Hvordan redusere sementforbruk ifm. injeksjon, uten å redusere kvaliteten?

Pregrouting and hydrodomains in tunneling

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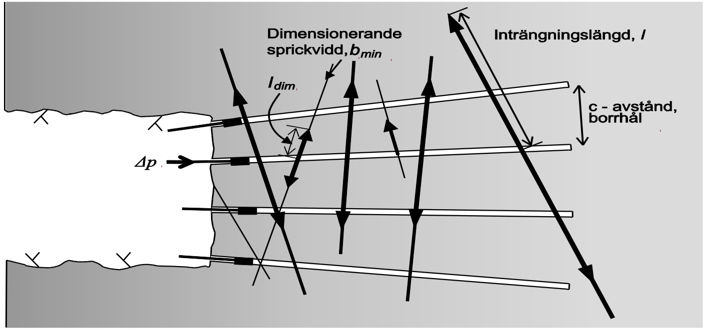
Bærekraftige tunneler og anleggsplasser,
Tekna, Trondheim, Norge 8-9 Januari

BACKGROUND

- Pre-grouting
  - Allot of boreholes,
  - many are tight or takes very little grout
  - Many boreholes are only ”hole-filled”, not unusal that 50% of the boreholes are tight in one grouting fan



- Political grouting
  - We grout to avoid responsibility if it goes sideways.
  - We grout to cope with the local demands (ground water lowering, avoid settlements of buildings) but neglecting the global goals or demands (CO2).
- Pre-investigations
  - Focuses on the most poor parts (often already known) like fracture zones, valleys, etc.
  - The good rock in a early stage of the design reamains good rock<u>, but</u>
  - due to lack of qualitative data it <u>becomes poor rock </u>in the late stage of the design to minimise risks

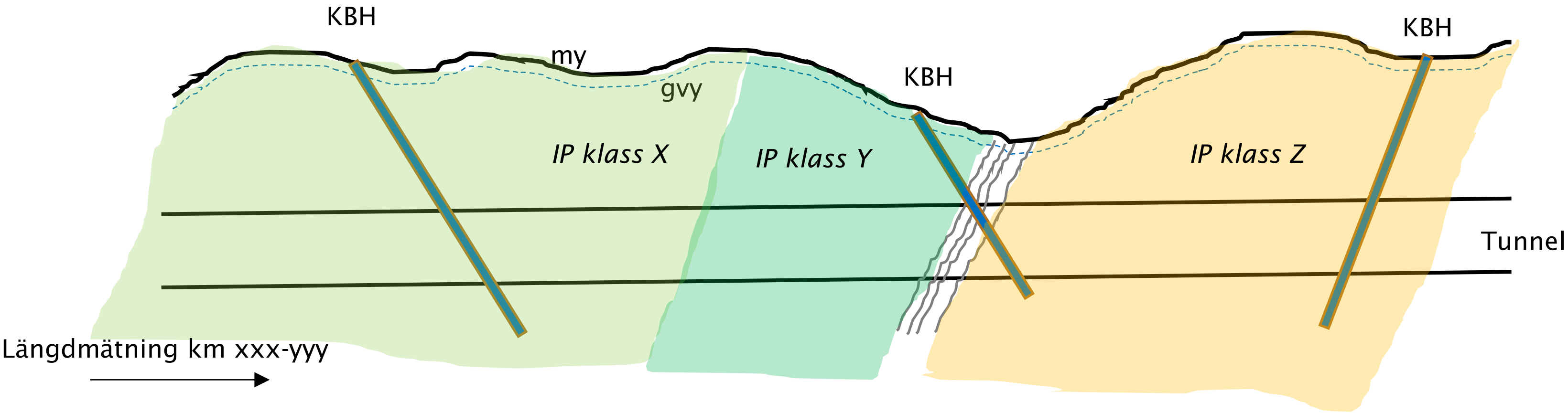
GROUT WHERE IT WORKS AND IS NEEDED!

