Tunnelling Contracts – Risk Management

Contracts are the fundamental mechanism for Financial Risk Management in every country in the world.

- Trend towards design + build contracts
- One-sided contract conditions
- High risk type construction methods
- Tight construction schedules
- Low financial budgets
- Fierce competition in construction industries
### Managing Hazards

**General Hazards**
- Contractual disputes
- Insolvency and institutional problems
- Authority interference
- 3rd party interference
- Labour disputes

**Specific Hazards**
- Accidents
- Unforeseen adverse conditions
- Inadequate designs and/or specifications
- Failure of major equipment
- Substandard, slow or out of tolerance works

### Tunnelling Contracts - Risk Management

In 1872, armed with the development of new drilling machines and explosives, Swiss engineer Louis Favre undertook to construct, what was once thought of as impossible: the 15 km St. Gotthard tunnel through solid rock to link Zurich with Milan.

Competition for the contract was high and Favre agreed to a fixed price of £1,898,845 to complete the works, a figure that allowed for no contingencies whatsoever.

Favre also agreed to complete the works in 8 years, for which he put up a £320,000 bond. The contract allowed for a bonus of £200/day for finishing ahead of schedule and a similar penalty for every day late, forfeiting the entire bond if not completed within a year of the scheduled completion date.
For 7 years Favre, continually threatened by the deadline, worked his men without thought for their health or lives. Pressured to the point of desperation, he would spend days on end in the choking atmosphere of the tunnel. Broken physically as well as financially, Favre succumbed in the tunnel to a heart attack, struggling up to his last breath to advance the work.

By the time the tunnel was completed (approximately 2 years late), Favre’s firm had exceeded the contract price by £590,000 in addition to having forfeited the bond of £300,000. The cost in lives was 310 men, with 877 seriously invalided.

Risk Management

- Risk analysis: a structured process which identifies both the probability and extent of adverse consequences arising from a given activity.
- Risk analysis includes identification of hazards and description of risks, i.e. probabilities and consequences (qualitative or quantitative)

Risk Acceptance Criteria

- Common sense: aim at reducing risk once identified.
- More formal criteria:
  - The risk shall be below a certain value
  - Cost-benefit type criteria / ALARP (As Low As Reasonably Practicable)
Risk Management

Planning/Contract/Schedule

Hazard Identification

Probability/Frequency Analysis

Consequence Analysis

Risk

Risk Acceptance Criteria

Risk Evaluation

Risk Reduction Measures

Acceptable

Risk is intolerable and shall be reduced regardless of costs.

Unacceptable

ALARP

Risk shall be reduced as long as the costs are reasonable compared to the risk reduction achieved.

Broadly Acceptable

NEGLIGIBLE RISK

Risk shall be reduced as long as the costs are reasonable compared to the risk reduction achieved.

No need for considering risk reduction.
Risk Management: Owner-Contractor Activity

Risk management activity flow

Phase I: Early design stages

- OWNER
  - Establish risk policy
  - Qualitative risk assessment
  - Specific (quantitative) risk assessment
  - Risk register

Phase II: Tendering and contract negotiation

- CONTRACTOR
  - Preparation of tender documents, including:
    - Description of significant technical risks
    - Technical requirements to mitigate risk
    - Description of required risk competence
  - Preparation of tender, including:
    - Proposed risk management system
    - Description of experience and competence in risk management
    - Identification and description of risks associated with the proposed technical solutions
    - Identification and description of proposed risk mitigation measures
  - Selection of contractor, evaluation of:
    - Contractor's ability to perform risk management
    - Risks involved in contractor's proposed technical solutions
  - Prepare contract with risk clauses
Risk Management: Owner-Contractor Activity

Risk management activity flow
Phase III: Construction

OWNER
- Supervision and inspection of contractor’s risk management
- Assessment and mitigation of owner’s risk
- Approve on contractor’s risk mitigation

Establish risk management system → Detailed risk assessment → Propose risk mitigation → Implement risk mitigation

Risk Management Process

Hazard Identification
- Hazard/Occurrence Id

Risk Assessment Workshop
- Quantitative Risk assessment for probability (P) and impact (I)
- Risk Register
- Risk Matrix
- Qualitative Risk Assessment

Risk Analysis
- Monte Carlo simulation to determine risk exposure

Risk Management
- Determine critical risks
- Decide mitigation measures
- Cost-benefit analysis

Enact Mitigation Measures
- Design, contract, schedule, etc.

