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Urban Tunnelling in Hard Rock

TRAINING MATERIAL PREPARED BY

Eivind Grøv
Research Manager Underground Technology SINTEF

STA

ASSOCIATION INTERNATIONALE DES TRAVAUX EN SOUTERRAIN
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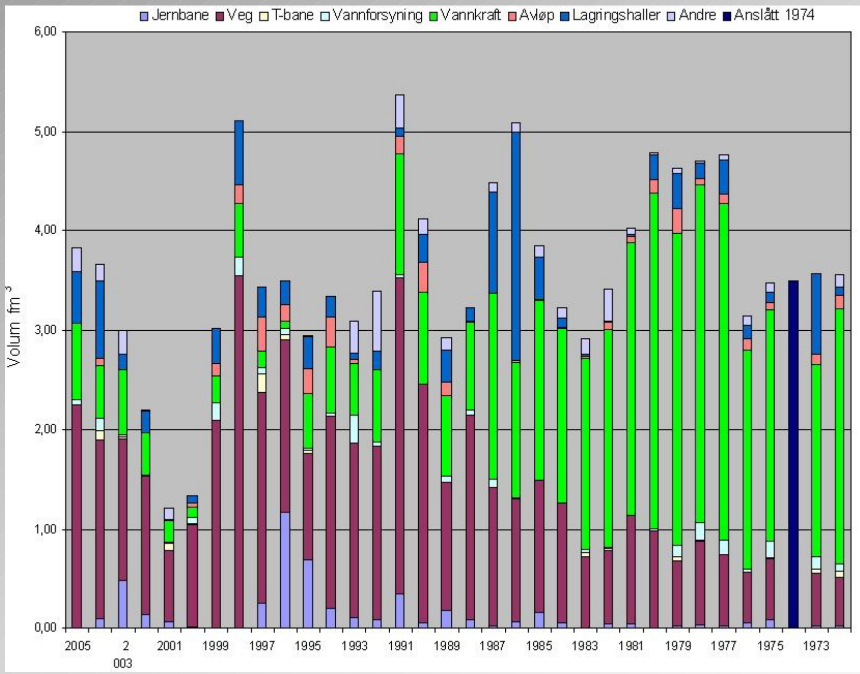
Introduction

- Tunnels have become a necessity in the growing infrastructures,
- Underground to take care of urban development has become a “must”
- Key to solve problems associated with such development
- Replacing exposed roads with tunnels, sometimes only locally may provide an improved standard of life



Extending urban planning from a 2-dimensional or a 3-dimensional approach seems obvious, and the 4th dimension should be to utilise the subsurface

Basis for implementation of sprayed concrete based tunnelling

What characterises a hard rock regime?

1. It's selfstanding capacity, i.e. the ability of the rock mass to maintain stability even after being subject to cavities being made, man made or natural.

"Stand-up" time implies that the rock mass is not a dead load. Engineering approach takes this capacity into account. Rock strengthening may be needed to secure specified capacities

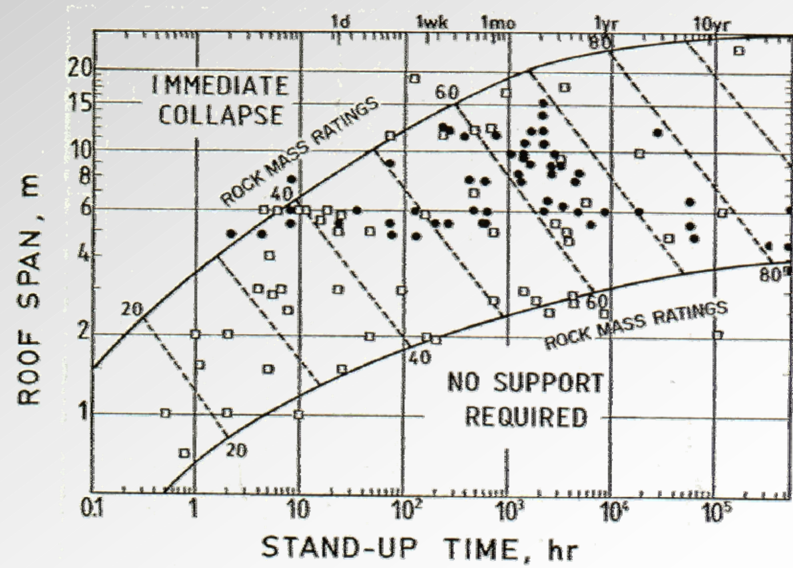
The mining industry learned us numerous cases with large span:

* Were 60-80 meters wide

* Were Stable

* With no rock support at all

WHY?



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Basis for implementation of sprayed concrete based tunnelling

What characterises a hard rock regime?

2. It's impermeable nature, i.e. the actual permeability of the rock mass and associated discontinuities may vary from 10-5m/sec to 10-12m/sec.

But it is neither homogenous nor continuous, but suffering:

Cracks and joints

Weaknesses

Weathering

•A typical jointed aquifer, water occurs on the most permeable discontinuities.

•The permeability of rock mass may be in the range of 10-8 m/sec.

•The most conductive zones must be identified and treated.

•Prevent the tunnel imposing an adverse situation in the ground-water regime.

Basis for implementation of sprayed concrete based tunnelling

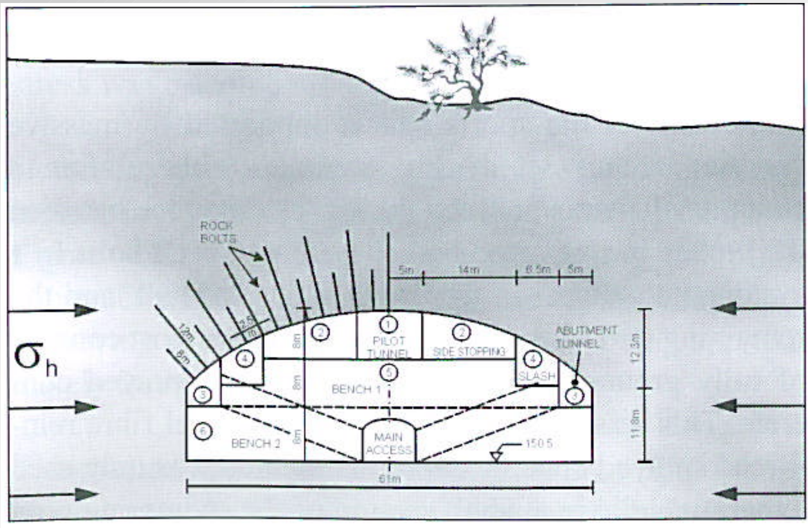
What characterises a hard rock regime?

3. It's stress induced confinement, the in-situ stress situation varying from stress released rock bodies through a pure gravitational stress situation to stresses originated by long tectonic history of the rock mass.

What made the Gjøvik hall feasible??

Sufficient high horizontal stress

In situ stress measurements were done; σ_h=3-5MPa at a depth of 25-50m which is far more than the theoretical gravity approach



Basis for implementation of sprayed concrete based tunnelling

What characterises a hard rock regime?

4. It’s thermal capacity, i.e. the capacity to store energy over significant amount of time. .

Water control in tunnelling

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Why make the tunnel or the underground opening a dry one?

Prevent an adverse internal environment.

•strict requirements to obtain a safe and dry internal environment, water is not allowed to appear on internal walls or roof in the tunnel.

Prevent unacceptable impact on the external, surrounding environment.

• risk of imposing adverse impacts to the surrounding environment by means of e.g.; lowering the groundwater table causing settlements of buildings and other surface; disturbing the existing biotypes, natural lakes and ponds.

Maintain hydrodynamic containment.