- Penetrate the water transmitting fractures
- Grout properly, correct grout, correct amount, enough number boreholes
- If fractures cannot be penetrated, dont pre-grout, perhaps post-grout
- Use sounding holes, controlholes and measuring weirs to have control of the leakages and execution

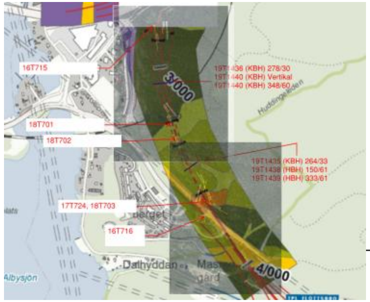
Of course, there are much things to do regarding the grout material; additives, fly-ash, Cem II quality, what is enough shear strength of grout? etc. This presentation focuses on how to limit the pre-grouting.

BASICS OF HYDRODOMAINS

- Geometrical division of the engineering prognosis (Geological Baseline report).
- Qualitative data from core drilled boreholes and percussion drilled holes
- Quantative data, the ”well archive”, mapping

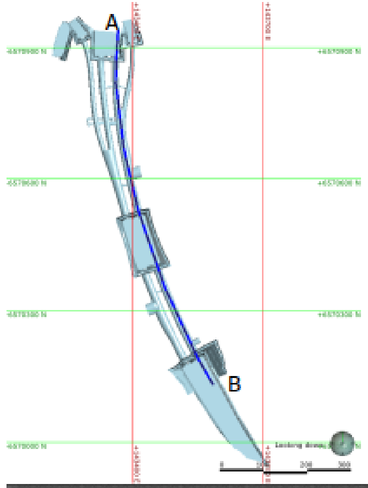


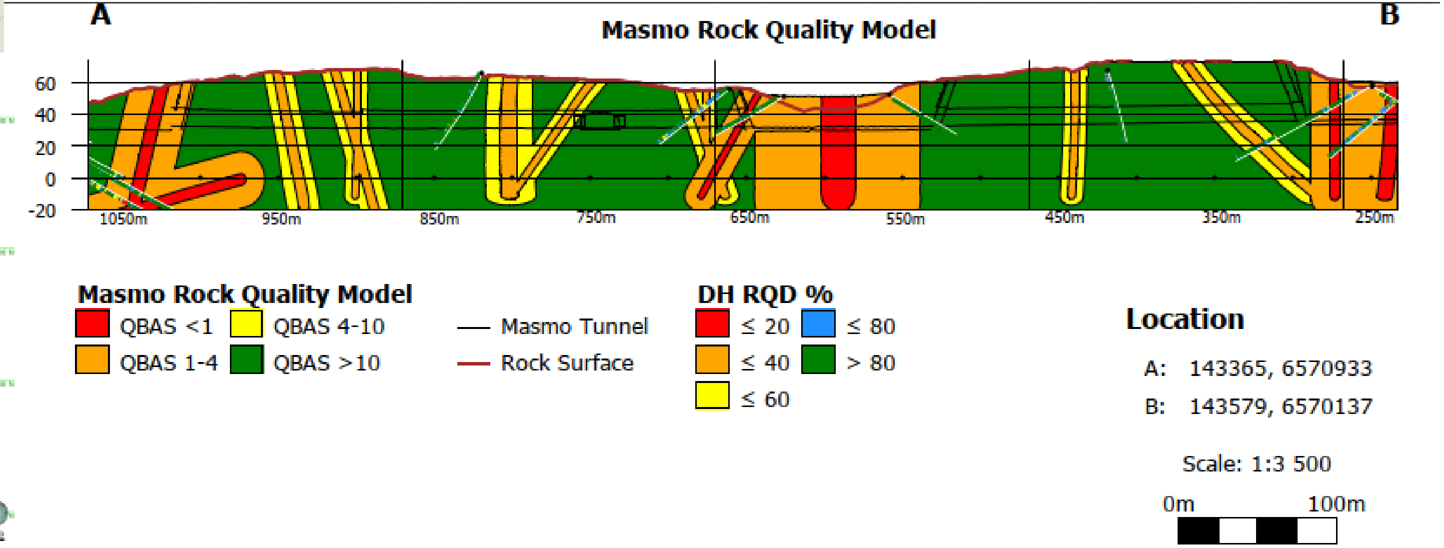
HYDRODOMAINS



Engineering prognosis- Nothing new with this!!