“No construction project is risk free. Risk can be managed, minimized, shared, transferred or accepted. It cannot be ignored.” - Latham (1993)
### Risk Management - Hazard Assessment

<table>
<thead>
<tr>
<th>Descriptive frequency class</th>
<th>Frequency class</th>
<th>Central value</th>
<th>Frequency Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very likely</td>
<td>5</td>
<td>1</td>
<td>&gt; 0.3</td>
</tr>
<tr>
<td>Likely</td>
<td>4</td>
<td>0.1</td>
<td>0.03 – 0.3</td>
</tr>
<tr>
<td>Occasional</td>
<td>3</td>
<td>0.01</td>
<td>0.003 – 0.03</td>
</tr>
<tr>
<td>Unlikely</td>
<td>2</td>
<td>0.001</td>
<td>0.0003 – 0.003</td>
</tr>
<tr>
<td>Very unlikely</td>
<td>1</td>
<td>0.0001</td>
<td>&lt; 0.0003</td>
</tr>
</tbody>
</table>

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**Flyvbjerg et al. (2002)**

### Risk Management - Hazard Assessment


<table>
<thead>
<tr>
<th>Rank</th>
<th>The top ten risks at Bumi Kamp</th>
<th>Rank</th>
<th>The top ten risks at Dai Ninh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Suburface conditions of geology</td>
<td>5</td>
<td>Subsurface conditions of geology</td>
</tr>
<tr>
<td>2</td>
<td>Design change</td>
<td>2</td>
<td>Tunnel collapse</td>
</tr>
<tr>
<td>3</td>
<td>Tunnel collapse</td>
<td>3</td>
<td>Design change</td>
</tr>
<tr>
<td>4</td>
<td>Overbreak</td>
<td>4</td>
<td>Subsurface conditions of ground water</td>
</tr>
<tr>
<td>5</td>
<td>Subsurface conditions of ground water</td>
<td>5</td>
<td>Overbreak</td>
</tr>
<tr>
<td>6</td>
<td>Error of topography, technology or geotechnical data for design input</td>
<td>6</td>
<td>Productivity of equipment</td>
</tr>
<tr>
<td>7</td>
<td>Imparable project management</td>
<td>7</td>
<td>Error of topography, technology or geotechnical data for design input</td>
</tr>
<tr>
<td>8</td>
<td>Lack of experienced site geotechnical engineers</td>
<td>8</td>
<td>Imparable project management</td>
</tr>
<tr>
<td>9</td>
<td>Productivity of equipment</td>
<td>9</td>
<td>Lack of experienced site geotechnical engineers</td>
</tr>
<tr>
<td>10</td>
<td>Availability, price and accessibility of key materials</td>
<td>10</td>
<td>Availability, price and accessibility of key materials</td>
</tr>
</tbody>
</table>

The top ten risks at Bumi Kamp vs. Dai Ninh projects
### Risk Management - Consequences

<table>
<thead>
<tr>
<th>Consequence</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</td>
<td>&gt; 30 F</td>
<td>3&lt; F&lt;30</td>
<td>1-3 F</td>
<td>1-3 SI</td>
<td>&lt; 3 MI</td>
</tr>
<tr>
<td>crew (No. of fatalities / injuries*)</td>
<td></td>
<td></td>
<td>3-30 I</td>
<td>3-30 Mi</td>
<td></td>
</tr>
<tr>
<td>Injury to third party persons</td>
<td>&gt; 3 F</td>
<td>1-3 F</td>
<td>1-3 SI</td>
<td>&lt; 3 MI</td>
<td>-</td>
</tr>
<tr>
<td>(No. of fatalities / injuries*)</td>
<td></td>
<td></td>
<td>3-30 I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic loss to third party (mio. $)</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. $)</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>½-2 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>Long term effects</td>
<td>Permanent severe damage</td>
<td>Impermanent minor damage</td>
</tr>
</tbody>
</table>

