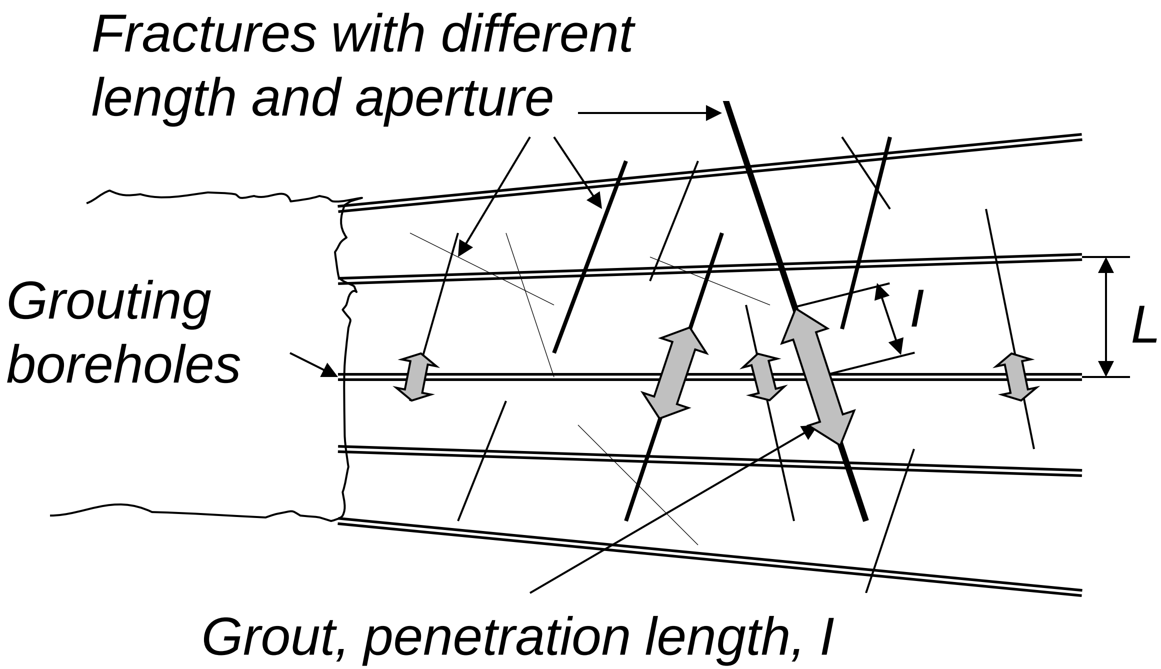
Rock and grout
Characterization, selection and modification/revision

Berg och bruk
Karakterisering, val och förändring/revidering

Åsa Fransson och Johan Thörn, Chalmers

- No grout – Too much grout
- Hydraulic aperture – Penetrability – Penetration Length
- Testing of rock (fractures) and grout (b_{hyd} vs 3*d95)

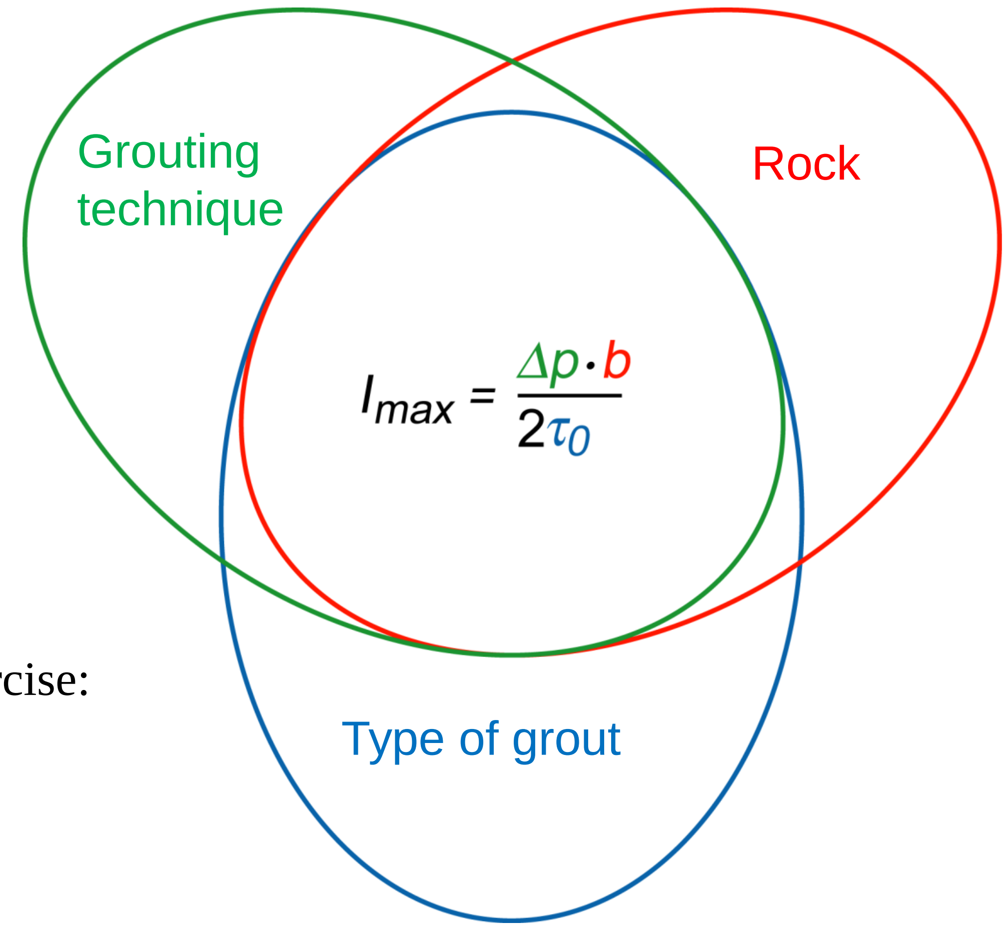
Penetration length and grouting fan design