But data must be <u>intrepreted with relevent tools</u> to estimate the effectiveness of the grouting

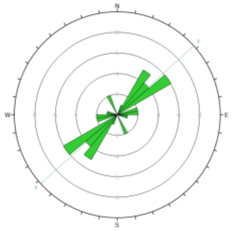


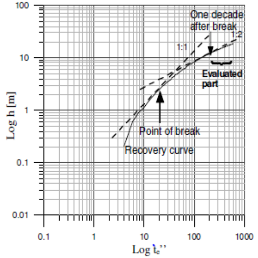


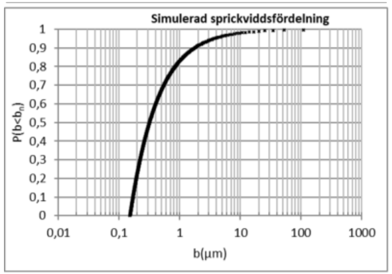
DATA FOR HYDRODOMAINS

Main five properties:

- ***Number of water transmitting fracture groups***
- ***Direction of fracture system that transmitts water i relation to the tunnel direction***
- ***Flow dimension in fractures by using pressure build-up tests***
- ***Hydraulic fracture aperture of the largest water transmitting fracture analysed using the pareto distribution***
- ***Water ingress without grouting***



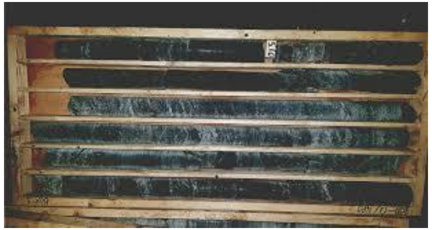




$$q = \frac{2\pi K_r L}{\ln\left(\frac{2H}{r_t}\right) + \left(\frac{K_r}{K_g} - 1\right) \times ln\left(1 + \frac{t}{r_t}\right) + \xi}$$

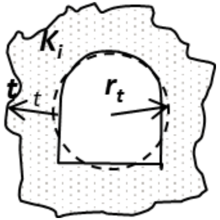
HOW IS GOOD DATA COLLECTED?