• to provide a containment to prevent leakage of stored products.

A few anecdotes

- In previous hydropower tunnelling projects water inflow was a ”plus”, few, if any mentioned environmental impacts
- The construction of the Lieråsen tunnel 30 years ago drained a sumpy area to become valuable land for a new housing complex
- The Gardermoen tunnel in late 90’es faced public, political, environmental and technical focus on a scale never experienced before

Water control in tunnelling

Normal requirements

- A maximum inflow of 30 l/min/100m is used in sub-sea tunnels or elsewhere with no specific requirements
- 2 l/min/100m in particular areas
- Various requirements may apply for different sections of a tunnel pending on the local consequences of groundwater lowering

Water control in tunnelling

Typical applications and achieved results

Project	Max inflow (l/min/100 m)	Measured inflow (l/min/100 m)
Baneheia	2.1	1.7
Storhaug	3-6	1.6
T-banen	7-14	4.3
Asker skøyen	< 4 to 16	Due to start
Holsfjorden	5-40	Future

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Water control in tunnelling

Aspects of a grouting strategy

- Evaluate the effect of the inflow criteria
- Identify conductive zones in the rock mass
- Aim at completing grouting after 1 round
- Focus on a limited area around the opening
- Choose grout type, mix, pressure & grout hole pattern
- Monitor inflow, evaluate modifications
- Integrate the grouting in the support system

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Water control in tunnelling

Organisation and contract requirements

- Organisation and contract must be well prepared
- Well proven and tested procedures
- Smooth co-operation contractor/owner
- Delegate responsibility to tunnelling staff
- Adaptation to the actual conditions
- Risk sharing unit rate contract, can choose
- Fixed price, functional requirements and incites for a time effective grouting

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Water control in tunnelling

Standardised, systematic grouting scheme through the whole tunnel is most advantageous for groundwater control and surprisingly also for the excavation cycle

- superplasticizers and silica additives increased the penetrability and pumpability for grouting and micro-cements;
- increased grouting pressure (up to 90 bar) yielded better penetrability and grouting capacity;
- reduced w/c ratios improved the quality of the grout; and
- that the pre-grouting efforts improved the rock mass stability.

Active design, a concept of hard rock tunnelling

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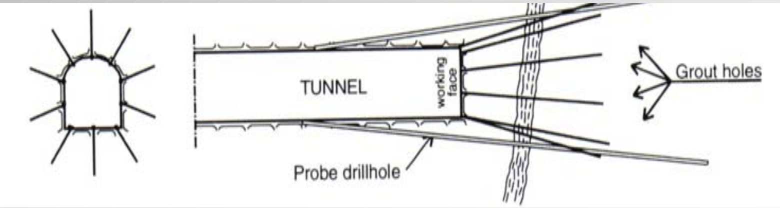
Sprayed concrete lining as permanent support, together with other tunnelling techniques constitute a tunnelling method ”Single shell shotcrete lining”

1 Ground water control



Probe drilling ahead of face
Pre-grouting
Impervious zone, reduce the water gradient
Tested and documented to 2 l/min/100m

2 Cautious blasting

Reduce the secondary cracking
Producing a smooth and even surface

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Active design, a concept of hard rock tunnelling

3 Empirical guidelines and analytical/numerical modelling

Several empirical methods at hand, Q, RMR etc

Numerical modelling is becoming popular

Design verification and assessment and follow-up

4 Observations and monitoring

Visual observation of rock surfaces is first step

Convergence pins, extensometers etc are second step

These are input to revisions of design, support, modelling

5 Working procedures

Ensure quality of works and ability to repeat work sycles

Critical work is carefully recorded and documented

Monitor support/grouting by experienced staff, adjust if needed

Active design,
a concept of hard rock tunnelling

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6 Drained structure

Support measures not designed to take the hydrostatic load
Excessive water is not allowed to build up behind support
Controlled handling of water

7 Primary support approved as permanent

Primary support is normally securing safe working conditions
Apply rock support that fulfils the specs for permanent work
Do as much as possible close to the tunnel face
Supplement primary lining; additional bolts, thicker shotcrete
⇒Permanent lining close to the tunnel face!!
⇒Approved primary support integrated in the permanent lining

Active design, a concept of hard rock tunnelling

Active design ⇒ adaptability

Establish geological model on information at hand prior to excavation works.