*F=fatality, S=serious injury, MI=minor injury.*

### Risk Management - Risk Matrix

<table>
<thead>
<tr>
<th>Risk Matrix</th>
<th>Disastrous</th>
<th>Severe</th>
<th>Serious</th>
<th>Considerable</th>
<th>Insignificant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Very likely</td>
<td>Unacceptable Unacceptable Unacceptable Unwanted Unwanted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likely</td>
<td>Unacceptable Unacceptable Unwanted Unwanted Acceptable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occasional</td>
<td>Unacceptable Unwanted Unwanted Acceptable Acceptable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlikely</td>
<td>Unwanted Unwanted Acceptable Acceptable Negligible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very unlikely</td>
<td>Unwanted Acceptable Acceptable Negligible Negligible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Risk Management - Risk Matrix

<table>
<thead>
<tr>
<th>Risk Classification</th>
<th>Example of actions to be applied against each class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unacceptable</td>
<td>The risk shall be reduced at least to Unwanted regardless of the costs of risk mitigation</td>
</tr>
<tr>
<td>Unwanted</td>
<td>Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportional with the risk reduction obtained (ALARP principle, as low as reasonably practicable)</td>
</tr>
<tr>
<td>Acceptable</td>
<td>The hazard shall be managed throughout the project. Consideration of risk mitigation is not required</td>
</tr>
<tr>
<td>Negligible</td>
<td>No further consideration of the hazard is needed</td>
</tr>
</tbody>
</table>

### Risk Management - Risk Reduction

![Risk Reduction Graph]

**Legend:**
- Opportunity to Minimize Risk
- Cost of Change

**Time:**
- Feasibility
- Preliminary Design
- Detailed Design
- Construction
- Operation
Risk Management – Site Investigation

Hoek & Palmén (1998)

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Tunnelling Contracts – Risk Management

- "the design can't be built" encourages Design-Build
- "construction standards are poor" gives rise to Design-Build-Maintain or Build-Operate-Transfer
- "costs are too high" leads to Build-Operate-Transfer

<table>
<thead>
<tr>
<th>Lump sum</th>
<th>Unit price</th>
<th>Time &amp; material</th>
<th>Reimbursable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractor</td>
<td>Company</td>
<td>Company</td>
<td>Company</td>
</tr>
<tr>
<td>Workmanship &amp; quality</td>
<td>Contractor</td>
<td>Contractor</td>
<td></td>
</tr>
<tr>
<td>Schedule &amp; Productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of labor &amp; equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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# Tunnelling Contracts - Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turnkey</strong></td>
<td>The contractor is responsible for site investigation, design and</td>
</tr>
<tr>
<td></td>
<td>construction of the project for a fixed price.</td>
</tr>
<tr>
<td><strong>Lump Sum</strong></td>
<td>A single price is given for all the work or for completed sections of the</td>
</tr>
<tr>
<td></td>
<td>work. Provision can be made for limited changes by the inclusion of a</td>
</tr>
<tr>
<td></td>
<td>contract price adjustment clause.</td>
</tr>
<tr>
<td>**Cost-</td>
<td>The contractor is paid the actual costs incurred in carrying out the</td>
</tr>
<tr>
<td>Reimbursable</td>
<td>work. A separate fee may be negotiated for management overheads and the</td>
</tr>
<tr>
<td></td>
<td>profit element.</td>
</tr>
</tbody>
</table>

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# Tunnelling Contracts - Construction Delivery

**Design-Bid-Build (design/tender)**

Is a project delivery method in which the Owner’s engineer carries out the design, which is then put out to bid. In this arrangement, the design team is impartial and looks out for the interests of the Owner.