Core mapping

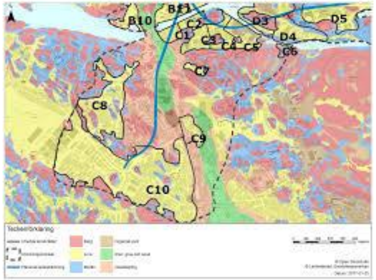


Water-loss measurements

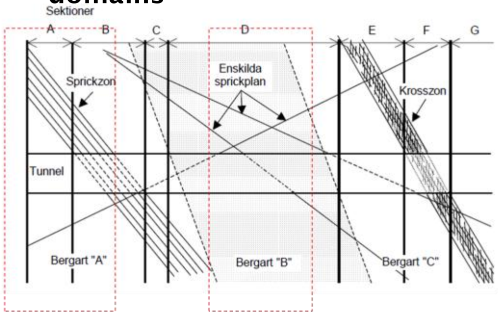
Ingress calculation



Sensitive areas and ground water lowering



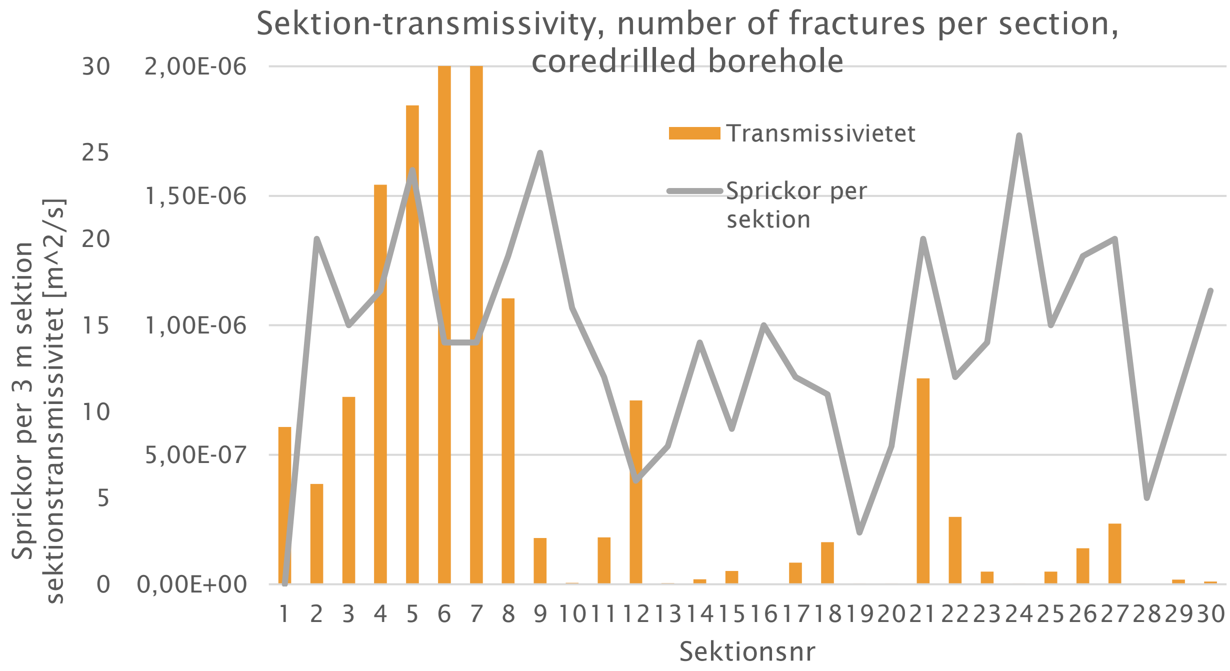
Hydrogeological domains



<u>Environmental ruling</u>

- Allowed ingress
- Allowed ground water lowering
- Control program
- Possible solutions/measures

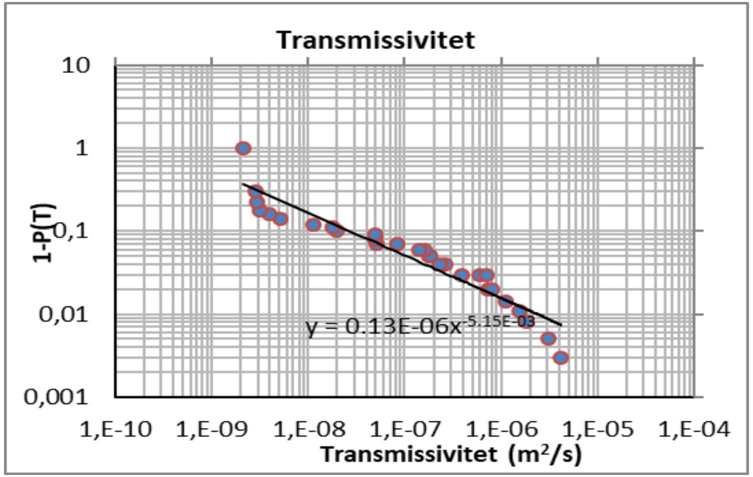
DESIGN; DATA; FRACTURES AND WATER-LOSS



Number of fractures in sections and corresponding water loss.

