5th CBT Conference, São Paulo, Brazil

TECHNICAL DETAILS OF SINGLE-SHELL NMT TUNNELS

Nick Barton and Eda Quadros

PLEASE NOTE! THE LECTURER HAS RECOMMENDED A COMBINATION OF *NATM* AND *NMT* ON SEVERAL PROJECTS – ALSO IN BRAZIL.

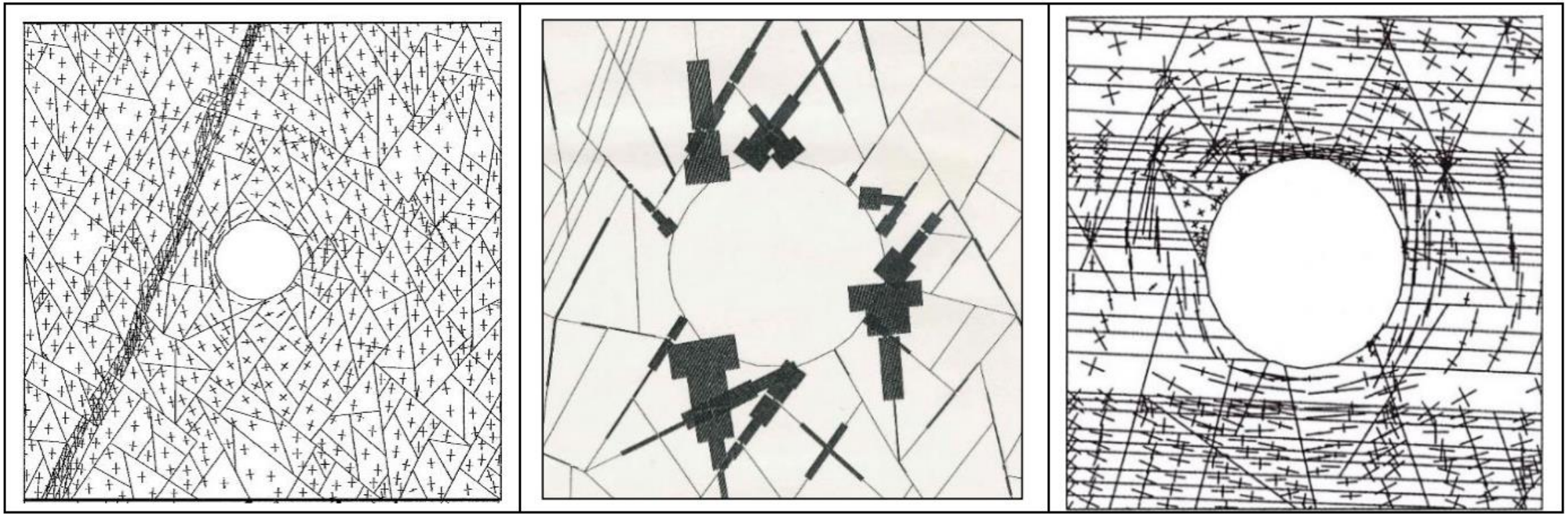
IF BOTH ARE DESIGNED CORRECTLY, BIG COST SAVINGS ARE POSSIBLE!

The use of ‘single-shell’ means that *the rock rather than the support are expected to take the huge majority of the tangential (arching) and radial stress.* (So the ‘usual’ shotcrete, bolts, mesh, lattice girders, final reinforced concrete is not taking much load – but this depends on the Q-value).

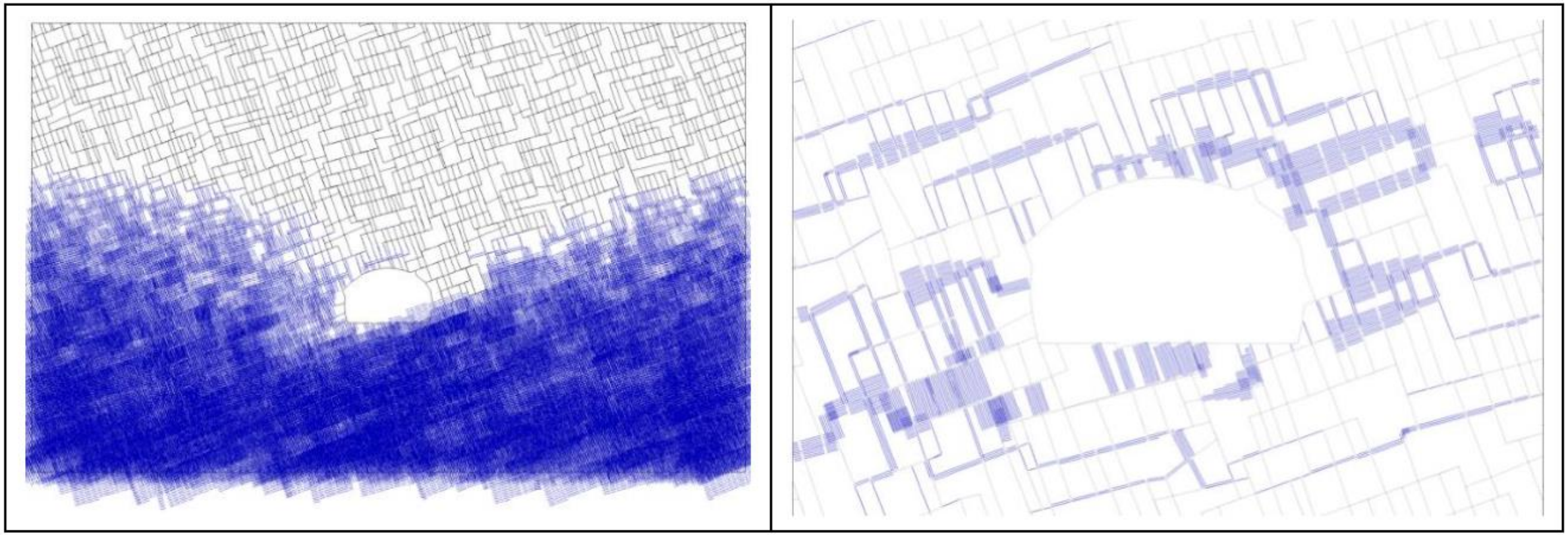
In NMT we use B + S(fr) in general, with bolt spacings from 1m up to 3m, and fibre reinforced shotcrete thicknesses from 25cm down to 5cm, as we move up the Q-value scale of (say) ***0.01(extremely poor)*** ➡ ***100 (extremely good).***

EDZ 1 – the stress redistribution inside the blocks
EDZ 2 – the joint shearing, closure, opening

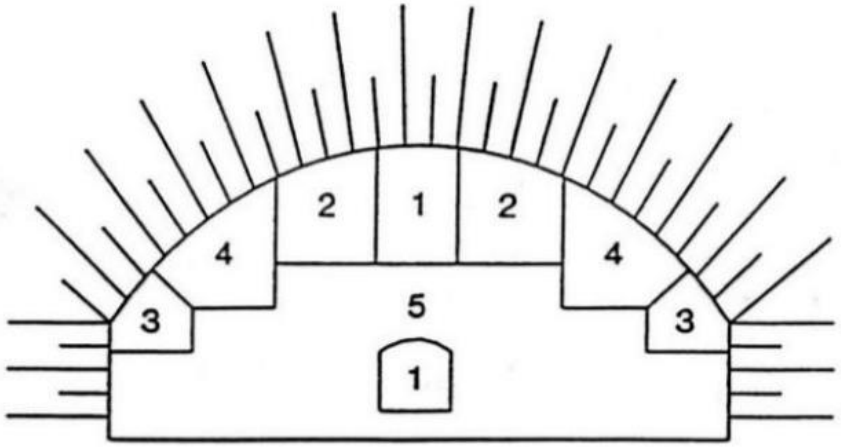
(The bolting and shotcrete ‘’keep things in place’ by specific amounts). NGI UK Nirex models. Barton 2000.

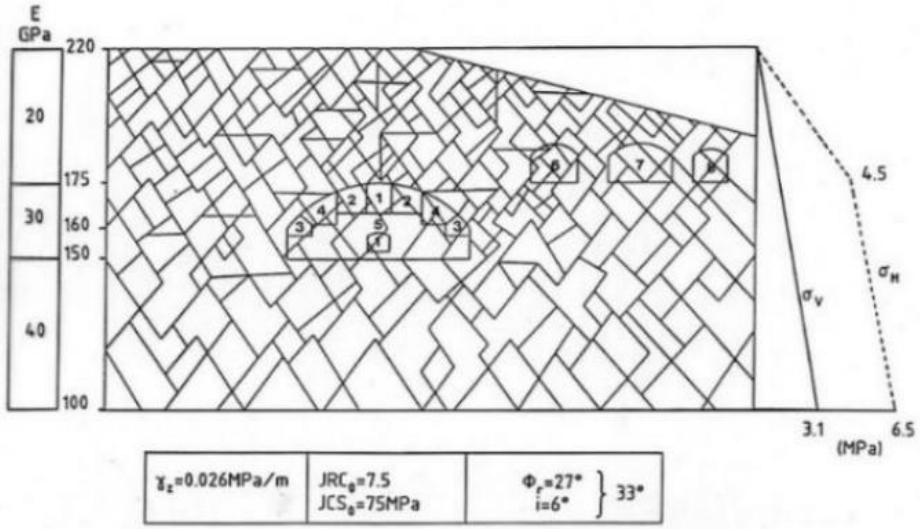


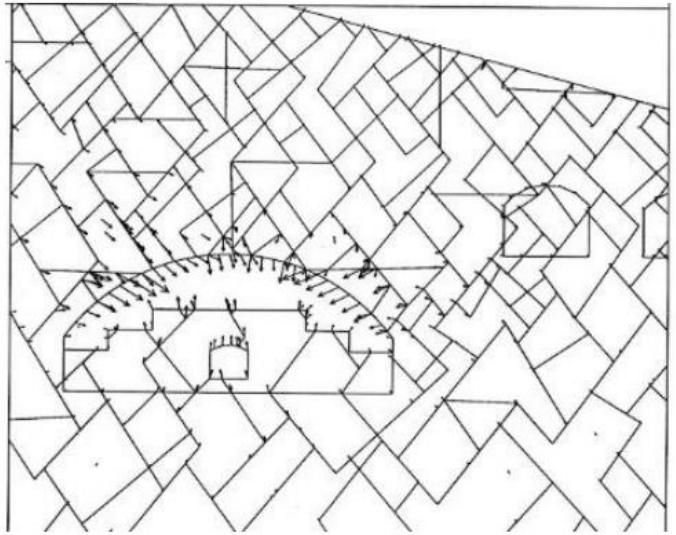
Within the EDZ 2 there may be flow of water, and e.g. drawdown above a tunnel, and risks of settlement damage. Barton, 2017 / K.Monsen UDEC-BB

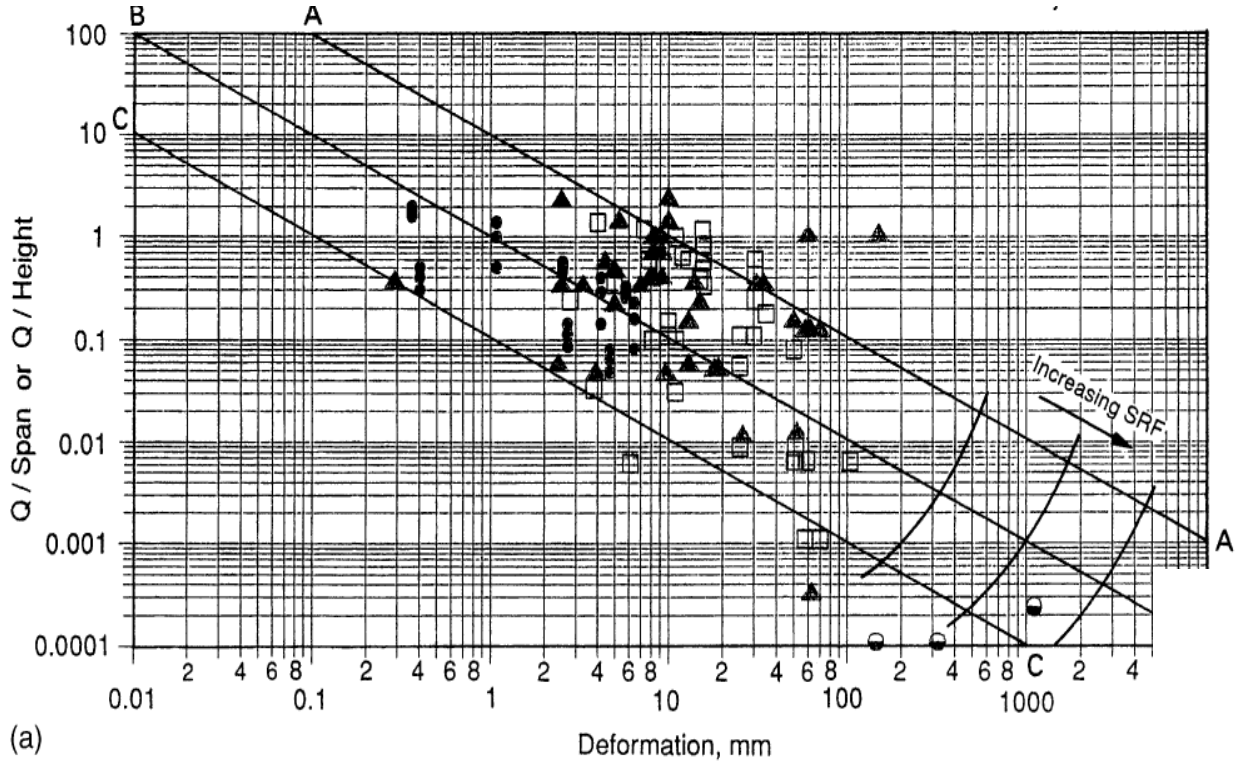


The combination of EDZ 1 and EDZ 2 means ***general deformation***: due to the modulus of intact blocks, joint shear and normal stiffness and strength.