Parameters:

- Aperture, b
- Yield stress, τ_0
- Viscosity, μ_g
- Grouting over-pressure, Δp
- Grouting time, t

Maximum penetration of grout



Calculation exercise:

b=100 µm

Δp= 5 bar

τ_0=5 Pa*s

Penetration length and grouting fan design

$$I_{\max} = \frac{\Delta p b}{2\tau_0} = \frac{5 \cdot 10^5 \cdot 100 \cdot 10^{-6}}{2 \cdot 5} = 5\,m$$

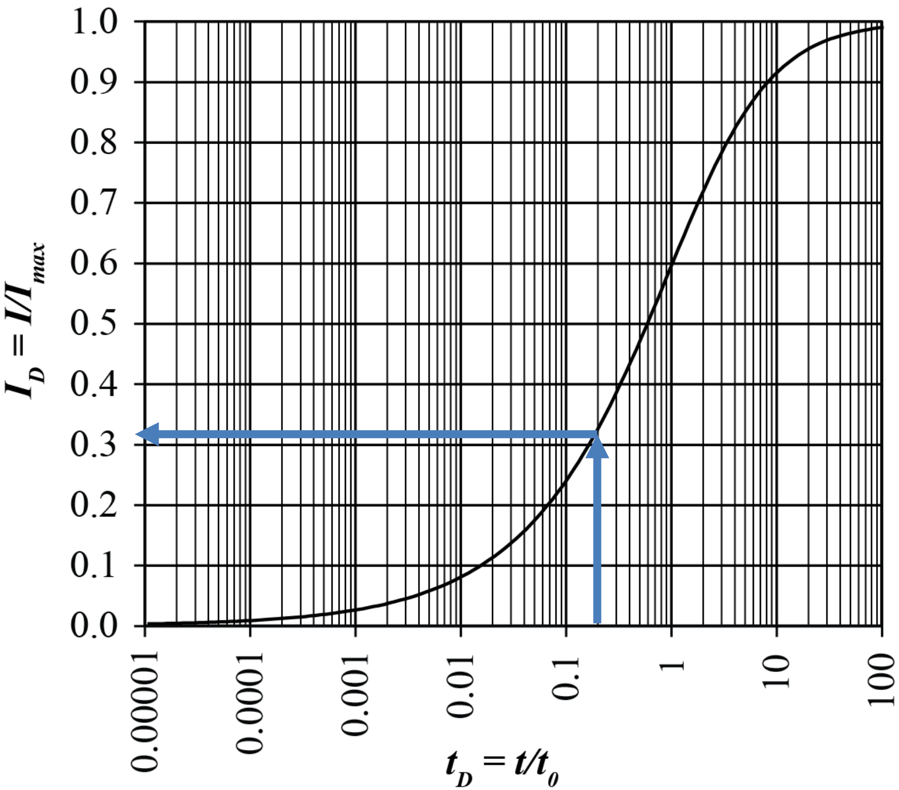
$$t_0 = \frac{6\Delta p \cdot \mu_g}{\tau_0^2} = \frac{6 \cdot 5 \cdot 10^5 \cdot 0.05}{5^2} = 50\,\text{min}$$

$$I_D = \frac{I}{I_{\max}}$$

How far do we get in 10 min?