- Poor correlation between high water loss and number of fractures
- fracture zones can be water tight
- Single fractures can transmit the most water
- Mapped aperture and water loss does never correspond!!!

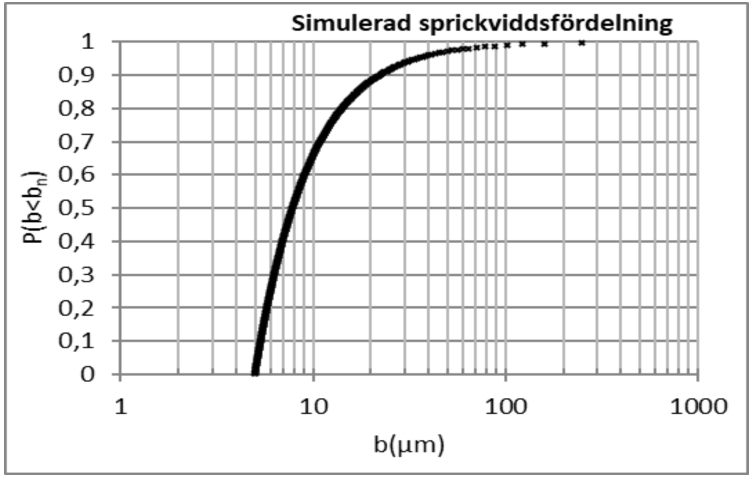
DESIGN. DATA; FRACTURE APERTURE



Pareto distribution. Good fit!. Gives an idea how much water is transmitted through the largets fracture compared to complete borehole.

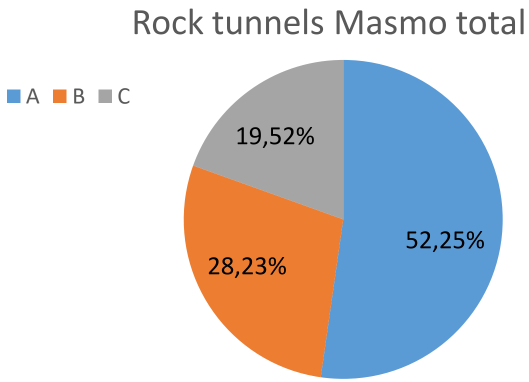
Rule of thumb= 80% is transmitted in the largest fracture for 20 m long borehole.

Largest fracture; 99% are smaller than 260 micrometers. Allot are smaller than 100 micrometers



CLASS AND WEIGHING IN HYDRODOMAINS

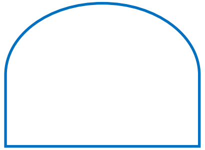
Class/properties	A	B	C	C1
No. of Water transmitting fracture groups	1 st	2-3 st	unkown, >3 st	-
Direction of the fracture system	Perpendicular	Parallell	Both	-
Flowdimension	Radielly-spherical	Radielly	Channel-radial	-
Aperture of fracture [µm]	>110	>80	>50	-
Ingress without grouting [l/min per 100 m tunnel]	<5	<10	>10	>15
”Verdict” properties				
Transmissivitity distributed	2-10	11-50	>50	-
T_{tot}/T_{max} [%]	>79	>50	<50	-



Klass/Egenskaper	A	B	C
No. of Water transmitting fracture groups	42%	42%	20%
Direction of the fracture system	9%	9%	12%
Flowdimension	7%	7%	10%
Aperture of fracture	5%	5%	17%
Ingress without grouting	37%	37%	41%
”Verdict” properties			
Transmissivitity distributed	20%	20%	70%
T_{tot}/T_{max}	80%	80%	30%

