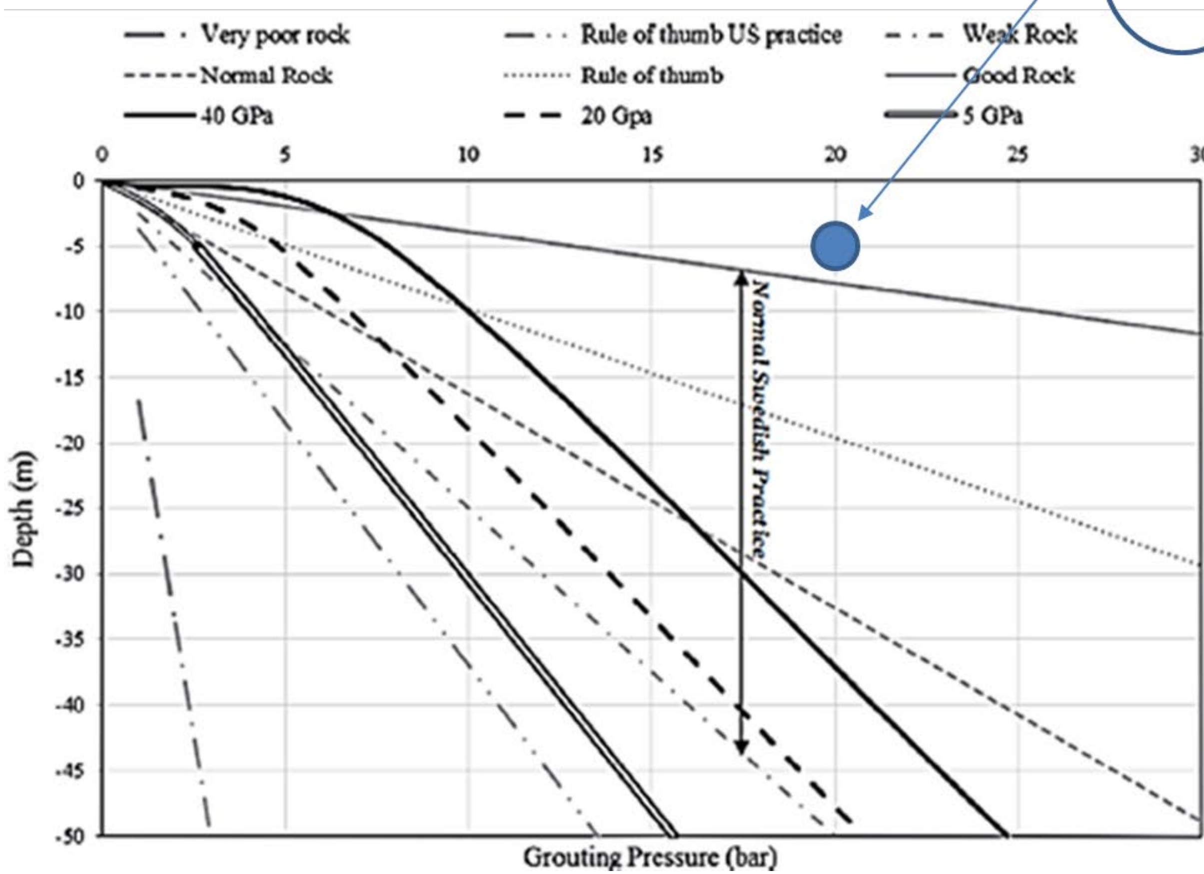
- Rock mass characteristics
- Grout material characteristics
- Grout additives, incl. coarse grained aggregates
- Mix design
- Grout distribution and penetration
- Grout hole geometry and hole number
- Grouting pressure
- Grout quantity (consume)

TIGHT-focus has been spot on these elements

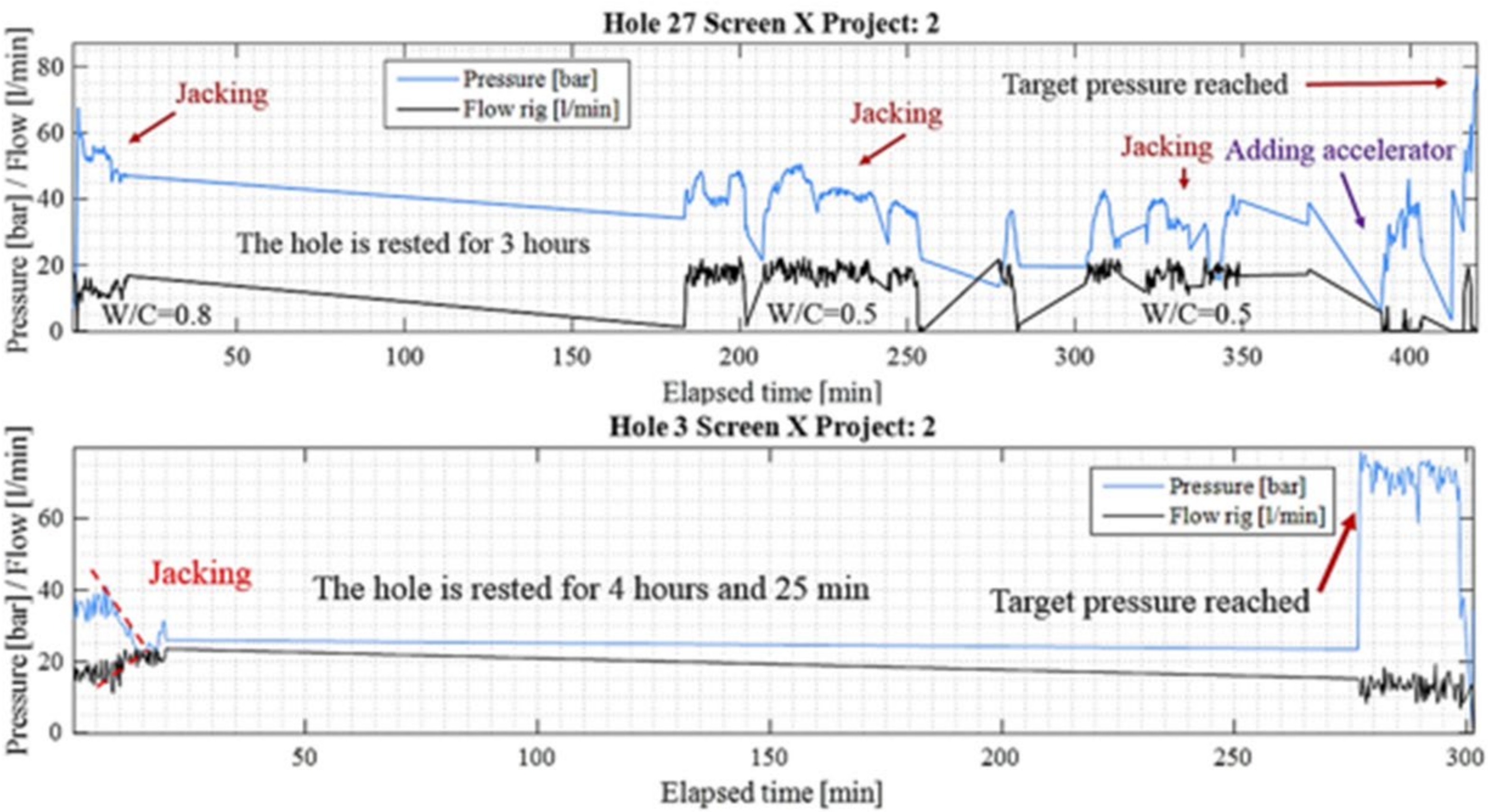
Do we follow the principles of Active Grouting?