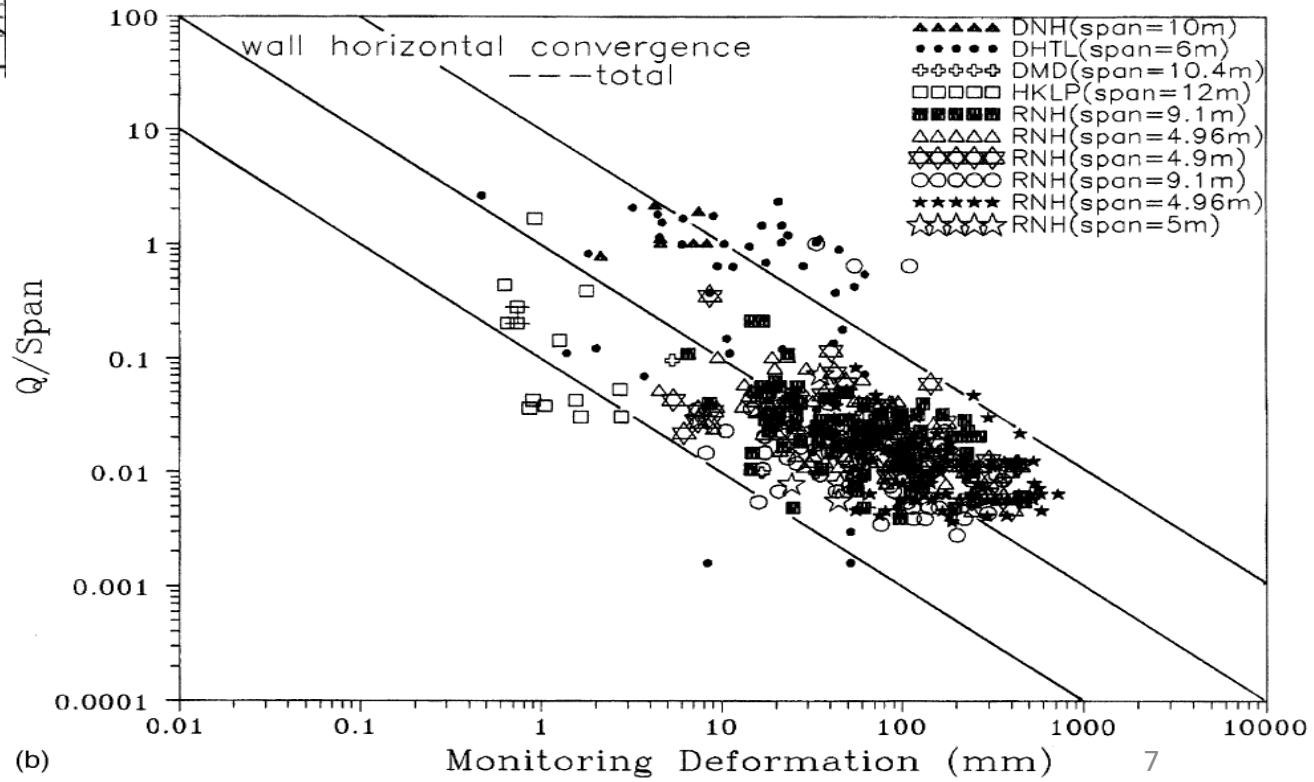
Barton et al. 1994 and later priv. comm. from Taiwan (Chen and Guo, 1996).

CENTRAL DIAGONAL (hundreds of tunnel data):

Δ mm

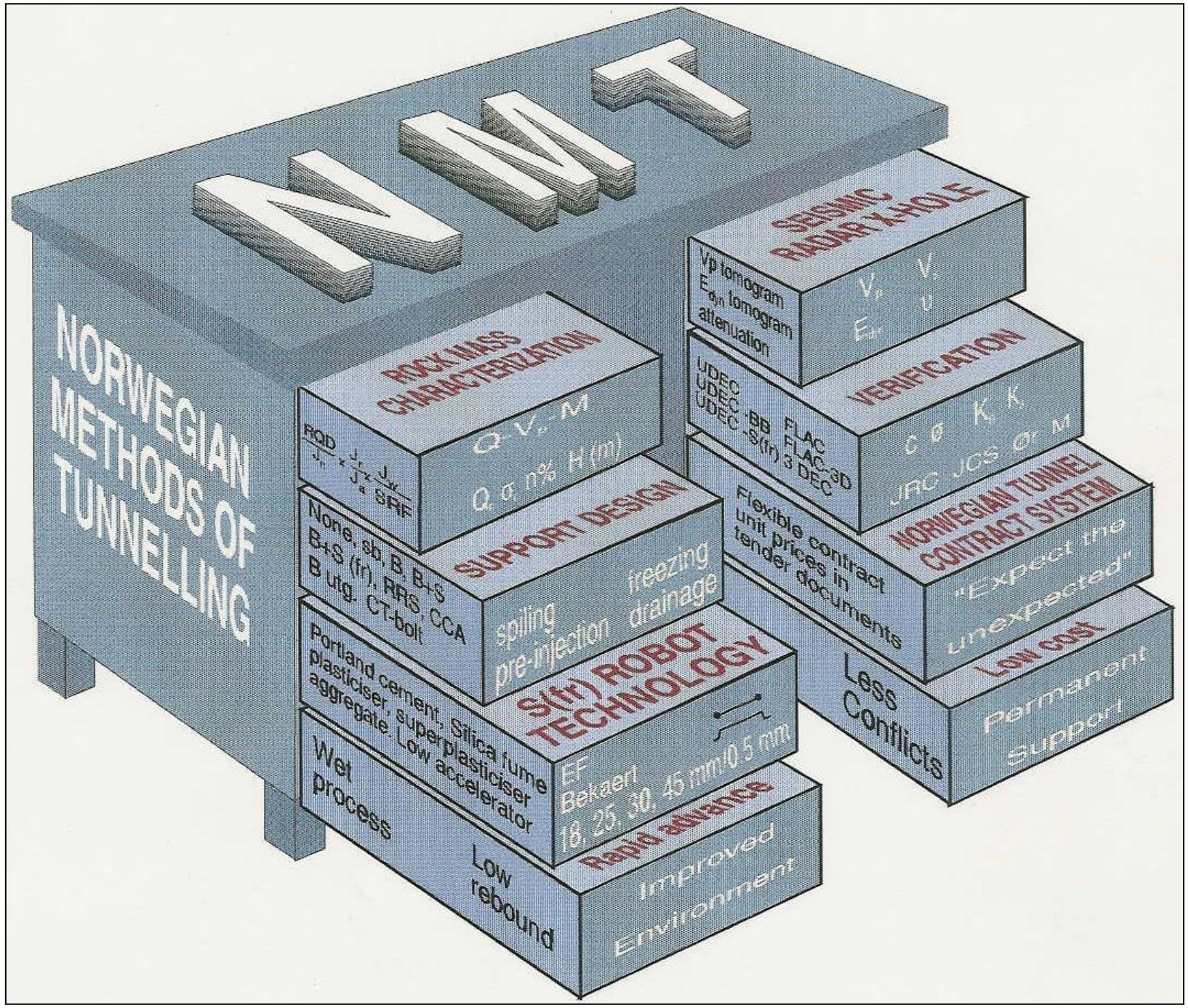
SPAN m

$$\Delta = \frac{SPAN}{Q}$$



NMT IN A NUT-SHELL.....

.....OR IN AN OFFICE DESK



A ‘spatial summary’ of NMT

Barton and Itoh, 1995

SOME DETAILS OF NMT (with Q-logging)

Design

Preliminary design is based on field mapping, drill core logging and seismic interpretation.

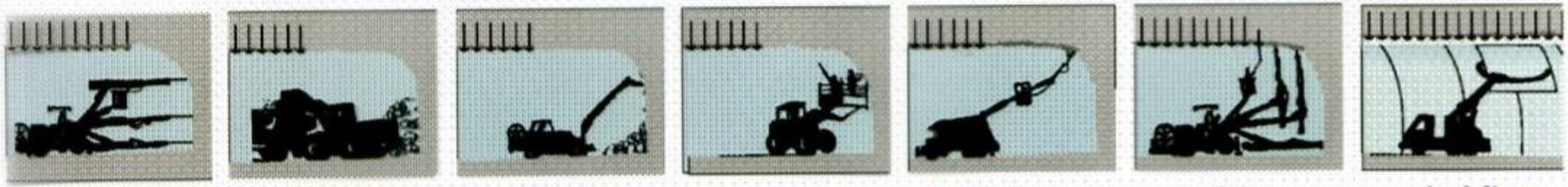
Final support is selected during tunnel construction based on tunnel logging and use of the Q-system support recommendations.

Support

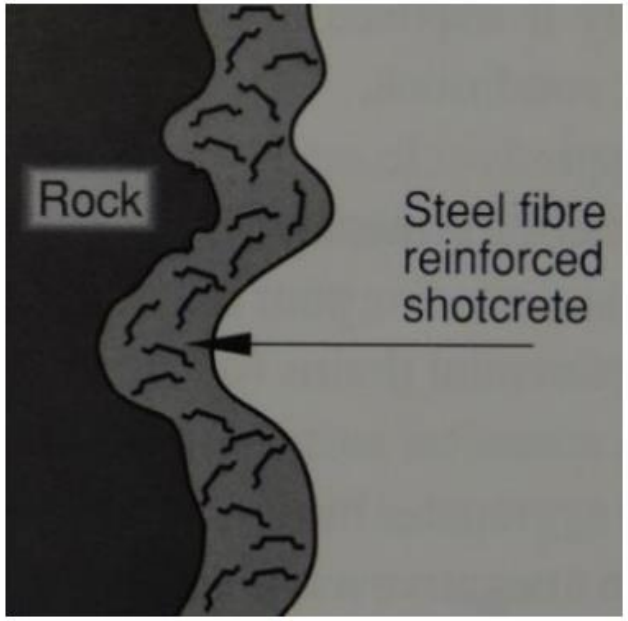
The permanent support usually consists of high quality wet process, fibre reinforced shotcrete and fully grouted, corrosion protected rock bolts.

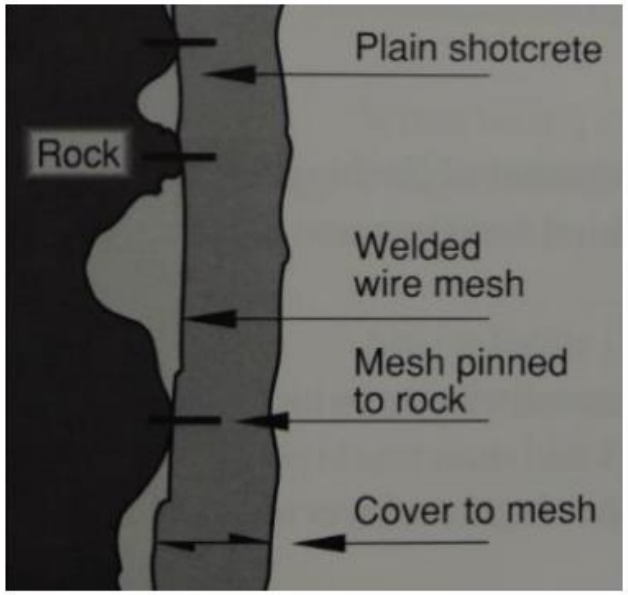
Contract

The owner pays for technically correct support. Needed support is based on the agreed Q-value, and may vary frequently.