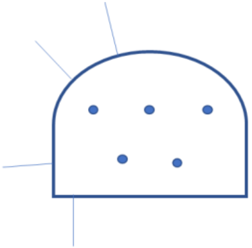
GROUTING WHEN REQUIRED

When we dont hit the fractures



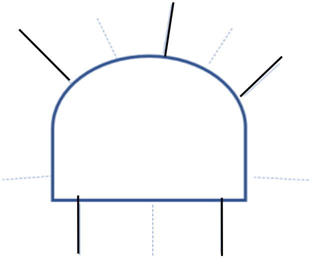
Hydrodomän A1	
Sounding holes	Non
Demand grouting	Leakage in measuring weirs
Grouting	Post-grouting

Sometimes grouting
Demand 10 l/min/100



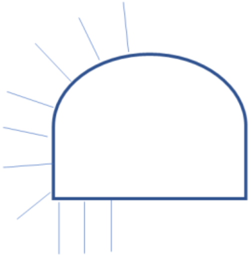
Hydrodomän A/PK1	
Sonderingshål	5 st/40 m lång/ valfri placering
Krav inj	1 sondhål läckande
Injektering	C-avstånd 5 m
Bruk	Cement, bkrit <90 mym
Teknik	20 bar/15 min

Possibly grouting
Demand 5 l/min/100



Hydrodomän B/PK2	
Sonderingshål	5 st/22m lång/ utspritt I skärm
Krav inj	1 sondhål läckande
Injektering	C-avstånd 4 m
Bruk	Cement, bkrit <90 mym
Teknik	20 bar/15 min

Always grouting
Demand 5 l/min/100



Hydrodomän C/PK3	
beräkning	Pareto
Krav inj	Minsta sprickvidd/läck age
Injektering	C-avstånd 4 m
Bruk	Cement, bkrit <90 mym
Teknik	20-30 bar/10-20 min

SOUNDING HOLES AND DECISION

Binomial distribution; statisctically independent, not connected….

Results in an value of confidence

Critical transmissivity, T_{crit} coupled to the demand on ingress

Antal sonderingshål	Antal sonderingshål som överstiger T_{krit}					
	0	1	2	3	4	5
1	0,50					
2	0,75	0,25				
3	0,88	0,50	0,13			
4	0,94	0,69	0,31	0,06		
5	0,97	0,81	0,50	0,19	0,03	
6	0,98	0,89	0,66	0,34	0,11	0,02
7	0,99	0,94	0,77	0,50	0,23	0,06

SOUNDING HOLES AND DECISION

Depth to tunnel	H	50 m
Tunnel radius	r_t	5 m
Skin factor	ξ	5
Length sounding holes	L_t	20 m
Allowed ingress	q_d	10 l/min/m
Allowed ingress	q_d	1,7E-6 m^3/s/m

Example
Critical transmissivity in sounding holes becomes:
*Tcrit=ln(2H/rt)+ξ2π·LtH·qd=ln(2·50/5)+52π·2050·1,7·10-6=8,5·10-7*m^2/s

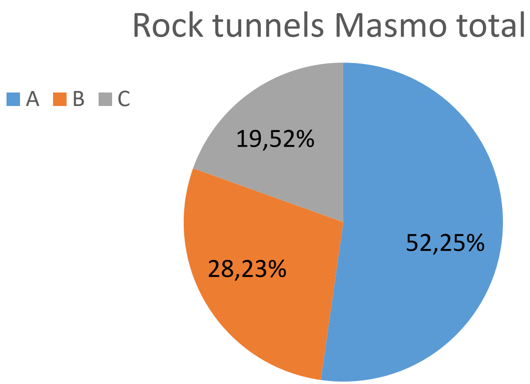
Critical transmissivitety using water loss measurements:
T=Q/dh yields the flow in the sounding holes, Q_{crit}.
Qcrit=Tcrit·H=8,5·10-7·50=2,6 l/min

Choice of 5 sonding holes where one is allowed to leak more than the critical values results in a confidence of 81% that the targeted ingress will be met. This means here that if two or more boreholes leak more than 2,6 l/min we will commence with grouting, otherwise start excavation.

