Norwegian Tunnelling Technology Workshop in Singapore 17-18 February 2009

Support Design and Documentation during Tunnelling

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NGI

Content

- Main principles of the Norwegian tunnelling
- Rock mass classification with the Q-system
- Support design
- Energy absorption and ribs of sprayed concrete
- Documentation during excavation

Tunnels in Norway

- 700 railway tunnels

Total 285 km railway tunnels

Longest railway tunnel 14,5 km

- 914 road tunnels

Total 802 km road tunnels + twin tube

Longest road tunnel 24,5 km

(longest in the world)

- About 4000km of hydropower

tunnels. More than 200 underground

power houses

NMT- Norwegian Method of Tunnelling
Norwegian Tunnelling Technology

- Mainly in hard rock ($\sigma_{c\,=}$ 3-300 MPa)
- Mainly drill and blast, but also TBM
- Rock Mass Classification with the Q-system
- Rock support mainly Sfr + B and RRS
- Temporary support forms part of permanent support
- Design as you go based on the Q-system++
- Drained solutions. Pregrouting in built up areas and subsea
- Sfr single shell as final lining + B for rock support
- Water shielding and frost protection
- Ventilation, illumination, security installations

NMT-priciples

Difference between NATM and NMT

NMT

- Most appropriate for hard rock
- Temporary support based on rock mass classification (Q-system ++)
- Monitoring when deformation is expected
- Fibre reinforced sprayed concrete + rock bolts +RRS as temporary and permanent support
- Temporary support+supplement and water shielding act as permanent support
- Drainage +ventilation+illumination
- **Cost 4,000 -9.000 Euro/m tunnel**

NATM

- Most appropriate for soft ground
- Temporary support based on 5 or 6 classes (deformation and hardness)
- Monitoring of deformation
- Steel sets +lattice girders + sprayed concrete as temporary support
- Permanent support is pre designed
- Watertight membrane
- Cast concrete lining including the invert as final support
- Ventilation+illumination
- **Cost 21.000-50.000 Euro/m tunnel**

Basis for decision of rock support

- The rock should be a part of the construction
- Various background experience (tomb rules, practice etc.)
- Systematic rock mass classification
- Numerical analysis
- Geological conditions
- Variation in stability
- Various application of the underground structure
- Required level of safety and durability

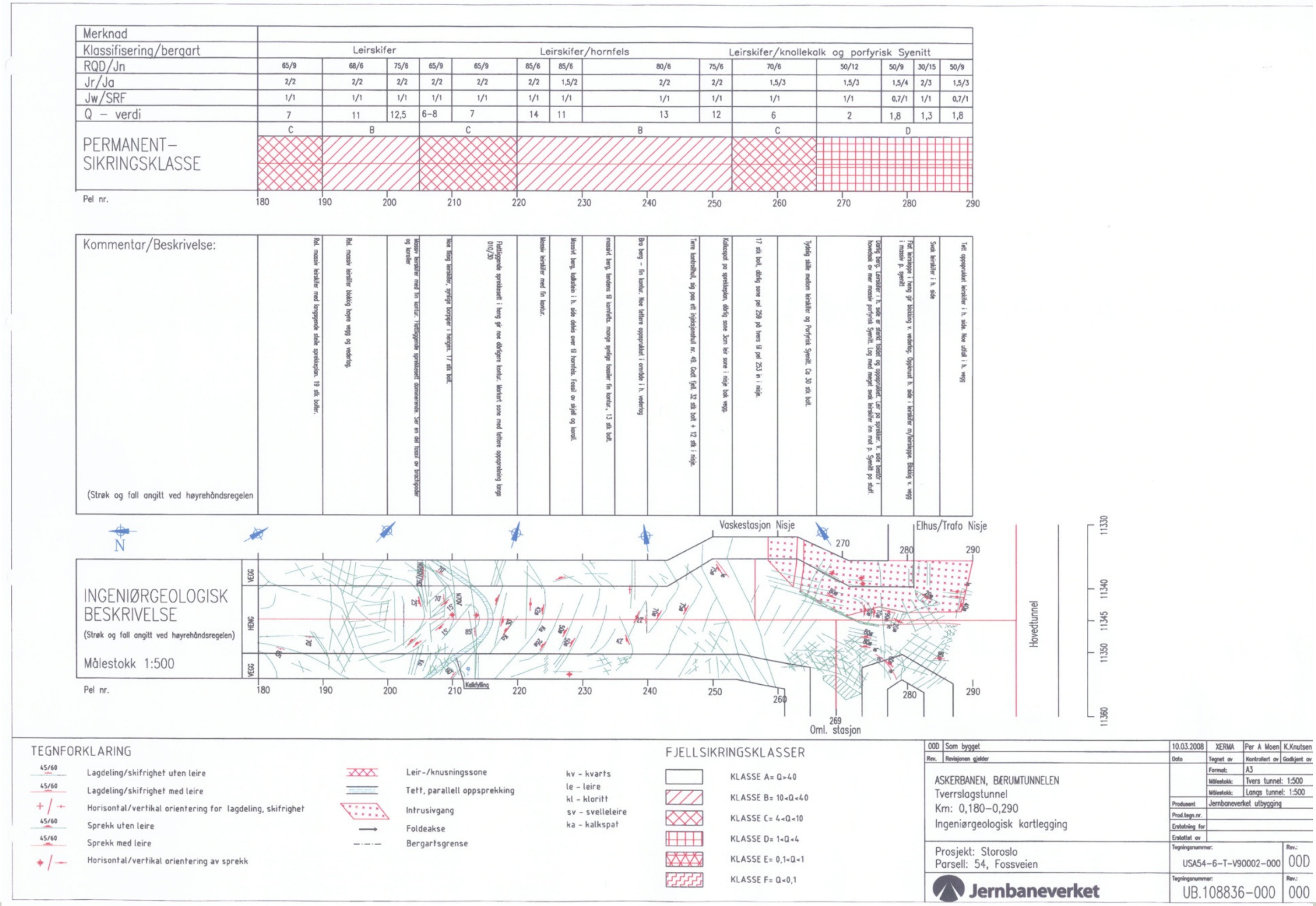
Preinvestigations with Q-system

- Some of the parameters may be uncertain in the terrain, but will give a god tool for rock mass classification
- RQD, J_n og J_r are normally raliable in the terrain
- Joint frequency and weathering increase towards the surface
- J_a and J_w are often difficult to map in the terrain (J_a OK in fresh rock cuttings)
- SRF has to be estimated from topography, overburden and knowledge about rock stress in the area. Stress measurements may be performed.
- Q-values, (also J_w from water loss tests) from core logging

Rock mass classification in tunnels

- Mapping before spraying of concrete
- Has to be done from a platform or basket close to the crown and face
- General geological mapping– rock types, structures, joint geometry, orientation of weakness zones, width, mineral filling etc.
- Map sections of the tunnel with uniform Q-values if many rounds are available at the same time before spraying
- Large single blocks, long joints parallel to the tunnel etc., has to be evalutaed in addition to the general rock mass classification

Tunnel map with Q-values and support classes



Estimation of Q-values from drill cores

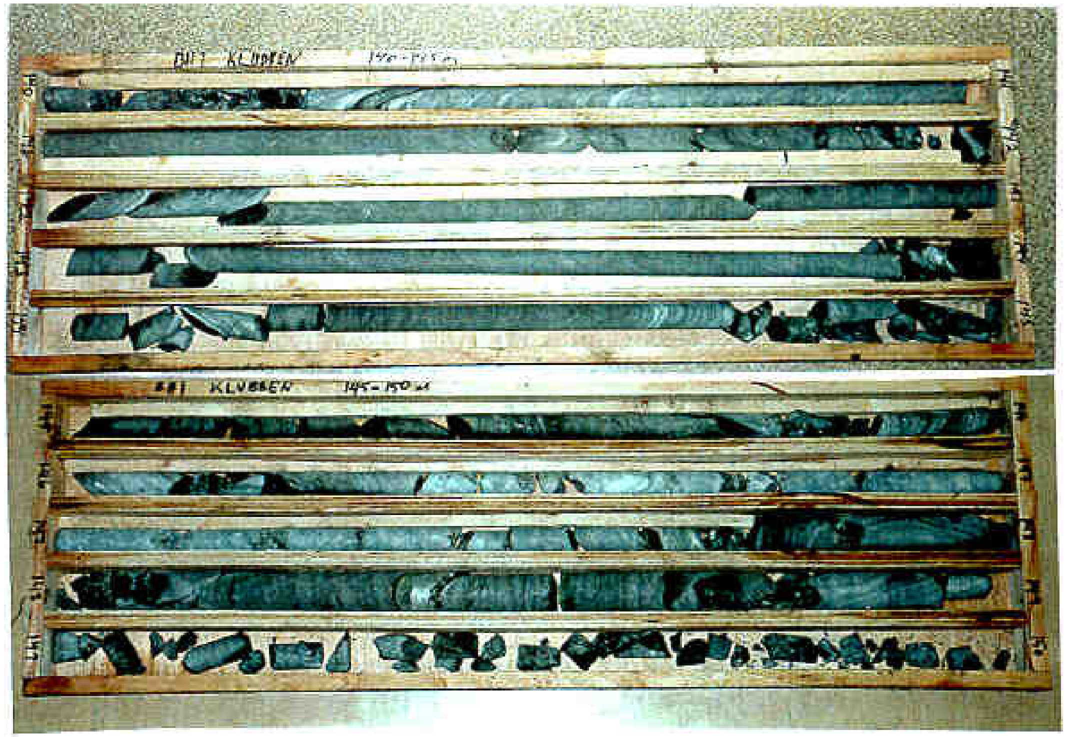
RQD

Jn (longitudinal joints under-representative)