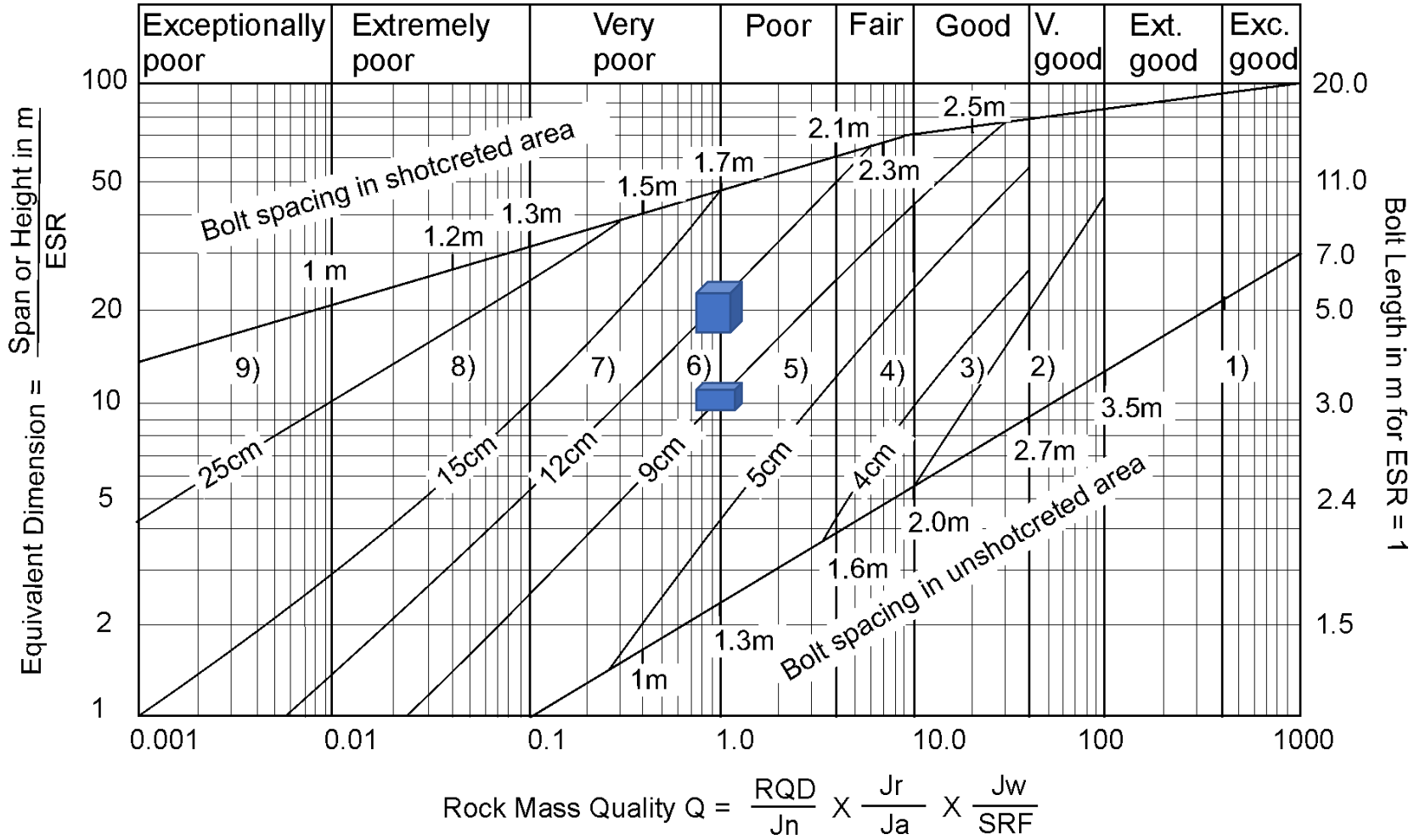
Drilling | Mucking | Pigging | Q-Logging | S (fr) Robot | Bolting | Cladding





Wet process S(fr) used since 1980……

For good reasons



REINFORCEMENT CATEGORIES

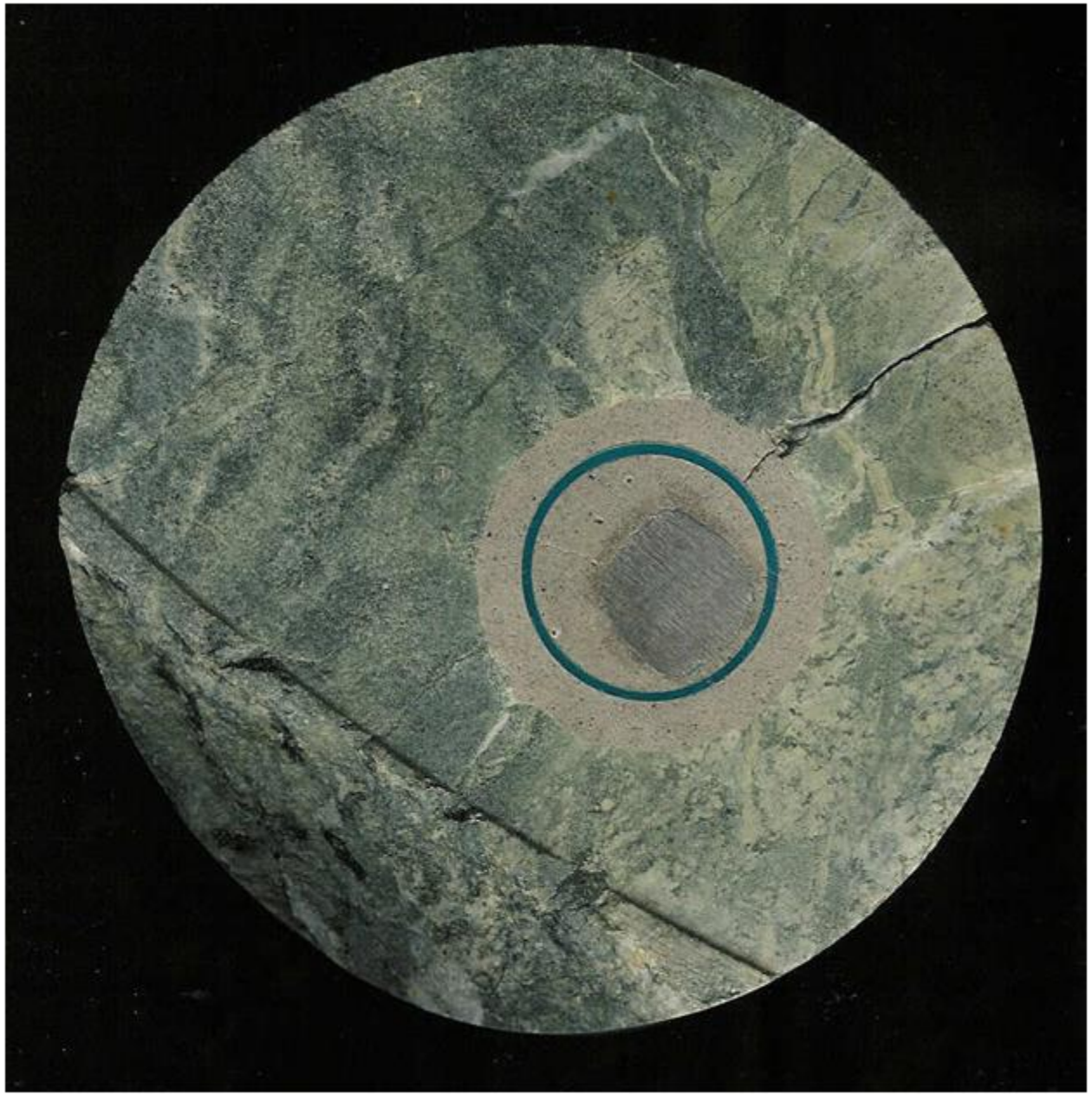
1) Unsupported
2) Spot bolting, sb
3) Systematic bolting, B
4) Systematic bolting (and unreinforced shotcrete, 4-10cm, B(+S)
5) Fiber reinforced shotcrete and bolting, 5-9cm, Sfr+B
6) Fiber reinforced shotcrete and bolting, 9 - 12cm, Sfr+B
7) Fiber reinforced shotcrete and bolting, 12 - 15cm, Sfr+B
8) Fiber reinforced shotcrete > 15cm, reinforced ribs of shotcrete and bolting, Sfr, RRS+B
9) Cast concrete lining,CCA

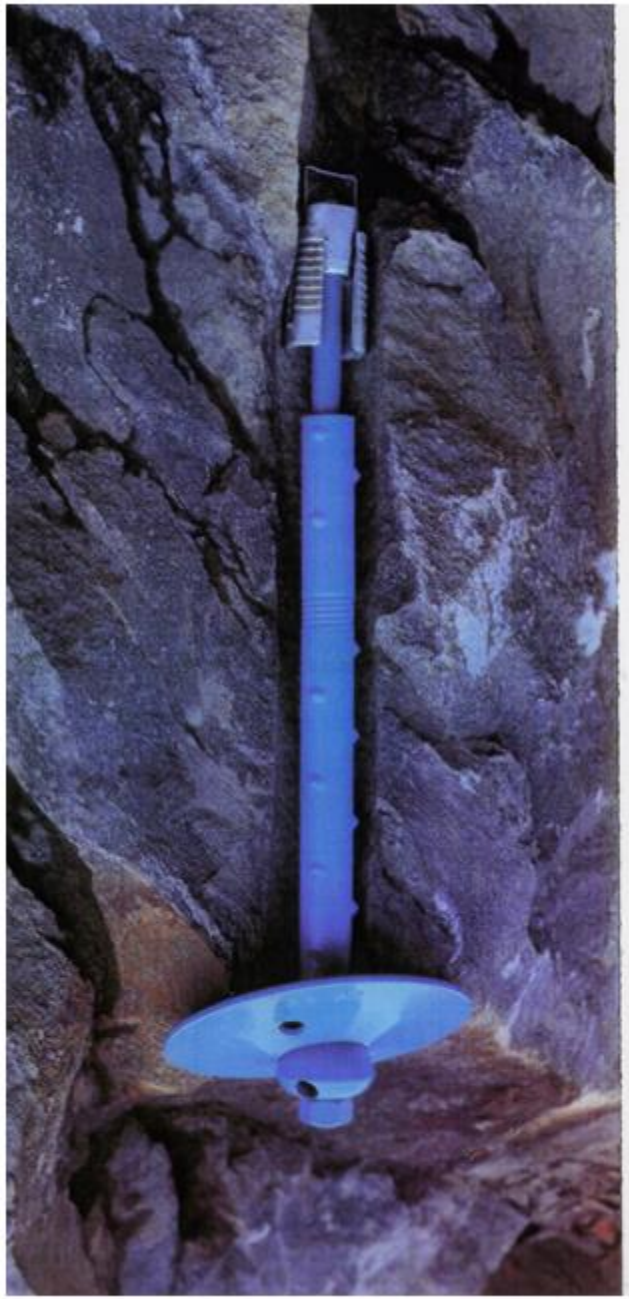
Examples:

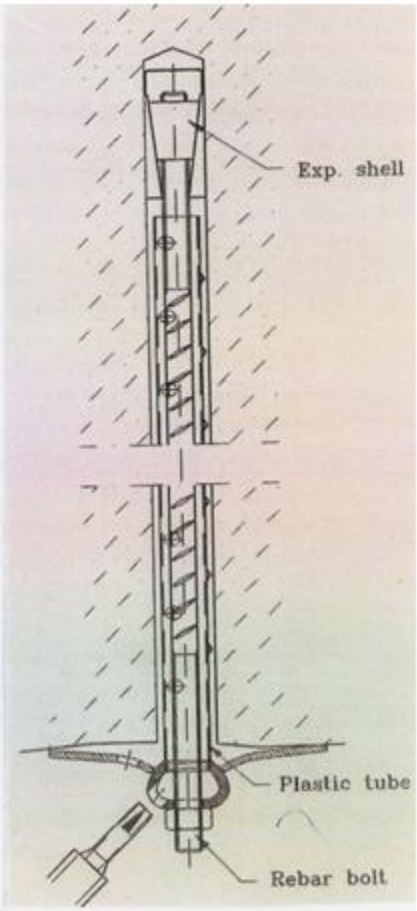
Cavern 20m tunnel 10m: Q = 1

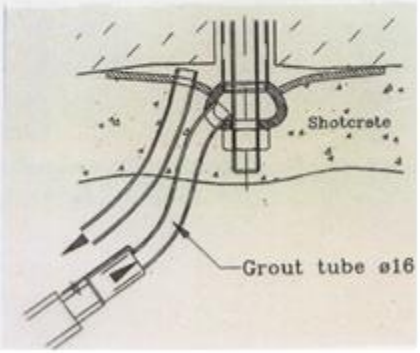
B 1.7m c/c (both) + 12cm or 9cm S(fr).