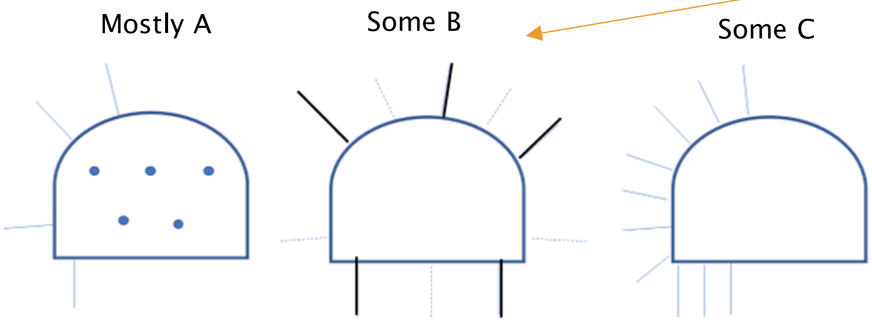
Choice of **control hole** to contro the grouting. NEW critical value of the transmissivity, $T_{crit,inj}$ according to:
Tcrit,inj=qD·Lt2πH=1,7·10-6·202π·50=1,1·10-7m2/s.
Means a inlow of 0,3 l/min in the control holes.

If 1 out of 5 control holes leaks less than 0,3 l/min the grouting is deemed to be succesful.

EXAMPLE OF RESULTS



Tunnel	Class	Tunnel stretch	**Choosen Domain**
South Masmo 425 m	A=	45%	A
	B=	37%	
	C=	18%	
South Masmo, zone	A=	0%	B
	B=	85%	
	C=	15%	
Norra masmo 300 m	A=	12%	B
	B=	78%	
	C=	10%	
Rest of Masmo	C=	100%	C



EXAMPLE OF RESULTS

Masmo with HD=A

No pre grouting, NO sounding holes.

The fractures are not penetreting the parallell fractures and the results of sounding holes becomes indiscriminately/arbitrarily

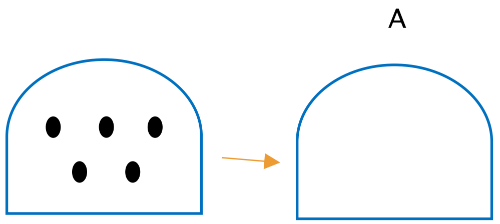
<u>Solution: Post- grouting</u>

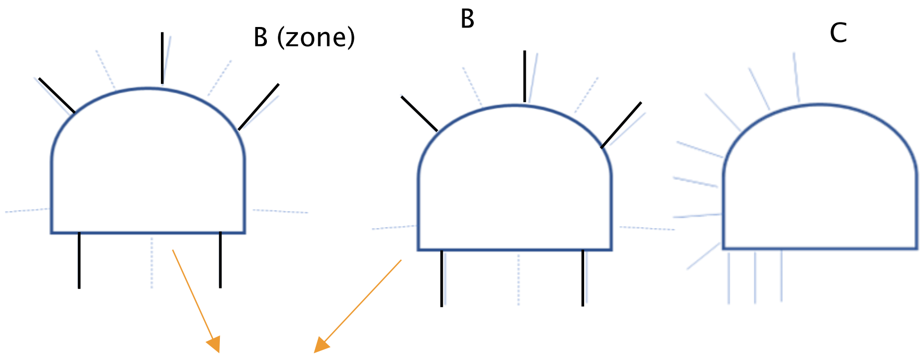
Masmo with HD=B, and fracture zone

<u>Grouting with sounding holes in grouting position</u>

Masmo with HD=C

<u>Always pre-grouting.</u>





Verfication using the binomial distribution

CONCLUSIONS

With proper pre-investigations it is possible to have a design of grouting that is risk-based and ”calcuable”.

Give back the risks to the client

To have just enough grouting, that is the target

A coupled LCC –analysis for both production of tunnel and coming maintenence is needed!

The concept has not been executed yet, but is part of the contracts

Thank you Norway for having me!