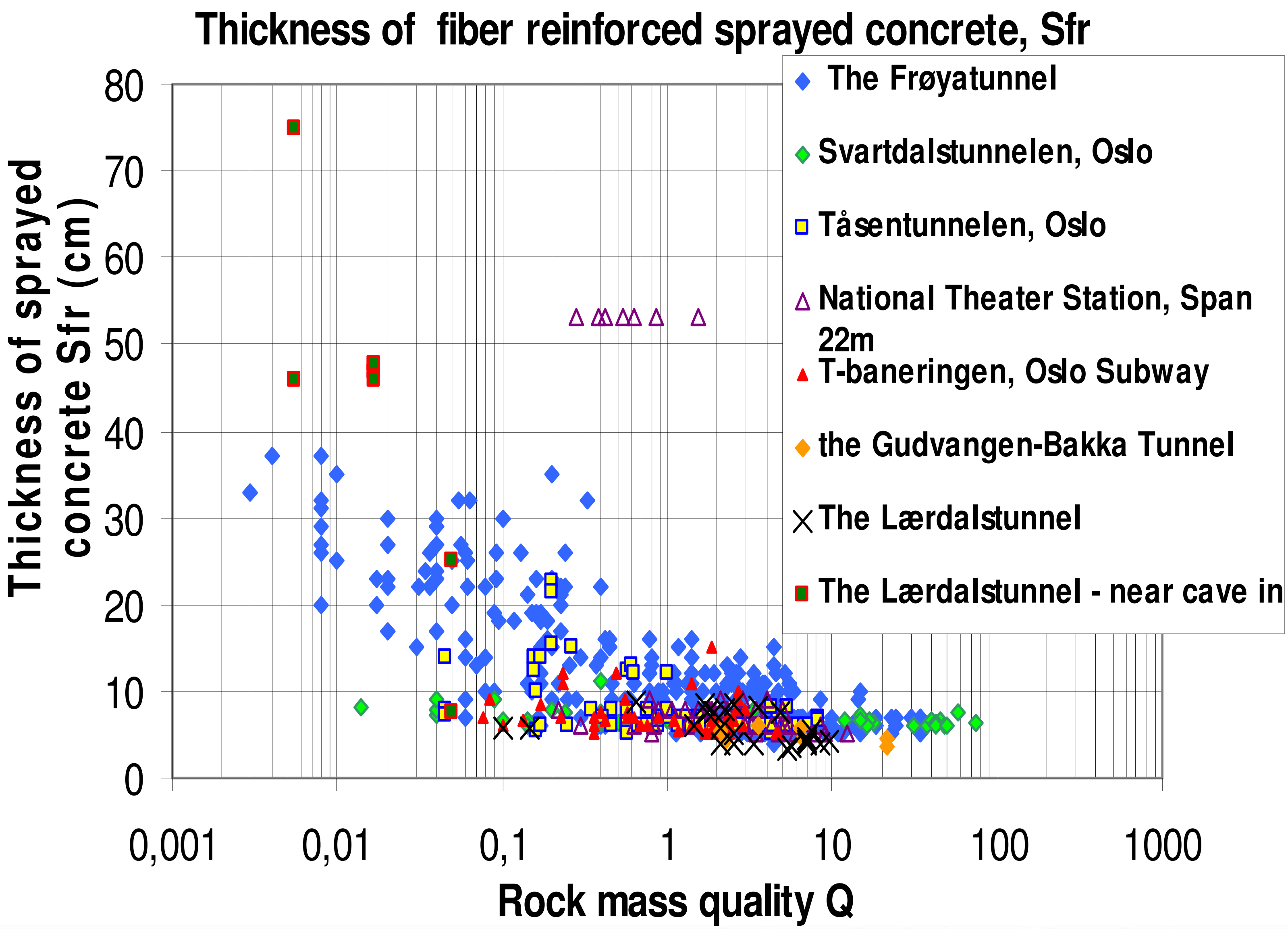
Jr

Ja

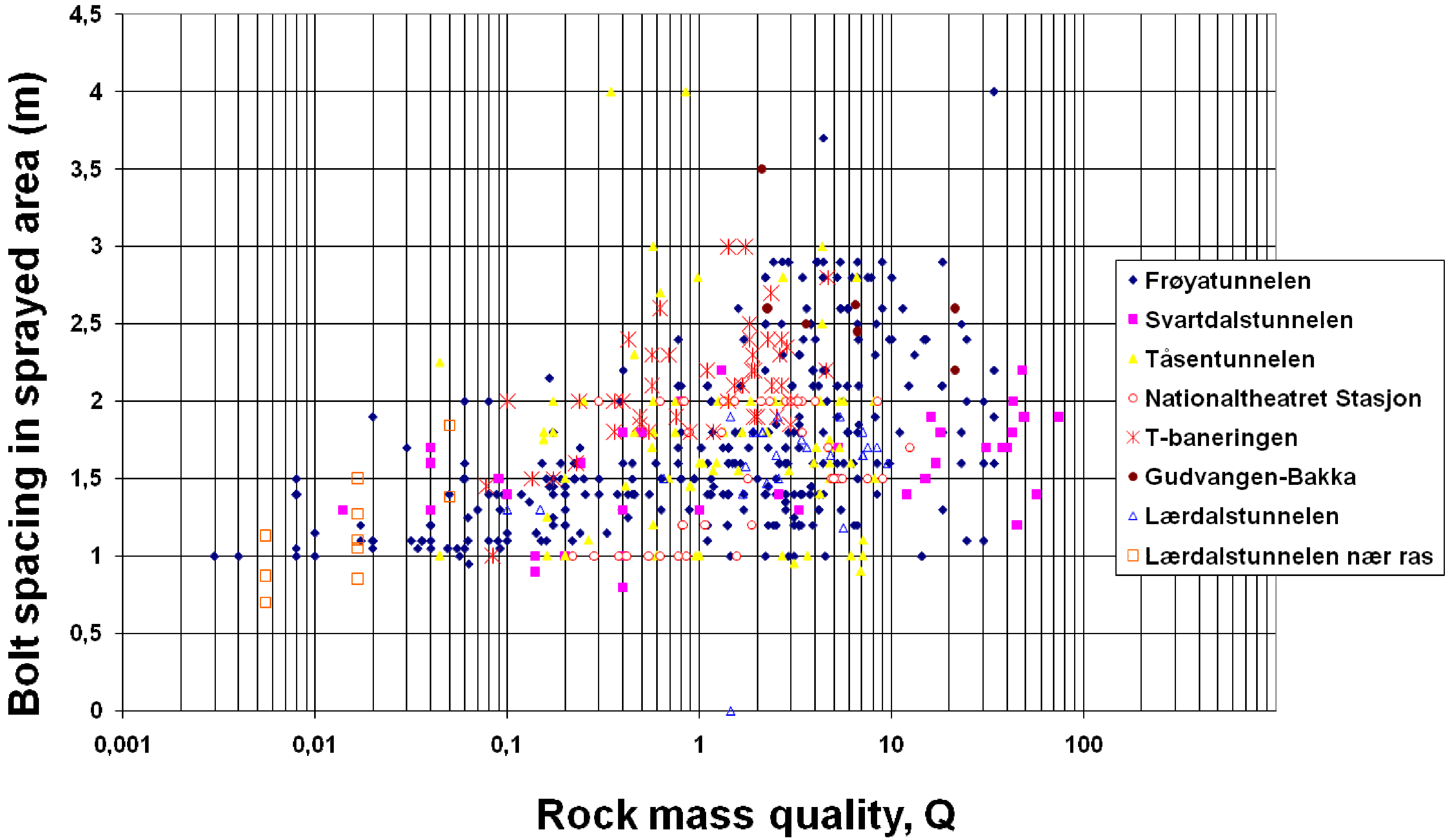
Joint frequency



Thickness of Sfr related to Q

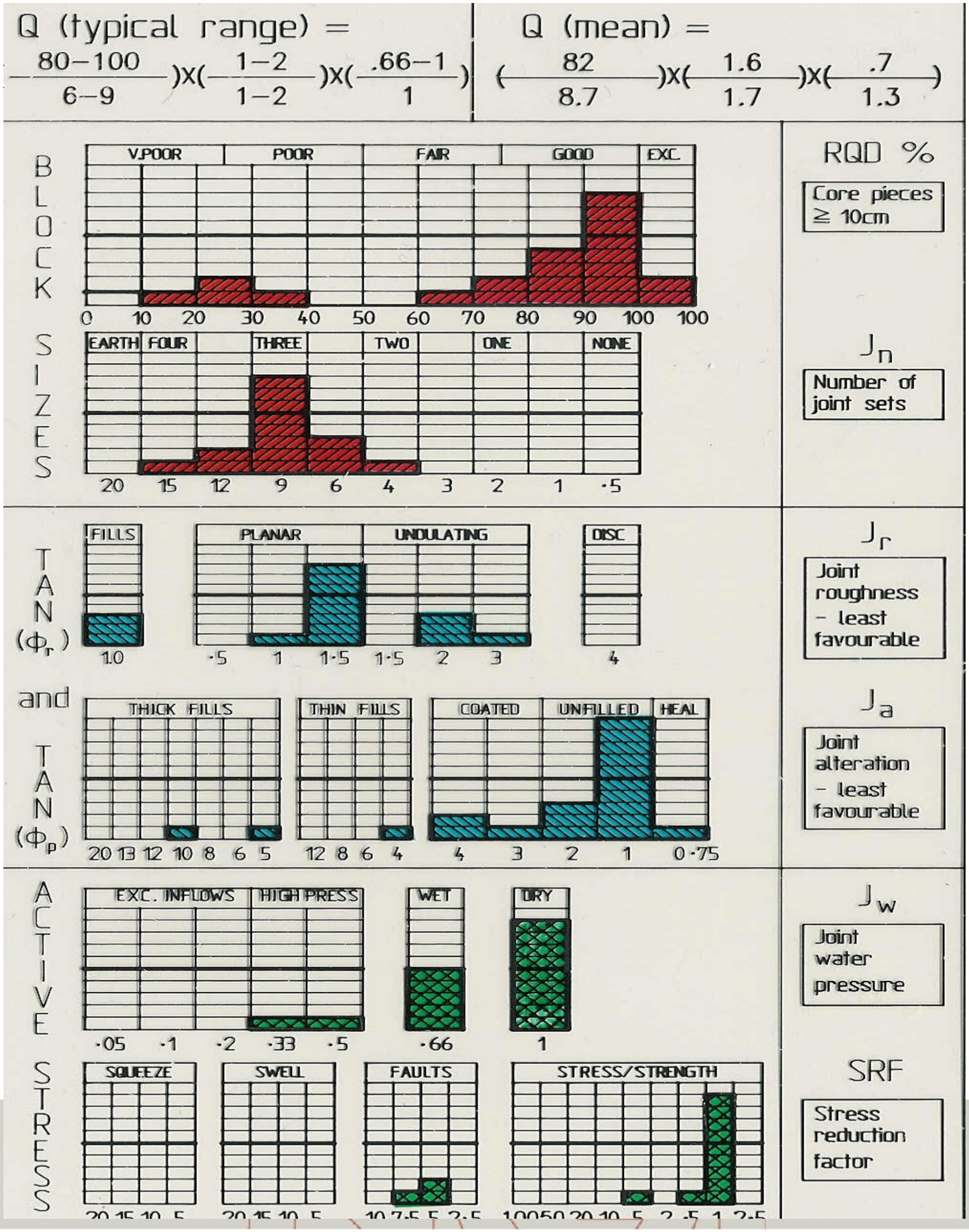


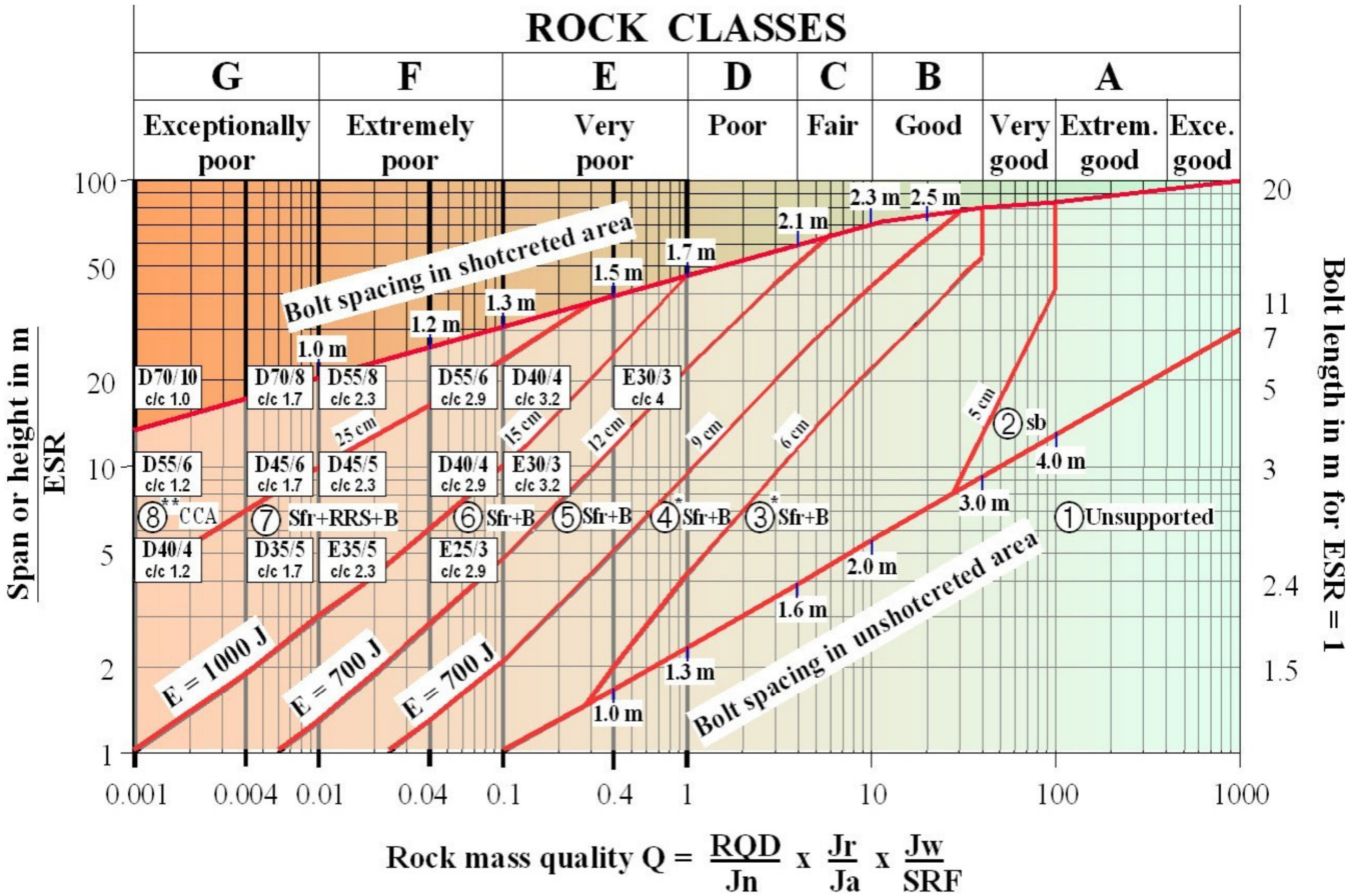
Bolt spacing in area with sprayed concrete



Registration of parameters in histograms gives a good overview for much data.

Spreadsheet gives Max., Min., Average and Typical Q-values for most frequent parameters





REINFORCEMENT CATEGORIES

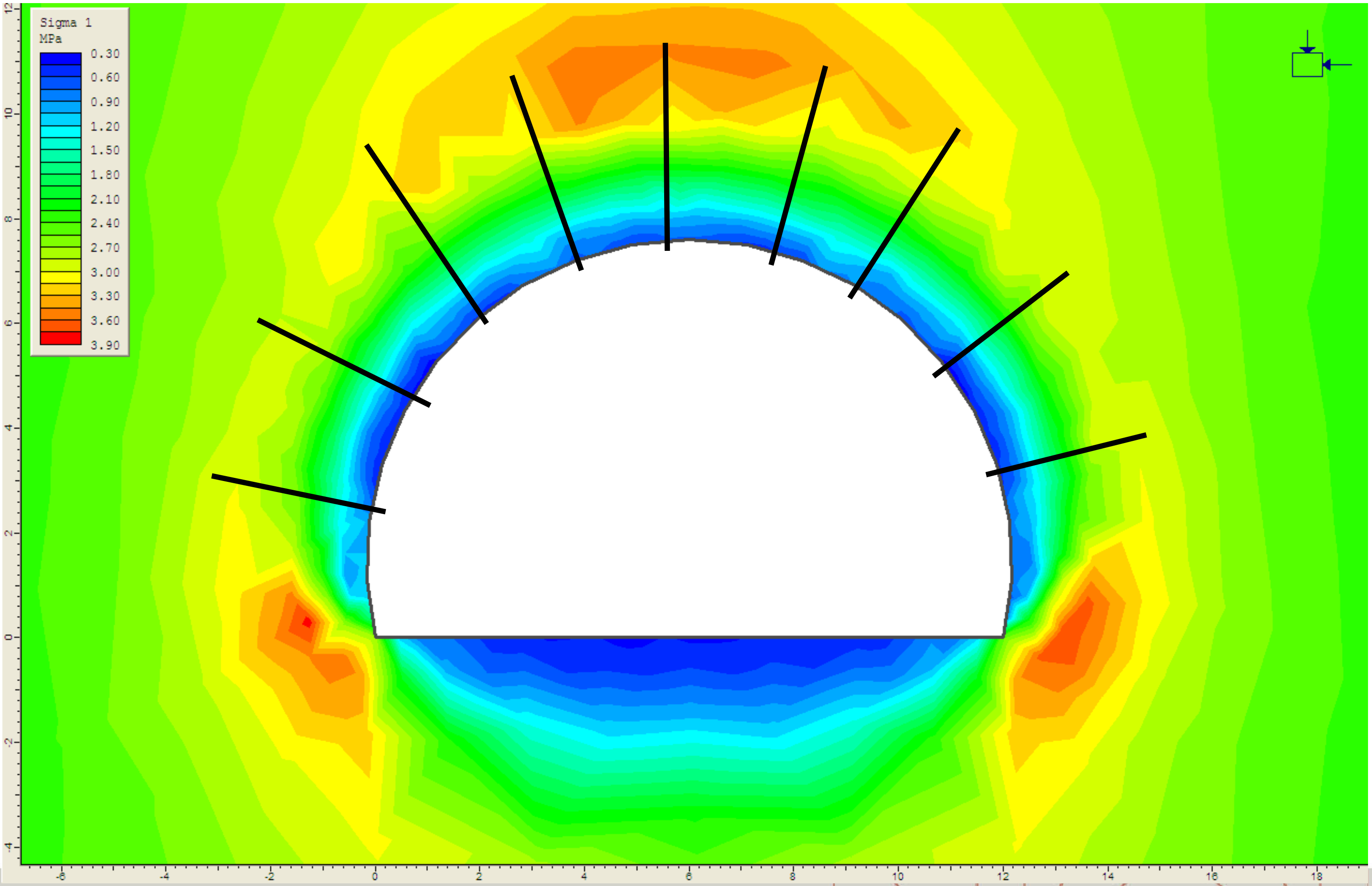
1) Unsupported
2) Spot bolting, **sb**
3) Systematic bolting,
   (and unreinforced shotcrete, 5-6 cm), **B(+S)**
4) Fibre reinforced shotcrete and bolting, 6-9 cm, **Sfr+B**
5) Fibre reinforced shotcrete and bolting, 9-12 cm, **Sfr+B**
6) Fibre reinforced shotcrete and bolting, 12-15 cm, **Sfr+B**
7)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

E) Energy absorbtion in fibre reinforced shotcrete at 25 mm bending during plate testing

D45/6 c/c 1.7 = RRS with 6 reinforcement bars in double layer in 45 cm thick ribs with centre to centre (c/c) spacing 1.7 m. Each box corresponds to Q-values on the left hand side of the box. (See text for explanation)