Maksimaltrykk skal overholdes:

	MAKSIMALTRYKK	
OVERDEKNING	**Borehull heng/vegg**	**Borehull såle/stuff**
0 – 5 m	20 bar	30 bar
5 – 15 m	40 bar	60 bar
> 15 m	100 bar	100 bar



Do we follow the principles of Active Grouting?



Strømsvik, H. Nordic Grouting Symp. 2016

There is little here that demonstrates Active Design!

The goals of TIGHT

The project is supposed to develop:

- in-depth competence on how the rock mass is affected by various grouting parameters
- design for optimum water controlling of tunnels

The Main Goals are:

- increase the understanding of rock mass grouting
- lead to significant differentiation on use of materials & pressure
- improved knowledge of the method and equipment
- reduce risk of constructional/operational requirements not being met

The tools we have – the power is the WPs

WP1 Project management

WP2 Collecting existing material & current state-of-the-art

WP3 Grout materials understanding

WP4 Flow models in rock description

WP5 Numerical modeling of coupled flow & rock models

WP6 Scaled laboratory model

WP7 Full scale testing work site/underground test facility

WP8 Monitoring

WP9 State-of-the-art at project completion. Innovation potential

WP10 Dissemination

Important also are students, TIGHT have had :

1 PhD
8 MSc

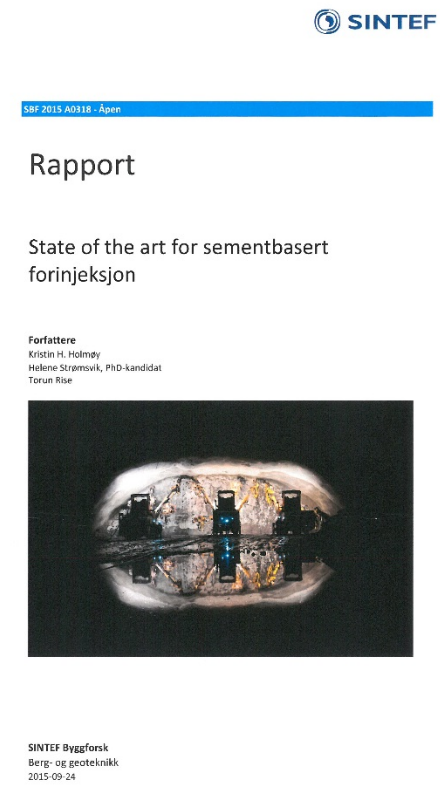
State-of-the art on completion to be issued Nov. 2019

WP 2 State-of-the-art report

Task of WP:

Collect existing material and describe current state-of-the-art. The starting point to be established which is also identifying and narrowing the research path to be taken in TIGHT

Prepared a state-of-the-art report at the project start up.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SBF 2015 A0318 - Åpen

Rapport

State of the art for sementbasert forinjeksjon

Forfattere
Kristin H. Holmøy
Helene Strømsvik, PhD-kandidat
Torun Rise

SINTEF Byggforsk
Berg- og geoteknikk
2015-09-24

WP 3 Grout Materials Understanding

Task of WP:

Focus understanding grout materials to clarify why some cements are better than others. Results presented in publications in TUST

Description of base material and testing on.

- Rheological description/physical material description
- Structure building OPC/MC
- Testing of material structure by exposure to pressure in laboratory
- Testing materials + different additives
- Testing cured core


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TIGHT-WP3: Grout material Understanding

LABORATORY STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF GROUTING CEMENTS-A LITERATURE REVIEW


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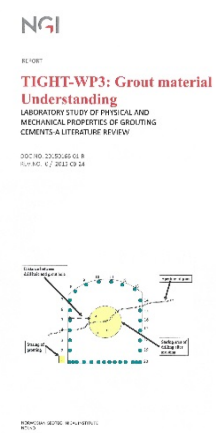
Rapport

TIGHT - Prøving av injiseringssementer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TIGHT-WP3: Grout material Understanding

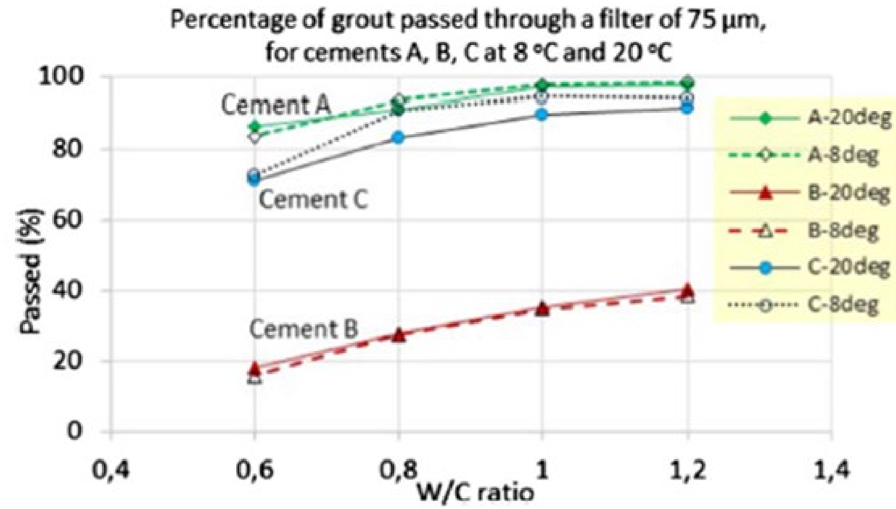
LABORATORY STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF GROUTING CEMENTS-A LITERATURE REVIEW

WP 3 Grout Materials Understanding

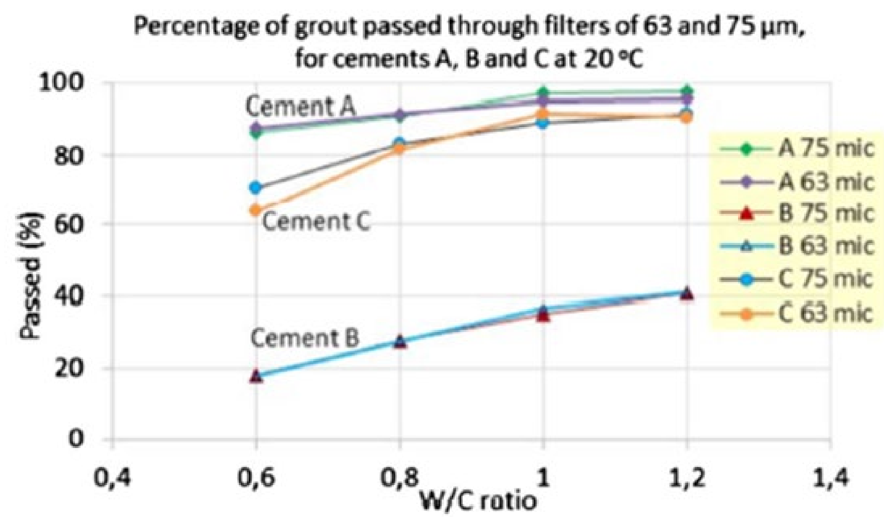
Filter test is considered a reasonable way to demonstrate penetrability.