Grimstad and Barton, 1993

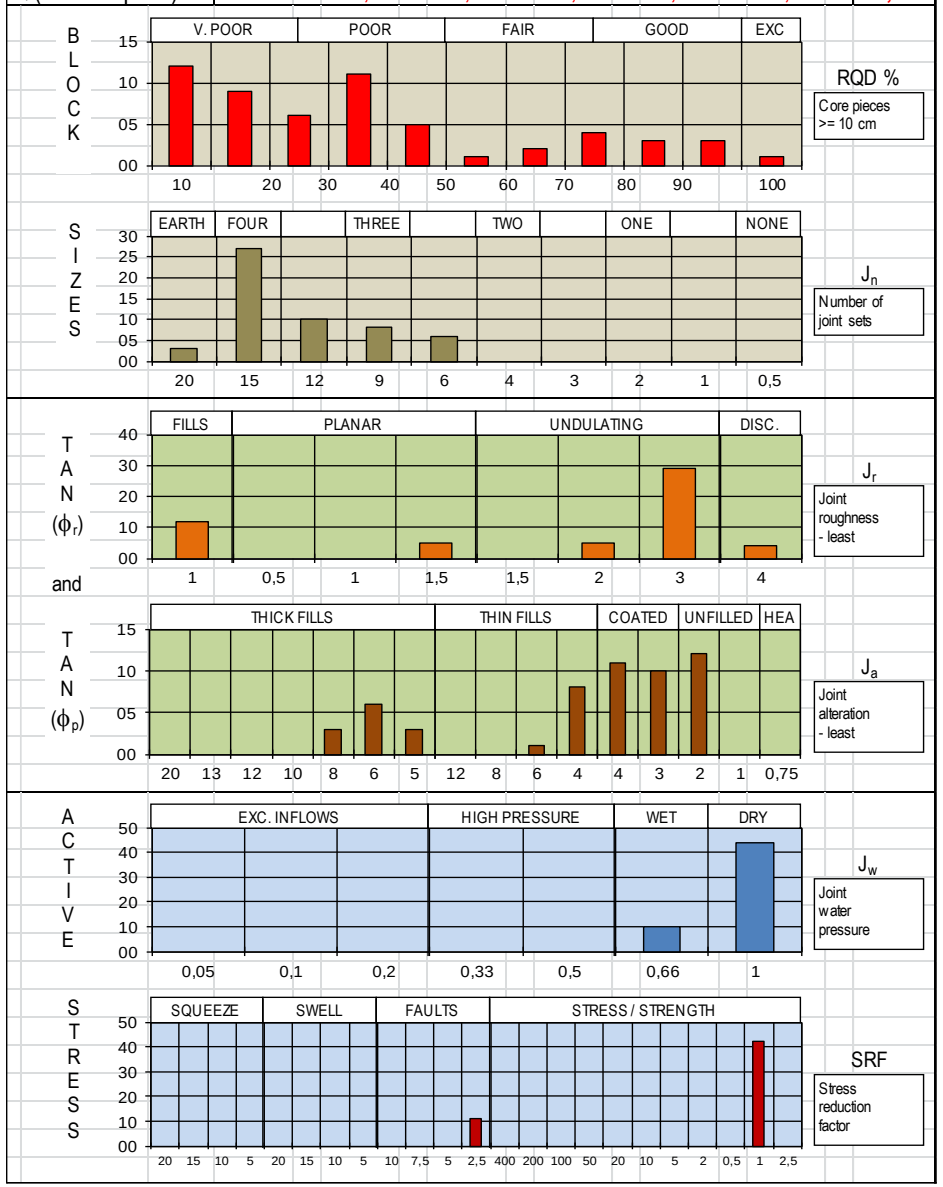





Exp. shell
Plastic tube
Rebar bolt


Shotcrete
Grout tube ø16

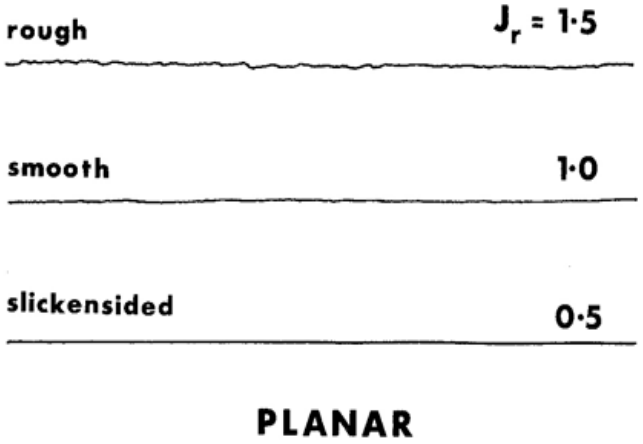
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	10	/	15,0	*	1,0	/	6,0	*	0,66	/	2,5	=	0,029
Q (typical max)=	75	/	6,0	*	4,0	/	2,0	*	1,00	/	1,0	=	25,0
Q (mean value)=	38	/	12,8	*	2,4	/	3,9	*	0,94	/	1,3	=	1,29
Q (most frequent)=	10	/	15,0	*	3,0	/	2,0	*	1,00	/	1,0	=	1,00

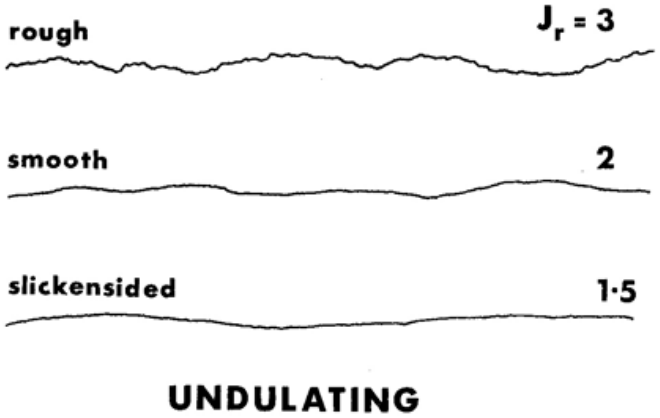


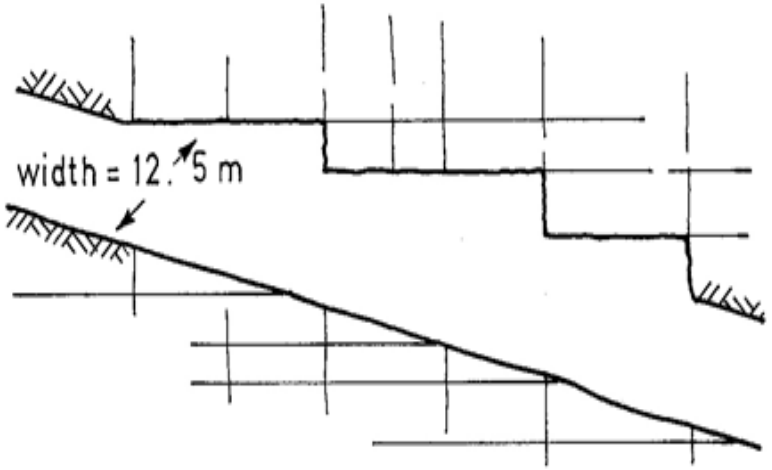
Q IS ONLY PART OF A ROCK MASS DESCRIPTION EXERCISE.

I	**ROCK MASS STRUCTURE**			
1	RQD	Deere et al., 1967)	block size	Q
2	J_n	= joint set number		Q
3	F	= joint frequency (per metre)		
4	J_v	= volumetric joint count (Palmström, 1982)		
5	S	= joint spacing (in metres)		
6	L	= joint length (in metres)		
7	w	= weathering grade (ISRM, 1978)		
8	α/β	= dip/dip direction of joints (Schmidt diagram)		
II	**JOINT CHARACTER**			
9	J_r	= joint roughness number	shear strength	Q
10	J_a	= joint alteration number		Q
11	JRC	= joint roughness coefficient		
12	a/L	= roughness amplitude of asperities per unit length (mm/m)		
13	JCS	= joint wall compressive strength		
14	ϕ_r	= residual friction angle		
15	r,R	= Schmidt rebound values for joint and rock surfaces		
III	**WATER, STRESS, STRENGTH**			
16	J_w	= joint water reduction factor	active stress	Q
17	SRF	= stress reduction factor		Q
18	K	= rock mass permeability (m/s)		
19	σ_c	= compressive strength		
20	σ_1	= major principal stress		

THE DUAL ROLES OF Jn (number of sets) and Jr (roughness)

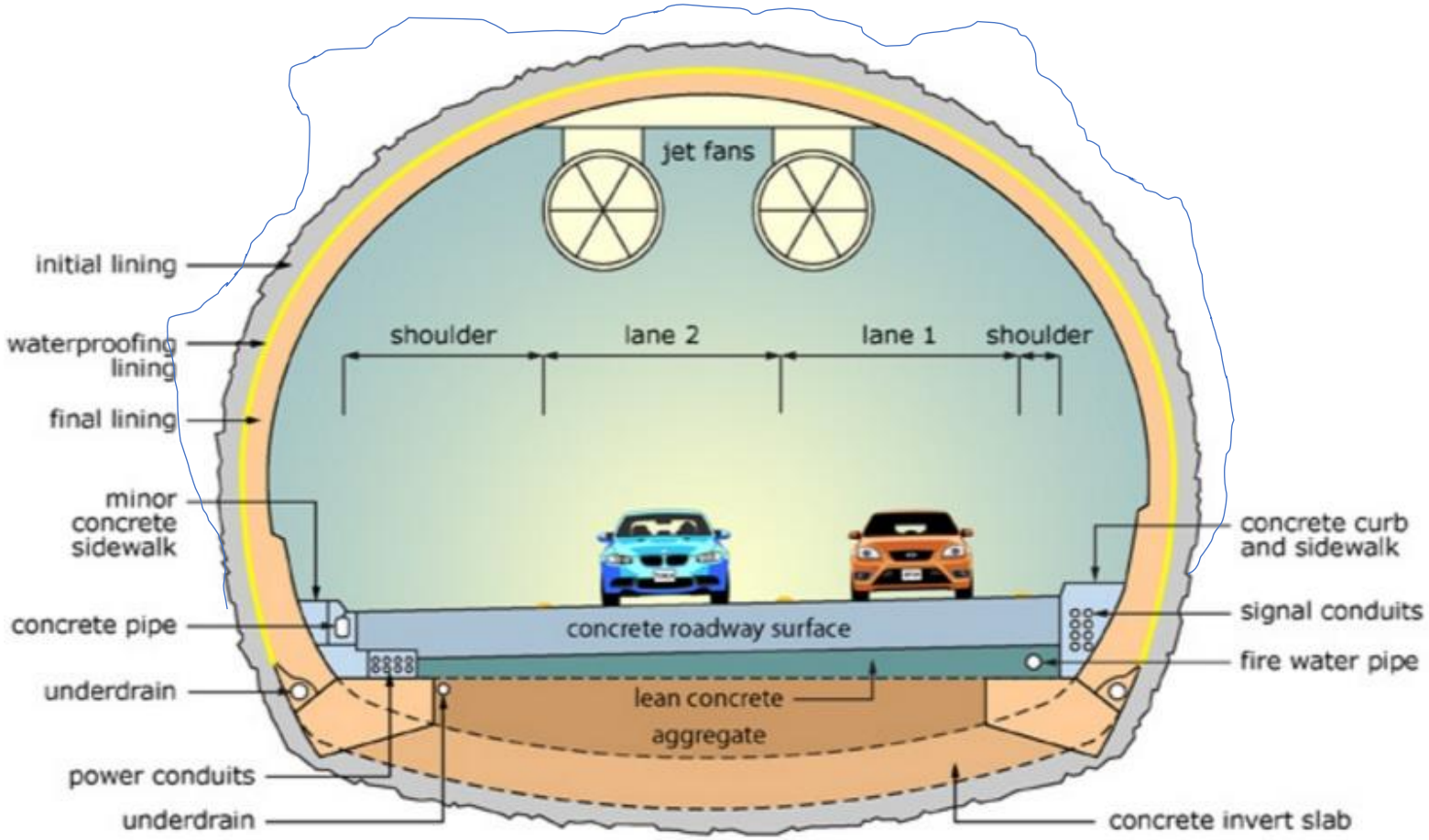






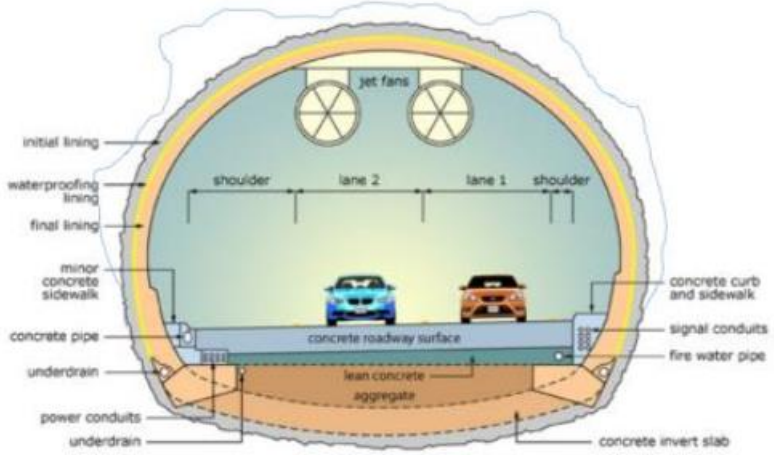
4/2, 6/2, 9/2, 9/3, 12/3, 15/3…….6/1, 9/1.5, 12/2, 15/2 (Jn/Jr ≥ 6)

