Specific Conditions and Requirements for Tunnelling in Urban Areas: General and Environmental Aspects

TRAINING MATERIAL PREPARED BY

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Contents

1. Introduction

2. Conditions and Requirements for Urban Tunnelling

3. Design Aspects

4. Construction Methods

5. Conclusions and References

Tunnelling in Urban Areas
Introduction

1. Increase of the urban population (after the 2nd World War)
2. Environmental Era (after 1960)
3. Tunnelling technology
Introduction

Environmental Era → Urban Trend

Tunnelling in Urban Areas
Favourable Factors for Urban Tunnelling

1. Better Behaviour Understanding
   - Control of settlements and displacements
   - Evaluation of induced damages

2. Technology Advances
   - Works safer, cheaper and built in short time
   - New generation of TBMs (pressurised face) – tunnelling in any geological conditions and urban environment

3. Seismic resistance

Tunnelling in Urban Areas
Introduction

Demand of Urban Tunnelling

1. Mass Transit Systems and Motorways
2. Public Utilities (water, sewage, cables etc.)
3. Flood Control
4. Revitalisation of City Centres
5. Public Buildings

Tunnelling in Urban Areas
Tunnelling in Urban Areas

Difficulties in Deciding for Underground Structures

• Safety
  – During Construction
  – During Operation

• Costs
### Difficulties in Deciding for Underground Structures → Costs

<table>
<thead>
<tr>
<th>Construction Methods</th>
<th>Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface *</td>
<td>1.0</td>
</tr>
<tr>
<td>Viaduct *</td>
<td>1.5</td>
</tr>
<tr>
<td>Cut &amp; Cover *</td>
<td>2.5</td>
</tr>
<tr>
<td>Tunnel (single track)</td>
<td>3.0</td>
</tr>
<tr>
<td>Tunnel (double track)</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*Not including surface land buying*

* Tunnelling in Urban Areas
Tunnelling in Urban Areas

Introduction

1. Global Cost Assessment for Underground Structures
   - Cost of the surface space
   - Indenisation during construction (negative impacts of surface works)
   - Devaluation of real estate nearby to infrastructure

Tunnelling in Urban Areas
Urban Tunnelling

Tunnelling Methods

Conventional
Mechanised
Special

Soft Ground
Hard Ground
Mix Ground

Tunnelling in Urban Areas
Introduction

Urban Tunnelling → Soft Ground Tunnelling

Conventional
- Ground Improvement

Mechanised
- Full Face Excavation

Special
- Trench Methods

Tunnelling in Urban Areas
Main concern during excavation is the stability of the opening.

Most cases of soft ground tunnelling are in urban environment.

Tunnelling-induced displacement field may reach surface and affect existing nearby structures.

Design may be dominated by admissible-displacement criteria.
Major concerns of soft ground and urban tunnelling are related to (Kovari & Ramoni, 2004):

- Urban Environment
- Ground Conditions
- Risk Scenarios
Conditions and Requirements

Urban Environment

• Shallow overburden
• Existence of nearby structures
• Foreign objects inside the ground
• Constraints for alignment
• Restrictions for auxiliary works
• High visibility of damage

Tunnelling in Urban Areas
Conditions and Requirements

Shallow Overburden

- Access ways as shallow as possible
- Larger and larger tunnel diameters

- Concept of Shallow Tunnel
  - Type of Failure
  - Displacement field up to surface or existing structures
Conditions and Requirements

**Shallow Overburden**

(Sauer & Mergelsberg, 2003)

*Tunnelling in Urban Areas*
Conditions and Requirements

Existence of Nearby Structures

- Types of structures (transport ways, public utilities, buildings, historical sites etc.)

- Affected by the induced displacement field, but they also affect it

- Sensitivity to potential damages
Existence of Nearby Structures

Tunnelling in Urban Areas

Conditions and Requirements
Conditions and Requirements

Foreign Objects inside the Ground

1. Direct conflict with tunnel alignment
   - Structural elements (foundation, anchors, sheet piles)
   - Public utilities
   - Wells
   - Tree trunks and roots

*Tunnelling in Urban Areas*
Foreign Objects inside the Ground

Tunnelling in Urban Areas
Conditions and Requirements

Constraints for Alignment

1. Usually dominated by transport demand
2. Influenced by urban constraints (p.ex. location of ventilation towers)
3. Preferable under public ground
4. Unavoidable to underpass existing structures
5. Cope with existing ground conditions
Conditions and Requirements

Restrictions for Auxiliary Works

1. Exploitation
2. Shaft of attack
3. Ventilation towers
4. Muck transport and disposal
5. Dewatering
   - Ground improvement
   - Monitoring