The test results from 3 different cement types show great variety in penetrability.

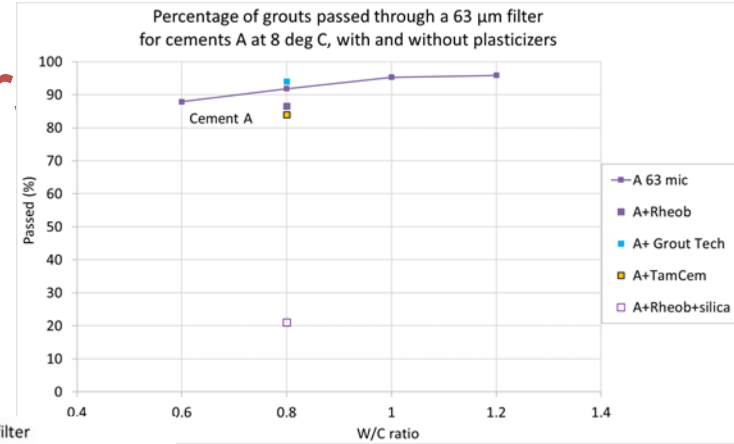
All tests were anonymous.



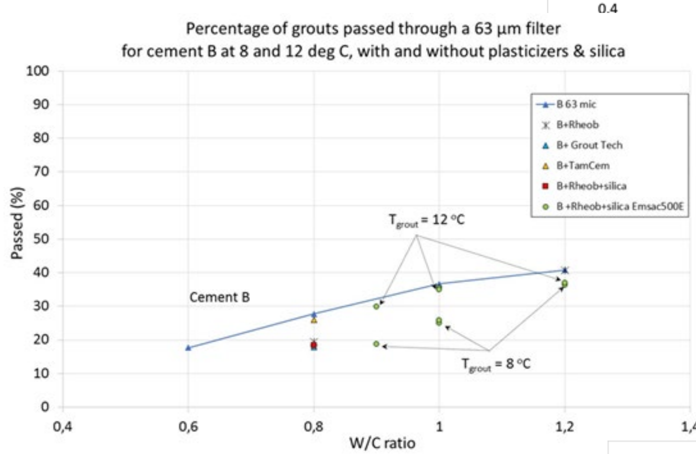
(a)



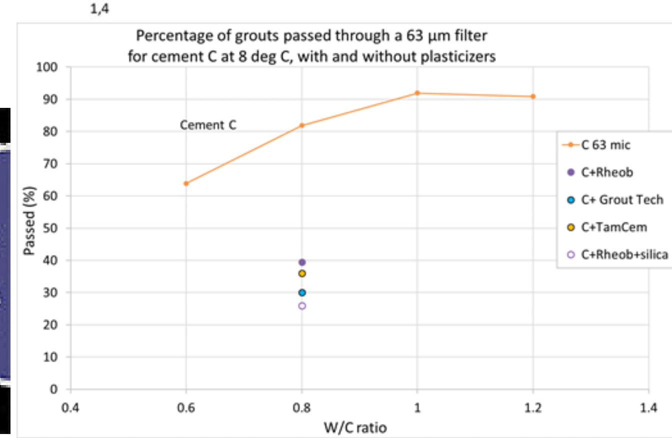
WP 3 Grout Materials Under



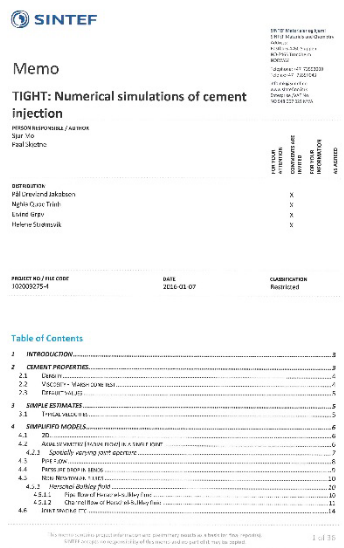
Filter tests with additives. Negative impact on the pene-trability. Surpricing result. Retesting to be sure the results were OK after heavy criticism.



Lesson learned – Test various combinations of brand and type – not always improvement



WP4 Flow models in rock description



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Memo

TIGHT: Numerical simulations of cement injection

PERSON RESPONSIBLE / AUTHOR
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Helene Strømsvik		X		

PROJECT NO / FILE CODE	DATE	CLASSIFICATION
102009275-4	2016-01-07	Restricted

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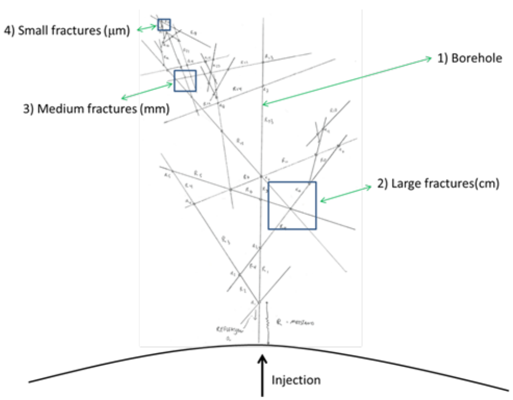


Task of WP:

Review fluid flow from pump to fracture network, assess mobility in the fracture network, and aggregate good data on fracture network statistics.

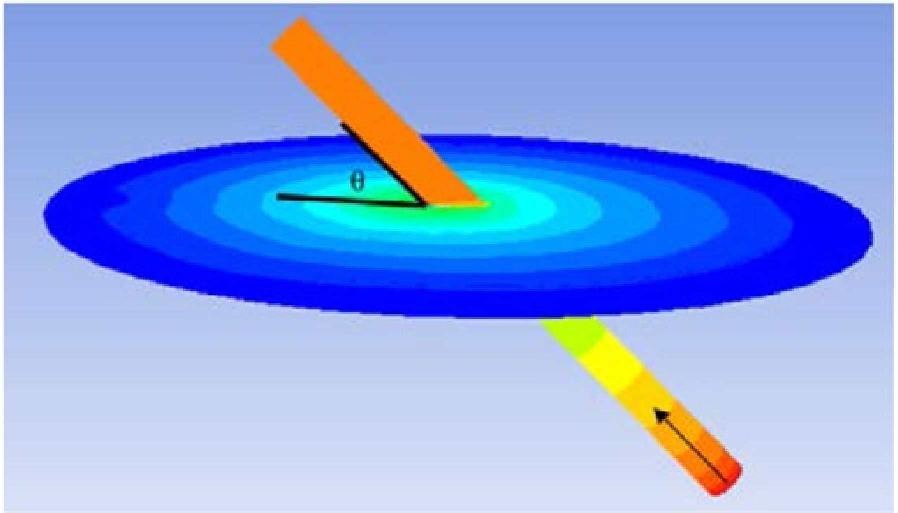
Couple to hydro-dynamic flow simulations.