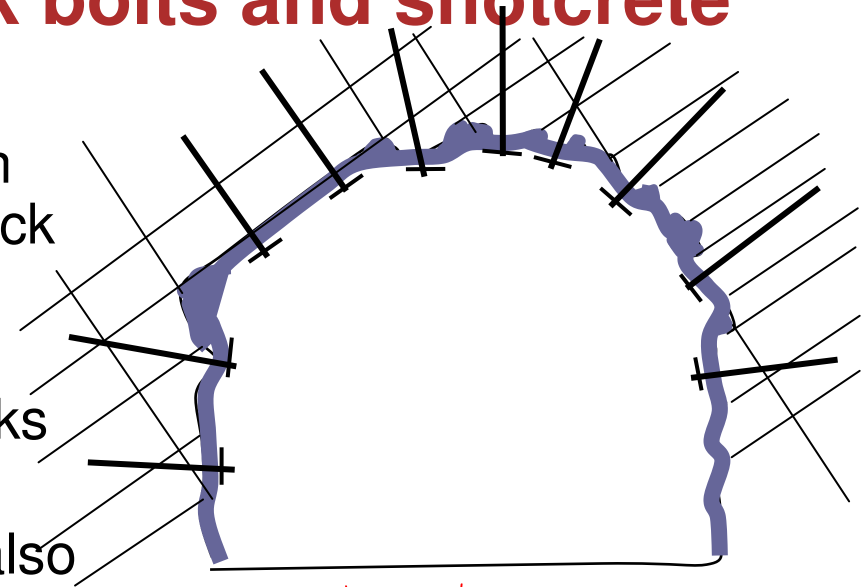
*) Up to 10 cm in large spans
) Or **Sfr+RRS+B

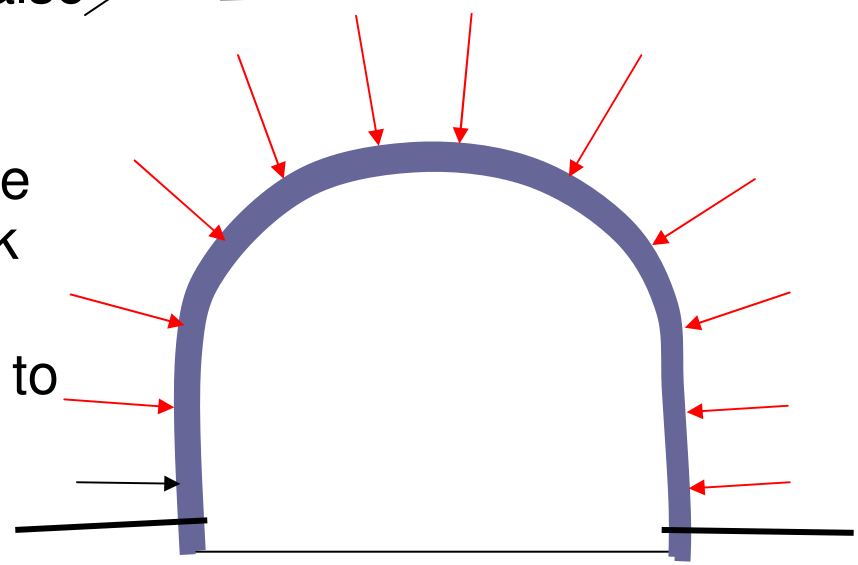
The rock is also a part of the construction when the rock bolts transfer the forces up to the stable arch



Interaction between rock bolts and shotcrete

- Thin layers of shotcrete is a skin taking care of small pieces of rock at the tunnel periphery
- Rock bolts take care of large wedges and prevent larger blocks from falling
- Thick layers of shotcrete need also rock bolts if the periphery is uneven
- Only an even arch may carry the load from poor rock without rock bolts
- Rock bolts always transfer load to the rock





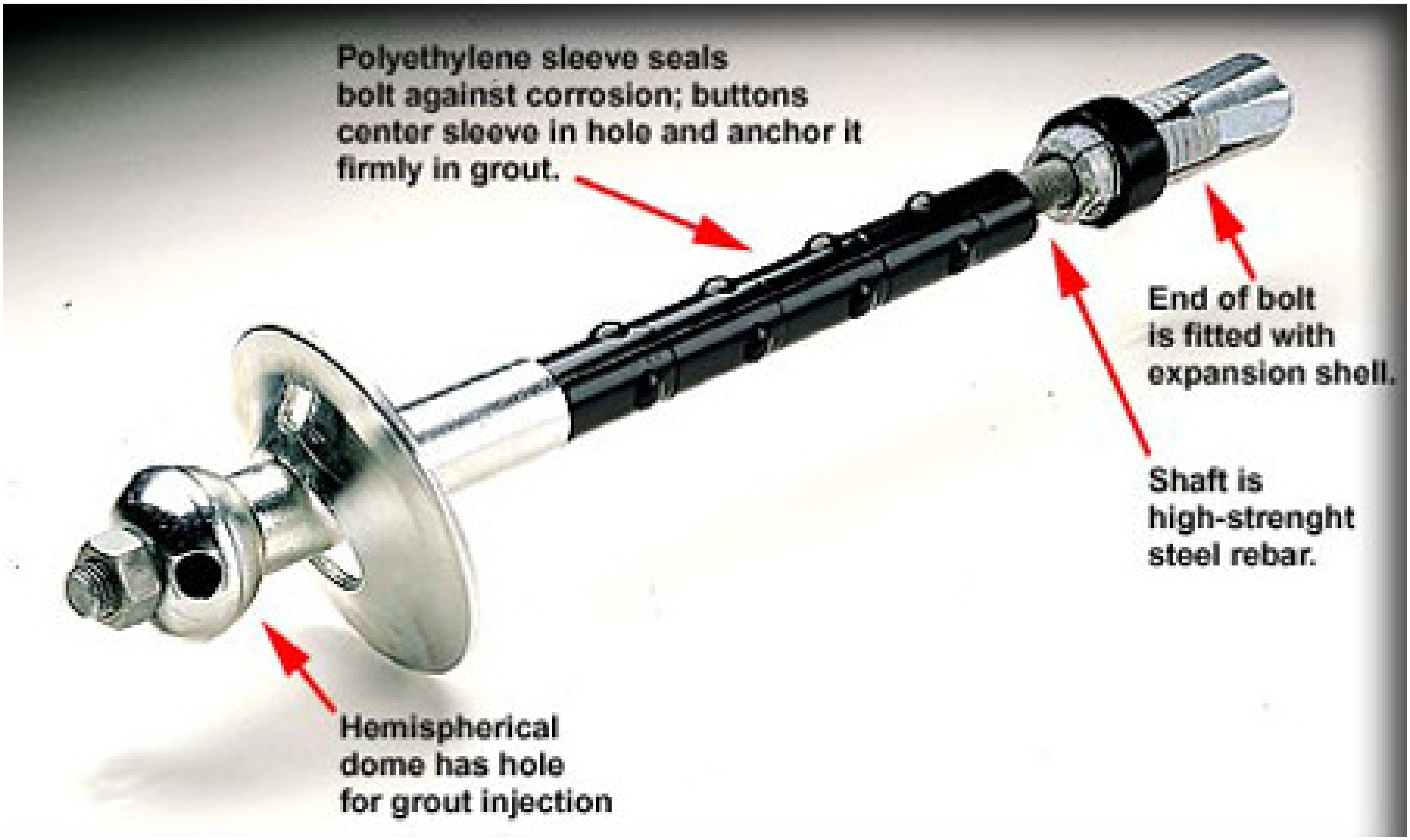
Rebar end-anchored bolt

- The bolt is pretensioned
- Works after a few minutes
- The Resin anchored bolt is developed especially for installation during excavation
- Excellent in high stresses, also as permanent support

Rebar bolt for grouting

•The bolt is fully grouted but not tensioned
•Works after many hours
•Suitable for permanent support

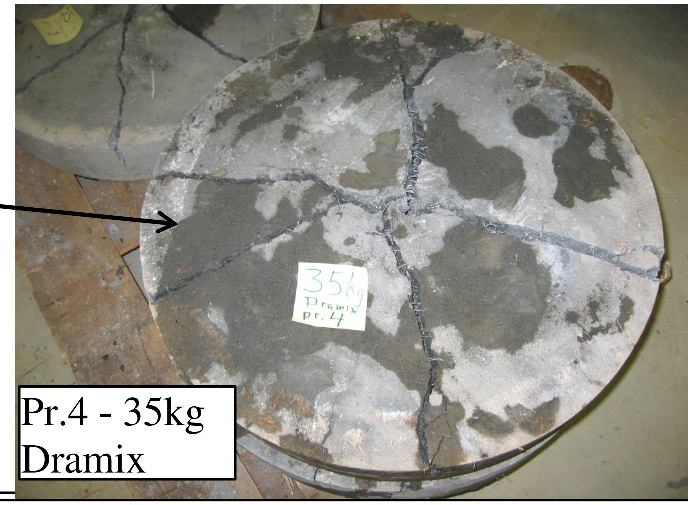
The CT-bolt 5 x corrosion protected
Combined temporary and permanent bolt

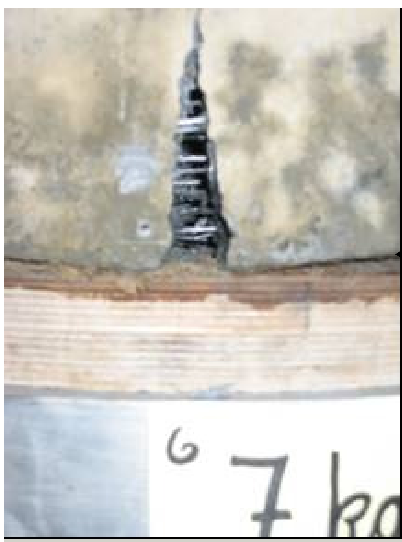


Testing of energy absorption in sprayed concrete

Some panels were pressed further from 25 to 40mm deflection.

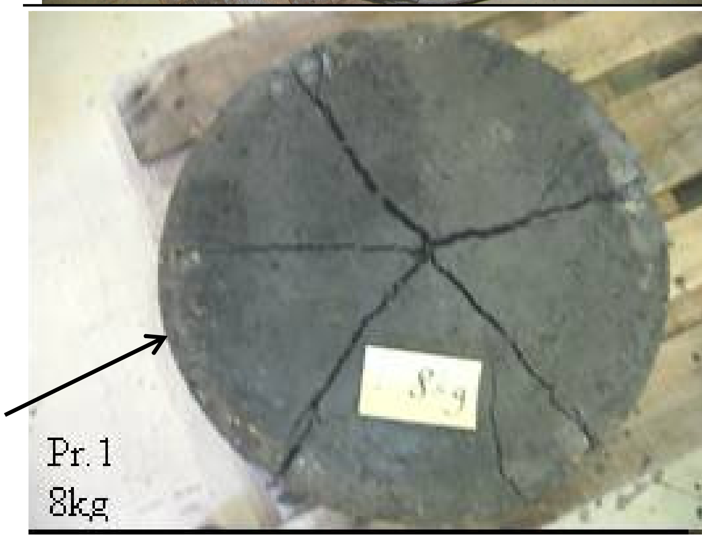
35 kg Dramix RC65/35BN steel fiber /m^3



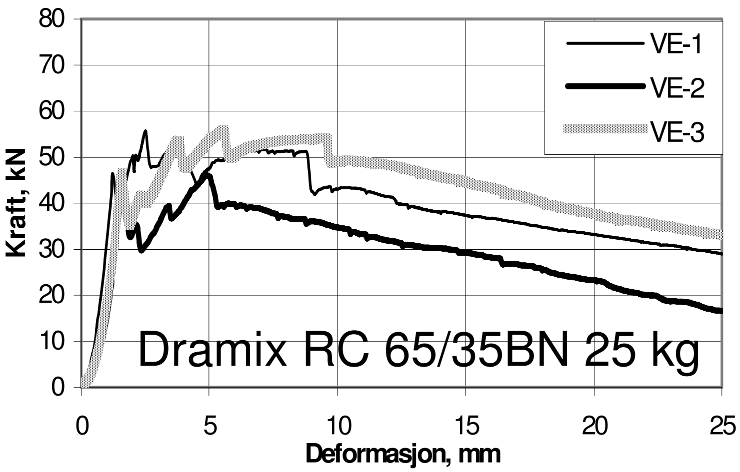


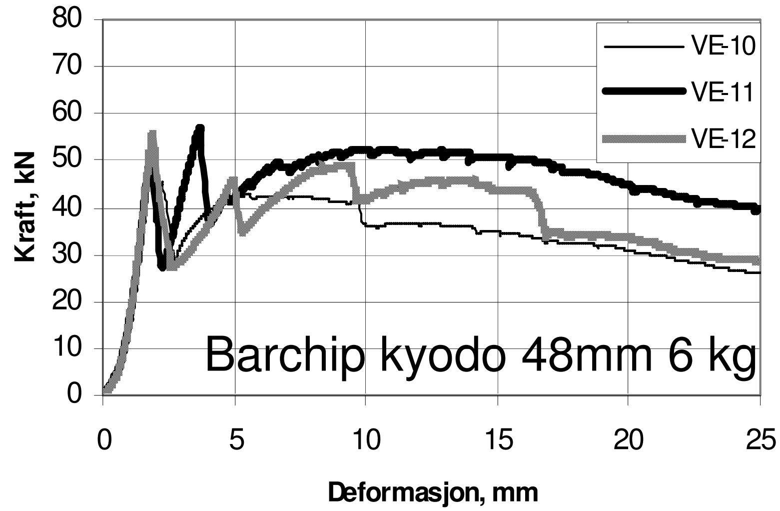
Panel with 7kg Barchip fiber after 40 mm deflection.