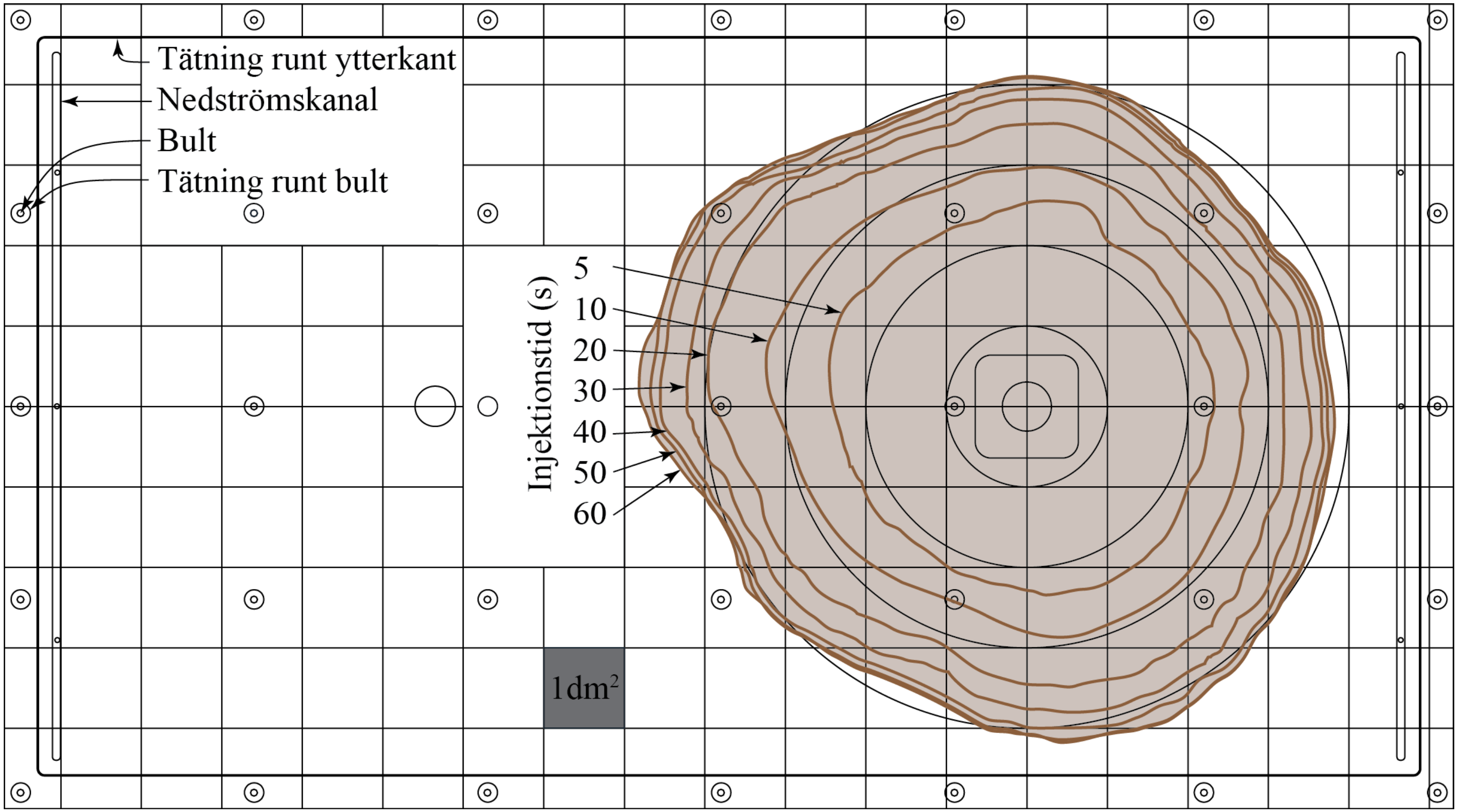
$$t_D = \frac{t}{t_0} = \frac{10}{50} = 0.2$$

$$I = I_D \cdot I_{\max} = 0.32 \cdot 5 = 1.6\,m$$



Gustafson and Stille (2005), Gustafson et al (2013)