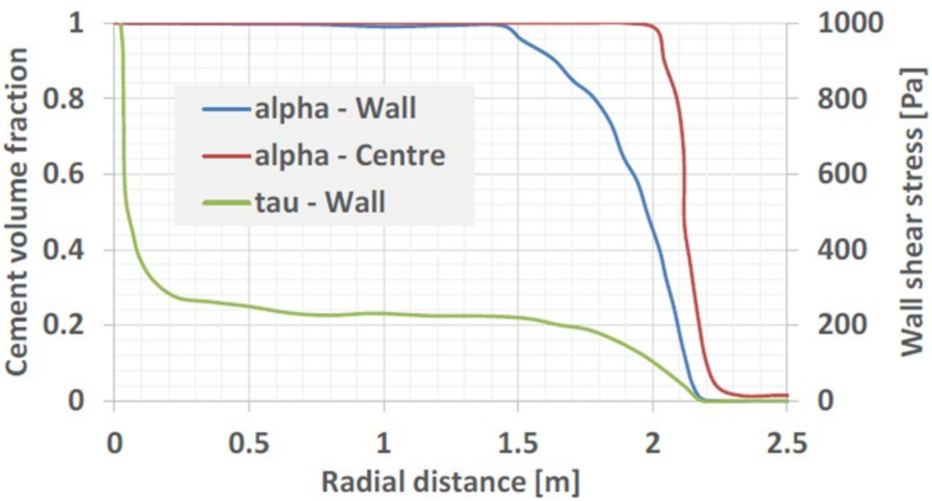
- Identify existing flow models, theoretical
- Identify/document the flow and head loss from pump to rock mass, and prepare statistical description of rock

Make a descriptive constitutive model of grout flow and flow loss through the entire system

WP4 Flow models in rock description

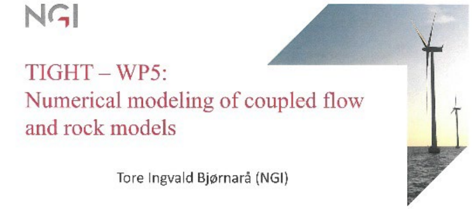
Numerical modelling shows that angle between a grout hole and joint to be grouted can be almost anything but parallel, no importance.





In water filled joint grout wetting results in a reduction of shear forces and produces better flow.

WP5 Numerical modelling of coupled flow & rock models



Task of WP

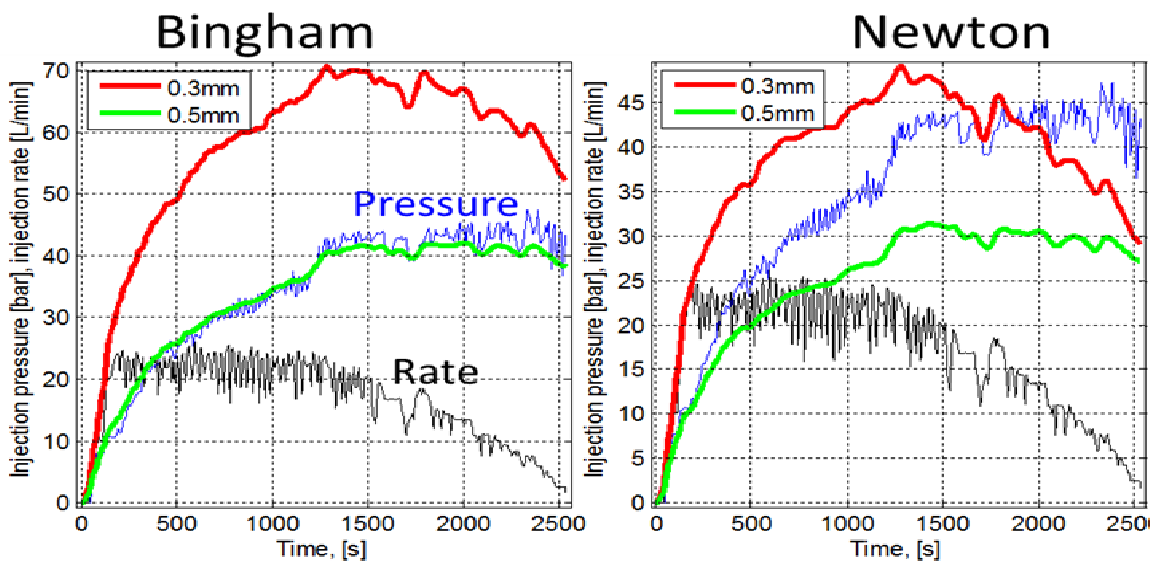
Build modeling tools for different aspects of the problem and integrate these in structured workflow that can be used for research and ultimately engineering calculations. Test simulations to be done using a series of defined base cases with representative rock quality, including synthetic models.

Numerical modelling of coupled flow & rock models.

- Establish constitutive model
- Identify suitable software code
- Run tests to indicate connections and responses

WP5 Numderical modelling of coupled flow & rock models

Validating real grouting data against numerical data shown in red and green

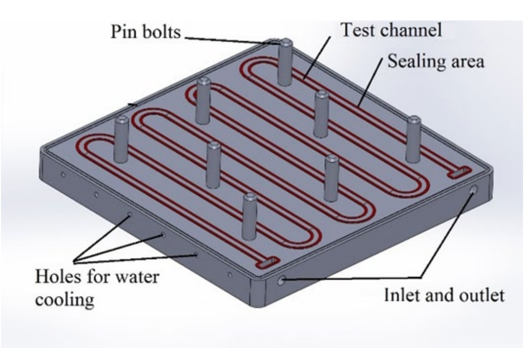


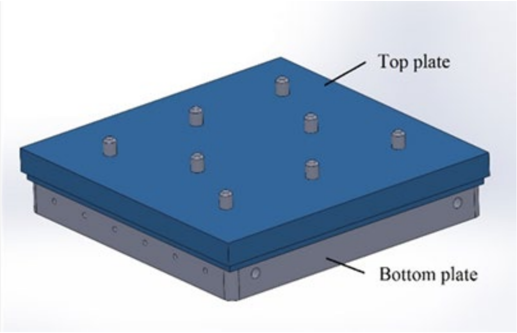
Water Pressure Testing being a useful tool to simulate grouting

WP6 Scaled laboratory model.

Scaled laboratory model, functionalities from application.