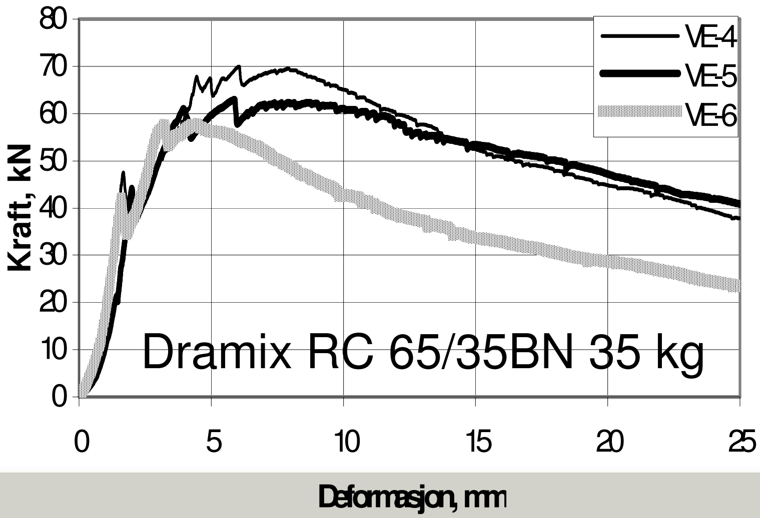
8 kg 48mm Barchip/m^3

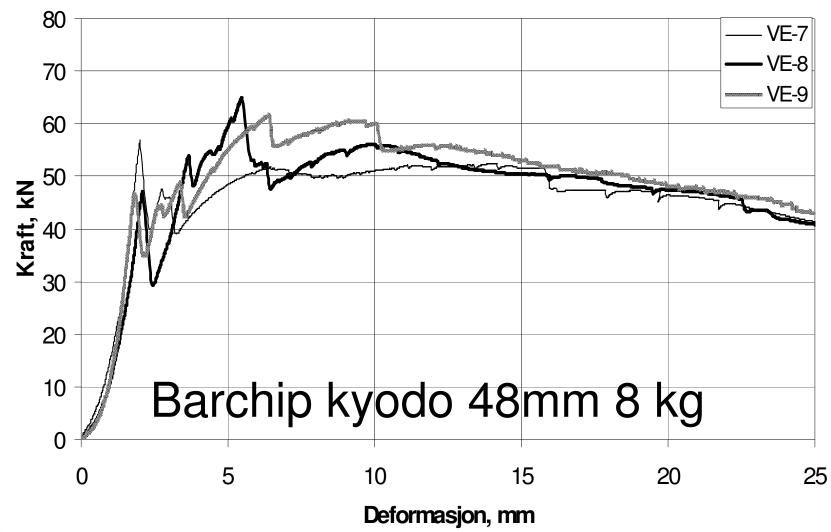


Comparision between load/deformation curves for panels with Dramix steel fiber and Barchip-composite fiber

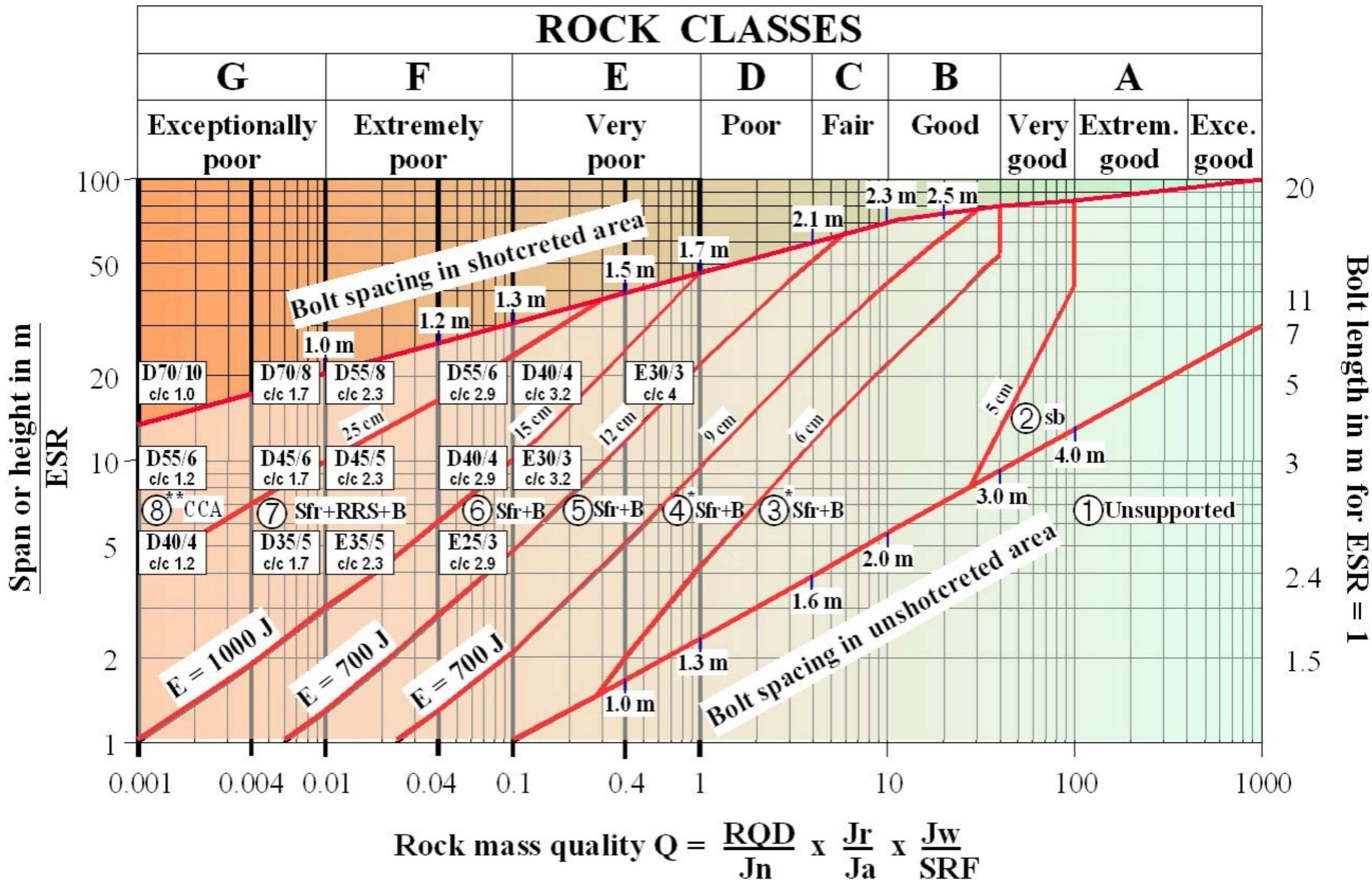








Energy absorption classes E500, E700 and E1000

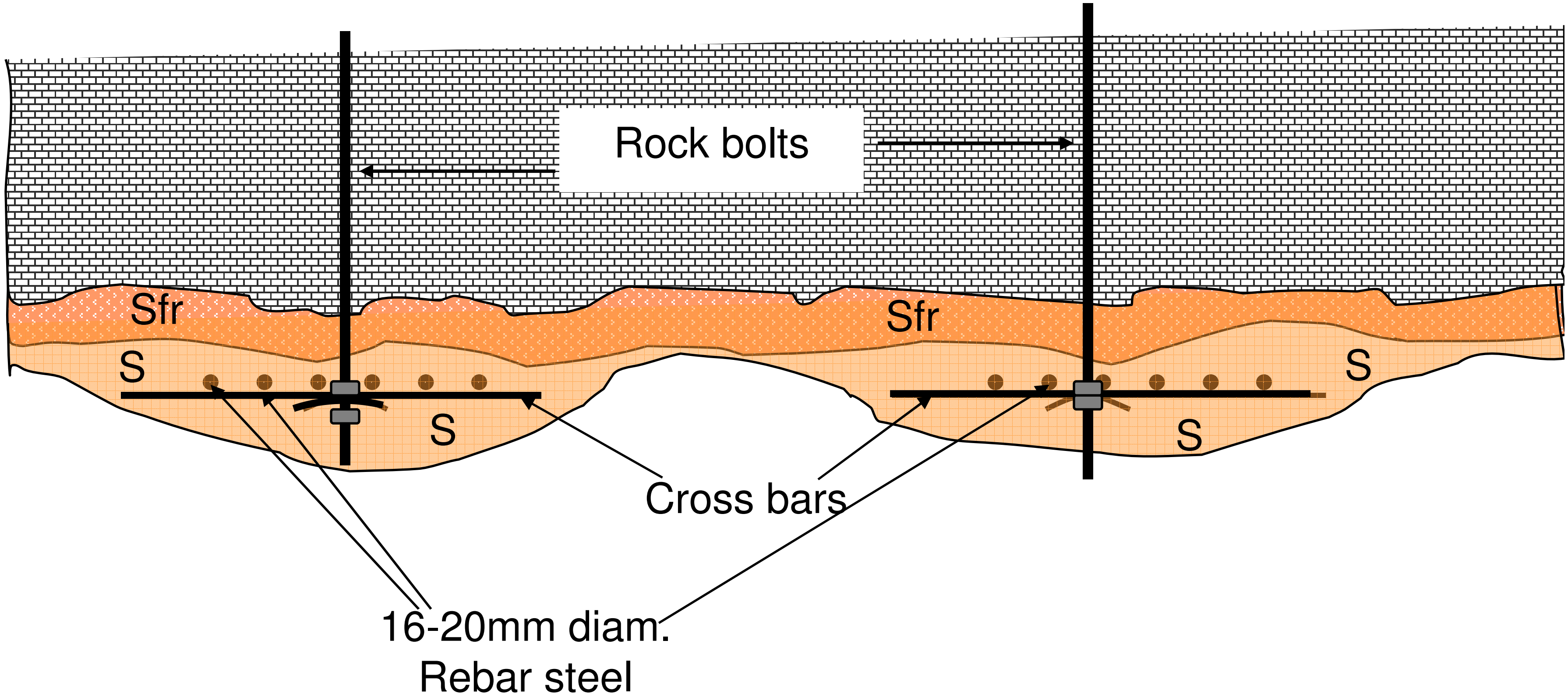


Energy absorption classes

- 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

- The Norwegian Road Authority require minimum 8cm thickness of sprayed concrete from the year 2008
- Higher energy absorption classes than recommended by the Q-system
- The Norwegian Road Authority increases the factor of safety in all rock classes

Cross section of two sprayed ribs

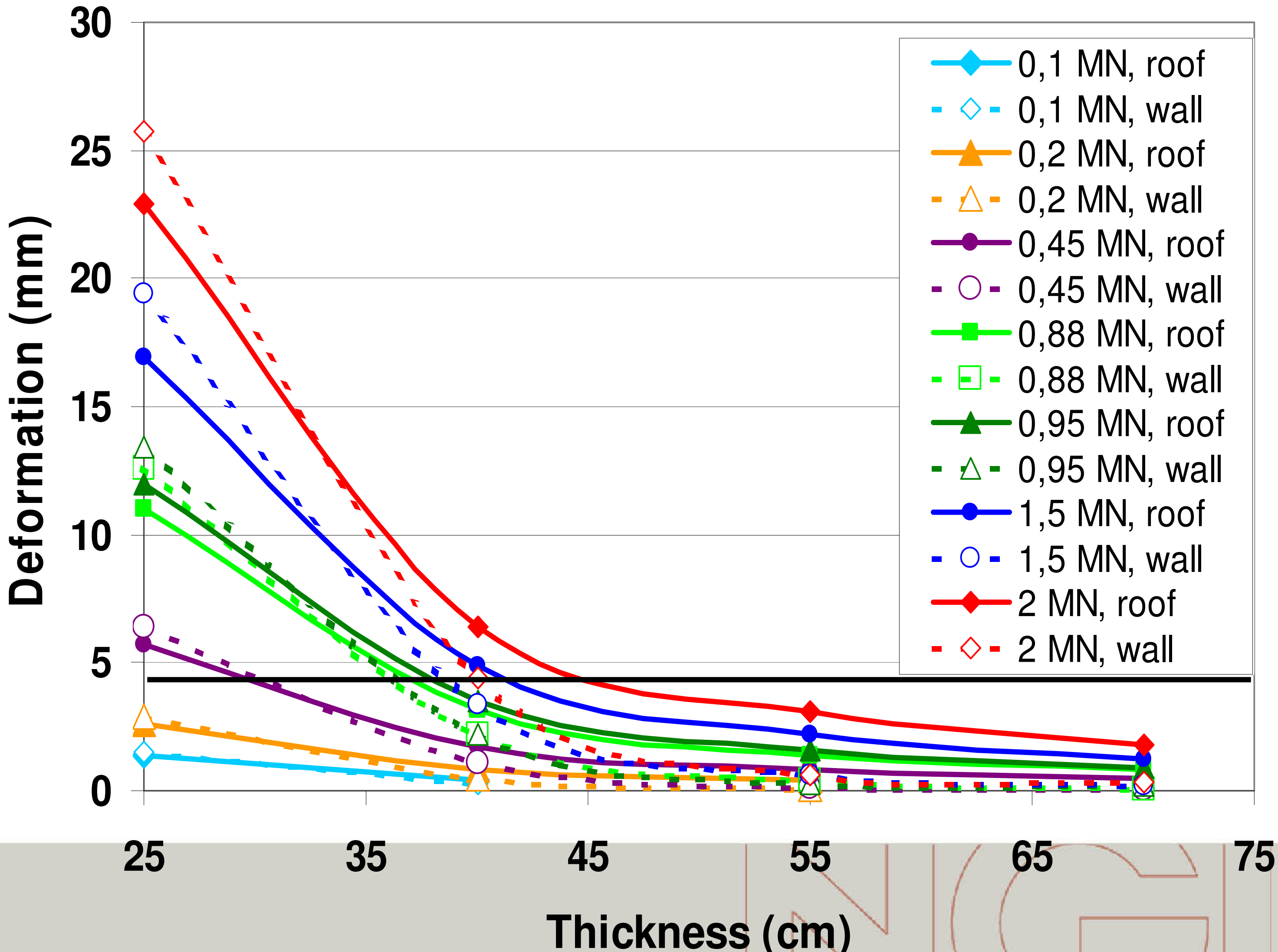


REINFORCED RIBS OF SPRAYED CONCRETE

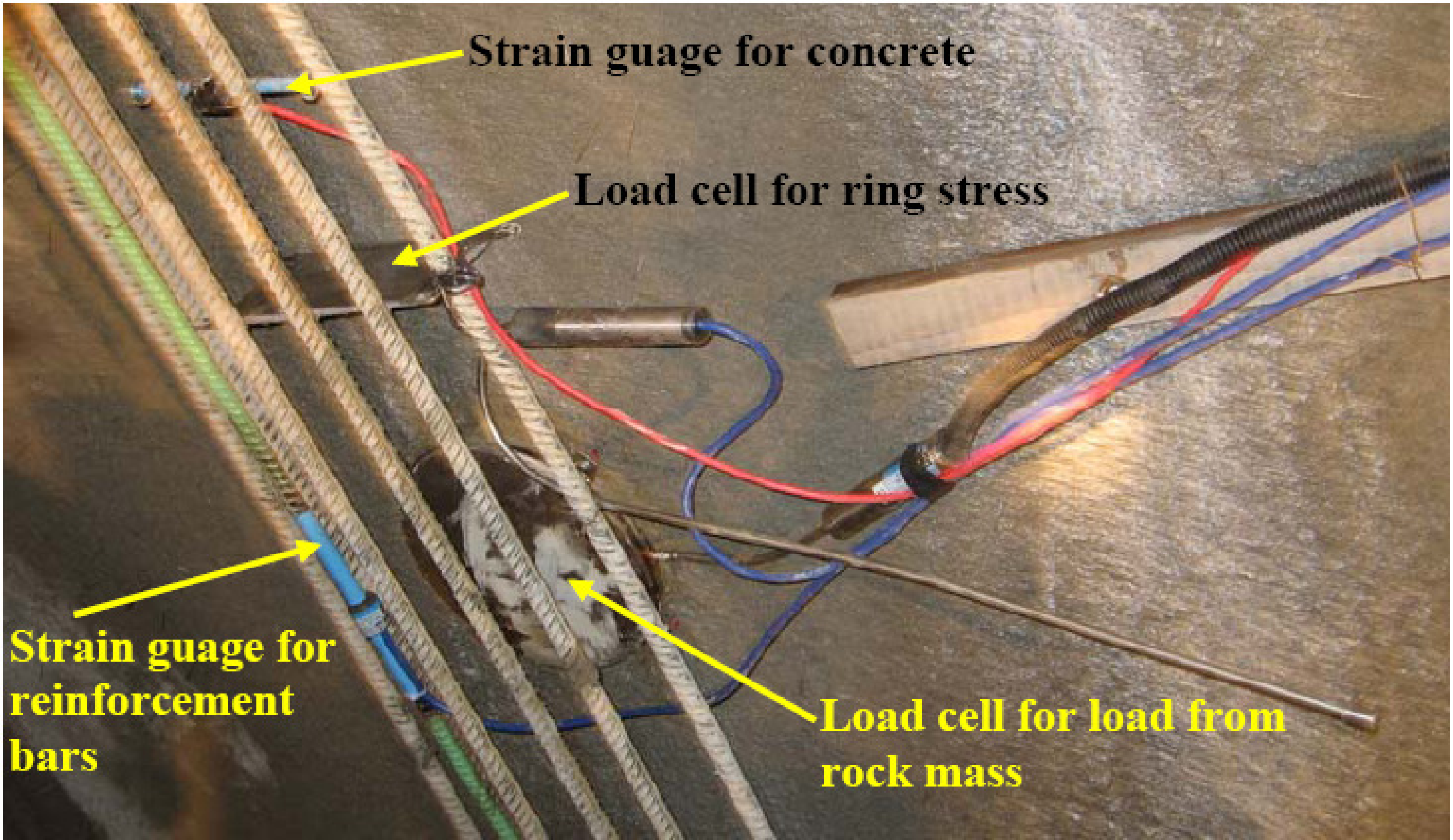
SEEN PERPENDICULAR TO THE TUNNEL AXIS

Reinforced ribs of sprayed concrete in the 22 m wide National Theater Metro Station in Oslo, Norway. Used as the permanent support.