Validation of penetration length

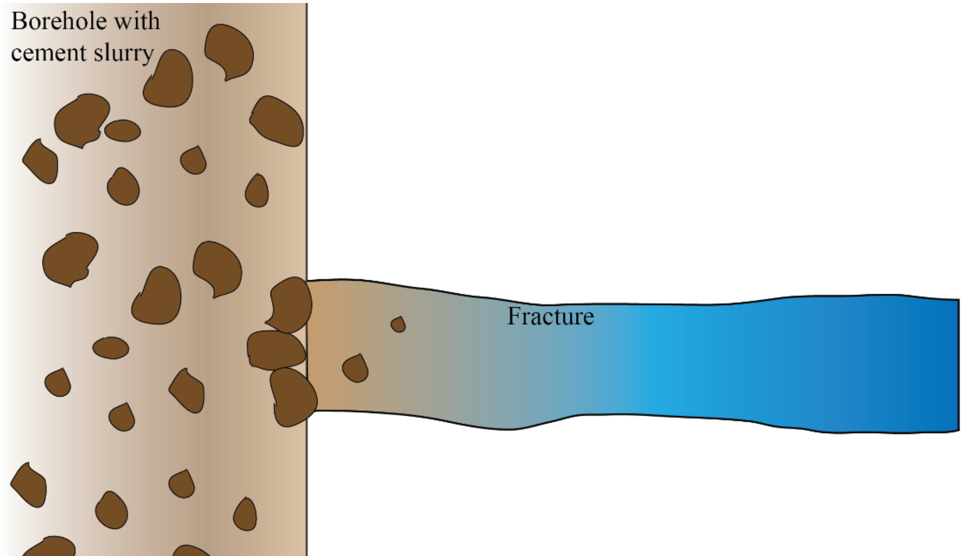


Funehag och Thörn (2014)

View movies at www.chalmers.se/hydrogeologi-injektering

Hydraulic Testing and Selection of Grout

- Estimate **penetration length** and adapt **borehole and fan geometry.**
- Investigate **grout properties** in the laboratory.
- Check **grout properties** in the field.
- Use **hydraulic tests** in grouting boreholes as a basis for **selection of grout (b_{hyd} vs 3*d95)**.



Grout properties

- Penetrability – e.g. PenetraCone
- Density - e.g. Mud-balance
- Yield stress and Viscosity –e.g Yield stick with mud balance and Marsh-cone flow time

Photo: Nina Zanders

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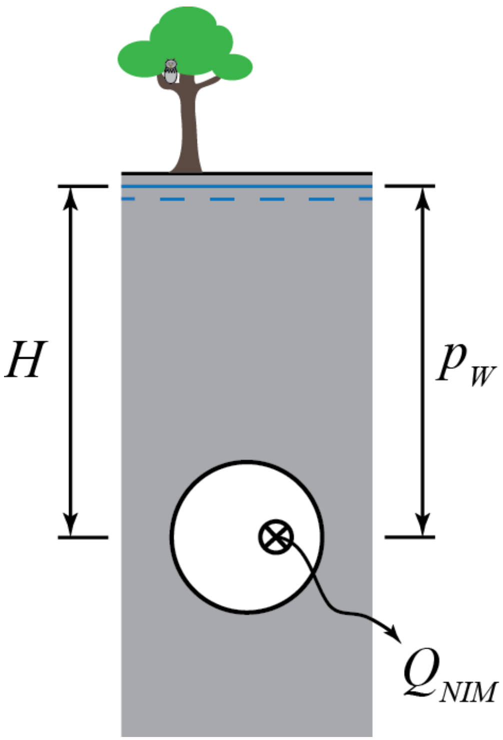
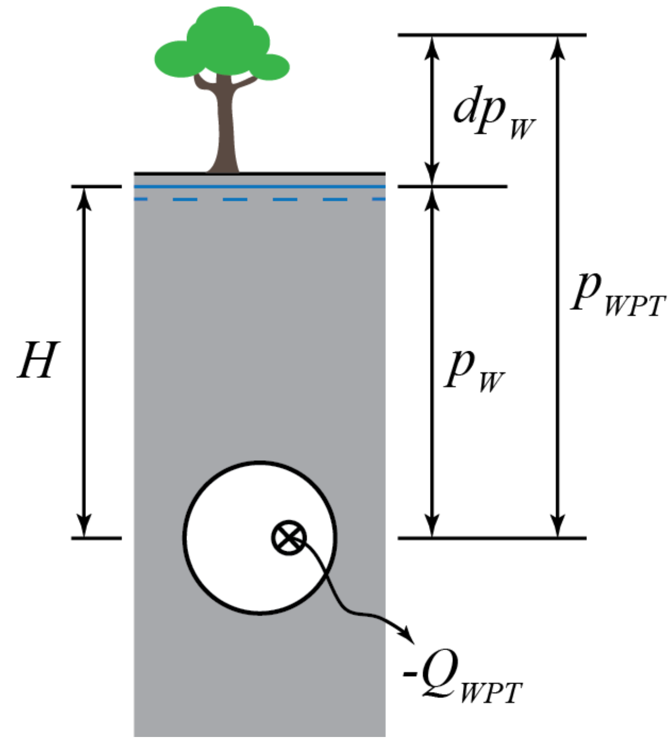
Hydraulic Tests – Selection of Grout