- Run tests on laboratory test equipment
- Vary parameters as grout/additives/rock type/grout hole diameter modelling
- Be as much as possible similar to real works





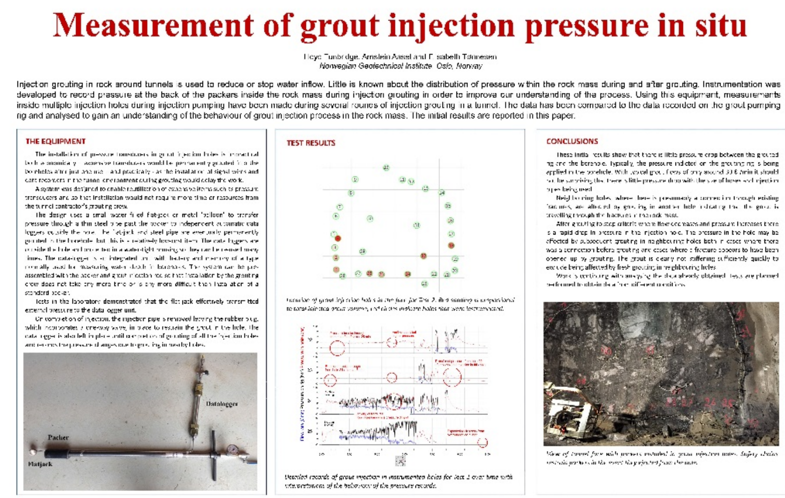
- Steel model, 1 joint 4,5m long, aperture 30-100 µm
- possible to add more joints 600x600 mm model size
- Run tests on grout usually used for PEG in Norway
- Vary parameters for grout, grout mix, grout pressure and fracture aperture
- Use in-situ equipment

Not yet operative

WP 7 Full scale testing work site/underground test facility.

Task of WP:

Do full scale tests of penetration capabilities of various materials in various rocks at different pressures and water content – influence of fracture aperture relative to the grain size of the cement used in the grouting mass, viscosity, pressure loss, etc.



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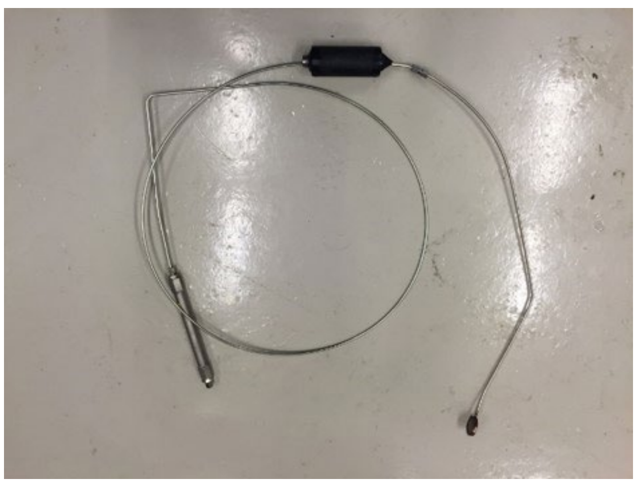
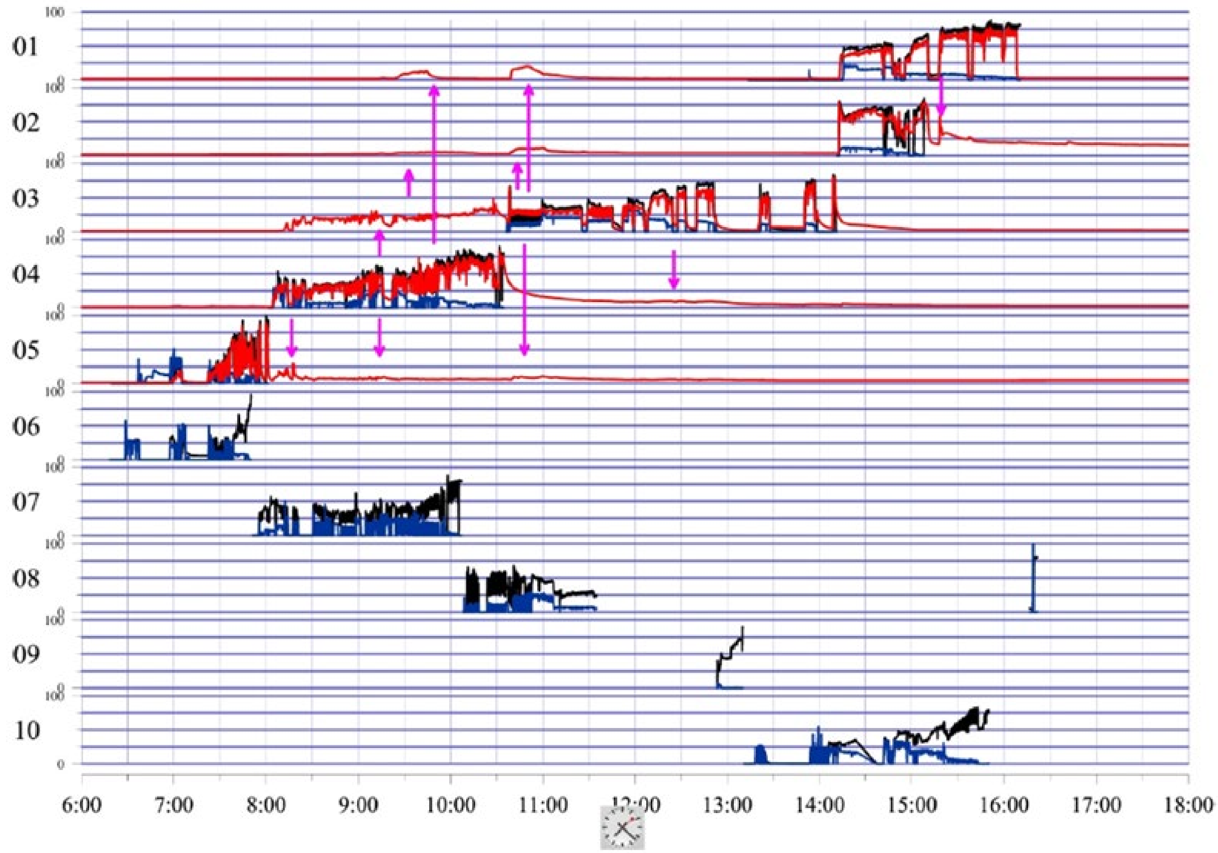
Poster at WTC2016 San Francisco, see also WTC2017

Test theories by full scale testing under controlled circumstances.

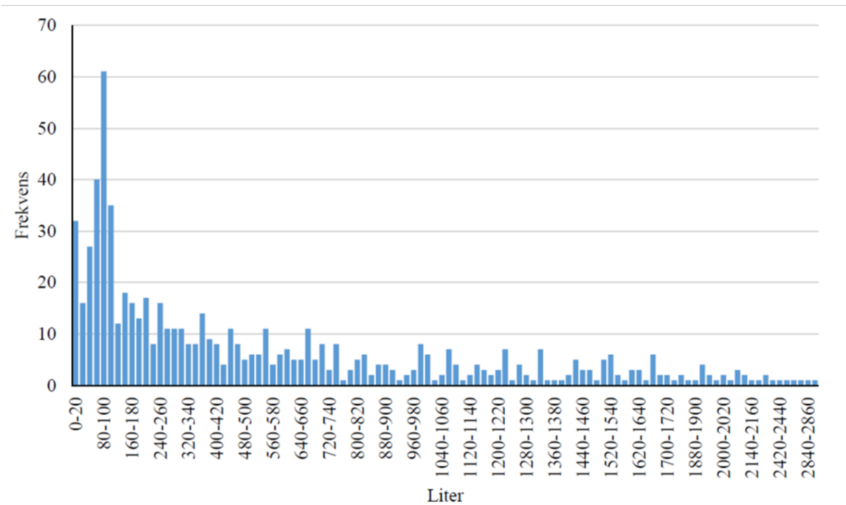
WP 7 Full scale testing work site/underground test facility.