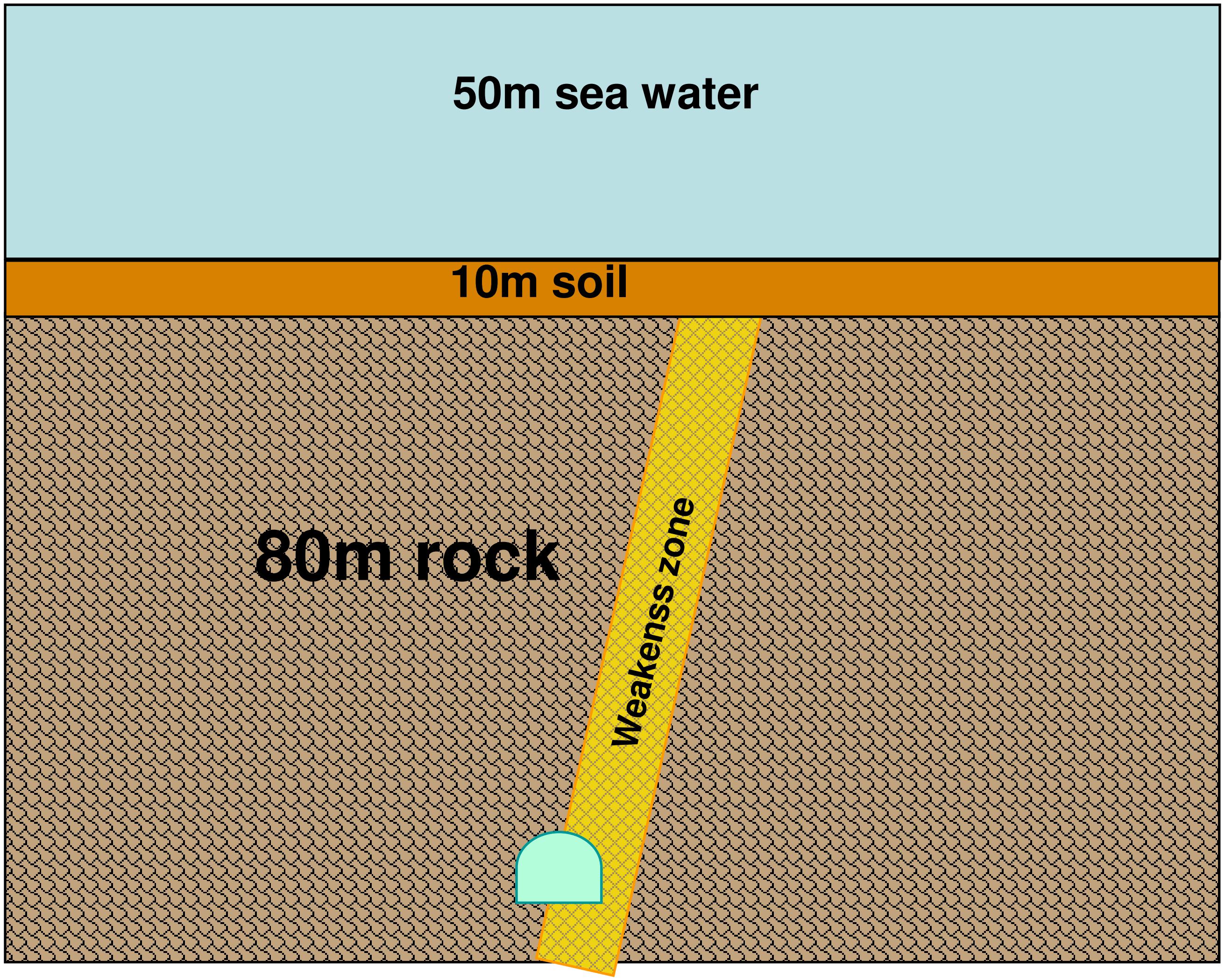
Deformations in the crown and walls related to thickness of RRS and load in a 10 m wide tunnel



Installment of instruments in a RRS



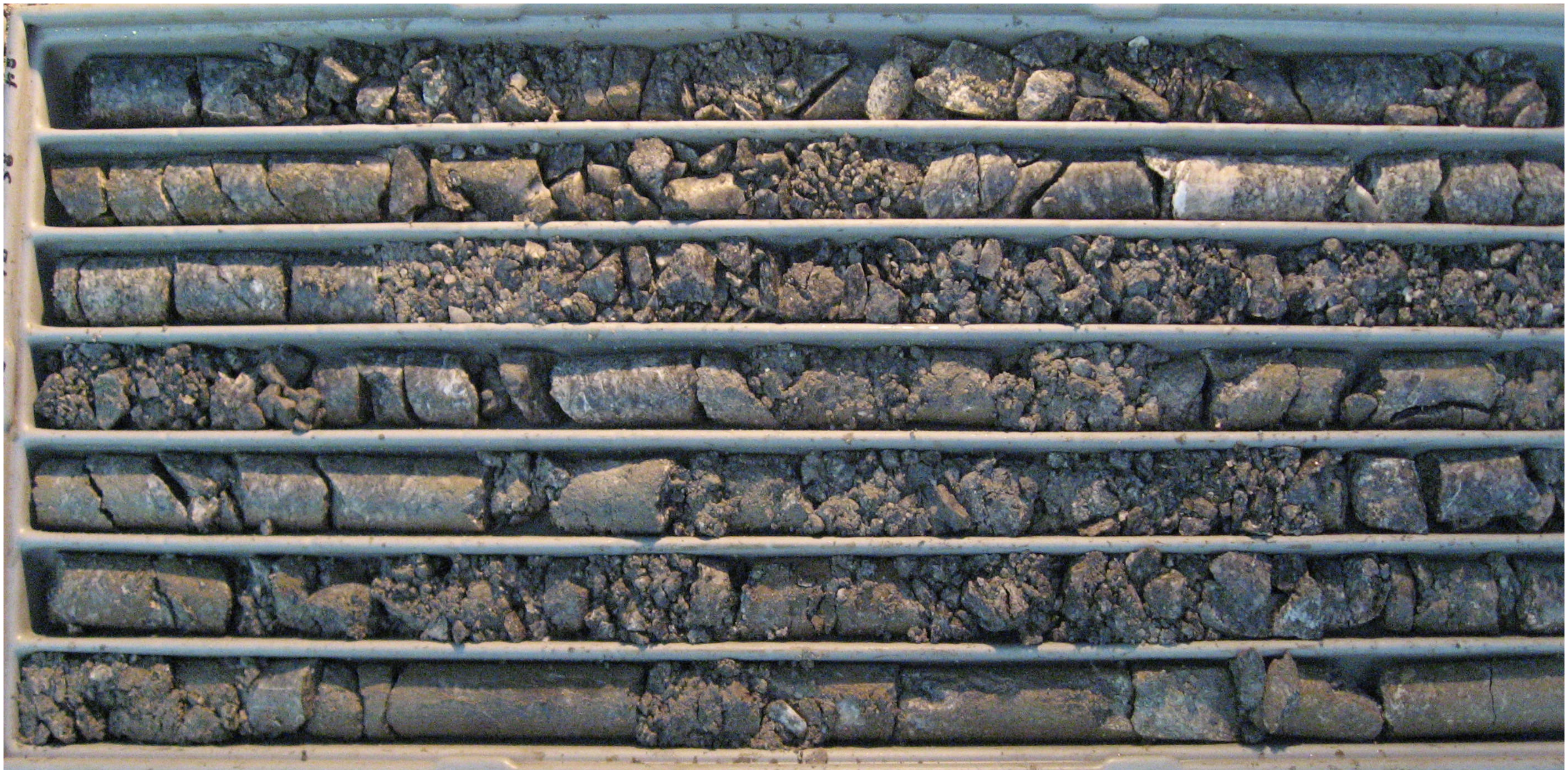
Finnfast subesea tunnel



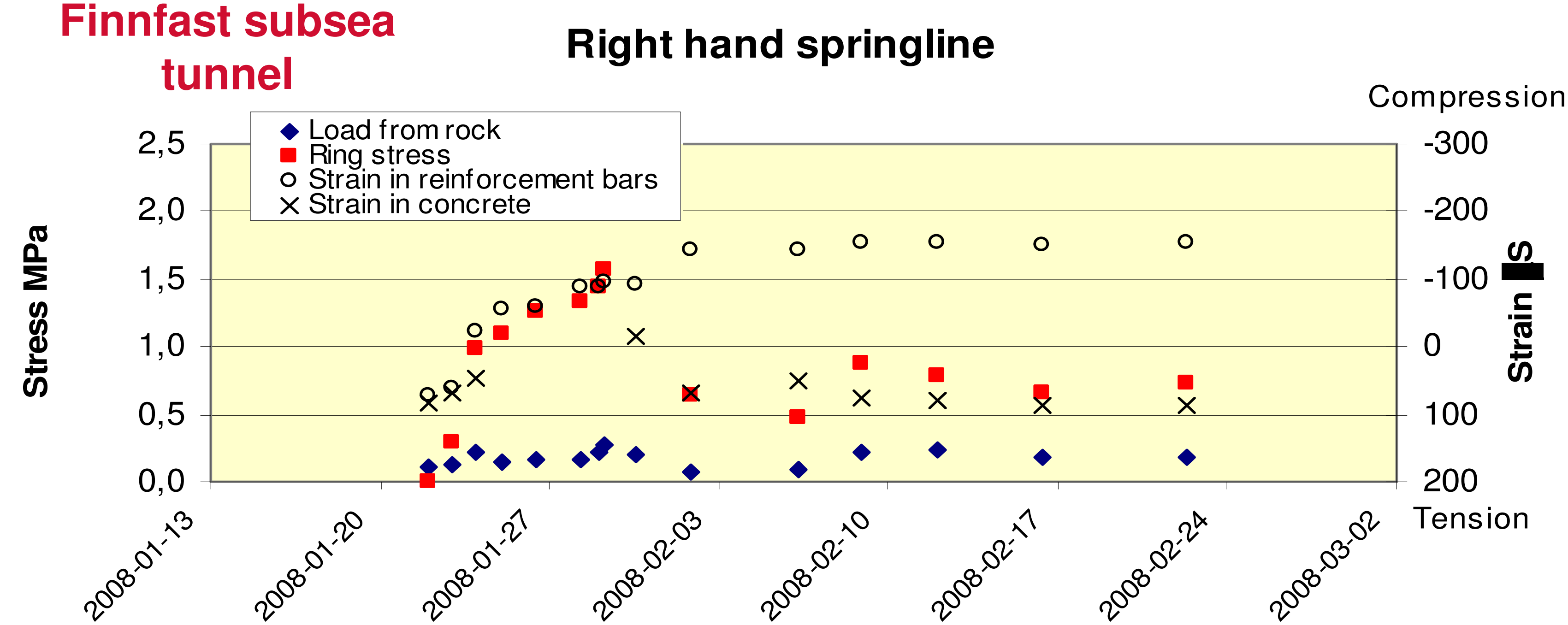
Drill core from the instrumented weakness zone

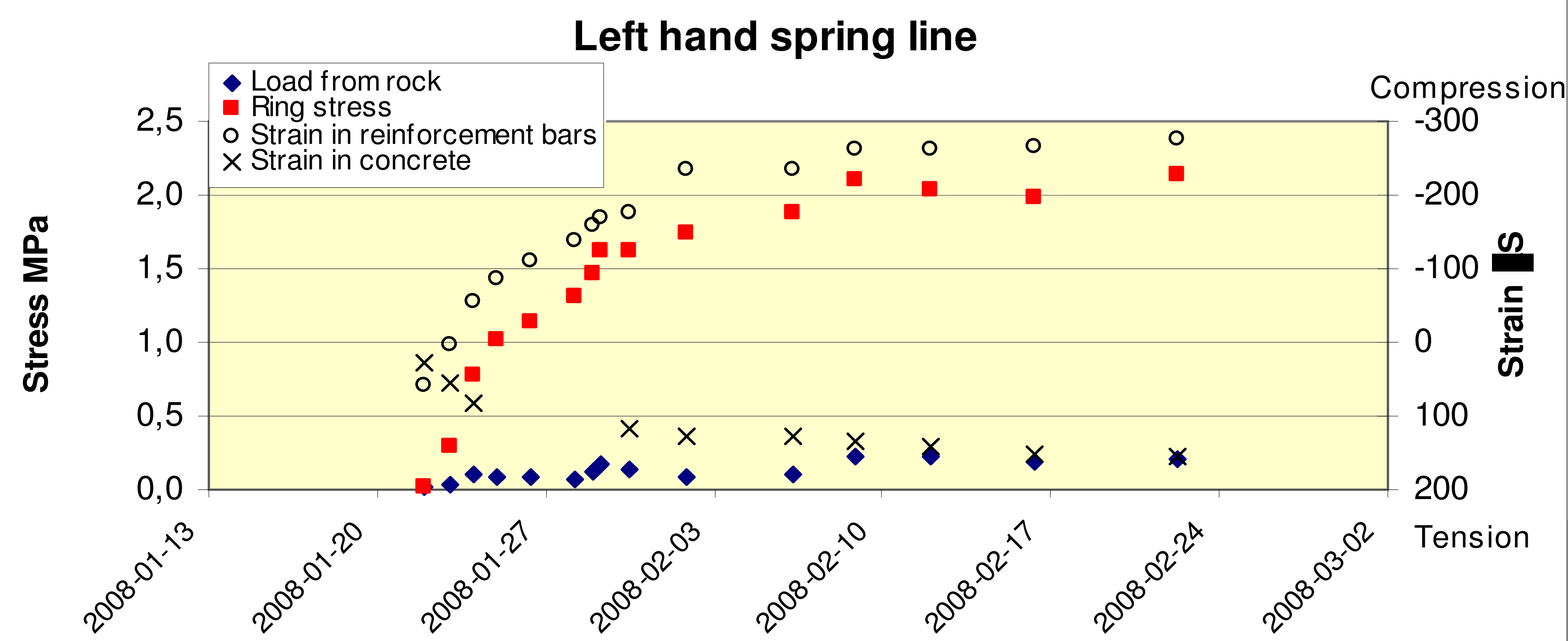
Rock mass quality, Q = (10/20)x(1/10)x(1/5) = 0,01

Exceptionally to Extremely poor. Contains swelling clay.