$$T = \frac{\rho g b^3}{12\mu_w} \approx \frac{Q}{dh_w}$$

$$b = \sqrt[3]{T \cdot \frac{12\mu_w}{\rho_w g}}$$



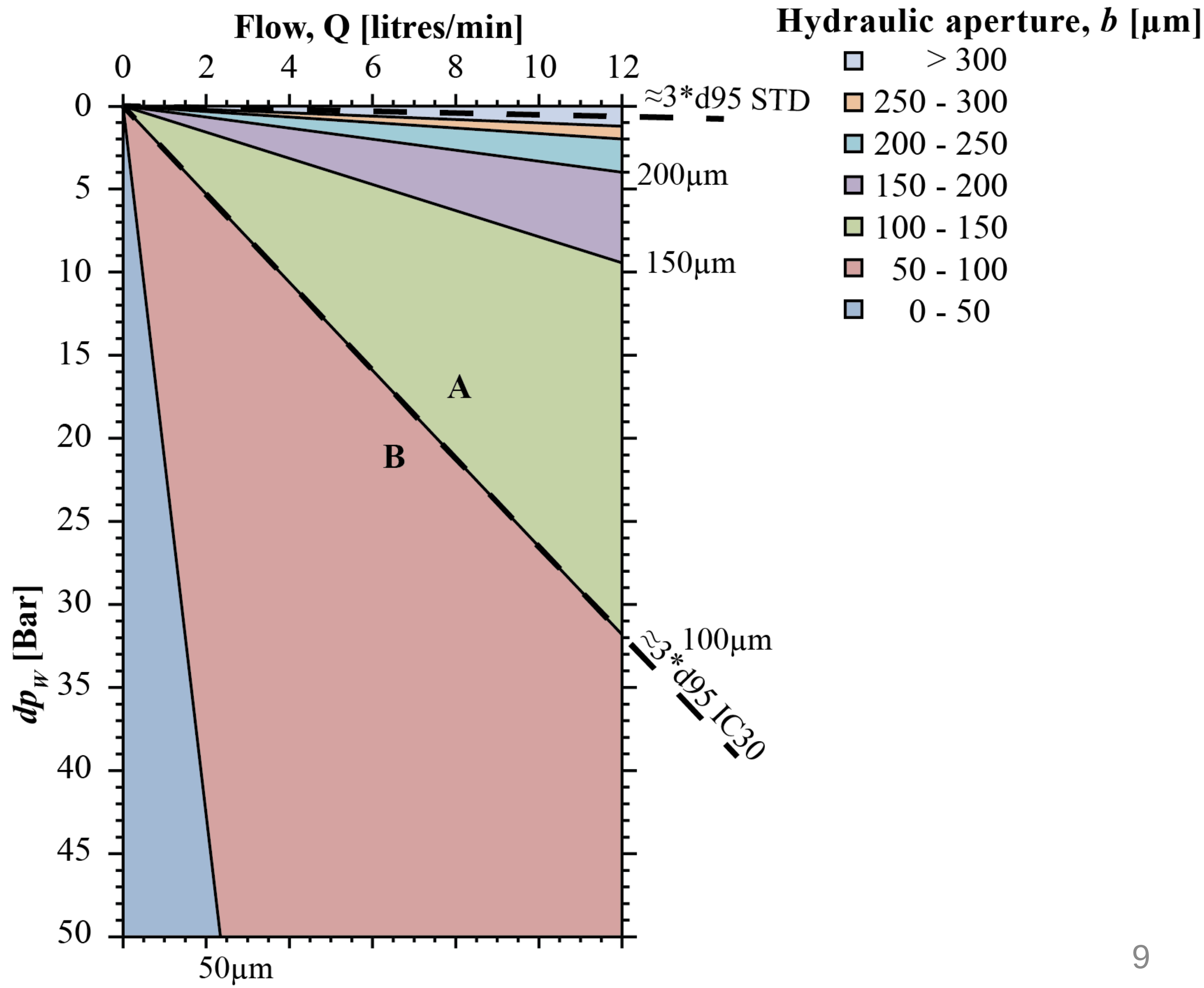
Natural inflow measurement

* Measure pressure (stabilised), p_w *or* h_w
* Open borehole
* Measure inflow, Q_{NIM}

Water Pressure Test

* Measure pressure (stabilised), p_w
* Injection of water: p_{WPT} & Q_{WPT}
* Calculate dp_w ($p_{WPT} - p_w$) or dh_w