Tunnelling in Urban Areas
High Visibility of Damages

- Sensitivity of potential damages
- Loss of public confidence is very jeopardising to tunnelling industry
Conditions and Requirements

Risk Scenarios

- Collapses up to surface
- Damages due to tunnelling-induced displacements

Design Criteria in terms of:
- Failure
- Admissible Displacements

Tunnelling in Urban Areas
Ground Conditions

• Existing ground conditions
  – Recent geological formations
  – Fills
  – Frequent changing conditions (weathering)
  – Groundwater

• Ground Improvement and Reinforcement

Tunnelling in Urban Areas
Conditions and Requirements

Ground Conditions

Tunnelling in Urban Areas
Principles of Tunnelling

1. Ground excavation
2. Support installation
3. Monitoring

Ground-Support Interaction
Bearing Ring of Reinforced Ground

Observational Method

Tunnelling in Urban Areas
Ground-Support Interaction

Design Aspects

Tunnelling in Urban Areas
Elements of Tunnel Design

**Design Aspects**

1. Geology
2. Lab and In-Situ Tests
3. Designer Experience
4. Global Investigation
5. Geotechnical Properties
6. Excavation Method and Support System
7. Structural Model and Design Predictions

**Tunnelling in Urban Areas**

- **Ok?**
  - Yes → Construction
  - No

- **Construction**
Design Aspects

Stress-Strain-Displacement Analysis

- Empirical Formulations
- Closed-Form Solutions
  - Simple Geometry
  - Homogeneous and Isotropic Media
  - Linear Elastic Behaviour
- Numerical Methods
  - Boundary Element
  - Finite Element
  - Discrete Element

Tunnelling in Urban Areas
Tunnelling-Induced Displacements

Design Aspects

Tunnelling in Urban Areas
Design Aspects

Checking for Tunnelling-Induced Damages

- Calculate the green field settlement trough
- For structures inside the settlement trough, check potential damages due to green field settlements and distortions
- For those in critical state, run a more accurate analysis taking into account the structure stiffness
- Perform reinforcement when required

Tunnelling in Urban Areas
Elements of Construction

Contractor Experience

Construction Methods

Ok?

Yes

No

Construction

Monitoring

Ok?

Yes

No

Safe

Tunnelling in Urban Areas
Construction Methods

Conventional
  Ground Improvement

Mechanised
  Full Face Excavation

Special
  Trench Methods

Tunnelling in Urban Areas
Special Methods

• Open Trenches
• Cut-and-Cover Structures
  – Direct and Inverse Excavation
• Door-Frame Method

• Immersed Tunnels
  – Caisson and Door-Frame Methods
Construction Methods

Door Frame Method

(Sauer & Mergelsberg, 2003)

Tunnelling in Urban Areas
Construction Methods

Conventional Tunnelling

- Excavation
- Ground Conditioning
- Support Installation

Stress Relaxation

Tunnelling in Urban Areas
**Construction Methods**

**Tunnelling in Urban Areas**

(Sauer & Mergelsberg, 2003)

_Tunnelling in Urban Areas_
Construction Methods

Support Installation

Tunnelling in Urban Areas
Construction Methods

Tunnel Waterproofing

Tunnelling in Urban Areas
Construction Methods

Mechanised Tunnelling
- Excavation
- Support Installation

Avoid or Minimise Stress Relaxation

Tunnelling in Urban Areas
Construction Methods

Mechanised Tunnelling

Tunnelling in Urban Areas
Relevant factors for the TBM selection are (Kovari & Ramoni, 2004):

- Grain size distribution
- Type of predominant mineral (quartz contents)
- Soil strength (cohesion)
- Overburden
- Heterogeneity (mix ground, weathering)
- Piezometric pressure
Construction Methods

Conventional versus Mechanised Tunnelling

- Geometry Flexibility
- Geology Flexibility
- Contractual Flexibility
- Political Flexibility
- Lower costs for short tunnels and cheaper labour

- Lower impact to ground
- Higher and more constant quality (industrial process)
- Lower load to workers
- Safer
- More accurate costs and schedule

Tunnelling in Urban Areas
Construction Methods

Conventional versus Mechanised Tunnelling

(Sauer & Mergelsberg, 2003)
Conclusions and References

1. Majors concerns are opening stability and control displacement field

2. Soft ground tunnelling is likely dominated by failure and admissible displacement criteria

3. Ground conditioning (improvement and reinforcement) plays an important role

4. Tunnelling methods and technology vary depending on geology, tunnel location, length and geometry, local tradition etc.

Tunnelling in Urban Areas
Conclusions and References


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