Water control in Norwegian tunnelling

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Water control in Norwegian tunnelling
Tunnelling, a chain of activities
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Hard rock environment

- The Scandinavian host rock varies from poor to extremely good rock.
- Folding, faulting and high tectonic stresses influence the stability in tunnels.
- Weakness zones can exhibit great variation in quality, Q-values from extremely poor to good.
- The width of such zones may vary from a few centimeters to tens of meters.
- The CHALLENGE: to deal with a frequently changing ground.

It is typical Hard Rock, but not necessarily “Good Rock”
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Some anecdotes from Norwegian tunnelling

- 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 Romeriksporten tunnel in late 90’s faced public, political, environmental and technical focus on a scale never experienced before.

The unfortunate affair at Romeriksporten triggered a new approach to water control in Norwegian tunnelling.
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Publications released recently
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Purpose of these publications

- Water control according to the pre-grouting concept “prevention is better than cure”
- Focus has shifted to environmental concern rather than practical tunnelling aspects
- Technical lessons have been learned
- Demonstrate and document Norwegian experiences
- Experiences believed to benefit tunnelling projects elsewhere
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Why water control?

There are various requirements to an underground project, one might be to produce a “dry tunnel”, why?

- Prevent an adverse internal environment in the tunnel
- Prevent unacceptable impact on the external, surrounding environment
- Maintain hydrodynamic containment
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Impact of ground water lowering

- Disturbing existing biotypes, flora and fauna might be sensitive to changes in groundwater conditions, new species may show up
- Draining of natural lakes and ponds in recreational areas
- Pore pressure reduction in soil deposits causing settlements of buildings and surface structures
- Lost containment could lead to leakage of stored products, i.e. contamination
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Normal requirements to maximum inflow

- A maximum inflow of 30 l/min/100m is used in e.g. 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
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The impermeable nature of the rock mass

The actual permeability of the rock mass and associated discontinuities may vary from 10-5m/sec to 10-12m/sec.

The rock mass is neither homogenous nor continuous, but suffering:
- Cracks and joints
- Weaknesses
- Weathering

• The permeability of rock mass may be in the range of 10-7 to 10-9 m/sec.
• A typical jointed aquifer, water occurs on the most permeable discontinuities.
• The most conductive zones must be identified and treated.
• Prevent the tunnel imposing an adverse situation in the ground-water regime.
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Basic aspects in water control

- Pre-grouting is dominant to post-grouting
- Membrane lining is used in rare occasions
- Re-infiltration is an option sometimes applied but we try to avoid it
- A drained concept applies
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**Drained concept**

- Excessive water is not allowed to build up behind support
- Support measures not designed to take the hydrostatic load
- Controlled handling of water, collection and discharge
- Inner lining to prevent water entering into the traffic area
- Inner lining does not interact with the tunnel support
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Pre-excavation analyses

- Empirical analysis, many places may have a comprehensive data base from previous projects
- Analytical formulas developed, back-calculating a number of cases
- Numerical modelling (2D & 3D) can be applied to simulate influence areas
- Sensitivity analysis are the modern tool
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Ground water balance

- There might be various indicators for assessing the influence of tunnelling on the GW.
- GW balance is a term of increased focus for
  - determination of inflow requirements
  - and follow-up and monitoring of inflow
- GW balance may be limited to natural changes
- The inflow can be defined by the level at which GW balance is restored
- A “Ground water law” has been proposed saying that: -residual flow < 5-15% of the mean annual flow from the catchment area is not acceptable
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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 design, pressure & grout hole pattern
- Include additives to custom design the properties of the grout
- Monitor inflow, evaluate modifications
- Integrate the grouting in the support system
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### Typical applications

<table>
<thead>
<tr>
<th>Project</th>
<th>Max inflow</th>
<th>Measured inflow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(l/min/100 m)</td>
<td>(l/min/100 m)</td>
</tr>
<tr>
<td>Baneheia</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Storhaug</td>
<td>3-6</td>
<td>1.6</td>
</tr>
<tr>
<td>T-banen</td>
<td>7-14</td>
<td>4.3</td>
</tr>
<tr>
<td>Asker skøyen</td>
<td>&lt; 4 to 16</td>
<td>4-7</td>
</tr>
<tr>
<td>Holsfjorden</td>
<td>5-40</td>
<td>Future</td>
</tr>
</tbody>
</table>
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Hydrodynamic containment

- Unlined caverns at shallow depth have been used for "Storage" to restrict product leakage
- Tunnelling may create a draw-down which could lead to a situation where: internal pressure > GW press
- To obtain a specified GW level/pressure:
  - pre-grouting of the rock mass
  - water injection to maintain the GW level
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Organisation and contract requirements

- Organisation, requirements and contract must be well prepared
- Well proven and tested procedures are used
- 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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Monitoring and follow-up

- Pre-construction assessment can be made, working procedures can be established
- Monitoring is needed to document the effect on the groundwater regime:
  - at surface before construction
  - at the tunnel face from probe holes
  - of water flow in the tunnel
  - at surface during construction
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Results from a research programme

- Standardised, systematic grouting scheme through the whole tunnel is most advantageous for ground water control and (surprisingly?!) also for the excavation cycle
- Increased drilling capacity allowed a greater amount of holes for optimal grouting
- Superplastizers and silica additives increased the penetrability and pumpability for grouting
- Increased grouting pressure up to 100 bars yielded better penetrability and grouting capacity
- Reduced w/c ratios improved the quality of the grout, and
- The pre-grouting efforts improved the rock mass stability
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Construction

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

- The Owner carries the risk for the rock mass conditions.
- 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 estimates on quantities on rock support, rock mass grouting etc. all expected measures are quantified in the tenders/contracts.
- The Contractor carries the risk for the appropriate and efficient handling of the works focusing to improve technical and organizational performance.
- The contracts include regulations for extension of construction time based on actually performed quantities.
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Contracts and risk sharing principle

- A figure obtained from a classical article by Kleivan
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Cooperation at site

- 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.
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Conclusion

"TIGHT ENOUGH FOR ITS PURPOSE"
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Thank you for your kind attention!

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