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Norwegian Method of Tunnelling (NMT)

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Norwegian Method of Tunnelling (NMT)

Content

- Essential features of NMT
- Safe and sustainable tunnelling practices (life cycle approach)
- Q-system of rock mass classification
- Ground investigations for tunnelling
- Tunnel mapping and construction
- Rock support in tunnel
- Numerical modelling for optimization of tunnel design

What is NMT

- A tunnelling method which effectively minimizes the use of concrete reducing production of CO_2
- Useful for construction of climate resilient infrastructures
- It has single shell characteristics which distinguishes it clearly from the classical double-shell NATM method

- NMT is considerably more cost effective than NATM

- Proof that NMT is cost effective (next slide)

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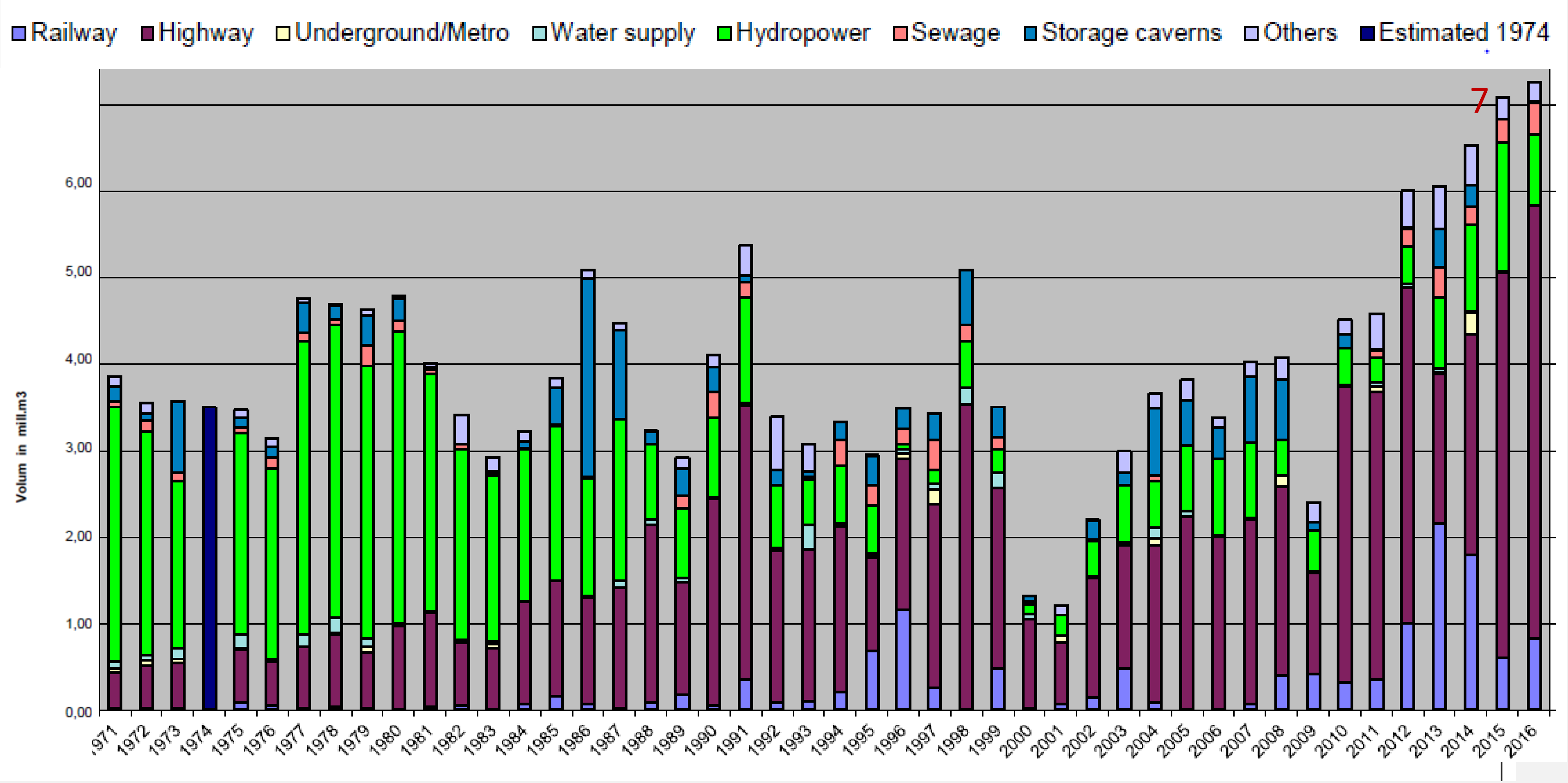
About 7000 kilometers of tunnels have been constructed in Norway

750 railway tunnels, 1000 road tunnels, 36 subsea-tunnels, in total almost 3000km in length
+ 4000km hydropower tunnels

Tunnel statistics,
Norwegian Tunnelling Association



Essential features of NMT

- Most approp. for jointed hard rocks and for weak rocks too
- Temporary support based on rock mass classification (Q-system)
- Monitoring when deformation is expected
- Fibre reinforced sprayed concrete + rock bolts +RRS as temporary support
- Permanent support consist of temporary support+supplement and water shielding (single shell)
- Drainage + ventilation + illumination
- Cost 10 – 15,000 USD/m tunnel in Norway

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(Barton et al, 1992, 2017)

Norwegian Tunnelling & Norway

- Norwegian landscape is characterised by long and deep valleys and high mountains
- Rock tunnels have been found to be efficient link to overcome infrastructure challenges
- Some 7000 kilometres of tunnels have been constructed in Norway (population 5 mill.)
- Annually, approx. 3 million m^3 rock is excavated
- NGI has contributed significantly to the development of Norwegian Tunnelling Technology