Selection of Grout & Penetrability $b_{hyd} > 3 \cdot d_{95}$



Selection of Grout & Penetrability $b_{hyd} > 3 \cdot d_{95}$

	Depth (m)	Flow Q (litres/min)	dh_w (m)	Grouting pressure p (MPa)	Aperture b (µm)	$3 \cdot d_{95}$ (µm)	Penetrability: Comments
Äspö Pillar	100	0.1	25	0.2-0.4*	≈ 50	36	Very limited
Äspö TASQ (tunnel)	450	2.5	340	Dp: 1-2	≈ 60	48	> 50 µm but not below 30 µm
Nygård (tunnel)	50	0.1-4.2	110	2.5*	< 100	90	Very limited

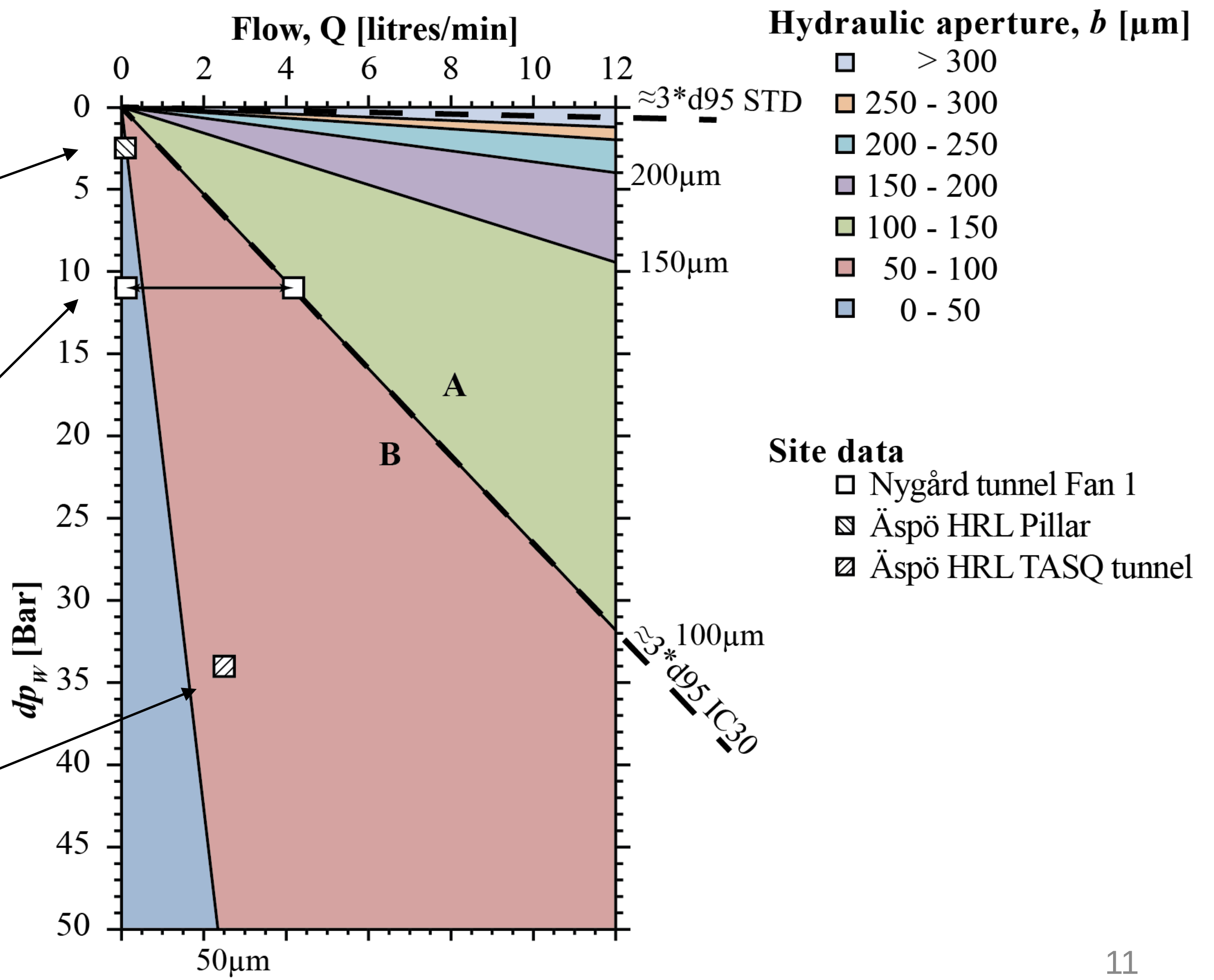
* Low water pressure: grouting pressure close to grouting overpressure

