Managing Geological Risks in a Rock Cavern Project (without a GBR)

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“Every tunnelling project is a prototype”

- Wulf Schubert
Geological Risks Due to Uncertainty

- **Inherent spatial and temporal variability** (Changes of ground conditions with location and time-dependent behaviour of rocks)
- **Measurements errors** (quite common but commonly ignored)
- **Model uncertainty** (mis-interpretation, wrong calculation model, wrong input data, wrong method of tunnelling, wrong support design)
- **Omissions** (Insufficient SI or SI not done properly, deliberate risk taking, failure to act, etc)

Source: Einstein, 2007

Risks – Some Basic Concepts

- Zero risks do not exist

- Risk events are probabilistic in nature (uncertain)

- *The lower the contract price, the higher the risk*
Uncertainty in Tunnelling Cost

![Graph showing costs with TBM and NATM distributions](image)

Source: Goricki, et al. 2003

Schedule Risks: 2 Activities in one path

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Min Dur</th>
<th>Duration</th>
<th>Max Dur</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Project</td>
<td>0d</td>
<td>130d</td>
<td>0d</td>
</tr>
<tr>
<td>2</td>
<td>A101</td>
<td>40c</td>
<td>50c</td>
<td>100c</td>
</tr>
<tr>
<td>3</td>
<td>A102</td>
<td>70c</td>
<td>60c</td>
<td>100c</td>
</tr>
<tr>
<td>4</td>
<td>Finish</td>
<td>0d</td>
<td>0d</td>
<td>0d</td>
</tr>
</tbody>
</table>

![Gantt chart showing task durations](image)

Source: David Hullet, 1999
**Risk Management Process**

1. Establish the context
2. Identify risks
3. Analyse risks
   - Likelihood & Consequences
4. Evaluate risks
5. Assess risks
6. Treat risks
7. Communicate and consult
8. Monitor and review

Source: AS4360:1999

**Design Risks**

1. Identify Hazards (H) Forms
2. Complete Hazard Identification and Risk Assessment Form (MIRA)
3. Check no further Risk can be eliminated
4. Complete Design Decision Form (DDF)
5. Identify Residual Hazards
6. Revise DDF with Residual Risk
7. Advice Client
8. Complete Risk Register
9. Issue to Contractor

Source: Wagner, 2006
Construction Risks

Source: Wagner, 2006

ITA Risk Matrix

Source: ITA 2006
ITA Guidelines on Risk Management

| Source: ITA 2006 |

<table>
<thead>
<tr>
<th>Risk Management Strategies</th>
<th>Disastrous</th>
<th>Severe</th>
<th>Serious</th>
<th>Considerable</th>
<th>Insignificant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury to workers and emergency crew (No. of fatalities / injuries*)</td>
<td>&gt; 3 F</td>
<td>3&gt;F&lt;30</td>
<td>1-3 F 3-30</td>
<td>1-3 SI 3-30 MI</td>
<td>&lt; 3 MI</td>
</tr>
<tr>
<td>Injury to third party persons (No. of fatalities / injuries*)</td>
<td>&gt; 3 F</td>
<td>1-3 F 3-30 I</td>
<td>1-3 SI 3-30 MI</td>
<td>&lt; 3 MI</td>
<td>-</td>
</tr>
<tr>
<td>Economic loss to third party (mio. Euro)</td>
<td>&gt; 3</td>
<td>0.3 to 3</td>
<td>0.03 to 0.3</td>
<td>0.003 to 0.03</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Economic loss to owner (mio. Euro)</td>
<td>&gt; 30</td>
<td>3 to 30</td>
<td>0.3 to 3</td>
<td>0.03 to 0.3</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>Delay in construction (per hazard)</td>
<td>&gt; 2 years</td>
<td>1-2 years</td>
<td>2-6 months</td>
<td>½-2 months</td>
<td>&lt; 2 weeks</td>
</tr>
<tr>
<td>Harm to the environment</td>
<td>Permanent severe damage</td>
<td>Permanent minor damage</td>
<td>Longterm effects</td>
<td>Impermanent severe damage</td>
<td>Impermanent minor damage</td>
</tr>
</tbody>
</table>