Finnfast subsea tunnel

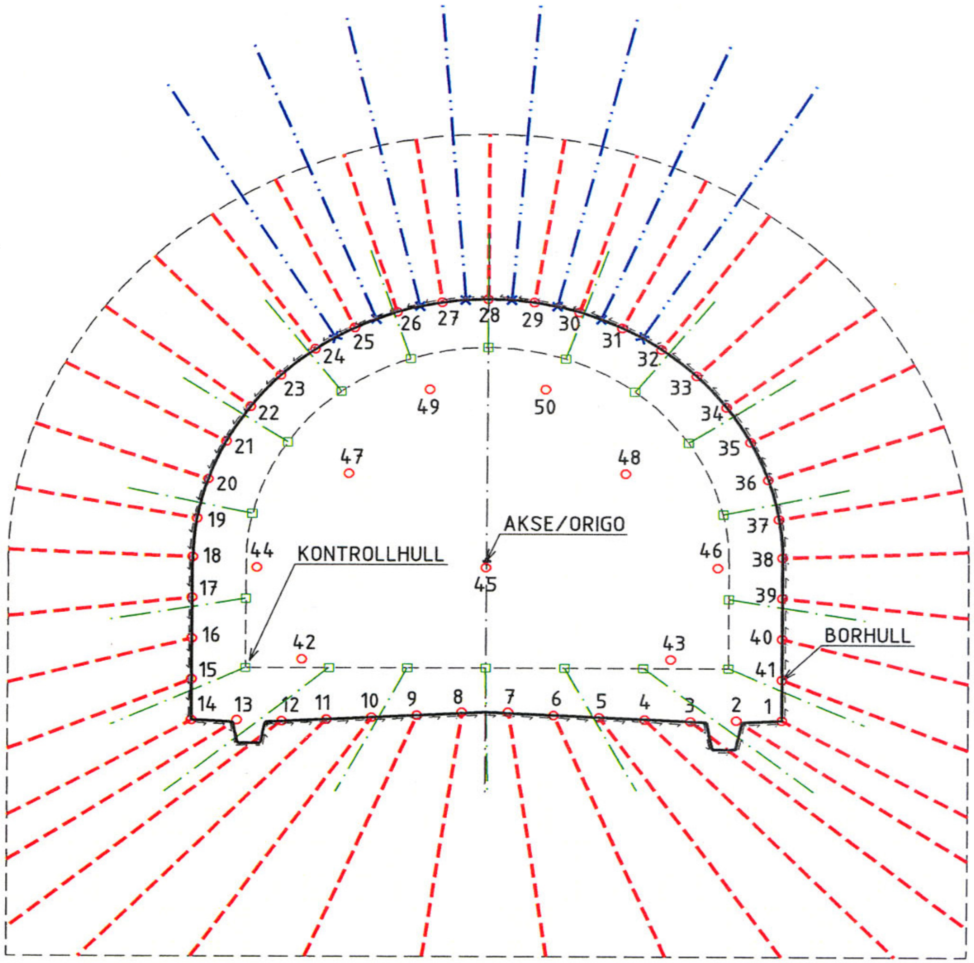




Conclusion

- The load from the rock seems to be lower than expected from theoretical calculation. This is most apparent in the crown.
- Both measurements and numerical simulation indicate tension in the rock close to the crown
- An even profile of the rib make it possible to calculate its capasity
- Strain measurements is more consistent than load cells
- Long term creep in the concrete stabilize after about two months
- Shrinkage in the concerte during curing (≈0,5-1,0 ‰ =10-20mm in 20m rib length) may give tension in the contact between the rib and the crown

Drill holes for pregrouting (50 holes)



TABELL OVER HULLANSETT, RETNING I FORHOLD TIL TUNNELAKSEN OG LENGDER.

HULL NR.		
PRIMÆSKJERM:	TUNNELAKSE	LENGDE
SÅLE:		
1, 2, 4, 5, 7, 8, 10, 11, 13, 14	11°	21 m
3, 6, 9, 12	25°	15 m
VEGG/HENG:		
16, 17, 19, 20, 22, 23, 25, 26, 28, 30, 31, 33, 34, 36, 37, 39, 40	10°	21 m
15, 18, 21, 24, 27, 29, 32, 35, 38, 41	23°	12 m
STUFF:		
42 - 50	0°	21 m
KONTROLLSKJERM ETTER INJEKSJON:		
SÅLE: 7 HULL	11°	15 m
VEGG/HENG: 11 HULL	10°	15 m
EKSTRAHULL VED OVERDEKNING MINDRE ENN 12-15 m:		
HENG: 8 HULL	20°	21 m

Cross section

Laser scanning with high resolution Lidar

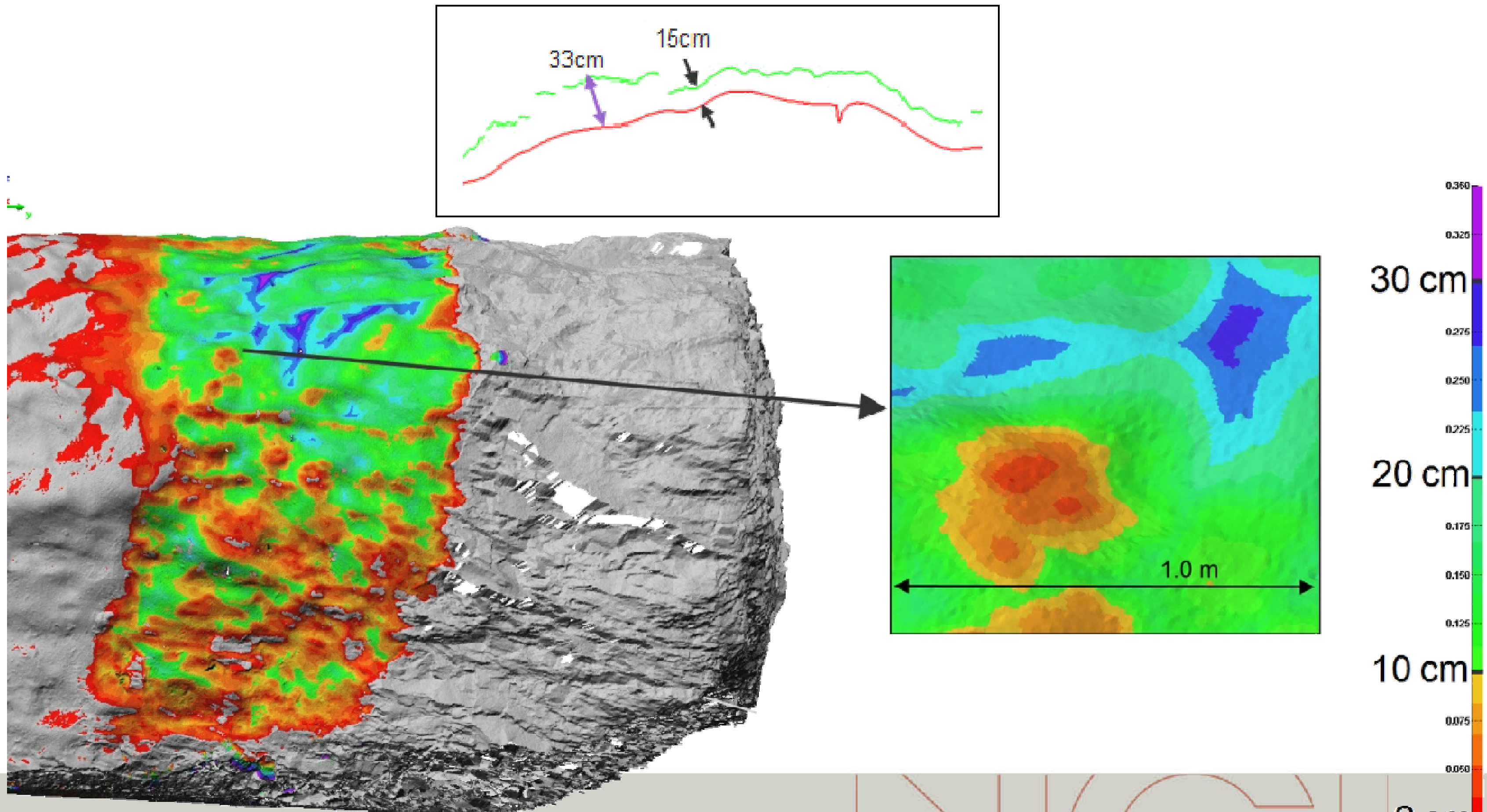
Data collection in tunnels under excavation

Set-up, scan, pack up:
8 minutes

Leica HDS6000

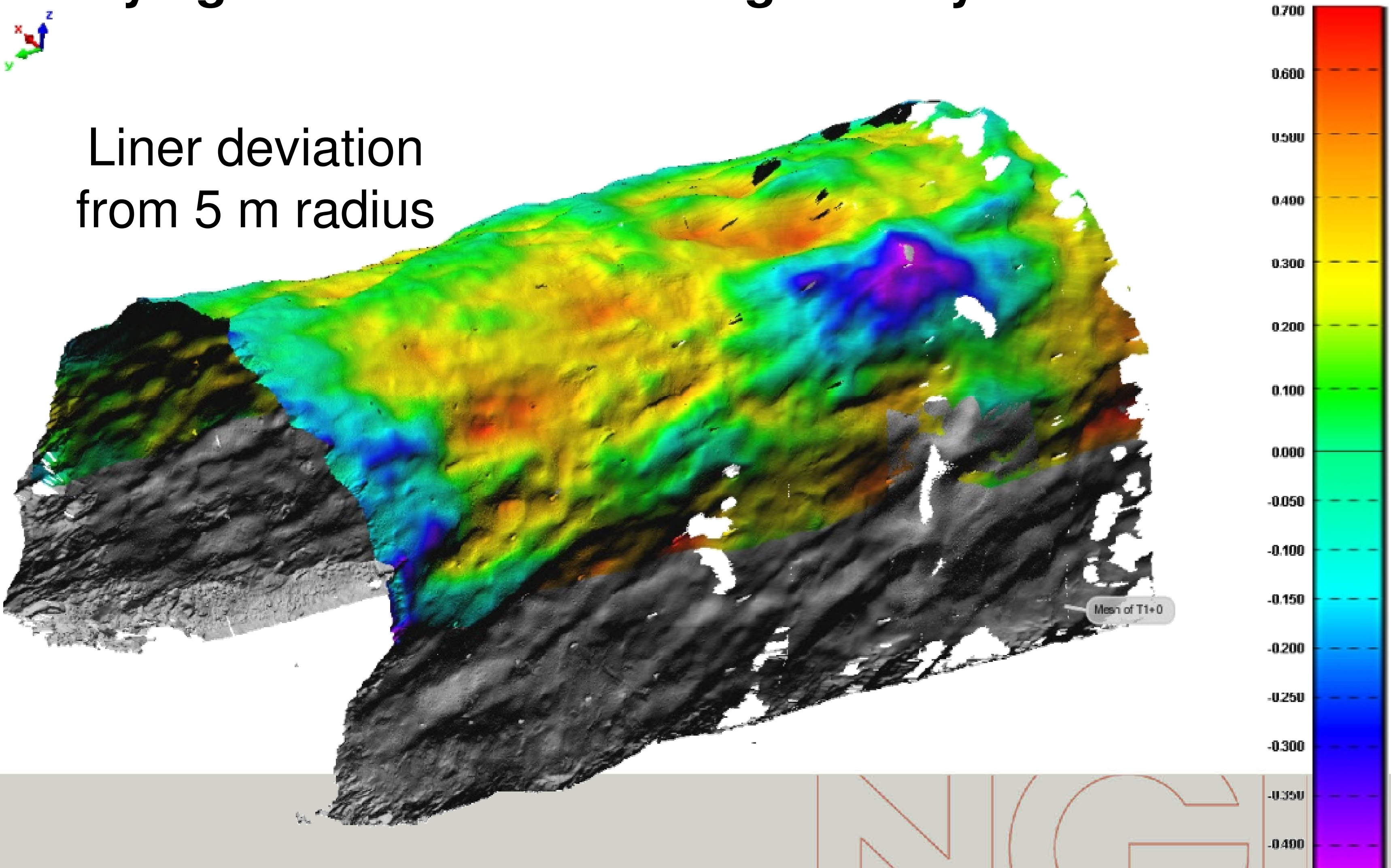
Operational Applications 1

Shotcrete Thickness Quality Control



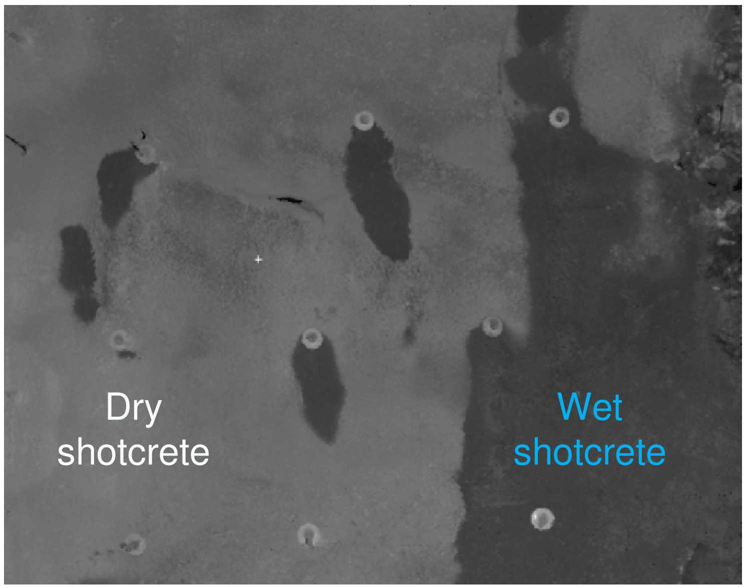
Operational Applications 2

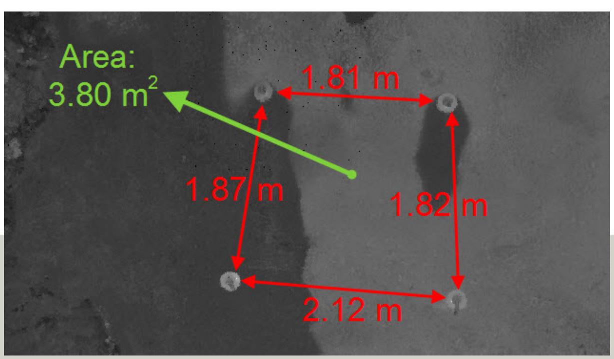
Verifying as-built lined tunnel geometry