Selection of Grout & Penetrability $b_{hyd} > 3 \cdot d_{95}$

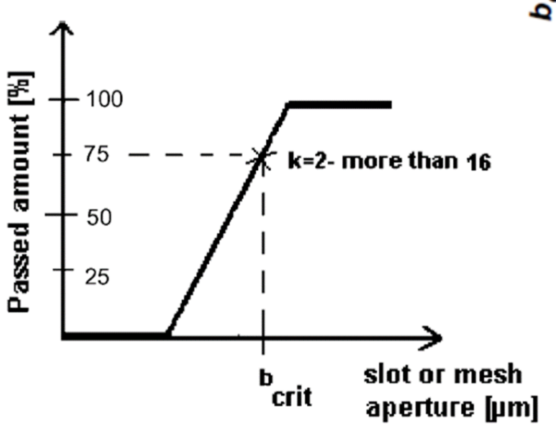
Äspö Pillar
b ≈ 50 µm
3·12 µm = 36 µm
Limited penetration

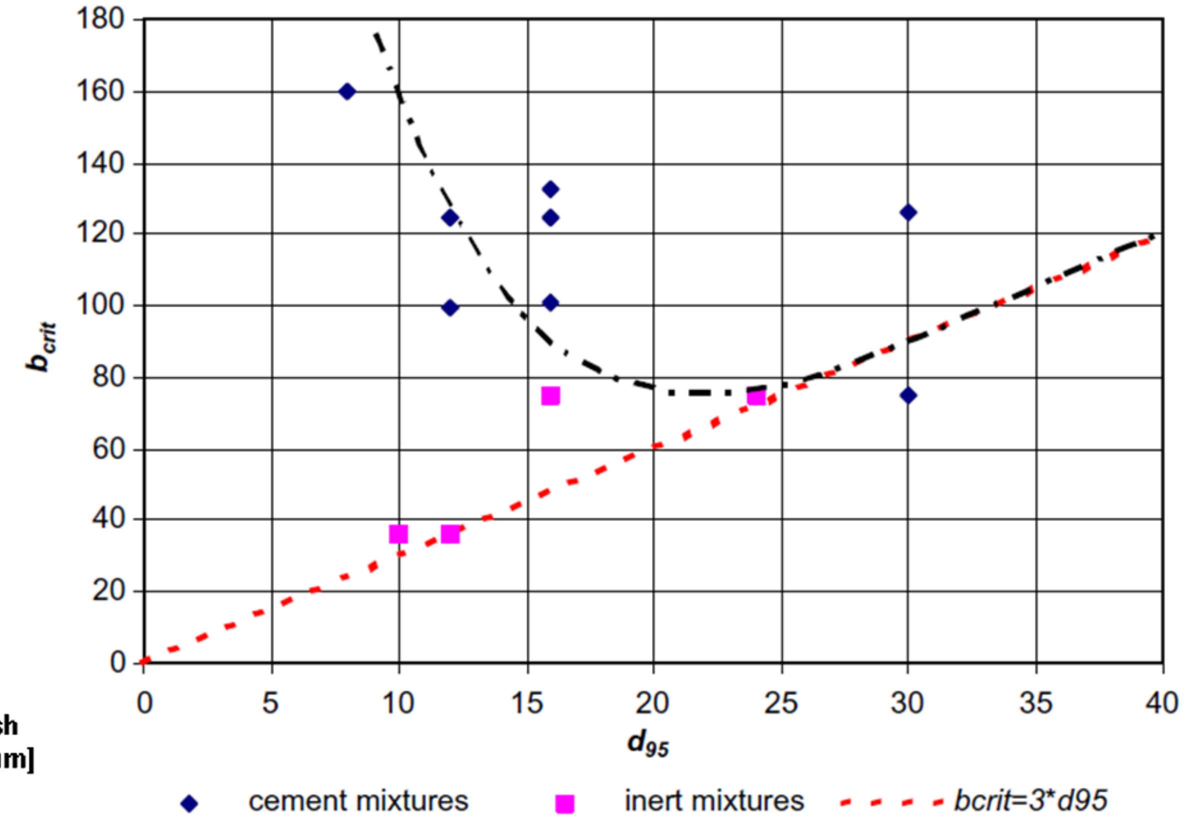
Nygård tunnel
b < 100 µm
3·30 µm = 90 µm
Limited penetration

Äspö TASQ-tunnel
b ≈ 60 µm
3·16 µm = 48 µm
Close to limit



Selection of Grout & Penetrability $b_{hyd} > 3 \cdot d_{95}$





Eklund & Stille (2008)

Conclusions

- The hydraulic aperture is an important parameter
- Influences penetrability and penetration length (fan geometry)
- Hydraulic tests (hydraulic aperture) in grouting boreholes useful as a basis for selection of grout.