- A predefined set of rock support classes based on, for example, empirical guidelines.
- A sound verification of these support classes by utilisation of analytical and/or numerical models.
- A quantitative rock mass classification.
- A confirmed procedure for the application of support classes, combined with rock mass classification, and rules to handle occurrences beyond the coverage of the system.
- A continuous evaluation of the geological model and the predefined rock support classes based on experiences gained with modifications if needed.
- An immediate classification of the rock mass quality at the tunnel face.

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Active design, a concept of hard rock tunnelling

Today's tunnelling industry sets forth a number of pre-requiaites:

•Flexibility, adaptability, experience, cost efficiency and decision making at the tunnel face.

•The tunnelling shall allow: reliability, predictability (time and cost), planning, cost control and documentation.

⇒"Active design" provides a flexible tunnelling approach to adapt the support and grouting efforts to the actual rock mass encountered

It is typically Hard Rock, but not necessarily Good Rock

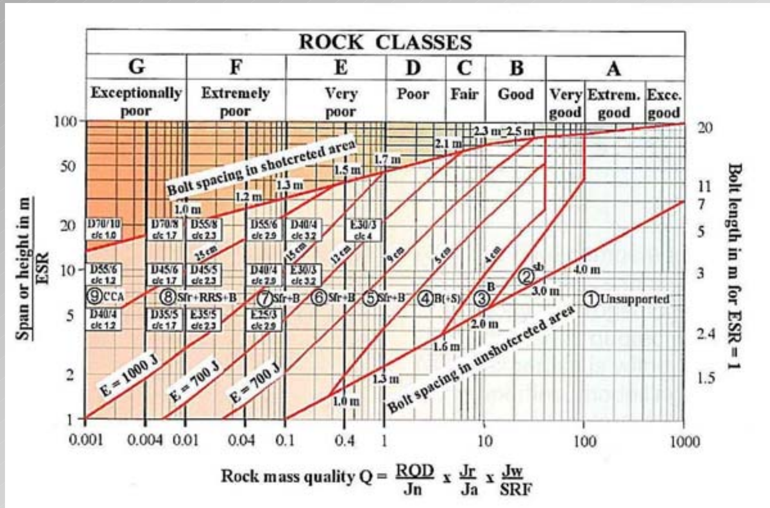
Sprayed concrete linings in adverse rock mass conditions

The Scandinavian host rock is generally from poor to extremely good rock.

The weakness zones can exhibit great variation in quality, Q-values from from extremely poor to good.

The widt of such zones may vary from a fewf centimeters to tens of meters

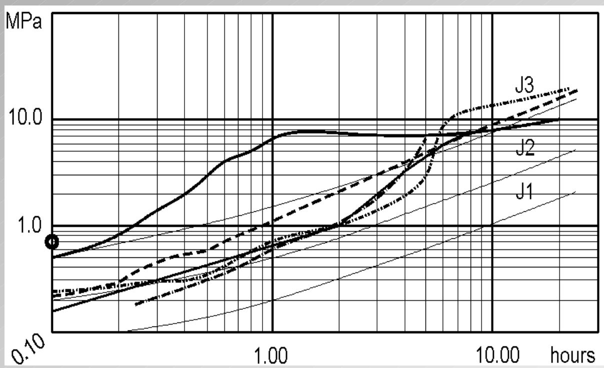
The CHALLENGE: replace cast-in-place concrete lining in poorer rock