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Important Principles of NMT

- Site investigations using geophysical methods
- Application of the updated Q-system of rock mass classification to estimate rock support
- Evaluation of parameters related to rock jointing and shear resistance of the joints, roughness, strength, permeability, aperture etc.
- Conversion of a three dimensional geologic excavation in a idealised 2D model for numerical modelling
- Integration of empirical and numerical approaches to validate rock support design
- Rapid advance of tunnel using modern excavation techniques and rock support

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Norwegian Tunnelling

- In NMT the important point is that forward prediction of conditions and agreed modifications for unexpected conditions should each be done as early as possible,
- so that on one hand tender documents are a fair reflection of revealed conditions, and unexpected conditions are agreed upon and tackled without delay by all parties concerned
- This minimises disputes and also minimises tunnel instability
- Forward prediction is based on the Q-system which was developed at NGI and used world-wide including India

Development of the Q-system for rock mass classification at NGI

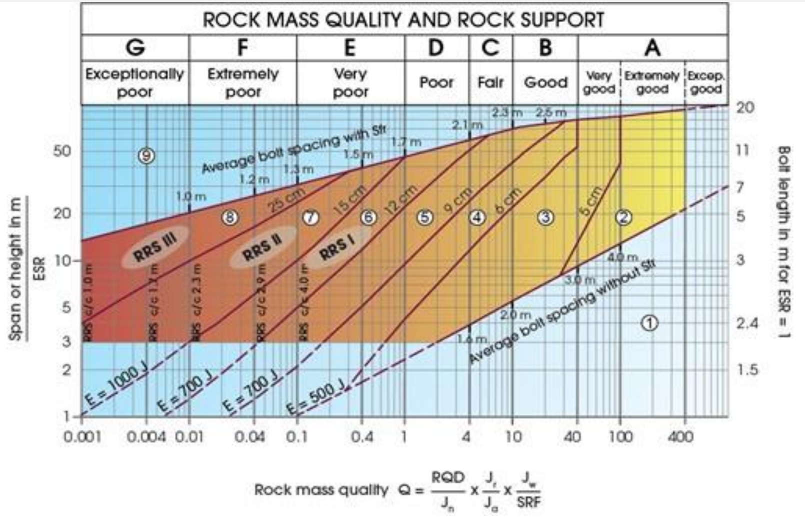
- The Q-system was developed at NGI in 1971 – 1974 based on case study of 200 underground openings (Barton et. al. 1974)
- It was an extensive updating of the system in 1993 based on 1050 examples (Grimstad and Barton, 1993)
- An updating in 2002 was based on 900 new examples
- Latest version of Q-system (2017) available at NGI website



Q-system for rock support and reinforcement

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

RQD – Rock Quality Designation
J_n – Joint set no.
J_r – Joint roughness no.
J_a – Joint alteration no.
J_w – Water reduction factor
SRF – Stress reduction factor



Support categories

1. Unsupported or spot bolting
2. Spot bolting, **SB**
3. Systematic bolting, fibre reinforced sprayed concrete, 5-6 cm, **B+Sfr**
4. Fibre reinforced sprayed concrete and bolting, 6-9 cm, **Sfr (E500)+B**
5. Fibre reinforced sprayed concrete and bolting, 9-12 cm, **Sfr (E700)+B**
6. Fibre reinforced sprayed concrete and bolting, 12-15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E700)+RRS I +B**
7. Fibre reinforced sprayed concrete >15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E1000)+RRS II+B**
8. Cast concrete lining, **CCA** or **Sfr (E1000)+RRS III+B**
9. Special evaluation

Bolts spacing is mainly based on Ø20 mm

E = Energy absorbtion in fibre reinforced sprayed concrete

ESR = Excavation Support Ratio

Areas with dashed lines have no empirical data

RRS - spacing related to Q-value

I: **Si30/6 Ø16 - Ø20 (span 10m)**
D40/6+2 Ø16-20 (span 20m)

II: Si35/6 Ø16-20 (span 5m)
D45/6+2 Ø16-20 (span 10m)
D55/6+4 Ø20 (span 20m)

III: D40/6+4 Ø16-20 (span 5 m)
D55/6+4 Ø20 (span 10 m)
D70/6+6 Ø20 (span 20 m)

Si30/6 = Single layer of 6 rebars, 30 cm thickness of sprayed concrete
D = Double layer of rebars
Ø16 = Rebar diameter is 16 mm
c/c = RSS spacing, centre - centre

The Q-system

Based on six parameters, a Q-value for the rock mass can be calculated

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

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RQD - Rock Quality Designation

1	RQD (Rock Quality Designation)		RQD
A	Very poor	(> 27 joints per m^3)	0-25
B	Poor	(20-27 joints per m^3)	25-50
C	Fair	(13-19 joints per m^3)	50-75
D	Good	(8-12 joints per m^3)	75-90
E	Excellent	(0-7 joints per m^3)	90-100

Note: i) Where RQD is reported or measured as ≤ 10 (including 0) the value 10 is used to evaluate the Q-value

ii) RQD-intervals of 5, *i.e.* 100, 95, 90, *etc*., are sufficiently accurate

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

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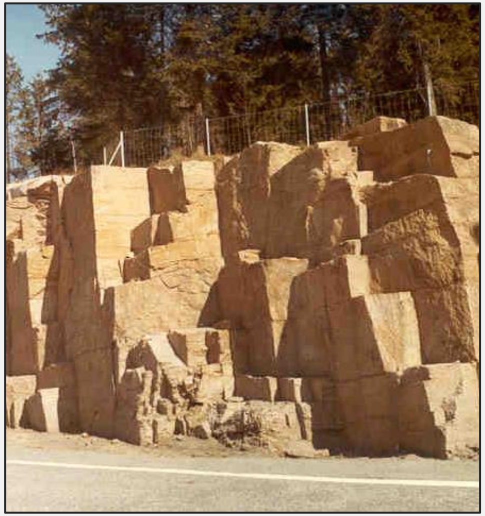
J_n - Joint Set Number