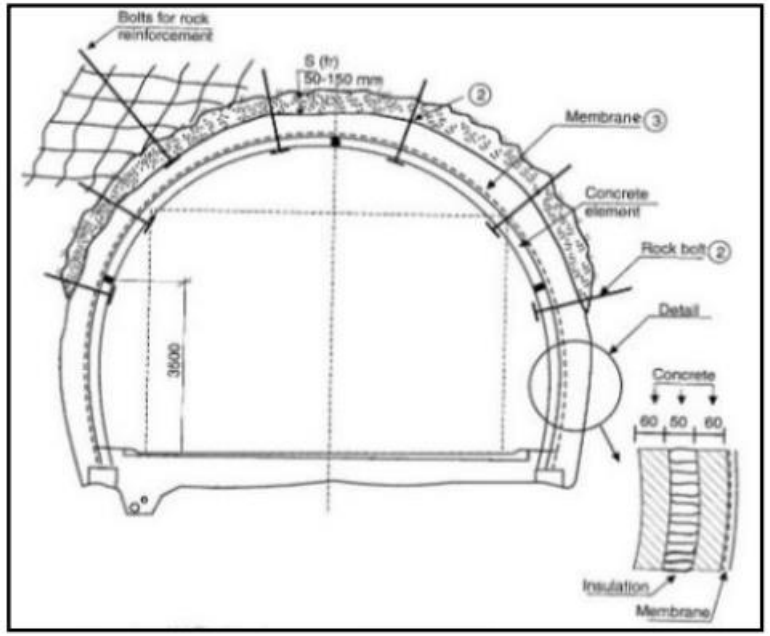
Over-break ignored in drawings, stability, volumes?

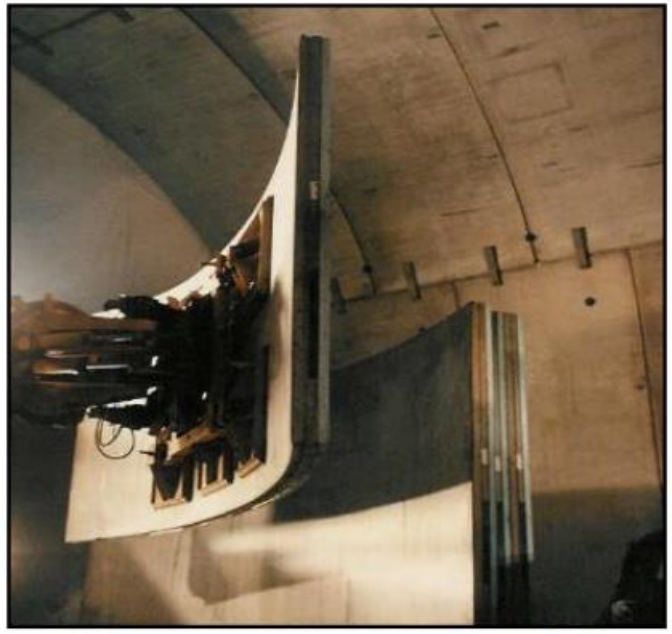


A Botniabanen tunnel, Sweden.

Over-break not an issue. B+Sfr solves it: IMPROVED economy.