*F=fatality, SI=serious injury, MI=minor injury

Risk Mitigation (or Risk Response Planning)

| Source: AS4360:1999 |

<table>
<thead>
<tr>
<th>Risk Mitigation (or Risk Response Planning)</th>
<th>Contractual, design, organisational, technical, management controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce likelihood</td>
<td>Contractual, design, plans, engineering, separation, community relations</td>
</tr>
<tr>
<td>Reduce impact</td>
<td>In-whole or in-part Insurance, commercial arrangements</td>
</tr>
<tr>
<td>Transfer</td>
<td>Do not proceed with activity</td>
</tr>
</tbody>
</table>

Source: AS4360:1999
Why Risk Sharing is Important

- Owner develops the concept
  - Location, alignment, layout, depth, dimensions, functions requirements
- Ground (and SI data) belongs to owner
- Owner imposes a schedule (often optimistic)
- Inherent uncertainties in geology

Goals of Risk Sharing

- Fair contractual practice
- More effective risk management
- More realistic (and better) price for client (when contractor does not have to take all the risks and does not have to price for uncertainties related to the geology)
Strategies for Risk Sharing

- Geotechnical Baseline Reporting
- Advance sharing of SI data with contractors
- Design-tender-build contract (need in-house engineering capability)
- Unit price contract (with pre-defined time units for construction activities)
- International Advisory Board
- Dispute Review Board (DRB)
- *Appropriate allocation of risks in the best interest of the project is key*

Norwegian Concept of Risk Sharing

- Owner - responsible for ground conditions, site investigation results, and the concept
- Contractor - responsible for performance to specifications

*Source: Norwegian Tunnelling Society, 2004*
The Most Important 1st Step - SI

“You pay for site investigations whether you have one or not.” Waltham, 1994

Don’t take everything for granite!

Considerations for SI Plan and Cost

- Purpose and scope of the investigation (feasibility, planning, or design)
- Expected subsurface material and ground water
- Size and extent of facility (e.g. road tunnels vs storage facilities)
- Site conditions (topography, access, etc)
- Project specific requirements
- Environmental constraints and impacts
- Availability of equipment, technology and specialists
- Time, budget, and resources
Cost Planning for SI

- Ratio of borehole length to tunnel length of 0.5-1.5 seems acceptable from contractual point of view.

Source: Hoek & Palmeiri, 1998

Norwegian tunnelling recommendations:
- 2-10% of excavation cost for road tunnels;
- 5-15% for subsea tunnels

UAF experience:
- about 1% of rock excavation cost; or
- about 0.25 equivalent ratio of borehole length to tunnel length.
UAF SI Cost Numbers

<table>
<thead>
<tr>
<th>Phase</th>
<th>Total Cost (1998 data)</th>
<th>Unit Cost, $/km(^2) (1998 data)</th>
<th>Unit Cost, $/km(^2) (2007 value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary</td>
<td>$0.8 mil</td>
<td>$0.2 mil</td>
<td>$0.3 mil</td>
</tr>
<tr>
<td>(area=4 km(^2))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detailed</td>
<td>$1.7 mil</td>
<td>$1.7 mil</td>
<td>$2.5 mil</td>
</tr>
<tr>
<td>(area=1 km(^2))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$2.5 mil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: the UAF project

SI Strategies for the UAF

- Preliminary SI to establish overall feasibility
- Main phase investigations based on selected method of tunnelling (Q-system based)
- Supplementary investigations during design and construction
- All SI work during design and construction paid by client
Summary of Main SI Work

<table>
<thead>
<tr>
<th>Type</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling</td>
<td>Soil boring; diamond core drilling</td>
</tr>
<tr>
<td>Surface geophysical surveys</td>
<td>Seismic refraction/reflection; electric resistivity tomography</td>
</tr>
<tr>
<td>Borehole surveys and testing</td>
<td>Borehole logging; seismic logging; borehole camera acoustic imaging; impression packer; borehole radar; Lugeon tests; rising head/falling head tests; cross-hole tomography</td>
</tr>
<tr>
<td>Laboratory tests</td>
<td>Point load; uniaxial/triaxial compression; Brazil tensile; 3-point flexural</td>
</tr>
<tr>
<td>In situ stress</td>
<td>Hydraulic fracturing; 3-D overcoring</td>
</tr>
</tbody>
</table>

