Monitoring of Tunnels in Urban Areas

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Systematic Monitoring as Part of Risk Management Can Prevent Catastrophic Failures

Monitoring of Tunnels in Urban Areas
Technical monitoring of tunnels provides methods and applications of measurements to control and observe entire construction projects.

The monitoring measurements are defined within the risk management process.

Therefore the following slides describe first the process of risk management and then the monitoring of tunnels in urban areas.
Risk management is the systematic process of identifying, analyzing and responding to project risks.

Risk management is

• not only a single event
• a continuous process during the entire project.

Therefore the risk control is part of the project life cycle from project initiation to project completion.
Risk Management Steps

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Risk management consists of:</td>
</tr>
</tbody>
</table>
| 3    | • Risk Management Planning  
      • Risk Identification  
      • Risk Analysis  
      • Risk Responding  
      • Risk Control |

Monitoring of Tunnels in Urban Areas
Risk Management Flowchart

1. Risk Management Planning
2. Risk Identification
3. Risk Analysis
4. Risk Responding
5. Risk Monitoring and Control

Monitoring of Tunnels in Urban Areas
### Risk Management

#### Classifications According to ITA Guidelines

<table>
<thead>
<tr>
<th>Probability of Occurrence (Frequency)</th>
<th>Impact (Consequence)</th>
</tr>
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<tbody>
<tr>
<td>• Very unlikely</td>
<td>• Insignificant</td>
</tr>
<tr>
<td>• Unlikely</td>
<td>• Considerable</td>
</tr>
<tr>
<td>• Occasional</td>
<td>• Serious</td>
</tr>
<tr>
<td>• Likely</td>
<td>• Severe</td>
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<tr>
<td>• Very likely</td>
<td>• Disastrous</td>
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</table>

The classifications can be defined according to the specific project.

## Risk Analysis Matrix According to ITA Guidelines

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Insignificant</th>
<th>Considerably</th>
<th>Serious</th>
<th>Severe</th>
<th>Disastrous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Likely</td>
<td>Unwanted</td>
<td>Unwanted</td>
<td>Unacceptable</td>
<td>Unacceptable</td>
<td>Unacceptable</td>
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<tr>
<td>Likely</td>
<td>Acceptable</td>
<td>Unwanted</td>
<td>Unwanted</td>
<td>Unacceptable</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Occasional</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Unwanted</td>
<td>Unwanted</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Negligible</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Unwanted</td>
<td>Unwanted</td>
</tr>
<tr>
<td>Very Unlikely</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Unwanted</td>
</tr>
</tbody>
</table>


**Monitoring of Tunnels in Urban Areas**
Unacceptable: The risk shall be reduced as least to *Unwanted* regardless of the cost risk mitigation.

Unwanted: Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportionate with the risk reduction obtained.

Acceptable: The hazard shall be managed throughout the project. Consideration of risk mitigation is not required.

Negligible: No further consideration of the hazard is needed.

## Risk Management
### Risk Responding, Possible Strategies

<p>| | | |</p>
<table>
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<tbody>
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<tr>
<td>5</td>
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</table>

### Avoid:
eliminate the uncertainty or execute the project in a different way

### Transfer:
transfer the risk to another party which is then responsible to handle the impact

### Mitigate:
reduce the risk to make it more acceptable to the project by reducing the probability and/or the impact

### Accept:
accept the risk (normally done for project risk which have a low priority or a low impact)
Risk Management

Risk Responding, Mitigation

Consequences, Impact

Initial risk

Residual risk

Likelihood, Probability, Frequency

(Quelle: Int. Tunnelling Association (ITA) and Risk; Parker, H.W.; George Fox Seminar; New York, 2005)
Technical monitoring consists of measurements and their continuous assessment to control a construction project.

- Technical monitoring is defined as part of the risk responding. The kind of measurements and the locations are defined.

- The measurement results are continuously recorded and assessed during the project as part of the risk control.

The following slides focus on the technical monitoring and describe methods and applications.
Monitoring of Tunnels in Urban Areas

Monitoring by
Investigations and Measurements

Monitoring of the surface
• Settlement control by levelling
• Vibration measurements
• Measurements by crackmeters and inclination sensors

Monitoring of tunnel structure and ground
• Investigations (geophysical Prediction, Exploratory Drillings)
• 3D-Reflector survey
• Extensometer-, inclinometer measurements
• Control of ground water table by piezometers

Monitoring of Tunnels in Urban Areas
Example Uetliberg Road Tunnel Overview

2 tubes (each 4.4 km)
Cross-cut with pedestrian access every 300 m
Cross-cut with vehicular access every 900 m
SOS niches every 150 m

Monitoring of Tunnels in Urban Areas
Example Uetliberg Road Tunnel
Selected Excavation Method: Core Method

Monitoring of Tunnels in Urban Areas
Example Uetliberg Road Tunnel
Section under Landikontunnel

Monitoring of Tunnels in Urban Areas
Example Uetliberg Road Tunnel Section under Landikontunnel

Monitoring of Tunnels in Urban Areas

Extensometer

Vibration measurements  Convergency measurements  Prisms (3D Optical Survey)
Example PTS-Tunnel Zurich Airport Overview

Monitoring of Tunnels in Urban Areas
Example PTS-Tunnel Zurich Airport
PTS and Road Tunnels

Monitoring of Tunnels in Urban Areas
Example PTS-Tunnel Zurich Airport Defined Risk Areas

Cut and Cover Midfield
Tunnel Construction ø 5.40 m

Legend:
- Starting Pit, Exit
- Runway 10/28
- Taxiways, Aprons
- TBM-Heading, general
- Undercrossing Terminal A
- Aircontrol Infrastructure canal
- Exit Pit

Monitoring of Tunnels in Urban Areas
Example PTS-Tunnel Zurich Airport
Excavation in Soft Ground with Hydroshield

Monitoring of Tunnels in Urban Areas
Example PTS-Tunnel Zurich Airport
Defined Risk Areas, Undercrossing Terminal A

Monitoring of Tunnels in Urban Areas
Example Circle Line, Stage 4+5, Singapore Top View

Existing buildings

Cut and cover section

Service lines (electricity, gas, water)

Tunnels

Monitoring of Tunnels in Urban Areas
Example Circle Line, Stage 4+5, Singapore

Monitoring of Tunnels in Urban Areas
Example Circle Line, Stage 4+5, Singapore

Predicted Ground Settlements

Monitoring of Tunnels in Urban Areas
Example Circle Line, Stage 4+5, Singapore

Monitoring of Settlements by Levelling

Settlement marker
(electrical cables)

Monitoring of Tunnels in Urban Areas
Monitoring of Tunnels in Urban Areas

Example Circle Line, Stage 4+5, Singapore

Monitoring of the Tunnel under Construction

- Optical prism
- Strain gauge
- Load cell
Example Dobrovskeho Road Tunnel, Brno, CZ

Monitoring of Tunnels in Urban Areas
Example Dobrovskeho Road Tunnel, Brno, CZ West Portal

Monitoring of Tunnels in Urban Areas
Example Dobrovskeho Road Tunnel, Brno, CZ
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