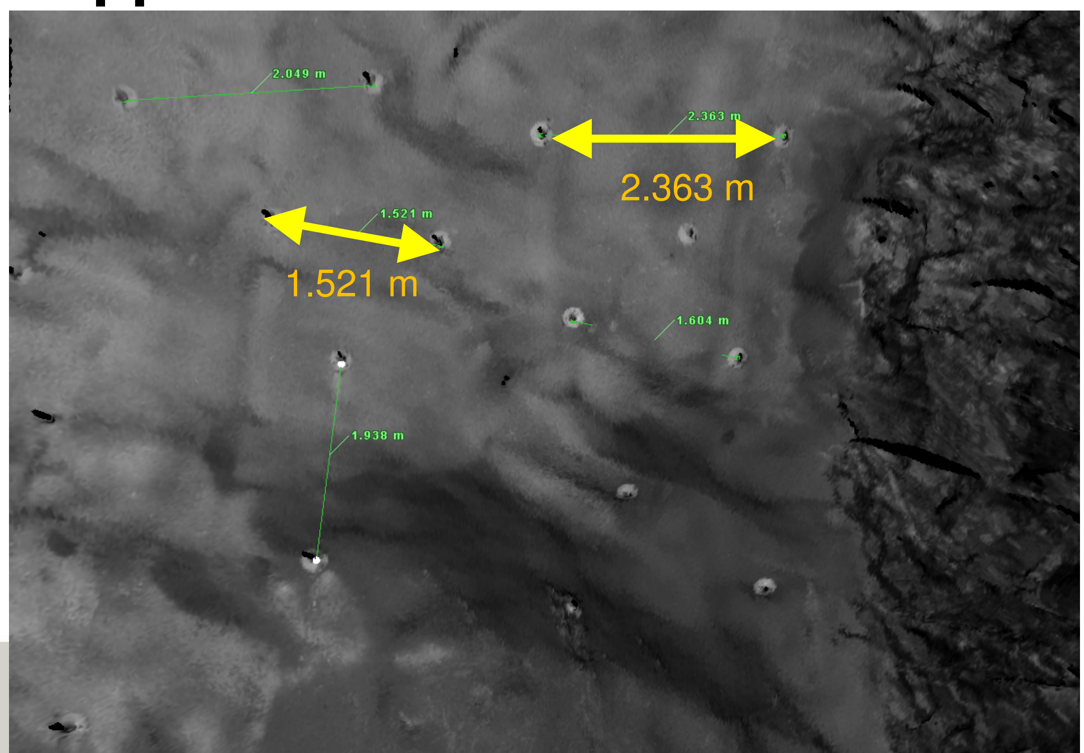
Operational Applications 4

Potential leakage zones



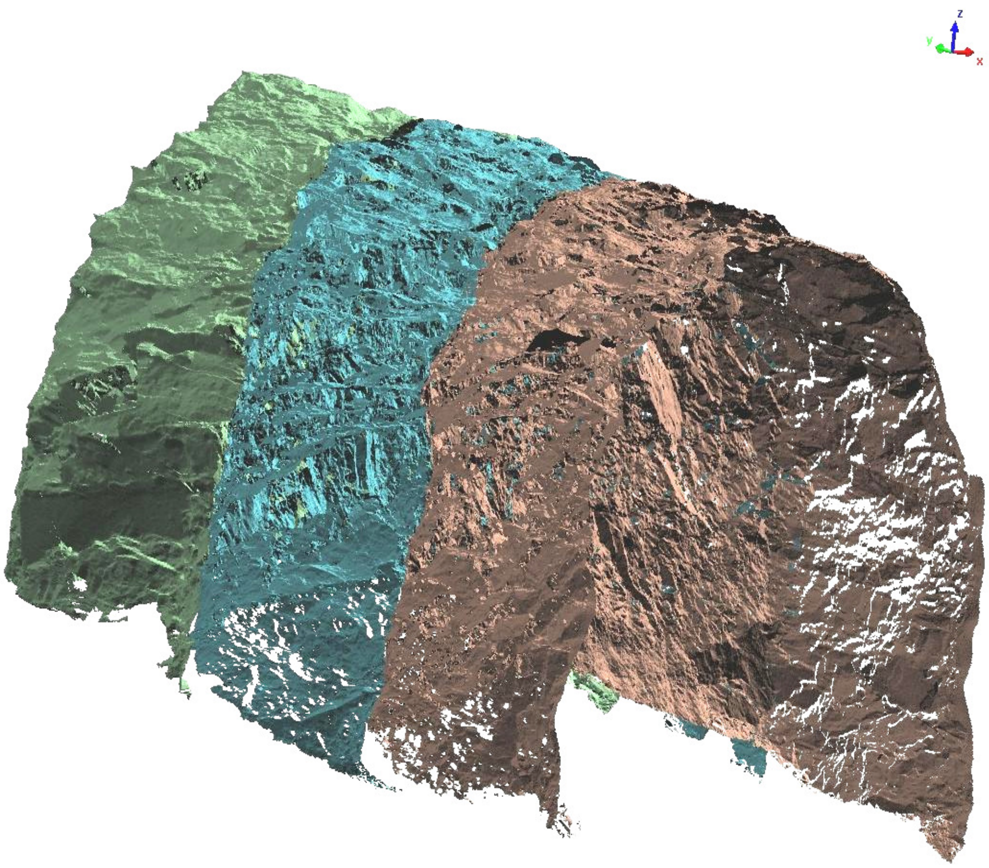


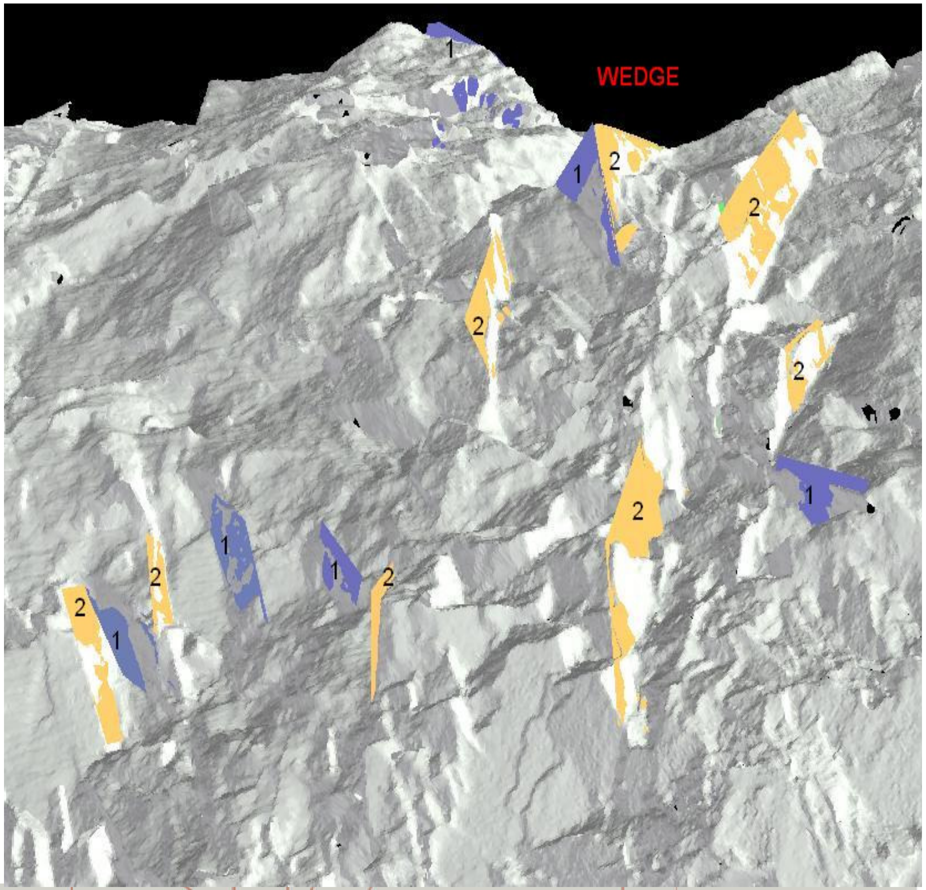
Support installation



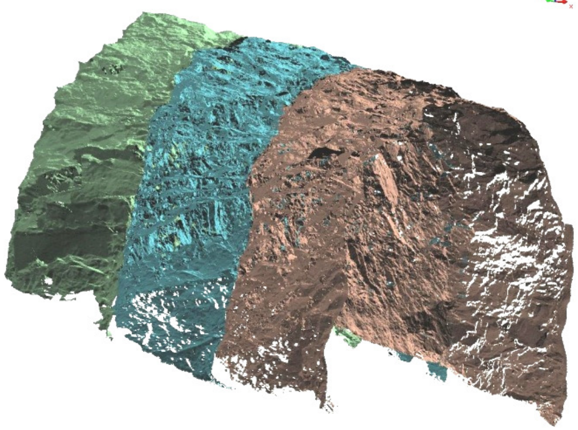
Geomechanical Applications

Joint surfaces identified defining joint sets

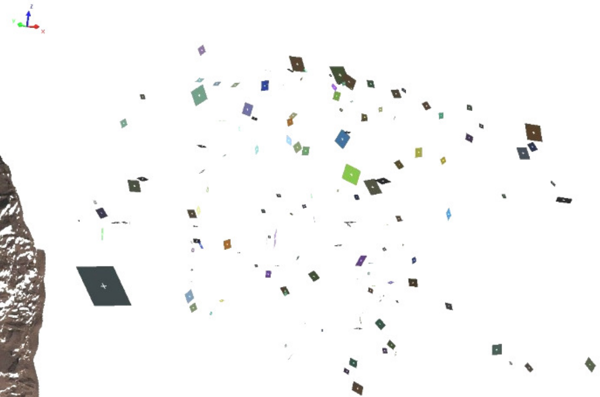




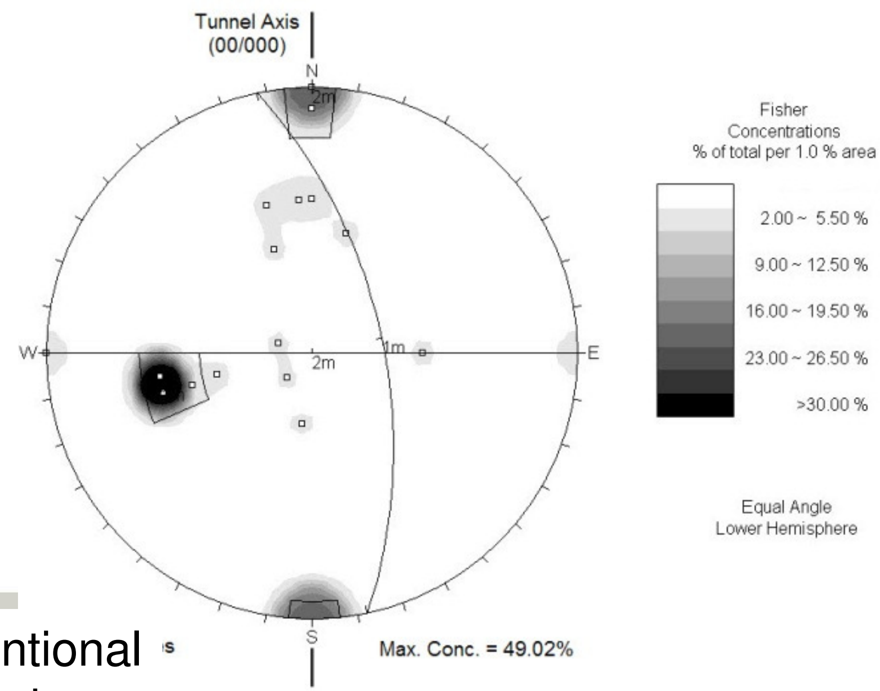
Geomechanical Applications 1



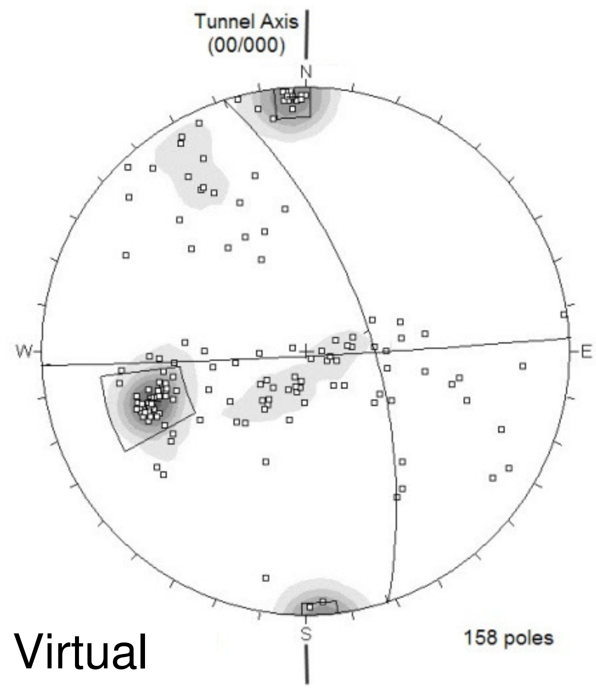
Three aligned 5 m scans-
rock surface only