2	**Joint Set Number**	J_n
A	Massive, no or few joints	0.5-1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random heavily jointed "sugar cube", *etc.*	15
J	Crushed rock, earthlike	20

Note: i) For intersections, use $3 \times J_n$

ii) For portals, use $2 \times J_n$



$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

J_r - Joint Roughness Number

3	**Joint Roughness Number**	J_r
a)	*Rock-wall contact, and*	
b)	*Rock-wall contact before 10 cm of shear moment*	
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating,	2
D	Slickensided, undulating	1.5
E	Rough, irregular, planar	1.5
F	Smooth, planar	1
G	Slickensided, planar	0.5
Note: Description refers to small scale features and intermediate scale features, in that order.		
c)	*No rock-wall contact when sheared*	
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1
Note: i) Add 1 if the mean spacing of the relevant joint set is greater than ca 3m (scale dependent). ii) J_r = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented in the estimated sliding direction.		

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

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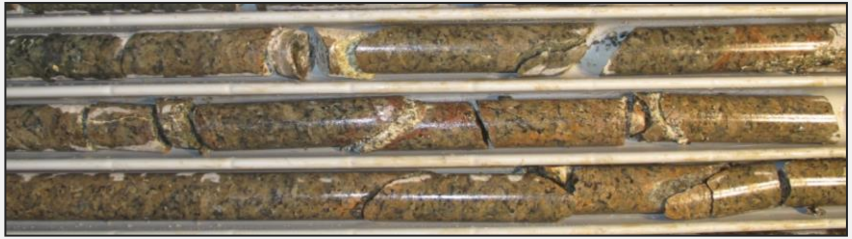
J_a - Joint Alteration Number

4	Joint Alteration Number	Φ_r approx.	J_a
a)	*Rock-wall contact (no mineral fillings, only coatings)*		
A	Tightly healed, hard, non-softening, impermeable filling, i.e., quartz or epidote.		0.75
B	Unaltered joint walls, surface staining only.	25-35°	1
C	Slightly altered joint walls. Non-softening mineral coatings; sandy particles, clay-free disintegrated rock, etc.	25-30°	2
D	Silty or sandy clay coatings, small clay fraction (non-softening).	20-25°	3
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc gypsum, graphite, etc., and small quantities of swelling clays.	8-16°	4

J_a - Joint Alteration Number (b)

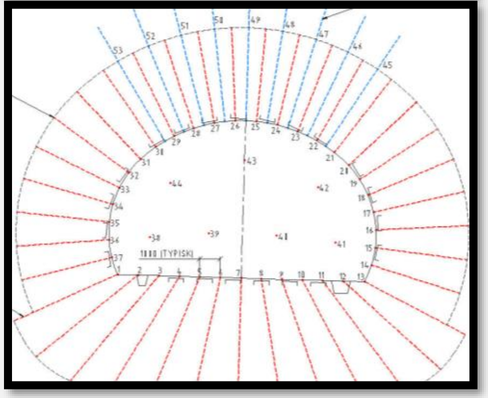
b)	*Rock-wall contact before 10 cm shear (thin mineral fillings)*		
F	Sandy particles, clay-free disintegrated rock, *etc.*	25-30°	4
G	Strongly over-consolidated, non-softening, clay mineral fillings (continuous, but <5mm thickness).	16-24°	6
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness).	12-16°	8
J	Swelling-clay fillings, *i.e.*, montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles.	6-12°	8-12



$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

J_w - Joint Water Reduction Number

5	Joint Water Reduction Factor	J_w
A	Dry excavations or minor inflow (humid or a few drips)	1.0
B	Medium inflow, occasional outwash of joint fillings (many drips)	0.66
C	Jet inflow or high pressure in competent rock with unfilled joints.	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings.	0.33
E	Exceptionally high inflow or water pressure after blasting, decaying with time. May cause outwash of material and cave in.	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay. May cause outwash of material and cave in.	0.1-0.05
Note:	i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed. ii) Special problems caused by ice formation are not considered.	



$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

Tunneling constitutes an important long-term mitigation measure to bypass landslides

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Bardong Landslide in Sikkim in 2000

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Mitigation strategy for Burdong landslide