Sprayed concrete linings in adverse rock mass conditions

Alkali-free accelerators

- Alkali-aggregate reaction reduction; by removal of the alkali content.
- Work safety improvement; by reduced aggressiveness of .
- Environmental protection improvement; by reducing the amount of aggressive and harmful components being released to the ground water.
- Final strength compensation; by forming a homogenous and compact concrete matrix.
- Alkali-free accelerators provides:
  - Early strength of 1 MPa after 1 hour.
  - Final strength reaching as a minimum the same level as without accelerator.
  - Low rebound.
  - 300 mm thickness sprayed in one operation.
  - Low corrosiveness.
  - Reduced permeability.



- No difference in personal dust exposure between the alkali-free and silicate based accelerators.
- Improved early strength development for the alkali-free accelerators compared to water glass.
- Wet conditions at spraying surfaces delay the early strength development for some accelerators.
- The tests indicate a durable, homogenous final product.

Sprayed concrete linings in adverse rock mass conditions

Reinforced ribs of sprayed concrete

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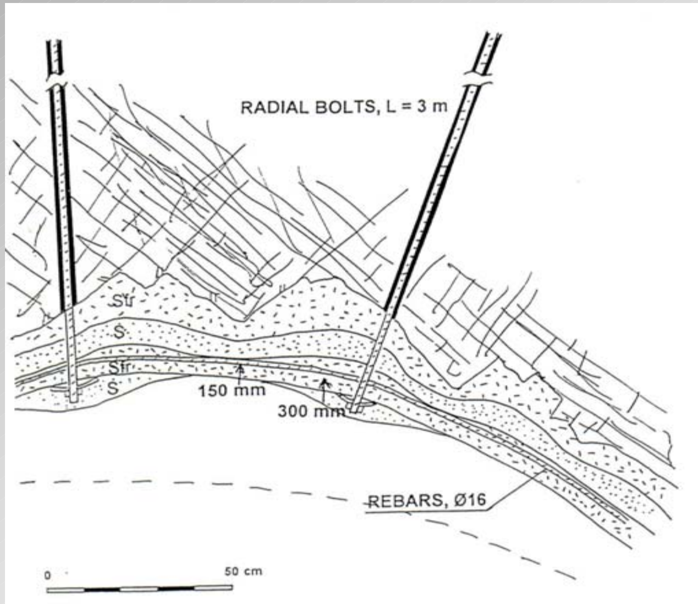
Q-value < 1, bolting as a support measure may not be adequate on its own.

Rock mass between the bolts must be stabilised by sprayed concrete.

Increased number of tunnelling projects encounters adverse rock mass conditions, thus alternative solutions have been considered.



Reinforced ribs of sprayed concrete is one solution for adverse rock mass conditions. It consists on fibre reinforced (and also plain) sprayed concrete, radial bolts, and rebars.

Sprayed concrete linings in adverse rock mass conditions

The system has the following advantages:

- Materials to be used are normally available on most construction sites.
- Convenient construction, easy to handle materials, and on-site production.
- Flexible installation and wide span in capacity.
- Cost effective.
- Ductile, allowing rock deformations without imposing load concentration on support.
- Allows tunnel progress shortly after installation.
- Easy to repair and custom design by spraying thicker concrete or adding new ribs.

Sprayed concrete linings in adverse rock mass conditions

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The most favorable combinations for support in the Frøya-tunnel were found to be: fibre reinforced sprayed concrete (Sfr), thickness 250 mm, combined with concrete lined invert and rock bolts (B) in roof and walls; reinforced ribs of sprayed concrete with 2 m spacing (RRS); and finally cast-in-place concrete (CCA), thickness 0.6 m in invert and 0.4 m in roof and walls.