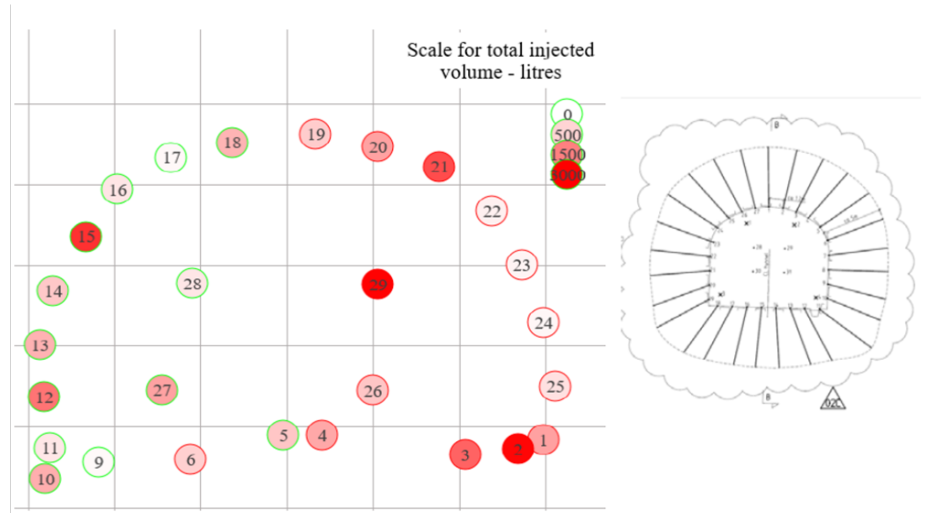




It is obvious connection between some grout holes

WP 8 Full scale testing work site/underground test facility



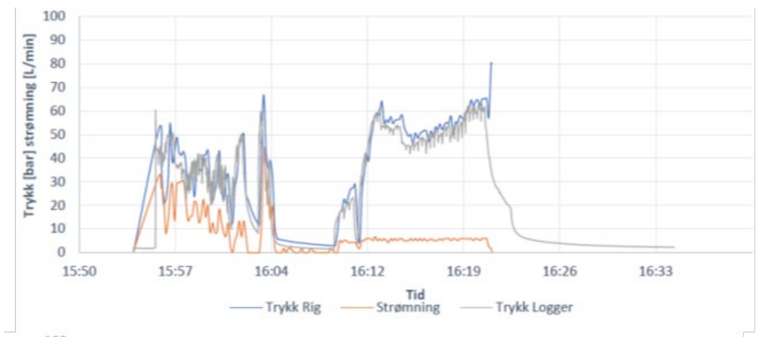


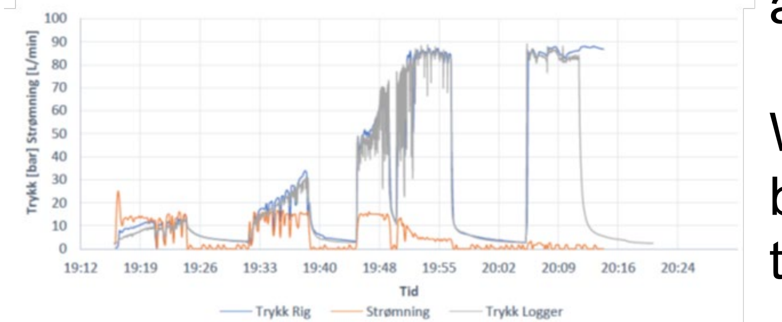
From MSc'er i TIGHT

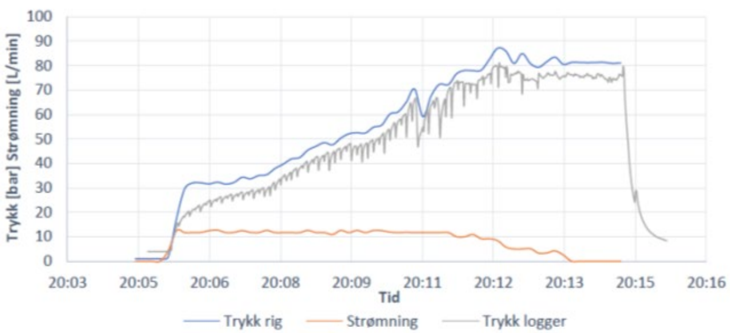
- Sølve Pettersen; "*> 30% of grout holes gave less than 120 liter*"
- Stine Moe: "*Grout rounds with high volume has a larger amount of holes of jacking*"
- Sondre Wenaas: "*Jacking leads to increased volume and groting time*"

Jacking may also occur if the pressure is less than expected from min. stress component and rock cover.

WP 7 Full scale testing work site/underground test facility.







A recent MSc-thesis has looked at data that NGI collected for TIGHT

The results show that for MC there is good coherence between grout pressure at the rig and measured in the hole.

Water was also tested with poor coherence between pressure at the rig and pressure in the hole

Insignificant loss of pressure

WP 8 Monitoring

Task of WP:

Develop an instrument that can measure pressure and transmit data from different depths in long boreholes for documenting actual grouting pressure inside the rock mass. An important tool to determine grouting materials and pressure that give the best results under different conditions.

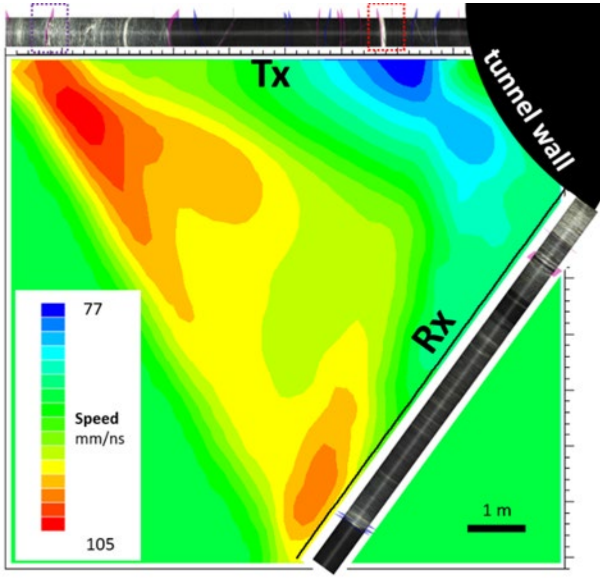
- Establish systems for pressure monitoring at various locations in the grout hole/rock mass – grout spread
- Wireless transmission

WP 8 Monitoring

The solution became testing of GPR 2D Tomography

It appears as GPR in boreholes can be used to evaluate the result of grouting and water bearing joints based on EM-velocity distribution.