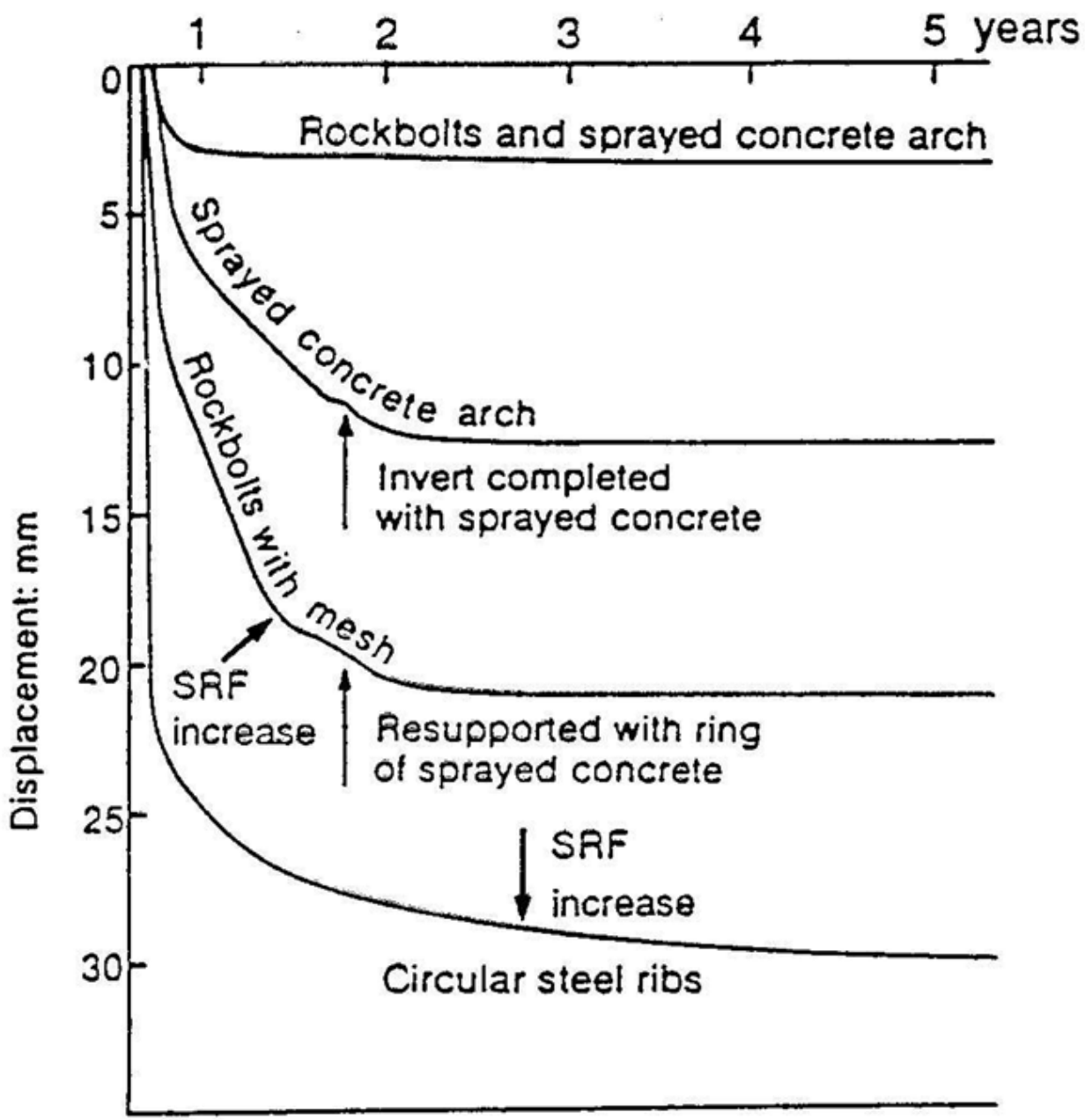


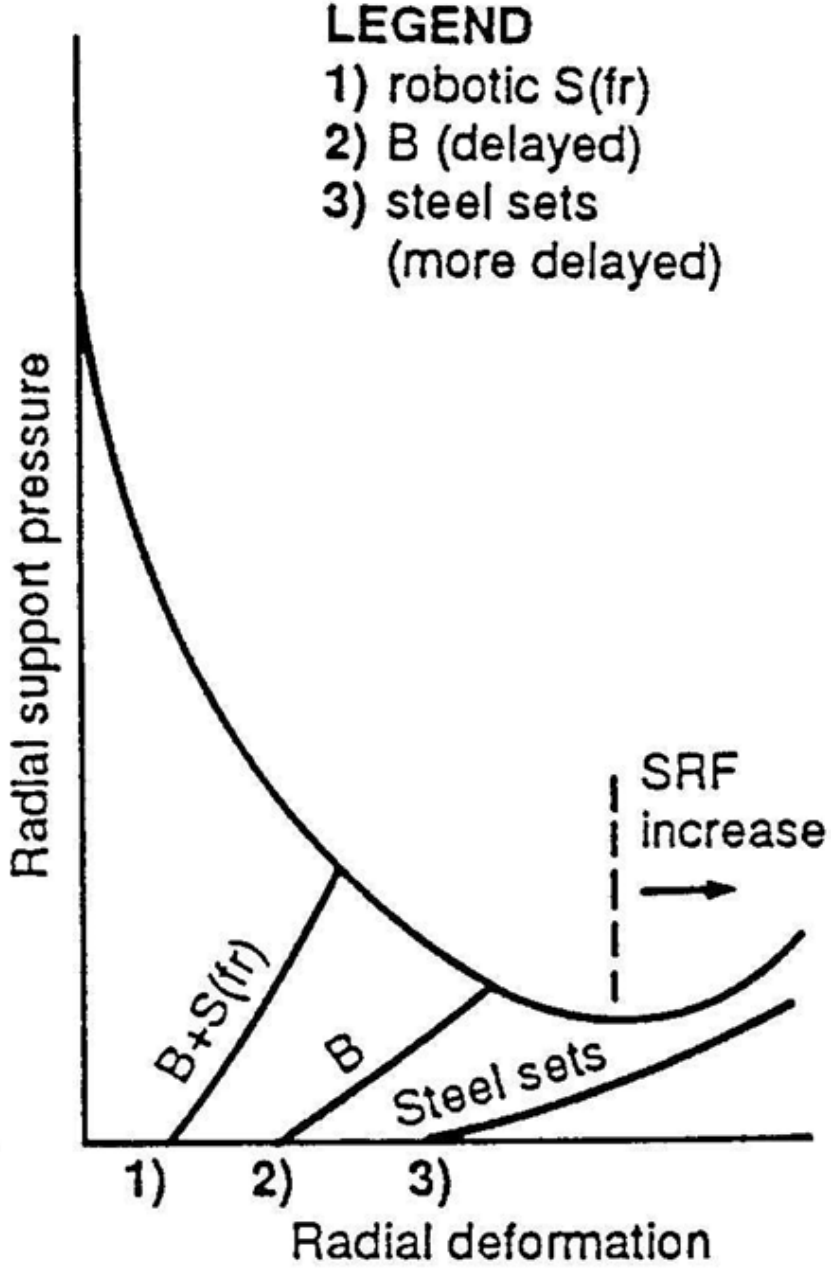


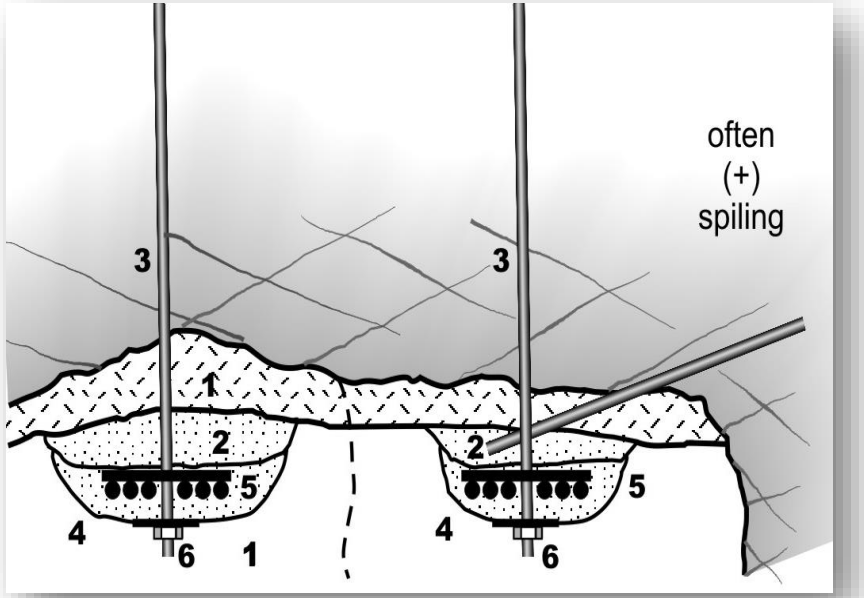


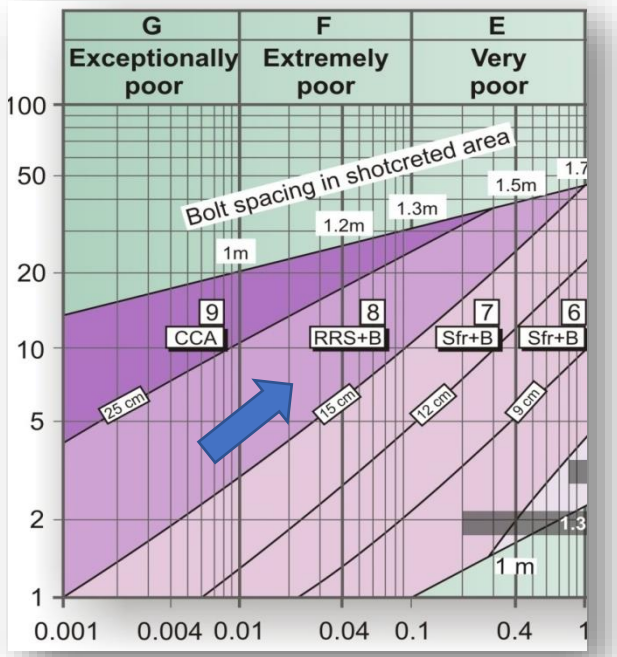
Over-break is usually the reality in jointed rock.

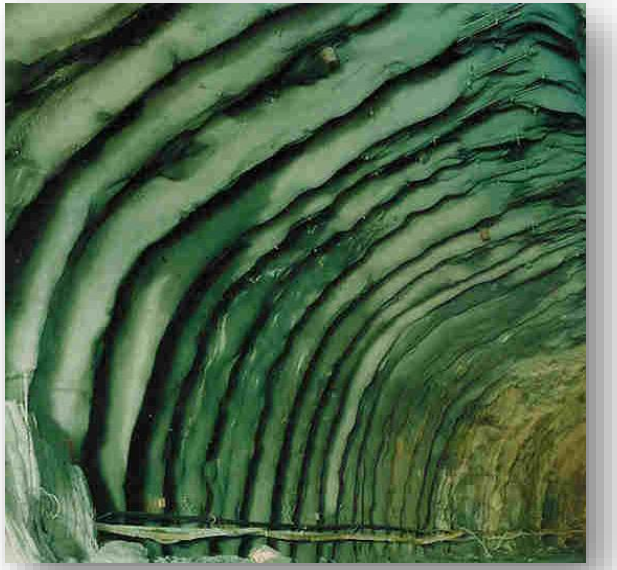
Concrete volume comparison (and CO2 footprint) does not favour NATM


1
2
3
4
5 years
0
5
10
15
20
25
30
Displacement: mm
Rockbolts and sprayed concrete arch
Sprayed concrete arch
Invert completed
with sprayed concrete
Rockbolts with mesh
SRF
increase
Resupported with ring
of sprayed concrete
SRF
increase
Circular steel ribs


LEGEND
1) robotic S(fr)
2) B (delayed)
3) steel sets
(more delayed)
Radial support pressure
SRF
increase
B+S(fr)
B
Steel sets
1)
2)
3)
Radial deformation

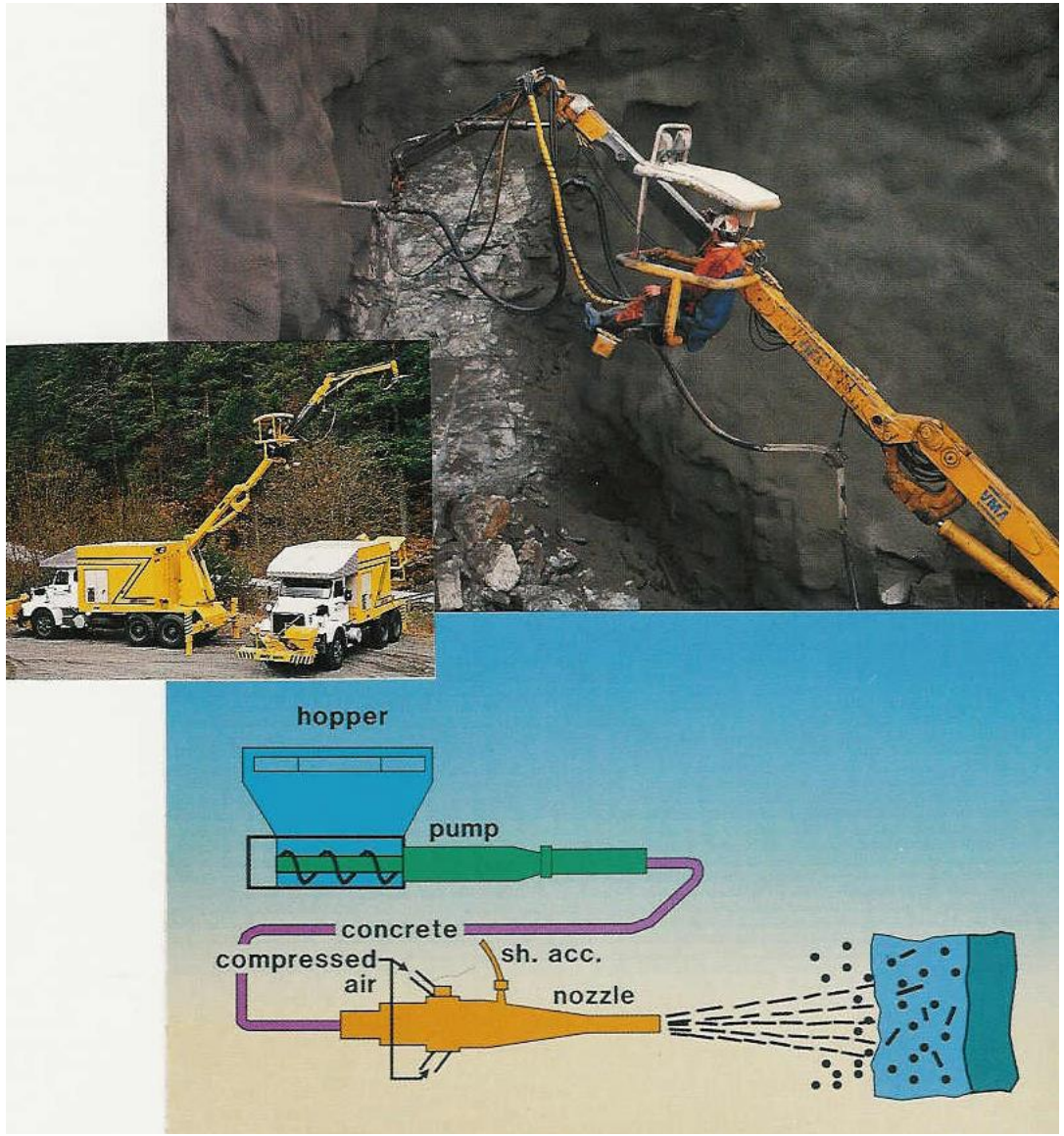


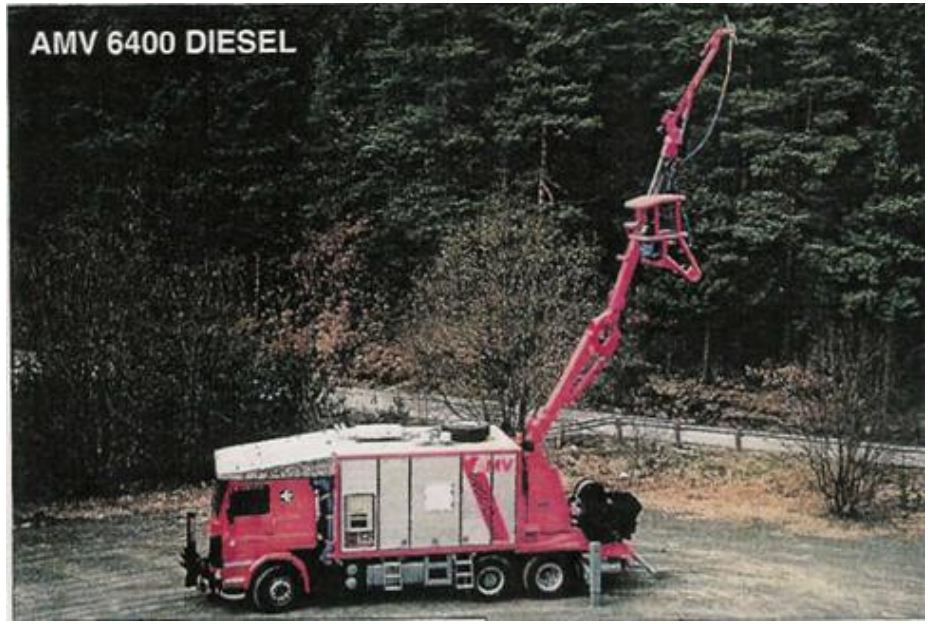




RRS is a flexible (until bolted) 'lattice' girder used in NMT.

3D effect because of S(fr) arches.





Portland cement (c)	450 – 550 kg/m³
Silica fume (s)	3 – 10 % of cement weight
Aggregate	0 – 10 mm
Plasticizer	0.3 – 1.0 % of cement weight
Superplasticizer	0.3 – 1.0 % of cement weight
Steel fibre	50 kg/m³ (dependent on toughness requirements)
Water/(c+s)	0.40 – 0.45
Slump	15 – 18 cm
Air content	< 4%
Temperature	15 – 20 °C

DETAILS of S(fr) and robots from 1990's contractor brochure.

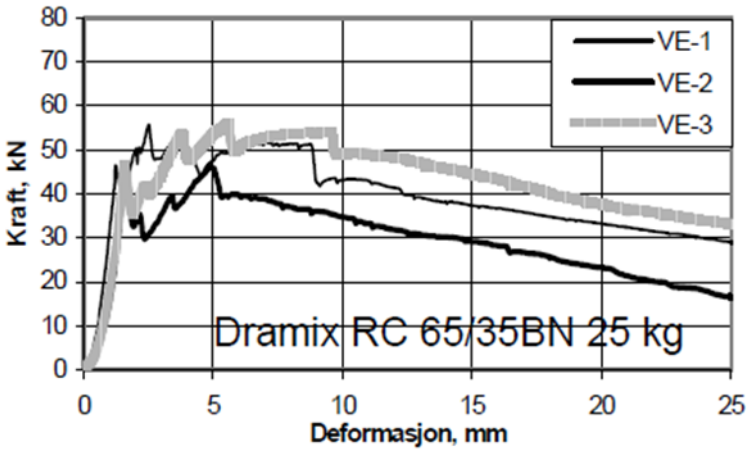
Nowdays 25-35kg of steel fibre, or 6-8kg of PP fibre.