Joint surfaces identified

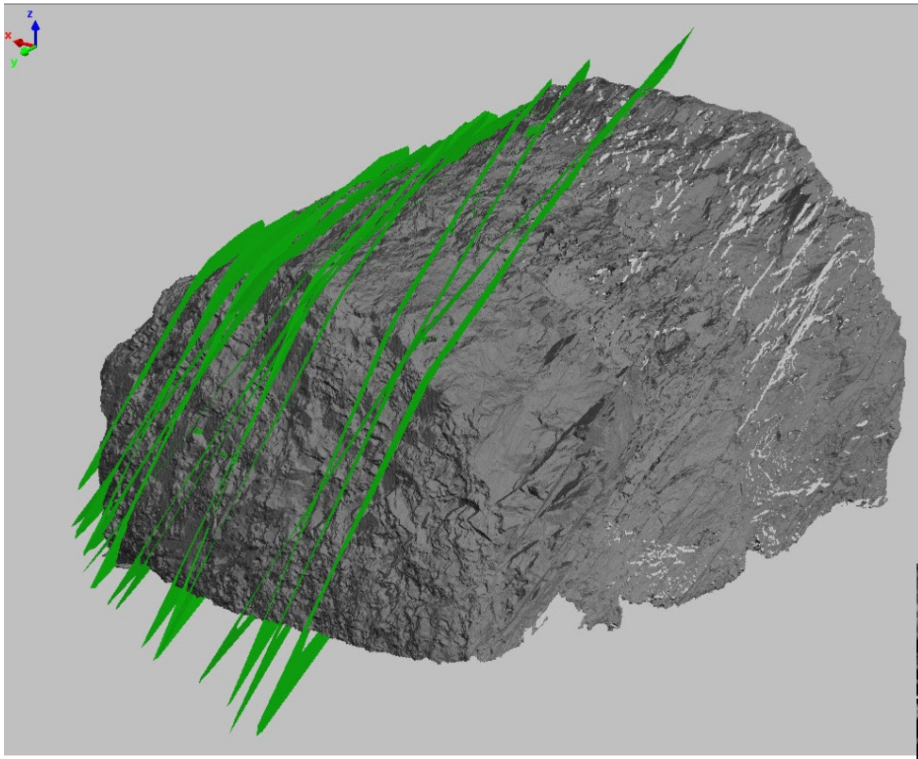


Conventional mapping

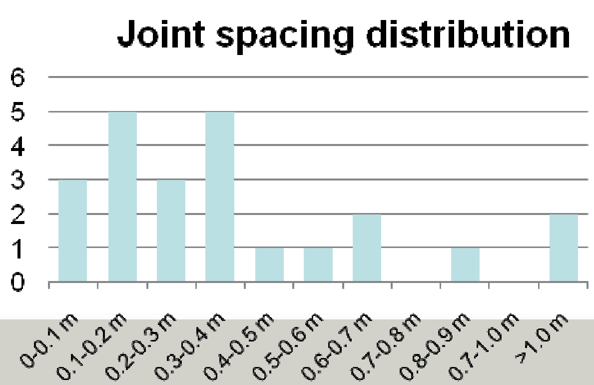


Virtual mapping

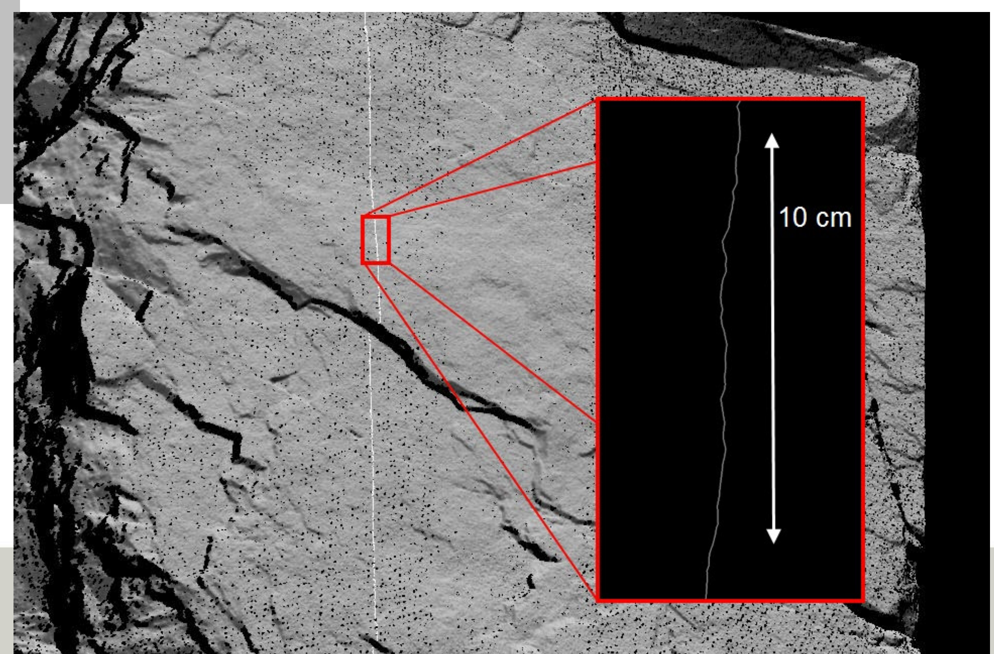
Geomechanical Applications 2



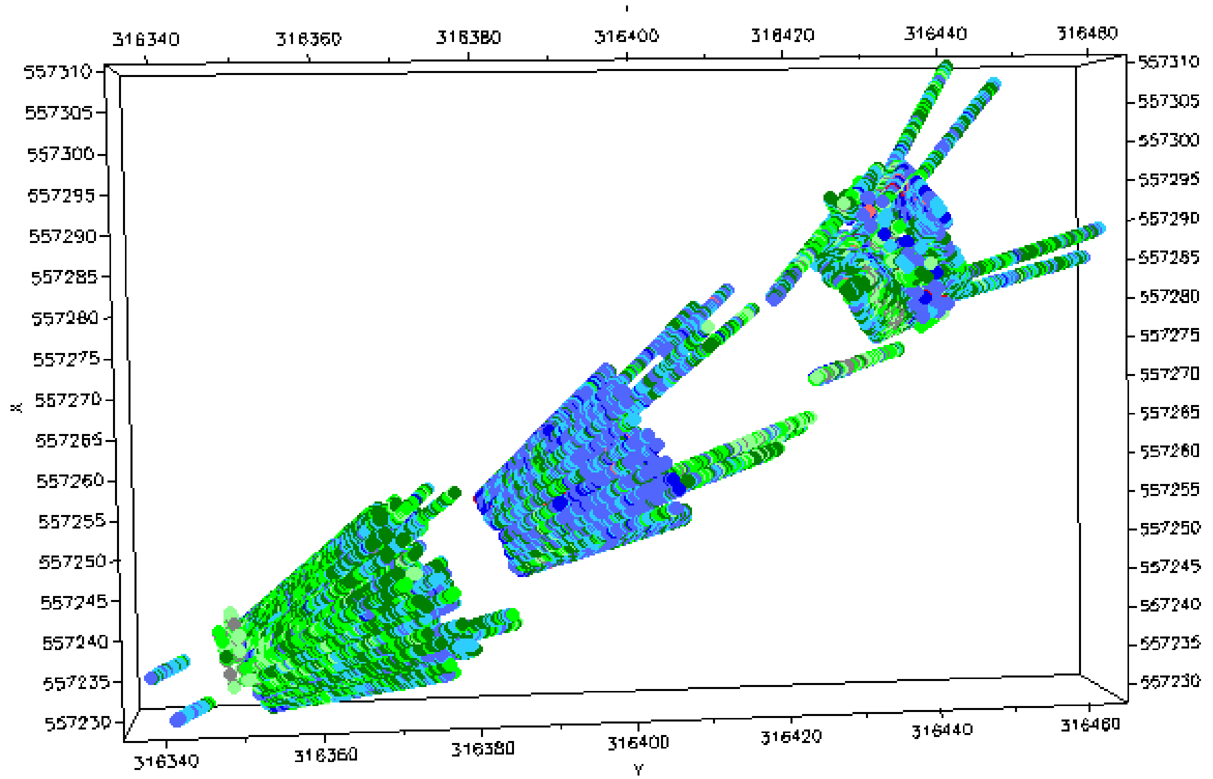
Joint spacing and roughness



Roughness profile



Measure while drilling

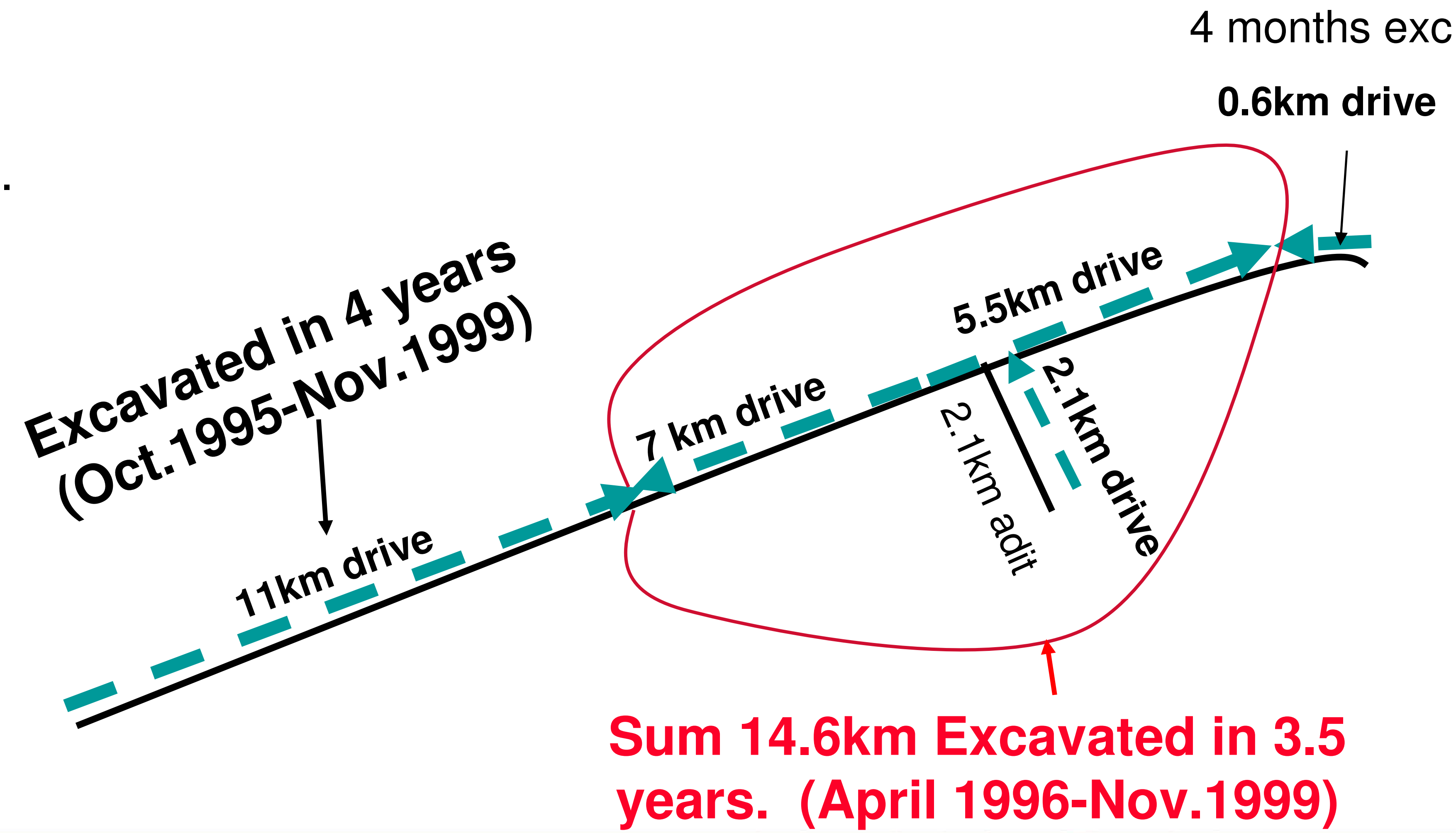


- Correlate 5 parameters from the drilling rig
- Gives data from all the drill holes, which may be correlated to Lidar data after blasting.

The Lærdal Tunnel-
The longest road tunnel of the world

- Length of the main tunnel 24.5km
- Access/ventilation tunnel 2.1km
- Cross section (theoretical) 56.5m^2
- Overburden max. 1450m
- 20km more than 800m overburden
- 3 roundabouts (each 6km) span 31m
- 16 turning points (niches) span 12m
- Max. theoretical vertical stress = 39MPa. The major and dominant stress was subhorizontal

The 24.5 km long Lærdal road Tunnel



Max. excvation per week per face was 108 m.

Total cost for the Lærdal tunnel when opened for traffic in the year 2000

- 1050 mill NOK ≈ 120 mill Euro ≈ 230 mill SGD
- 39300 NOK ≈ 4400 Euro ≈ 8700 SGD per meter tunnel
- 26700m excavated and supported, included access tunnel
- Included ventilation and illumination
- Included drainage system
- Included water shielding and frost protection (Rel. dry tunnel)
- Included warning and security measures
- Included 100m bypass tunnel for gas and dust cleaning

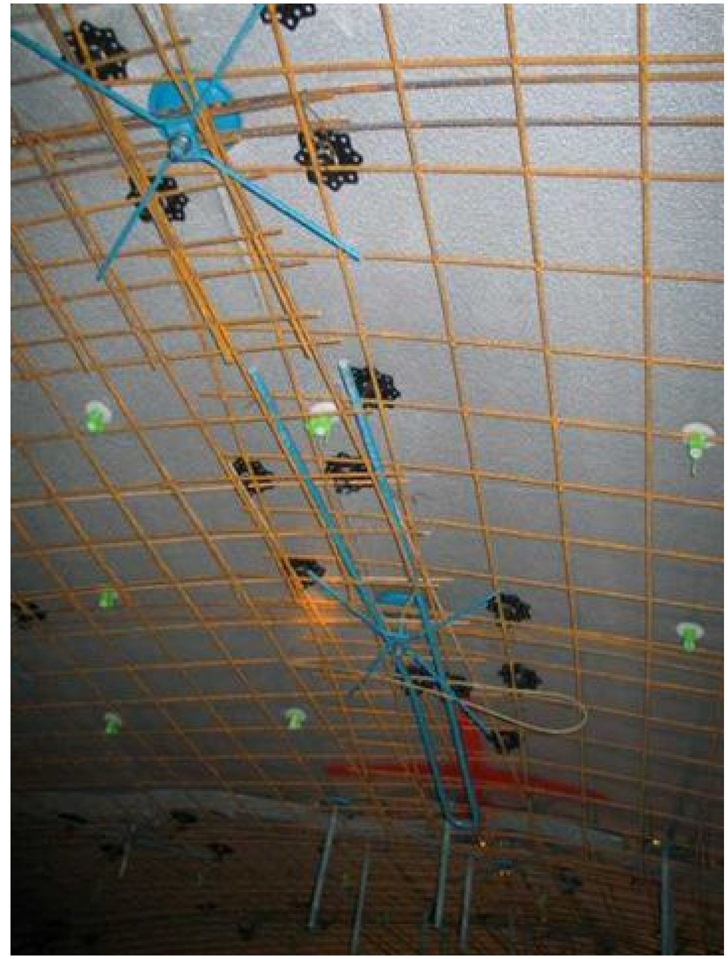
Poor rock mass quality gives deformation

- Empirical relation between deformation and rock mass quality, Q
- The temporary support will be deformed in poor rock
- Need for high residual strength and energy absorption in Sfr +B in poor rock
- Early installation of rigid support gives cracking and some times collapse in high stress or squeezing rock
- Installation of more rigid support when the deformation has been reduced to an accepted level
- During the last 15-20 years RRS has replaced CCA in the lowest rock mass qualities in Norway

Water and frost protection

PE-foam and mesh reinforced shotcrete.

Micro polypropylene fiber in shotcrete as fire protection



Precast elements in the wall

Water and frost insulation. Precast segments in the walls

Thank you

31M WIDE TURNAROUND CAVERNS IN THE
24,5KM LONG LÆRDAL ROAD TUNNEL