Type of Support	Sprayed concrete 250 mm, concrete invert, rock bolts	Reinforced ribs and sprayed concrete (RRS)	Cast-in-place concrete lining (CCA)
Max. Displacement after equlibr.	14.4mm	17.1mm	17.3mm
Max. axial loading on bolts	3.3 tons	11.6 tons	-
Max. axial load on the structure	1.96 MN (roof)	0.88 MN (roof)	1.4 MN (roof)
Max. joint aperture	3.3m m	3.3mm	3.5mm
Max. shear displacement	10.7m m	10.7mm	11.7mm

Sprayed concrete linings in adverse rock mass conditions

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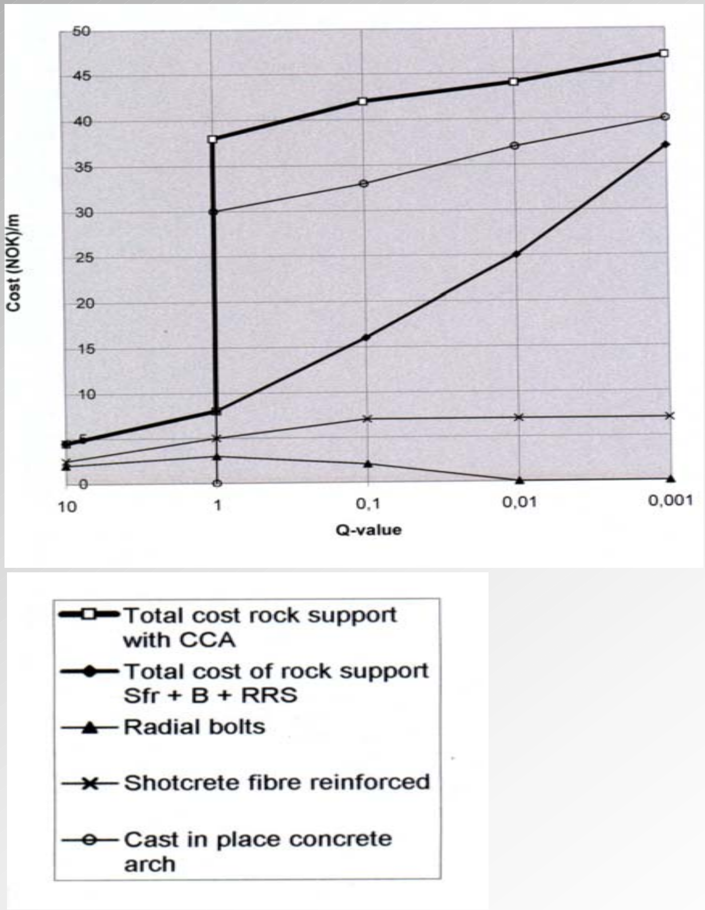
For rock mass classified as 1>Q>0.001, the application involving reinforced ribs was found to be the most cost-effective



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Some principles of Norwegian tunnelling

The main aims of the pre-investigations;
To establish a geological model
To establish a basis for predictions for time scheduling, cost assessments, tunnel prognosis, rock support and grout estimates.