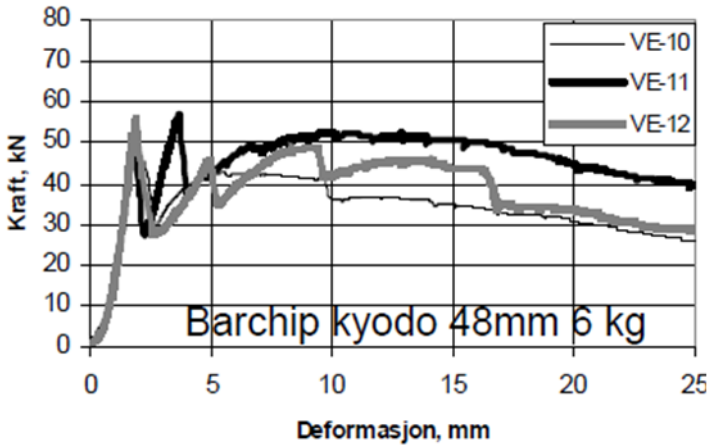
Fracture energy selections:

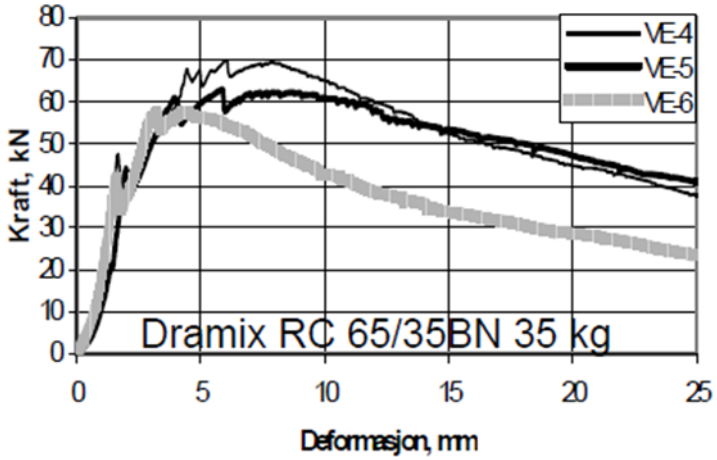
- E500 15-18kg steel fibre or 5kg PP fibre
- E700 20-25kg steel fibre or 6-7kg PP fibre
- E1000 30-35kg steel fibre or 8kg PP fibre

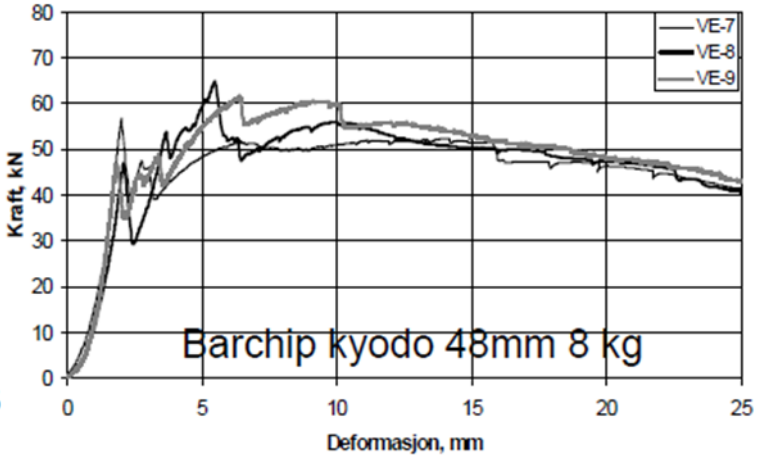
Left: AMV shotcrete robots

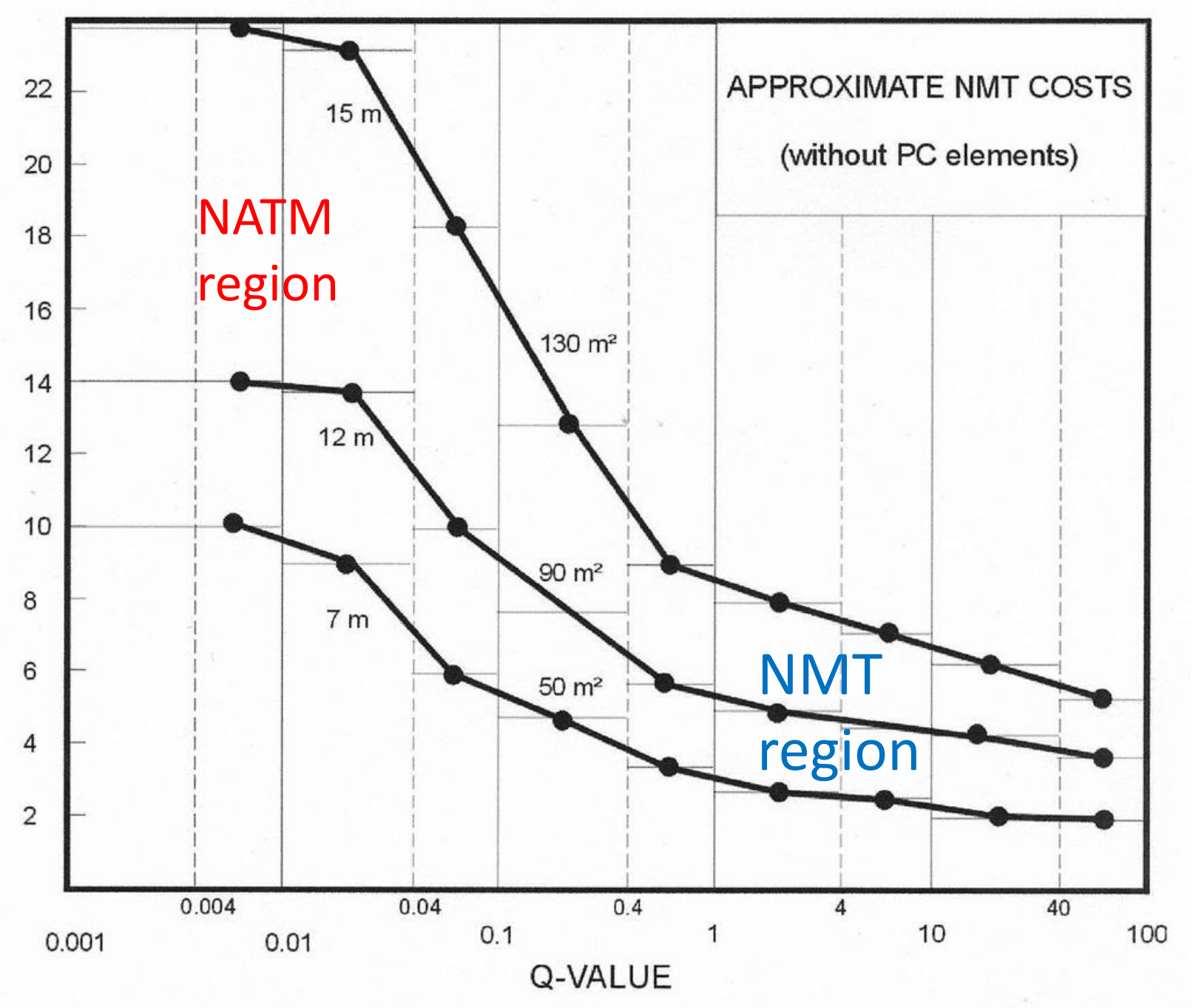
Dramix-Barchip fracture energy comparison below.











The expected Q-value range has a big influence on *(the correct)*.....

tunnelling method and cost.

Water control !

With a curved (tunnel) perimeter of about 30m there will be the *need for 12 to 15km of membrane welds per running kilometer of tunnel* (!)

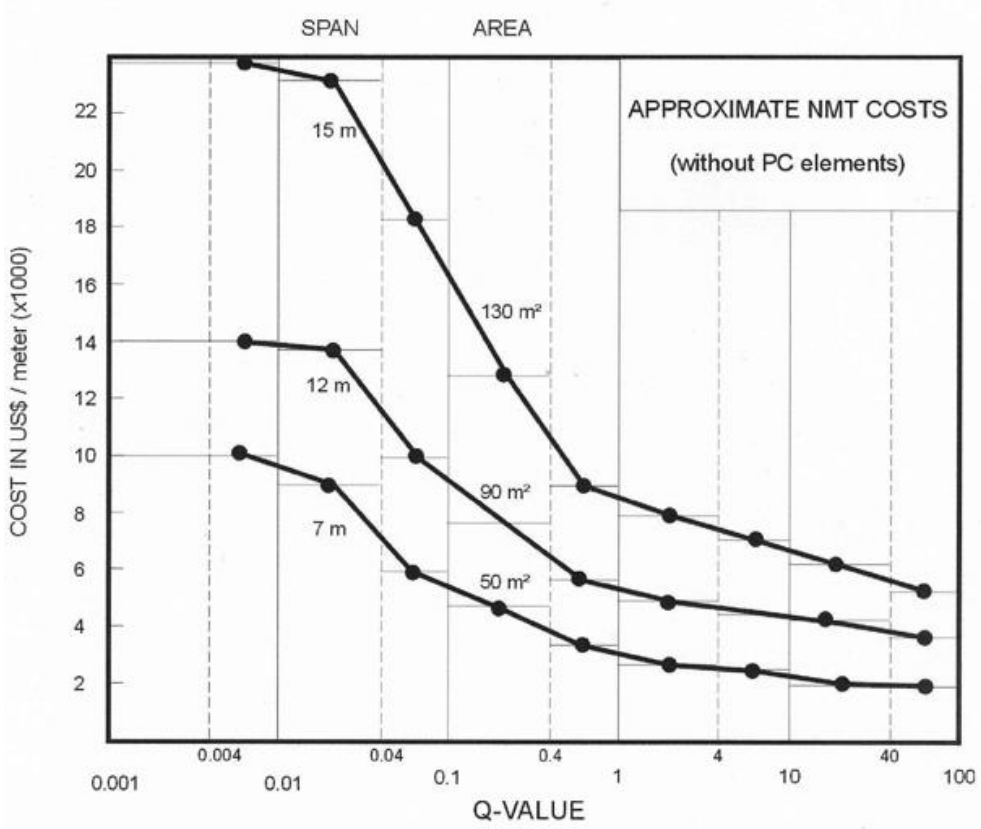
If membrane leakage should occur and enter the tunnel via a shrinkage crack in the concrete, the actual leakage location will not be detectable, so post-injection will likely fail.