Bjørkåstunnel bypassing hazardous rock fall areas along the coast

Common problems in the Hilly Regions

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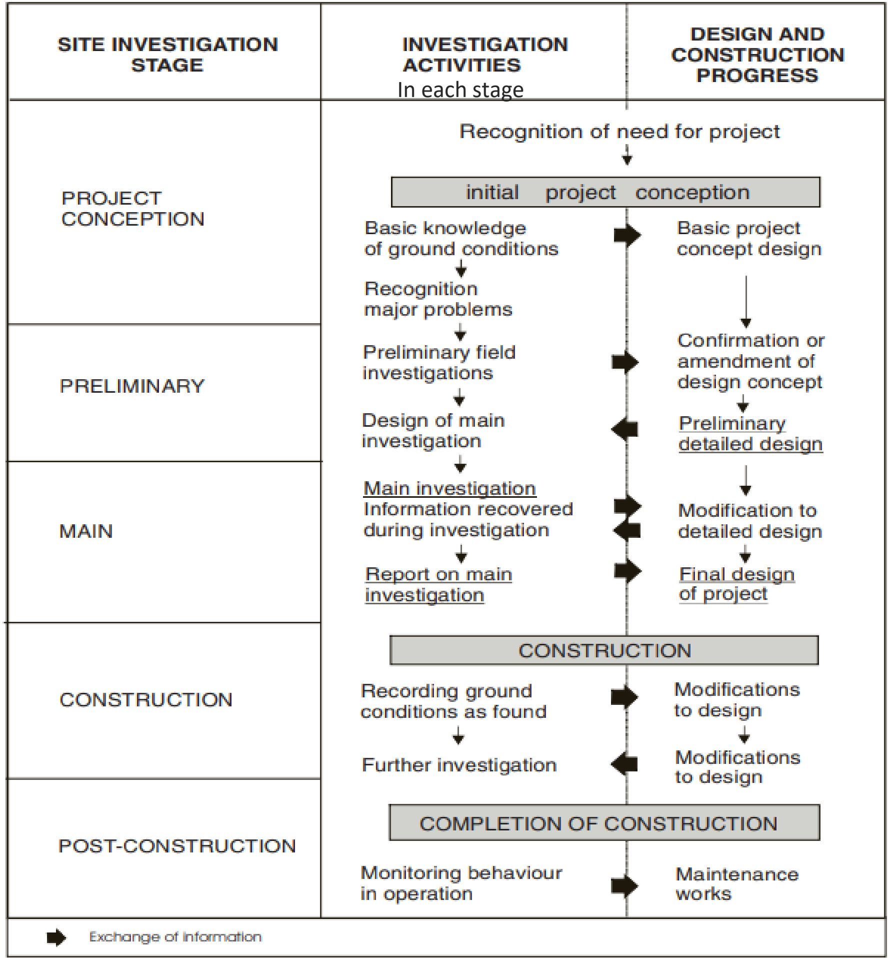
Long-term solution through climate resilient infrastructure

Ground Investigations for Tunnelling

Recommended Ground Investigations according to IAEG



Stepwise procedure for ground investigation of tunnels

1) Pre-construction			2) During construction	3) During operation
Project conception	Feasibility study	Detail investigation		
- Basic knowledge of ground conditions	-Desk study of maps, aerial photos, reports -Field investigation of key points -Visit to nearby excavations	-Eng.geol. mapping -Geophysical investigations -Drilling -Sampling -Lab. testing	-Tunnel mapping -Probe drilling -Monitoring (rock stress, convergence etc.) -Sampling -Lab. testing	-Monitoring (extensometer etc.) -Quality control
=> Recognition of major challenges	=> Preliminary design	=> "Final design"	=> Modification of design	=> Maintenance

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Nilsen, (2014)

Extent of Ground Investigation depends upon:

- The degree of difficulty or complexity of a project
- The requirement of safety

Eurocode 7 classification

Reliability class	Degree of difficulty		
	Low	Medium	High
CC/RC 1	1	1	2
CC/RC 2	1	2	2/3
CC/RC 3	2	2/3	3
CC/RC 4*	*	*	*

Class c, pre-investigations cost upto 8%, usually 3%

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Surface wave and refraction tomography

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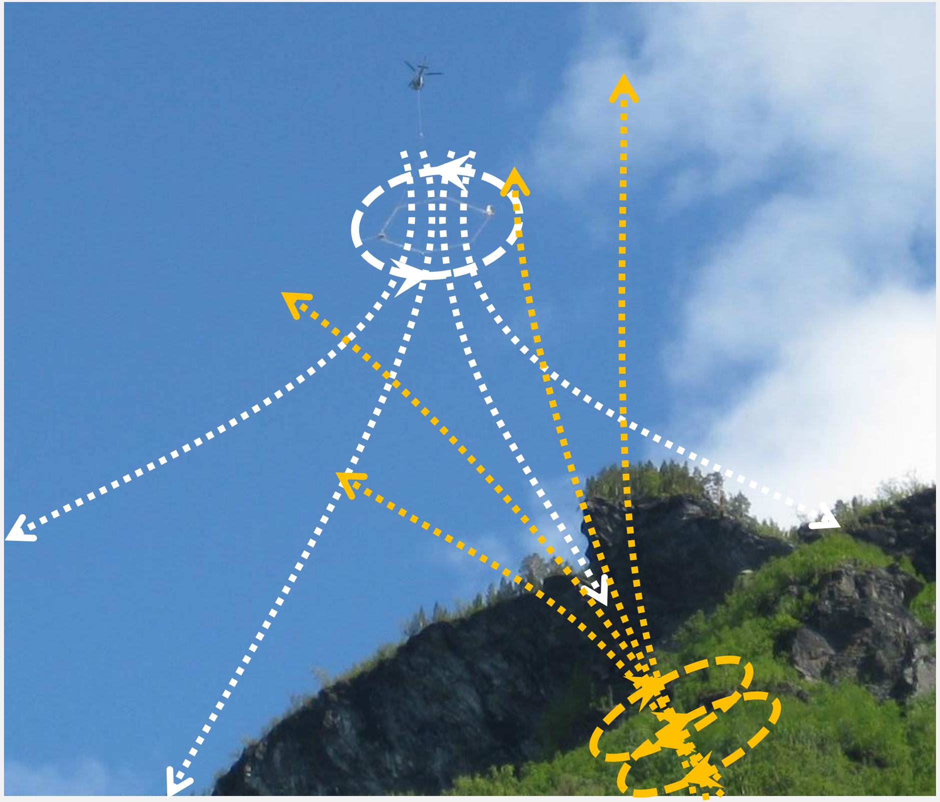
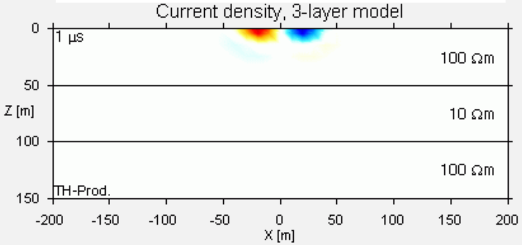
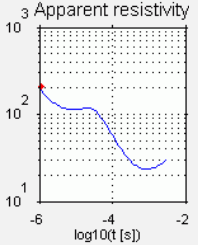
Airborne electromagnetic survey