Engineering Geology Report

- Comprehensive report with geological model, anticipated ground behaviour, and expected rock reinforcement

- Specific data on geological setting, structural geology, geological profiles, ground water, rock mass permeability, in situ stress, basic rock mechanics data, rock mass classifications
Use of “NMT”

- Mutual agreement on “tunnelling system”
- **Principles of Norwegian Method of Tunnelling:**
  - Engineering geology report as basis for estimates
  - Unit prices for various rock conditions; client pay according to actual rock conditions;
  - Preliminary design
  - Detailed design decided during excavation after tunnel mapping
  - Close collaboration between geologists of contractor and client
  - Forum for resolving differences on site
  - Emergency power to contractor for adverse conditions

**Support Design Using Q-chart**
### Typical Rock Support

<table>
<thead>
<tr>
<th>Class</th>
<th>Q</th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt;40</td>
<td>Spot</td>
<td>Spot</td>
<td>Spot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 mm</td>
<td>40 mm</td>
<td>40 mm</td>
</tr>
<tr>
<td>B</td>
<td>10-40</td>
<td>L3(2.4)</td>
<td>L4(2.4)</td>
<td>L5(2.4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 mm</td>
<td>40 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>C</td>
<td>4-10</td>
<td>L3(2.2)</td>
<td>L4(2.2)</td>
<td>L5(2.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 mm</td>
<td>40 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>D</td>
<td>1-4</td>
<td>L3(1.9)</td>
<td>L4(1.9)</td>
<td>L5(1.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 mm</td>
<td>50 mm</td>
<td>75 mm</td>
</tr>
<tr>
<td>E</td>
<td>&lt; 1</td>
<td>L3(1.5)</td>
<td>L4(1.5)</td>
<td>L5(1.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75 mm</td>
<td>75 mm</td>
<td>100 mm</td>
</tr>
</tbody>
</table>

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## Phasing of Rock Excavation

- **Pilot phase and main phase excavation**
- **Pilot phase - cost plus contract**
  - Appreciation of geological conditions and rock mass quality and effectiveness of excavation method and rock support
  - Data on cost, unit rates, and time
  - Verification of design assumptions and tunnel performance
  - Feedback for modifications of design and technical specifications
- **Main phase - lump sum with unit rates**
UAF - Cost Plus Contract for Pilot Phase

- Lack of local expertise and experience
- Sub-contractors and suppliers prices not certain
- Technology transfer
- Basis for rates for excavation work in main phase

Instrumentation & Monitoring

- As a form of risk management
- Verification of design assumptions
- Performance monitoring
- Feedback and support optimisation
- Plan by client; design by consultant
- Installation and initial checking by contractor
- Monitoring by client and 3rd party (NTU)
- Data analysis by 3rd party (NTU)
Key Points from the UAF Project

- Comprehensive SI work
- Rock engineering report (similar to GBR)
- Use of a “Tunnelling system”
- Sharing of SI data (factual & interpretation)
- Design-bid-construct contracts
- Early involvement of designer and contractor
- Active participation of owner
- Co-operative spirit and risk sharing

Issues for Risk Management

- SI - when and how much
- Who is responsible for SI and interpretation
- Geological modelling
- GBR - liability and use in contract
- Risk analyses and risk criteria
- Risk sharing - who and how
- Types of contracts
- Resolution of contract disputes (due to geology)
- Cost estimates, pricing, tender evaluation
Conclusions

- Clearly defined strategy for managing and sharing of geological risks
- SI program the most important step
- GBR as contractual framework for risk sharing
- Owner obligations to share financial risks with contractor
- Need to resolve anticipated increase in professional liabilities for designer
- Essential elements of experienced owners and contractors, on-site decision making and open communications