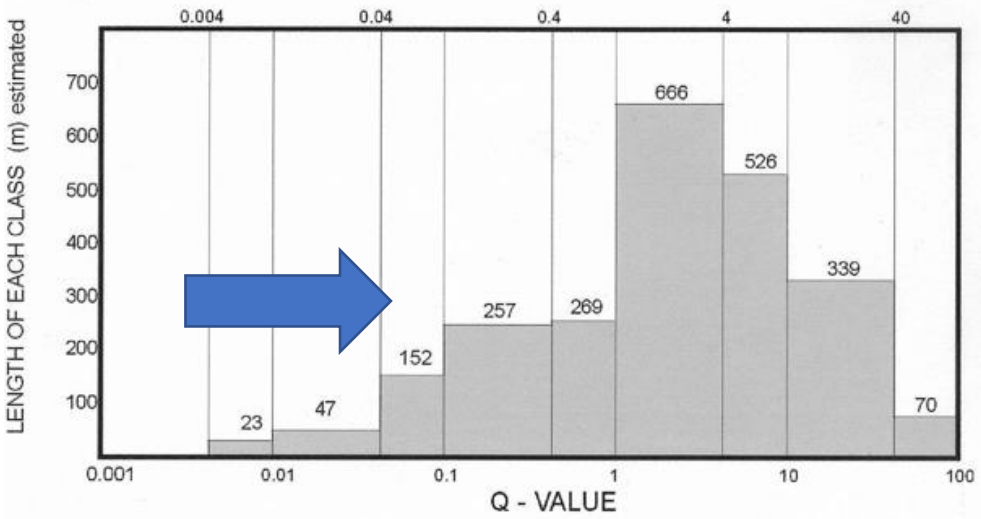
NMT (single-shell) tunnels even with

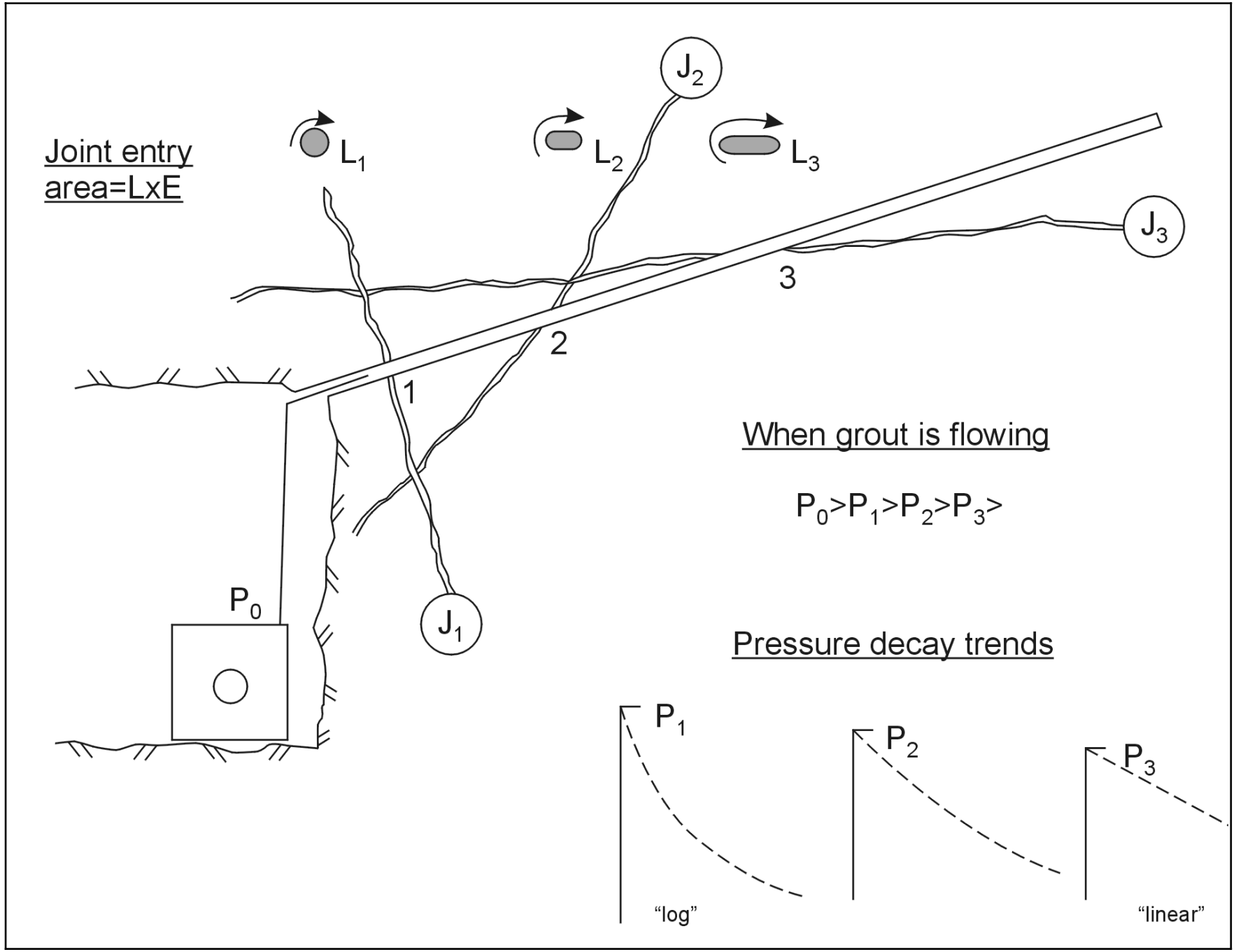
systematic pre-injection (for kilometers),

are still much cheaper than NATM.

Pre-inject (correctly) to remove most of low quality rock mass *(here Q-logging in uniformly spaced cored holes)*

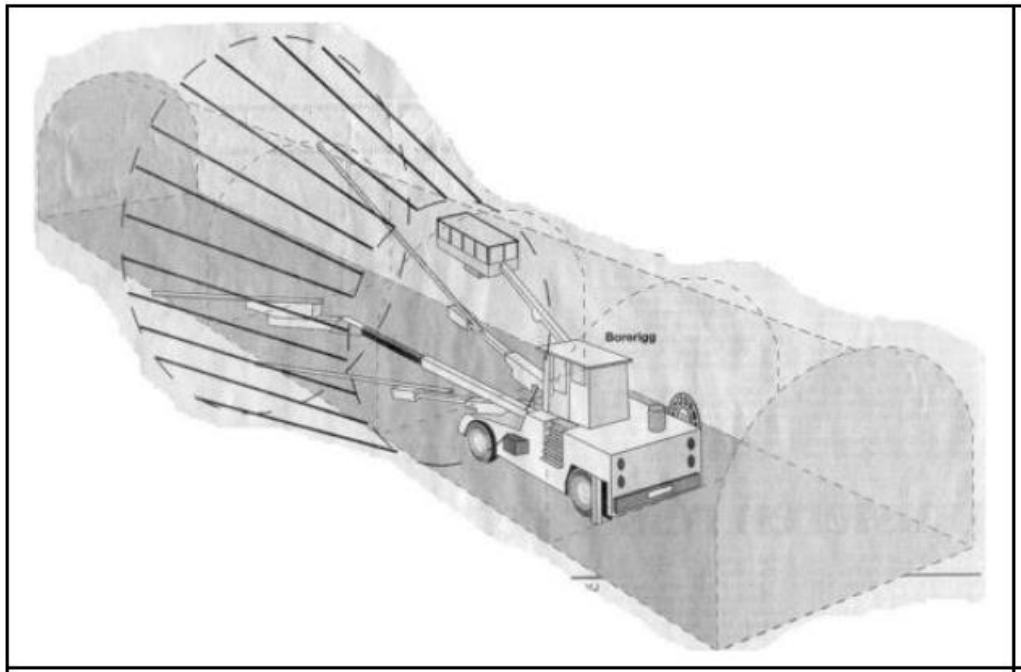






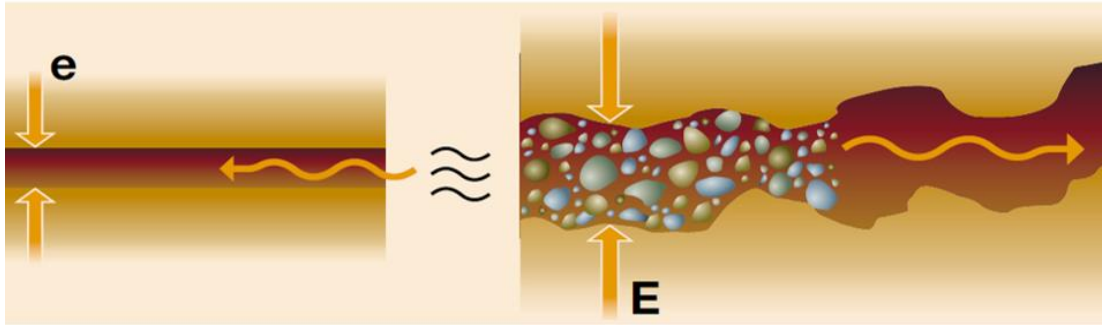
Pre-grouting will not be successful at too low pressures.

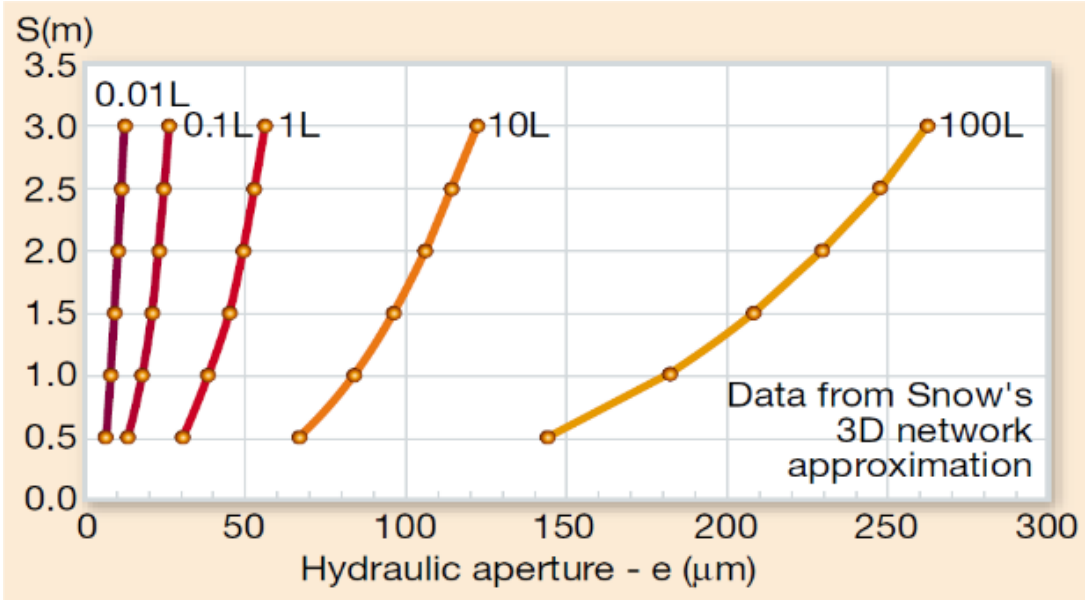
Rapid pressure decay: >50% loss within 1m of hole!

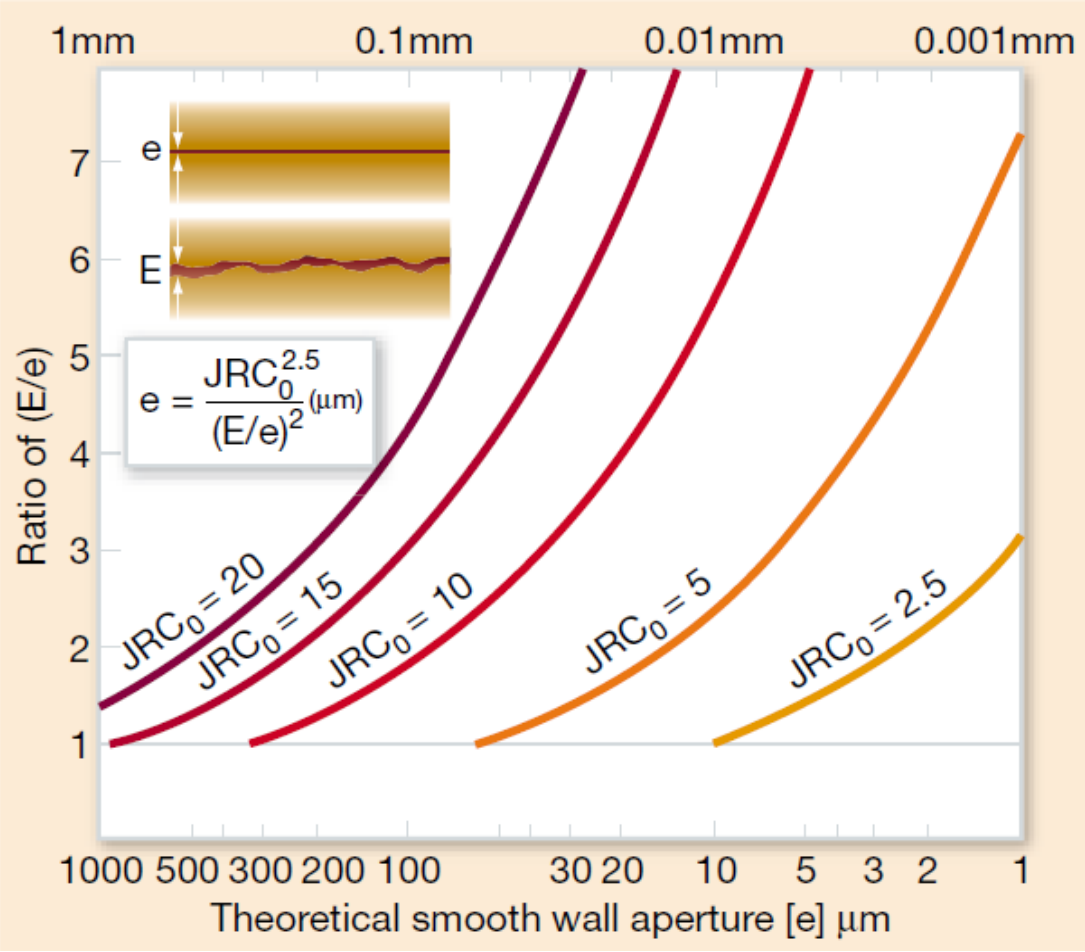


Pre-injection umbrella, and singular local post-injections.

Bærum Tunnel
q < 1 to 2 l/min/100m.







JRC$_{mean}$	***3.5***	***7.5***	***12.5***	***17.5***
	Jr = 1	***Jr = 1.5***	***Jr = 2***	***Jr = 3***
(e) µm	***E µm***	***E µm***	***E µm***	***E µm***
45	**45**	**80**	**160**	**240**
75	**75**	**110**	**200**	**310**
90	**90**	**120**	**220**	**340**
160	**160**	**160**	**300**	**450**

To finish. An extreme case of overbreak.

In NMT void is not filled with concrete.

In NATM over-break is filled with concrete