Performed before the construction of a project

Airborne Electromagnetic surveys







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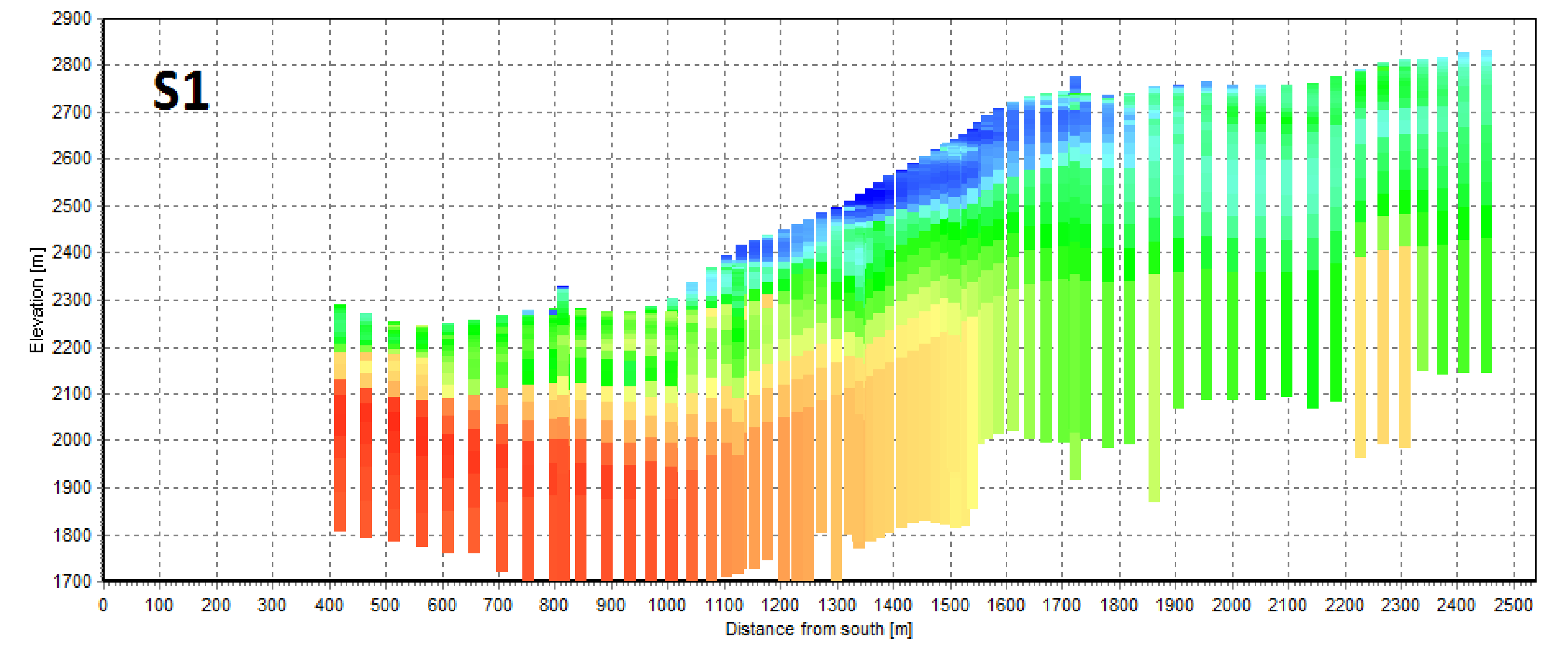
Eddy currents induced in conductive ground

Ladakh

Collaboration, NHIDCL, IAF, SkyTEM, AIA,EMerald Geomodelling

Resistivity in vertical section

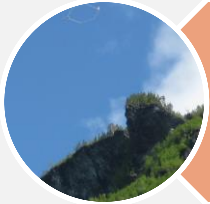


Resistivity in a vertical section (South-North) West of Nabesa. Red is conductive while blue is resistive

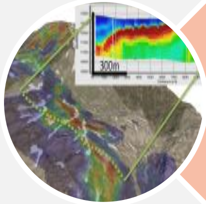
AEM for geotechnical work

Opportunities

Reduce costs & Extend database FAST (multi-method surveys)

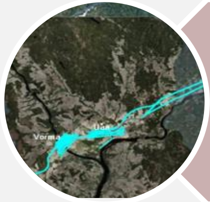


You can fly almost everywhere



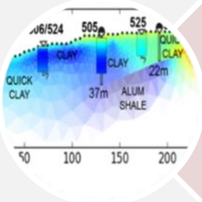
Penetration depth up to 300-700m

Limitations



Limited to medium to large projects

Difficult in urban areas / infrastructure



Lateral resolution better with ERT

Need "good" conductor

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Tunnel Mapping and Construction

Tunnel Mapping

- During excavation, continuous mapping of the ground conditions is very important for updating the interpretations based on pre-investigation, and for decisions regarding rock support.
- The emphasis on tunnel mapping has increased as tunnel projects have become more and more challenging (urban tunnels, deep subsea tunnels etc)
- In Norwegian tunnelling today it is common to allocate a special item for tunnel mapping in the tender specifications, often referred to as “the owners half hour”, which is intended for geological mapping and evaluation after each blast round. This means that the contractor is compensated for the time which is used for mapping