References

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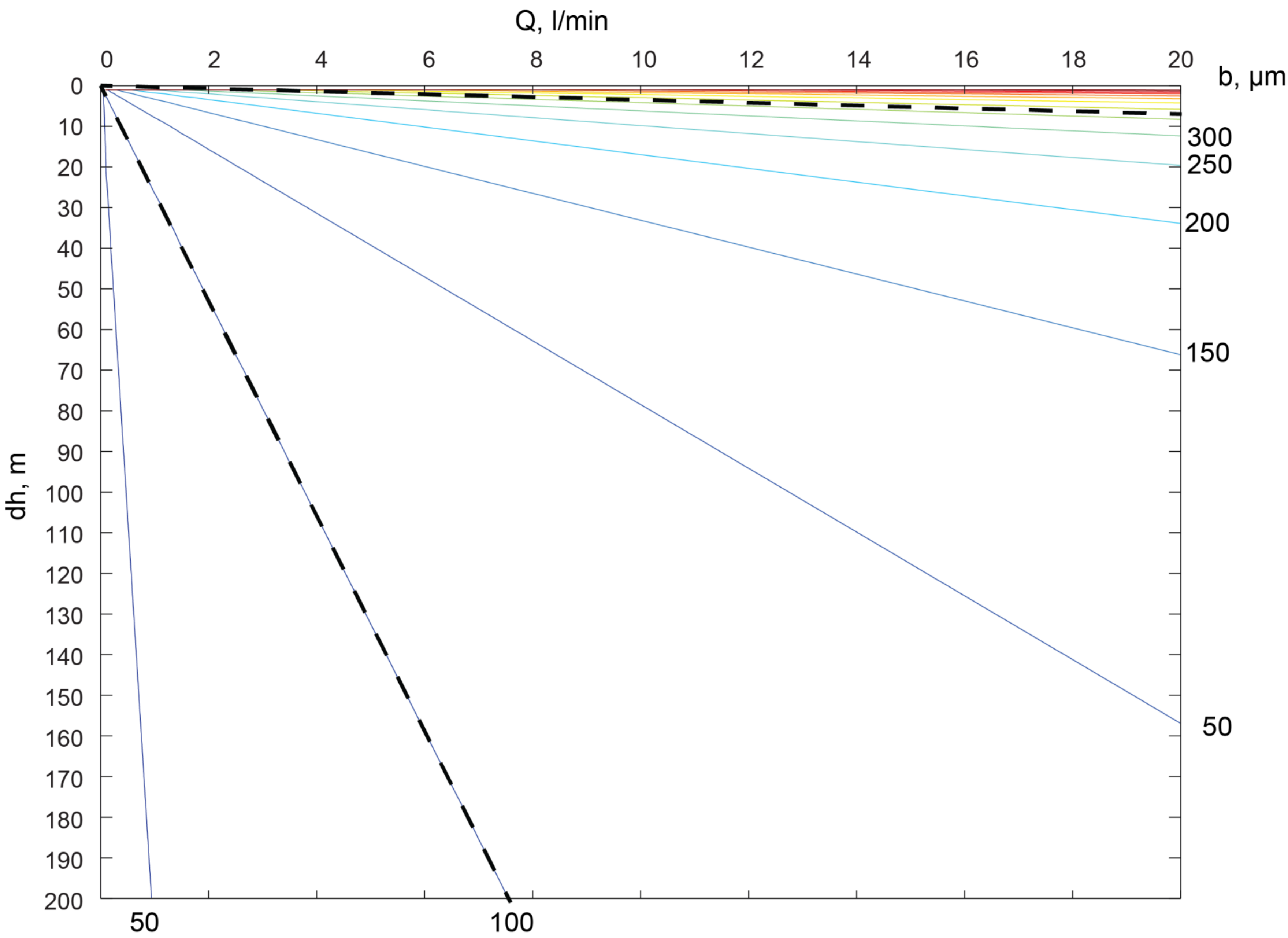
- Gustafson, G., Claesson, J., & Fransson, Å. (2013). Steering parameters for rock grouting. *Journal of Applied Mathematics, 2013*. dx.doi.org/10.1155/2013/269594
- Grout testing video: www.chalmers.se/hydrogeologi-injektering

Thank you!


Q, l/min
0
2
4
6
8
10
12
14
16
18
20
b, µm
dh, m
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30
40
50
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100