**Design-Build**

Incorporates the contractors’ means and methods into the design stage, contracted for with a single entity known as the design-builder. This system is used to minimize the project risk for an owner and to reduce the delivery schedule by overlapping the design phase and construction phase of a project. Where the design-builder is the contractor, the design professionals are typically retained directly by the contractor.

**Build Operate Transfer (BOT)**

Allows the builder concession to operate and derive revenue over the concession period before transferring it back to the government authority.
Public-Private Partnerships (P3s)

Describes a venture which is funded and operated through a partnership of government and one or more private sector companies. Typically, a private sector consortium is contracted to develop, build, maintain and operate the asset for a given period. The public sector usually retains ownership of the facility.

Government takes on a role of actively controlling some of the risks with involvement of statutory authorities who eventually take operational control.

Early tunnels were financed by individuals/private investors. As countries became industrialized, projects were paid for by taxation. However, governments found taxation to be inadequate for the huge infrastructure needs and project financing became a mix of private investment and public financing.

Tunnelling Contracts - Construction Delivery

<table>
<thead>
<tr>
<th>Types of contract</th>
<th>Basis for payment</th>
<th>Control needed by sponsor or purchaser</th>
<th>Project definition required</th>
<th>Level of contractor’s risk exposure</th>
<th>Level of contractor’s motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed price</td>
<td>Achievement</td>
<td>Least</td>
<td>Highest</td>
<td>Highest</td>
<td>Highest</td>
</tr>
<tr>
<td>(Lump sum/turnkey)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit quantities at specified rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target price</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reimbursable plus fee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple reimbursable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost plus (Cost-time-resource)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Geotechnical Reporting

Geological Data Report
- Compilation of all of the results of the site investigation process.
- Generally restricted to factual information and does not include very much interpretation.
- Contractor is left to assess the factual information and draw conclusions on the probable groundwater and rock mass behaviour; tasks that may be very difficult to accommodate during the bidding process.

Geotechnical Baseline Report
- Interpretative report in which all the factual data collected during the site investigation stages are analysed in terms of potential groundwater and rock mass behaviour and other issues that could cause problems during construction.
- Interpretations form a behavioural baseline which can be used in setting contractual limits.
- Contractor cannot make claims for ground behaviour which falls at or above the baseline while the owner has to accept responsibility for problems resulting from rock mass behaviour which is worse than that predicted in the baseline report.

Geotechnical Baseline Reports

Geotechnical Baseline Reports (GBRs) are charged with portraying a realistic interpretation of the subsurface conditions that are anticipated in the proposed construction. They should include not only the mean conditions of ground behaviour and groundwater conditions anticipated, but the report should also address the range of variances that is expected.

- Aims to establish a contractual understanding of the subsurface site conditions.
- Risks associated with conditions consistent with or less adverse than the baseline are allocated to the contractor and those significantly more adverse than the baseline are accepted by the owner.

Thus, the purpose of the GBR is to establish a realistic, common basis for evaluating any contractor claims for differing site conditions that develop during construction. The GBR is the basis for equitable contractual risk sharing and risk allocation between the project owner and their selected contractor.
Costing Stages

- **Scoping study** (± 30 to 50% accuracy)
  - Consider past experience and similar facilities.
  - Estimate an excavation cost and support cost.

- **Pre-feasibility study** (± 20 to 25% accuracy)
  - General layout is needed.
  - Ground conditions evaluated.
  - Excavation technique outlined (consider overbreak).
  - Total support (bolts, liners etc) considered.

- **Feasibility study** (± 10 to 20% accuracy)
  - Detailed design needed.
  - Excavation sequence detailed including ventilation, temporary and permanent support.
  - Prepare QA systems.
  - Critical path schedule.
  - Personnel requirement and costs.
  - Consumables and services provisions (temporary pumping).
  - Project safety.
Uncertainty in Ground Characterization

Increasing level of geological knowledge and confidence therein

Investigation
- JORC
- Inferred
- Indicated
- Measured

Monitoring
- Geotechnical Model
- Assumed
- Substantiated
- Measured

Behaviour Model
- Hypothesized
- Simulated
- Observed

Lecture References