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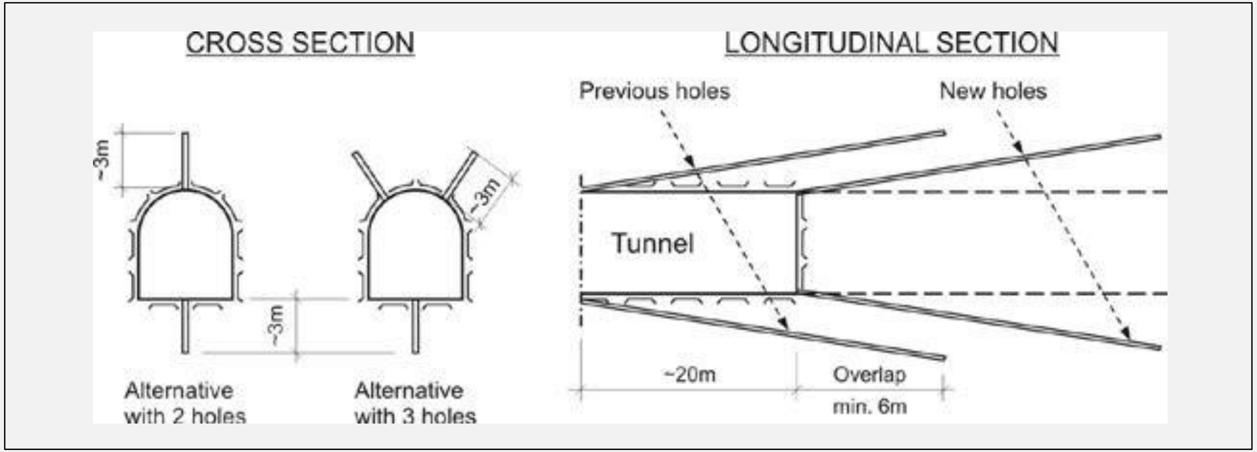
Tunnel Mapping

- Tunnel mapping documentation should contain all geological factors that may influence on the stability and conditions of the tunnel, such as rock type and character, jointing, faults, water leakage and potential rock burst problems, in addition to information about support work.
- For detecting water inflow and faults/weakness zones probe drilling is performed. The decisions regarding need for grouting are based on results from probe drilling



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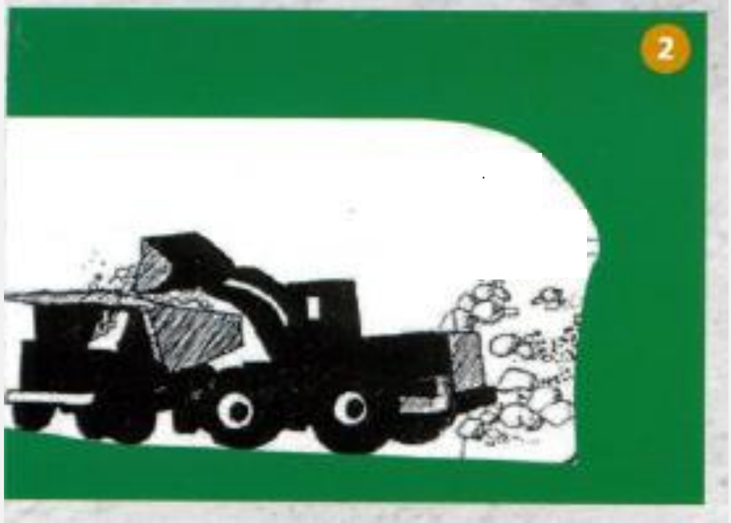
Drilling of holes for explosives