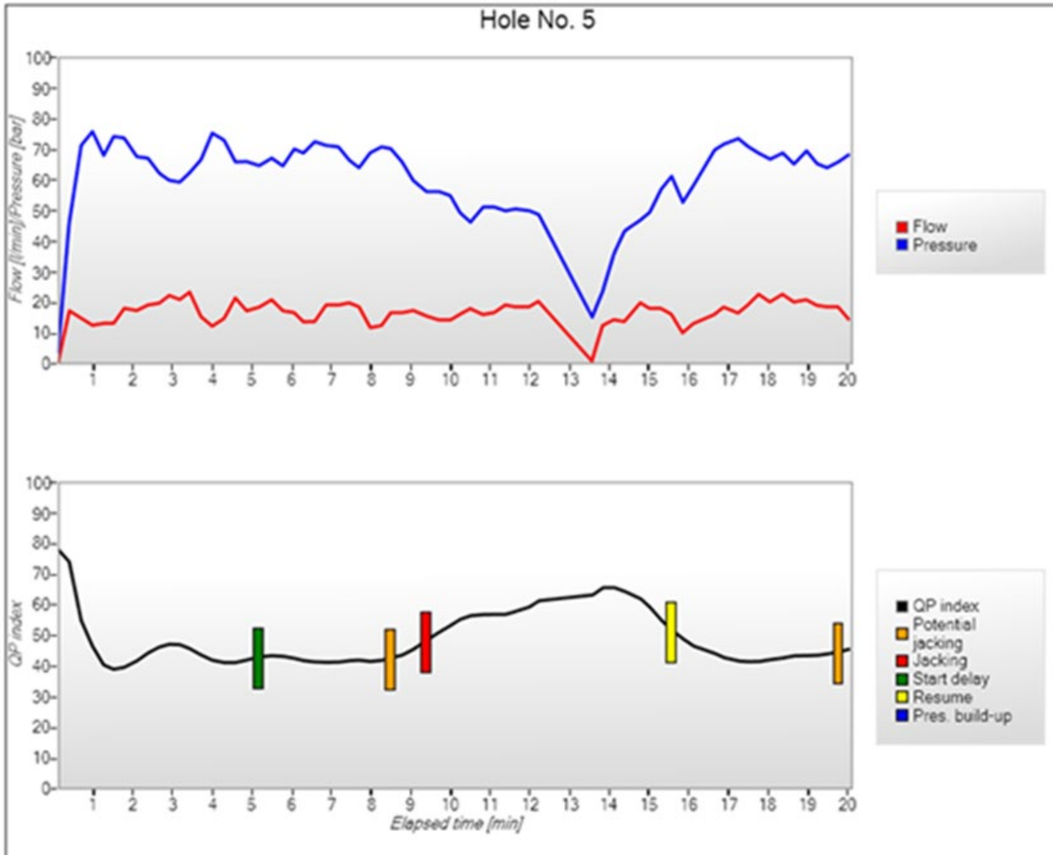
Very limited work on this and there is limited confidence in this testing



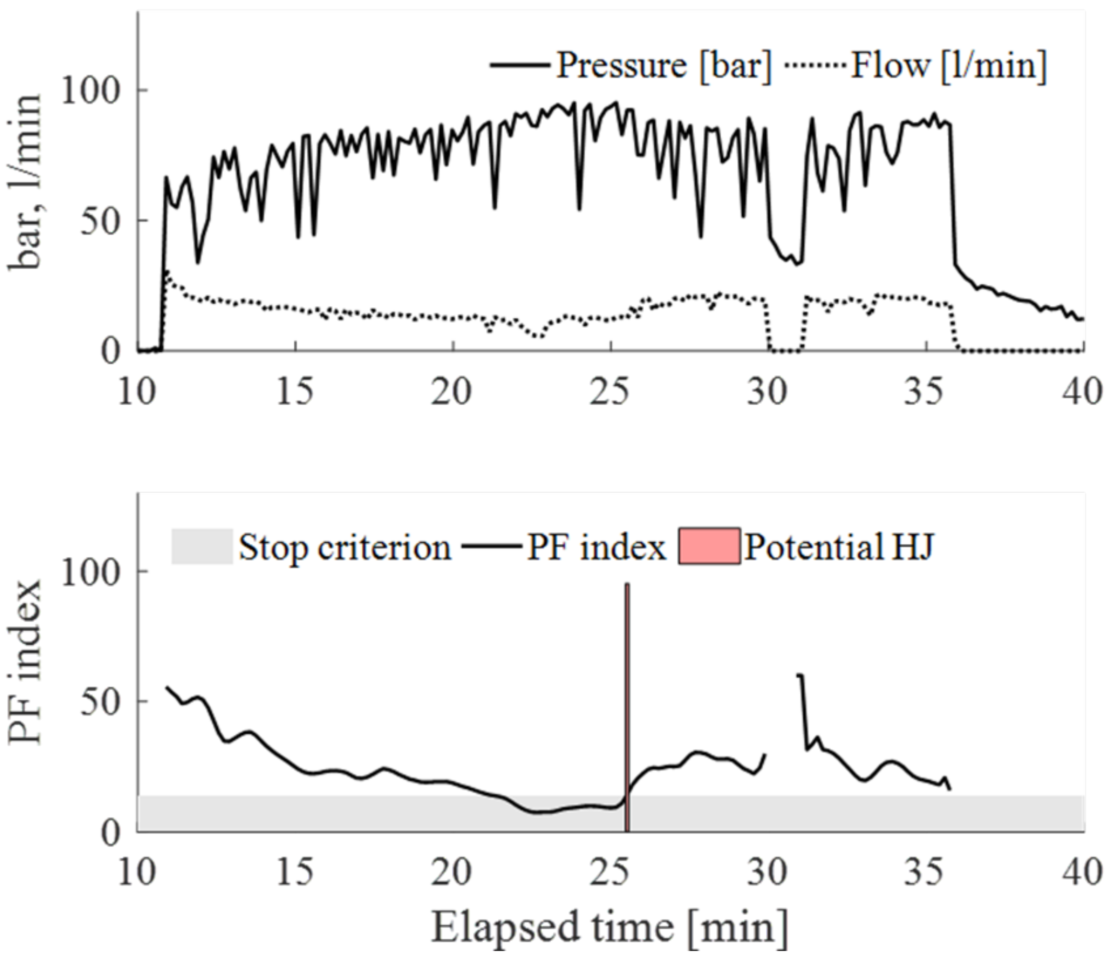
WP 8 Monitoring

The grout rig supplier AMV together with Bever Control are updating data loggers and date presentation to fulfil the requirements of TIGHT

- More frequent logging
- Logging after pump stops
- Better graphical interpretation
- Hopefully to be available real time – powerful tool