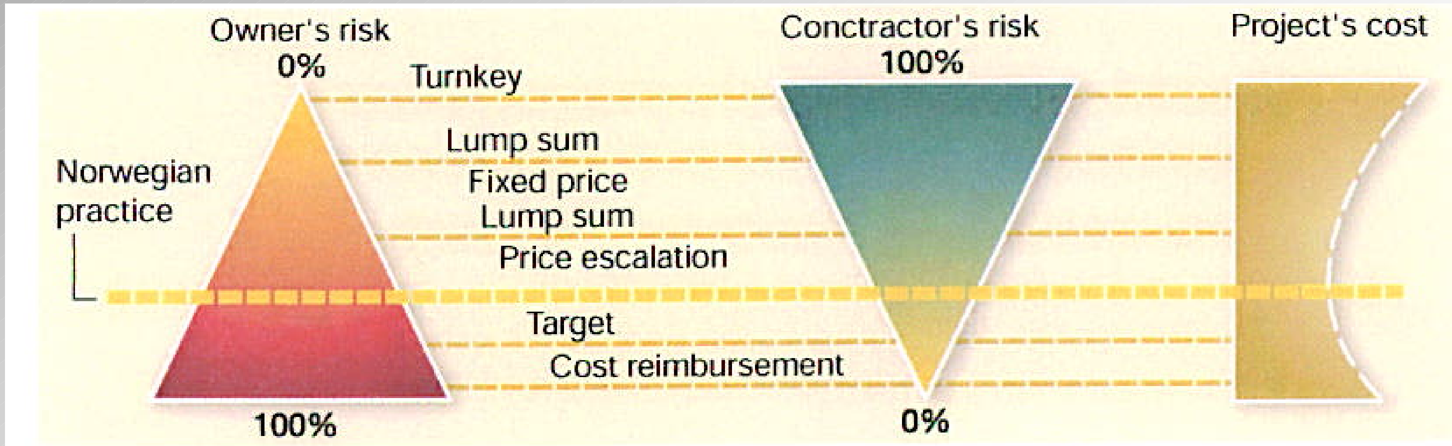
Further pre-investigations:

- Cost effective methods aimed at determining the variability of the rock mass.
- Critical areas call for specific investigations.
- Probe-drilling ahead of the tunnel face is acknowledged as a reliable investigation method.

Some principles of Norwegian tunnelling

Contractual matters

- The Owner carries the risk for the rock mass conditions
- The Contractor carries the risk for the appropriate and efficient handling of the works focusing to improve technical and organisational performance.
- The Owner is responsible for the collection of information on ground conditions. All information is disclosed to the tendering contractors for their own interpretation.
- The Owner presents their estimate on quantities on rock support, rock mass grouting etc. all expected measures are quantified in the tenders/contracts.
- The contracts include regulations for extension of construction time based on actually performed quantities.



Some main principles of Norwegian tunnelling

Construction

- High capacity equipment, multi-skilled workmen at the tunnelling face allowing high utilisation of the equipment .
- Adaptability to the actual ground conditions, careful following-up of the encountered rock mass by mapping and classification for a best fit the of rock support measures.
- Observation of the ground behaviour by visual surveying and physical measurements if required fulfilling the intentions of the Observational method.
- Installation of permanent rock support as close to the tunnel face as practically possible fulfilling the criteria for permanent support work.

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Some main principles of Norwegian tunnelling

Co-operation

In a broad perspective there are probably more common interests at the construction site than interest of conflicts.

- Respect for the different roles and values as tunnelling is a complex process and various skills are needed at the construction site.
- Constructive co-operation between the representatives of the involved parties.
- Experienced professionals participating in the decision making.
- Solve conflicts at construction site by negotiation after the technical issues have been settled.

Some main principles of Norwegian tunnelling

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Principle of sectional completion

Facts: In long tunnels (road and rail ways) there is a need of managing and utlising the construction time in an optimum way.

Excavation is the most time consuming activity.

Can anything be done simultaneously to reduce the time?

- Blast and excavate tunnel and ditche(s) in the same rounds
- Install infrastructure in the road embankment including a temporary asphalt layer every 1000-1500m
- Utilise the excavated rock as road embankment
- Place rock support close to the tunnel face
- Install other equipment in sections (cables etc)

$\Rightarrow$ An almost complete tunnel every 1000-1500m

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Some main principles of Norwegian tunnelling

Principle of sectional completion

Resulting:

Complicated logistics for the contractor with lots of work to plan and execute, but:

- Significant time saving has been achieved, shorter construction time and hopefully that has a positive economical impact for all parties
- Improved Health and Safety aspects, less exhaust gases, dust
- Reduced maintenance/cleaning on road and tunnel walls
- Reduced tear and wear on rolling stocks and improved fuel efficiency

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