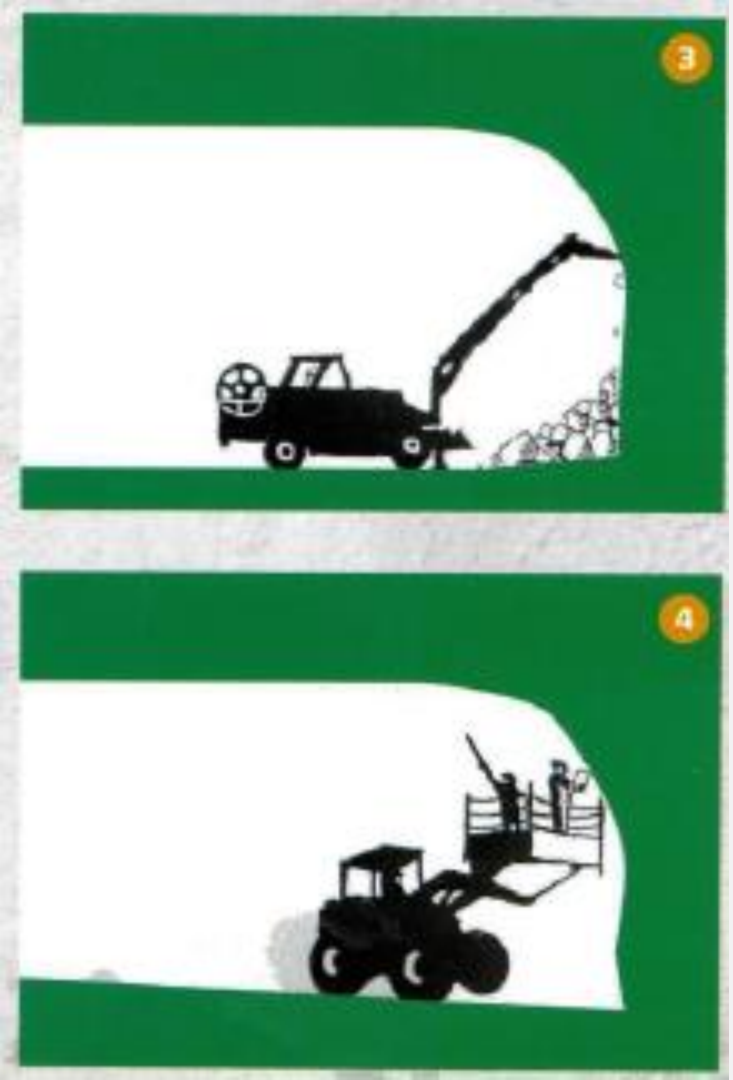
Mucking out after blasting



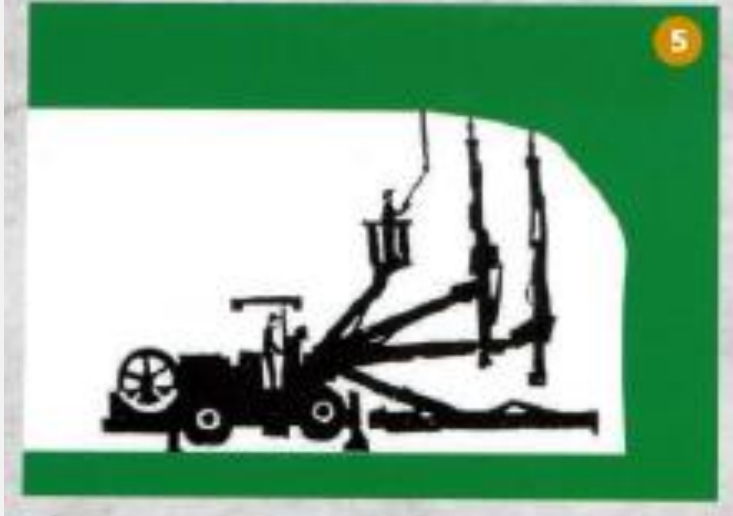
Scaling of loose rock
with hydraulic hammer

Manual control and scaling with scaling rod, combined with geological mapping and rock mass classification

This is the basis for support design



Drilling holes for rock bolts and installation of bolts. Number of bolts, spacing and length is based on rock mass quality.



Spraying of fibre reinforced concrete after or before installation of rock bolts depending on rock mass quality. Thickness based to rock mass quality.

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In very poor rock mass quality spraying of reinforced ribs of shotcrete (RRS) or cast concrete lining in addition to shotcrete and rock bolts

RRS has revolutionised tunnelling in weak rock in Norway

Classical steel ribs

Philippe Lazaro, 2013

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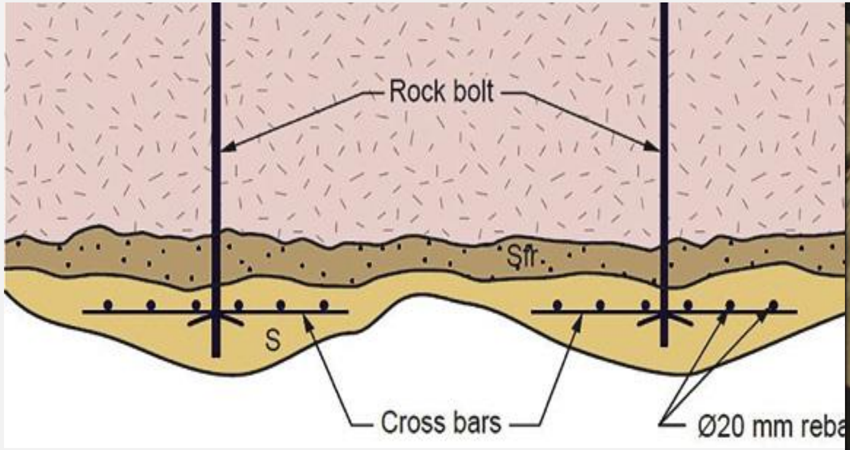
Optimising Rock Support

Rock Support Design



Finished product

Rishikesh, India

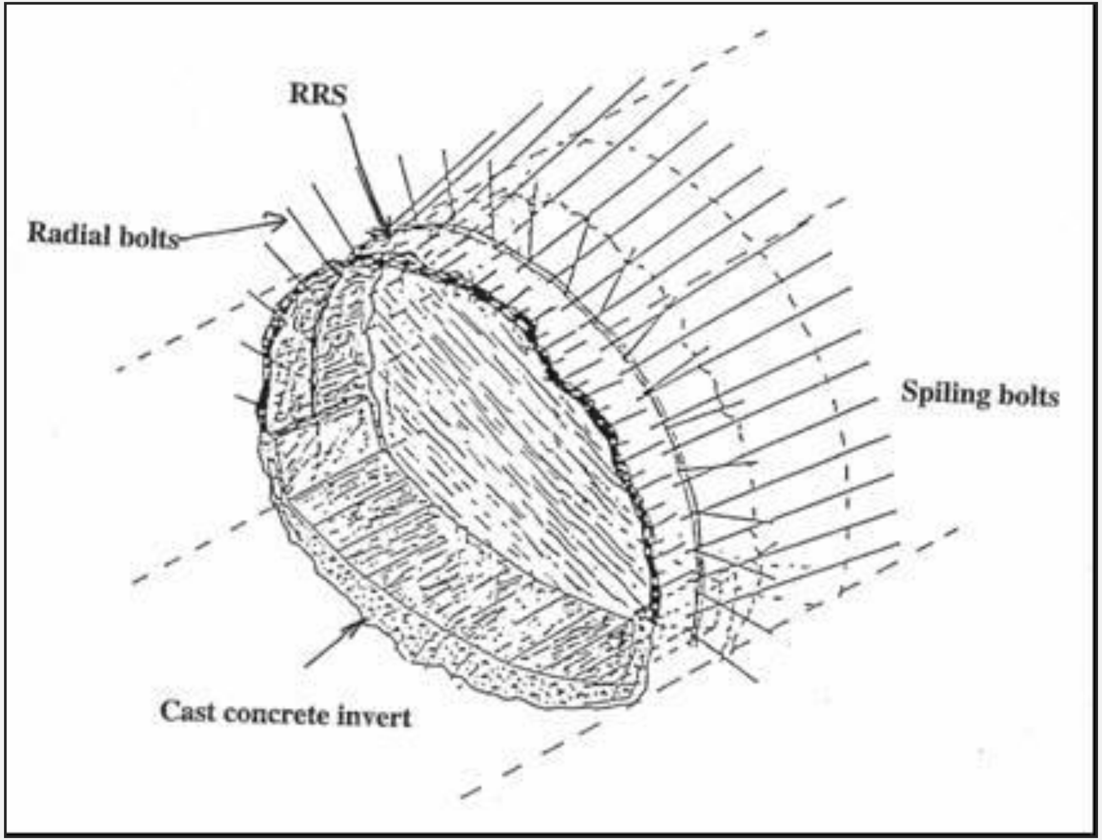
Installatation of Reinforced Ribs of shotcrete: Design and performance