From the PhD-works



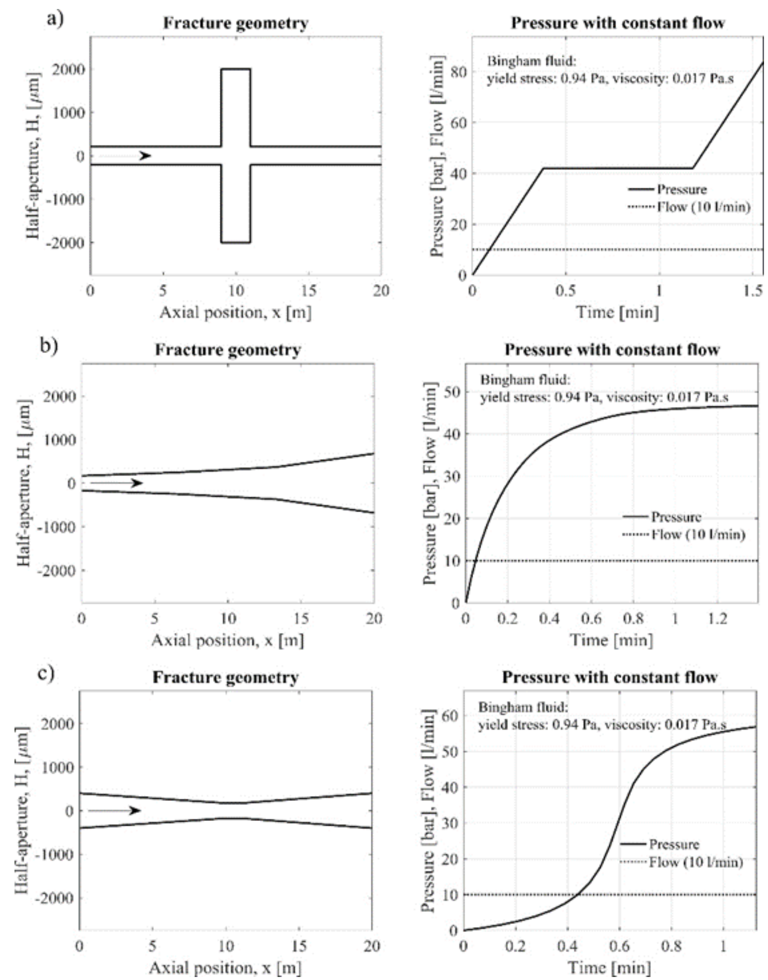
The PF-Index is an algorithm developed by Helene Strømsvik in her PhD - studying a large number of grouting rounds at different projects.

A tool to follow-up grouting works and identify jacking (Strømsvik et al 2018)

From the PhD-works

Numerical models show that if flow remains constant - pressure reduction occurs only if;

- Erosion or washing out of joint material/filling
- Change in viscosity of flow of grout/change in grout rheology
- Hydraulic jacking



Strømsvik, H. TUST 2018

No pressure release under normal conditions

What about jacking?

Raw Data from the Work Shop at Nordic Grouting Symposium in Oslo 2016 - All data was systematised in TIGHT

Several MSc-thesis's were done analysing Jacking and it occurs more often than we like it to happen

1. Jacking when grouting – an incident of positive or negative impact – wanted or unwanted?
2. How can we balance high pressure as something required for good quality grouting with the risk of jacking?

Jacking- an incident of postive or negative impact? (1)

All groups seem to accept that jacking occur when the grout pressure exceed the normal stresses acting over a fracture.

Higher pressure will give a faster flow

Jacking implies that the fracture aperture will increase.

The increase of fracture aperture will depend on the excess grout pressure and the spread of the grout.

Jacking- an incident of postive or negative impact? (2)

All groups seems to consider that jacking may have negative effect.

Common negative effects are lose of control and higher grout consumption. Some group have also take up the risk for open up new larger water channels. Some groups have indicated the risk for the workers.

Jacking- an incident of postive or negative impact? (3)

All groups have indicated that under some circumstances jacking may be beneficial.

In general the positive effect can be utilised for deep and rural tunnels. The effect may be a better pentrability, less risk for clogging and faster flow of the grout.

Some groups have pointed out that this require that resonable stop criterion is established and used to be in control and to prevent high grout consumption.

Jacking- an incident of postive or negative impact? (4)

Some issues to be further discussed

What happen with the spread and peneration of the grout into the finer fractures?

Lack of experiences from the field?

How to keep jacking under control? Stop criterion and indicators from monitoring of the grout course?

How to balance high pressure and good quality grouting (1)

Many groups suggest that the pressure should be close to the jacking pressure. Some groups indicate that a short period of higher pressure in the very start can be allowed.

Many groups suggest that monitoring should be used to control that jacking will not occur. Stop criterion is mandatory. (*N.B not stop pressure*).

Adapt the rheological properties to the actual situation. Use stable grout. Investigation of the insitu stresses and geology. Education of people involved.

What about jacking?

1. Is jacking wanted or unwanted?

Everyone seem to accept that jacking occurs when grout pressure exceeds normal stresses acting over a fracture, and that; pressure must remain below jacking pressure.

Consensus that jacking normally is unwanted. Some reasons were more frequently mentioned than others:

- Jacking results in a greater consumption of grout (67%).
- Risk of damage to workers and/or environment (56%).
- Jacking leads to loss of grouting control (45%).
- Jacking can lead to opening of new large water channels (22%).

What about jacking? On the Positive side

Positive aspects of grouting with high pressure:

- Faster injection (45%).
- Better penetrability (45%).
- Larger grout spread (22%).
- Less risk of clogging (11%).

- 33% pointed out that high pressure may increase effectiveness of grouting
- jacking can be accepted in rural areas to increase efficiency (22%), but most be followed by a stop criterion on quantity
- the pressure utilized should be as high as possible without invoking jacking

What about jacking?

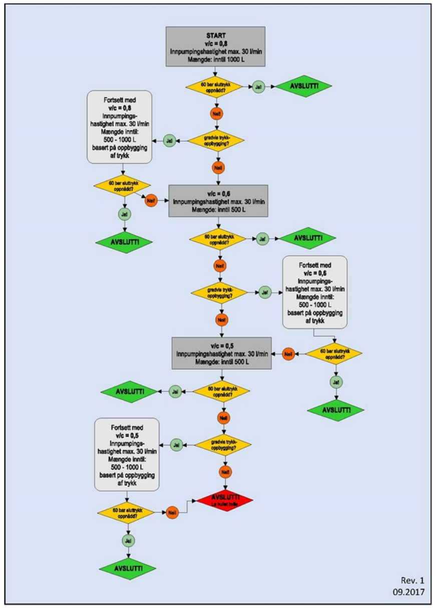
2. How can we balance high pressure required for good quality grouting with risk of jacking?

A few points came up several times:

- Applying high pressure just short of jacking pressure (45%)
- Measure and control of flow and pressure (45%)
- Using a high quality, stable grout (33%)
- A short period of higher pressure at the start of the injection before lowering it (22%)
- A stop criterion on quantity should be mandatory (22%)

Steps to take at the construction site

- Much more pre-construction testing on materials
- Involvement at tunnel face whilst grouting by all parties – grouting is 1/3 of excavation costs
- Start to use real time data from the grout rig to follow up and being a decision tool, client, consultant & contractor
- Test grout procedures before making them untouchable – all tunnel projects are unique and 'cut & past' don't work
- Need 'High Pressure' but need to closely follow-up and analyze what's going on – high flow rate is also a danger
- Make adjustment when jacking is observed



Further research

Tight was a 4 years stunt in Norway, but much more research is required:

- Better understanding of the spread of cement in the rock mass
- Tools to follow up the grouting works
- Contracts for a better control on quantity and quality – and better risk sharing
- Artificial Intelligence – AI – in the grouting works

Take Rock Mass Grouting into education, some steps been taken

Rock mass grouting – an adjustment of course

Based on TIGHT I believe there is a need to:

- Adjust the course of the Norwegian grouting approach
- High pressure is a need but not always and if, with caution
- Better and more site specific adaptation – geology/circumstances
- Look at procedures with new eyes and rewrite parts of it
- It's time to think new - out of the box

Thank you for kind your attention!