Drill core from the instrumented weakness zone

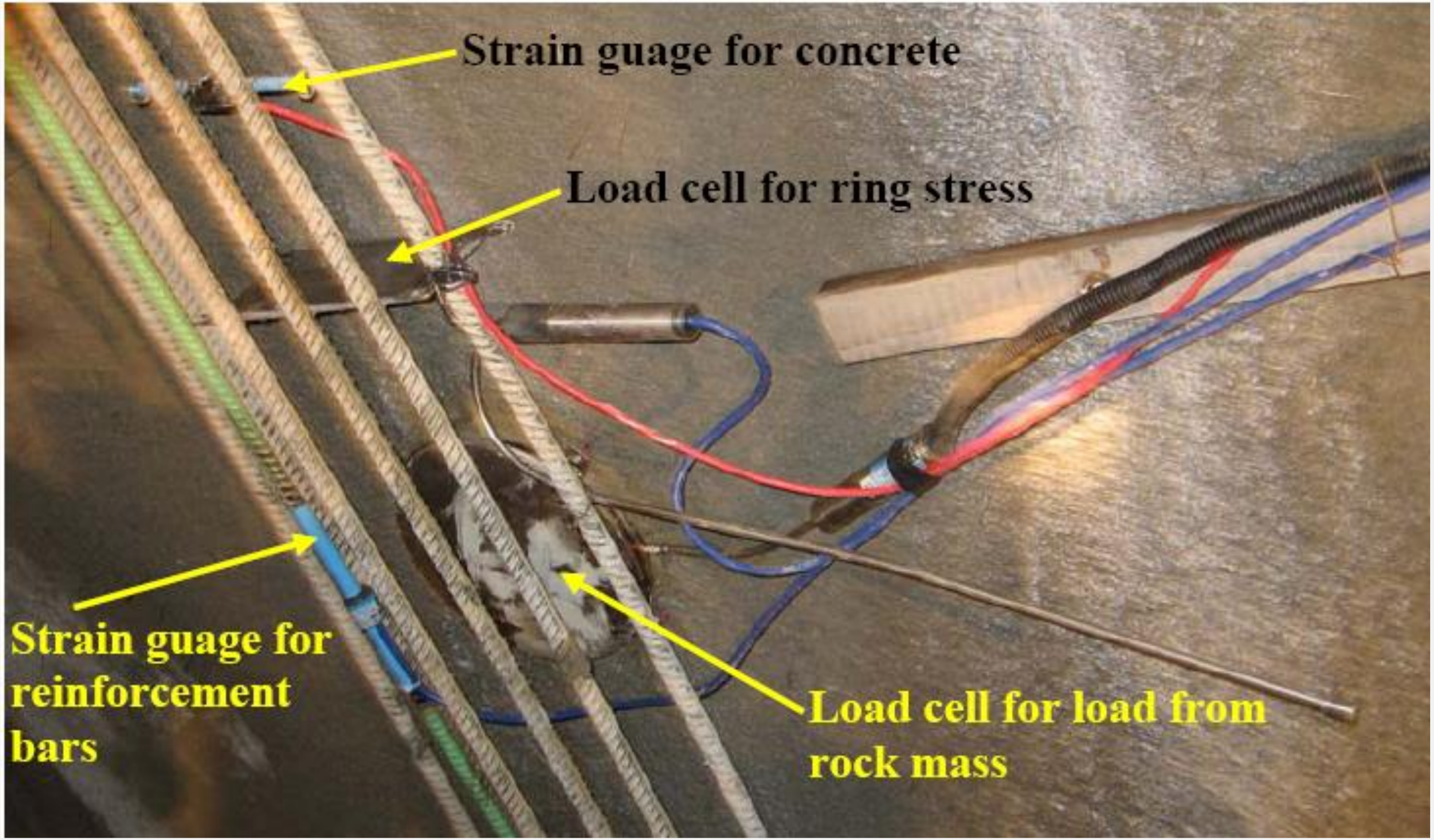
Rock mass quality, Q = (10/20)x(1/10)x(1/5) = 0,01

Exceptionally to Extremely poor. Contains swelling clay.

Support of poor rock masses by spiling bolts



Installment of instruments



Rishikesh
INDIA

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NMT-priciples

Difference between NATM and NMT

• NMT	NATM
•Most approp. for jointed hard rock	•Most appropriate for soft ground
•Temporary support based on rock mass classification (Q-system ++)	•Temporary support based on 5 or 6 classes (deformation and hardness)
•Monitoring when deformation is expected	•Monitoring of deformation
•Fibre reinforced sprayed concrete + rock bolts +RRS as temporary support	• Steel sets +lattice girders + sprayed concrete as temporary support
•Pemanent support consist of temporary support+supplement and water shielding	•Permanent support is pre designed
	•Watertight membrane
	•Cast concrete lining including the invert as final support
•Drainage +ventilation+illumination	•Ventilation+illumination+drainage
•Cost 10 – 15,000 USD/m tunnel	•Cost 35—80,000 USD/m tunnel

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Thank you for your attention

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