Urban Tunnelling: Constraints and Challenges

Master Course on Tunnels and Underground Space

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<td>4</td>
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<td>5</td>
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Introduction

- Increase of the urban population
- Environmental Era
- Tunnelling technology
Demand of Urban Tunnelling

- Mass Transit Systems and Motorways
- Public Utilities
- Flood Control
- Revitalisation of City Centres
- Public Buildings
Madrid Road Ring M-30
Difficulties in Deciding for Underground Structures

• Safety
  – During Construction
  – During Operation

• Costs (GC = CC + SB)
  – Expropriation
  – Indemnification
  – Devaluation
Urban Tunnelling → Constraints

Public Decision
Alignment defined by demand
Geology imposed
Urban Tunnelling in Soft Ground

- Most cases of soft ground tunnelling are in urban environment
- Main concern during excavation is the stability of the opening
- Tunnelling-induced displacement field may reach surface and affect existing nearby structures
- Design may be dominated by admissible-displacement criteria
General Trends in the Tunnelling Industry

- High risk type construction methods
- Trend towards design + build contracts
- One-sided contract conditions
- Tight construction schedules
- Low financial budgets
- Fierce competition in construction industries
Decade 1990

FOTO 02: Tabela 4.4, item nº 32
Colapso de Túnel em São Paulo, Brasil – 1993 (ANDERSON, 1997a)
“No construction project is risk free.

Risk can be managed, minimised, shared, transferred or accepted.

It cannot be ignored.”

Sir Michael Latham, 1994
Major concerns of urban tunnelling in soft ground and are related to (Kovari & Ramoni, 2004):

- Urban Environment
- Ground Conditions
- Risk Scenarios
Urban Environment

- Constraints for alignment
- Shallow overburden
- Existence of nearby structures
- Foreign objects inside the ground
- Restrictions for auxiliary works
- Complex geometry
Constraints for Alignment

- Usually dominated by the tunnel demand
- Influenced by urban constraints (p.ex. location of ventilation towers)
- Preferable under public ground
- Unavoidable to underpass existing structures
- Cope with existing ground conditions
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
Shallow Overburden ➔ Failure Mode
Existence of Nearby Structures

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

• Nearby structures are affected by the induced displacement field, but they also affect the displacement field → Interaction

• Sensitivity to potential damages
Existence of Nearby Structures
Foreign Objects inside the Ground

• Direct conflict with tunnel alignment
  – Structural elements (foundation, anchors, sheet piles)
  – Public utilities
  – Wells
  – Tree trunks and roots
Foreign Objects inside the Ground
Restrictions for Auxiliary Works

• Exploitation
• Shaft of attack
• Ventilation towers
• Muck transport and disposal
• Dewatering
• Ground improvement
• Monitoring
Ground Conditions

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

• Complex Local Geology requires Ground Improvement and Reinforcement
Face reinforcement by fiberglass elements FGE

Steel pipes umbrella
**Purpose of Ground Improvement**
(Grasso, 2009)

<table>
<thead>
<tr>
<th>Needs for Ground Improvement</th>
<th>CONV</th>
<th>TBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geo-problems (thrust zone, shear zone, fault zone especially when water-bearing, zone of very poor quality ground, Kartstic voids ...)</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Insufficient self-supporting time</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Unacceptable ground surface settlement</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Very low overburden underpasses in urban area</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Keeping natural water table</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Global face stability</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Face stability during machine maintenance</td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Modify Ground Reaction Curve (GRC) (radial and longitudinal directions)</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Water inflow with high pressure</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Interaction of newly designed underground structures with those excavated earlier</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Flowing ground</td>
<td>●</td>
<td>●</td>
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**Note:**

CONV: Conventional Tunnelling

TBM: Mechanised Tunnelling
Risk Scenarios

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

Design Criteria in terms of:
- Failure
- Admissible Displacements (damages)
High Visibility of Damages

- Sensitivity of potential damages
- Loss of public confidence is very jeopardising to tunnelling industry
Design and Construction Aspects

Principles of Tunnelling

1. Ground excavation
2. Support installation
3. Monitoring

Ground-Support Interaction
Bearing Ring of Reinforced Ground

Observational Method
Elements of Tunnel Design

Geology → Investigation → Geotechnical Properties → Excavation Method and Support System → Structural Model and Design Predictions

- Designer Experience

- Lab and In-Situ Tests

Yes

No

Ok?

Construction
Tunnelling-Induced Displacements
Loss of Ground \( V_p \) (m\(^3\)/m)

\[ V_s = V_p \]
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

Elements of Construction

Contractor Experience

Construction

Monitoring

Ok?
Yes

No

Safe
### Particle Size Distribution

<table>
<thead>
<tr>
<th>Percent Passing [%]</th>
<th>Particle Size [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0.002</td>
</tr>
<tr>
<td>20</td>
<td>0.006</td>
</tr>
<tr>
<td>30</td>
<td>0.01</td>
</tr>
<tr>
<td>40</td>
<td>0.02</td>
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<tr>
<td>50</td>
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<td>60</td>
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<tr>
<td>90</td>
<td>0.07</td>
</tr>
<tr>
<td>100</td>
<td>0.08</td>
</tr>
</tbody>
</table>

### Fluid-Supported

- **EPB**
  - Standard application + separation
  - Anti-clogging measures, high separation effort
  - Face support difficult, suspension filters

### Fluid-Supported

- **Fluid-Supported**
  - Water for consistency, foam for stickiness
  - Foam + Polymers, water pressure < 2 bar
  - Foam + Polymers + fines, no water pressure
  - Standard application + separation
  - Face support difficult, suspension filters

### Particle Size

- **GRAVEL**: coarse, medium, fine
- **SAND**: coarse, medium, fine
- **SILT**: coarse, medium, fine
- **CLAY**: coarse, medium, fine

**Note:** The diagrams represent the distribution of particle sizes for different applications and conditions.
Monitoring and TBM Active Control

**Control system**

- Controlling of Boring Process: guide parameters from interdisciplinary processing of geotechnical, geodetic and machine data
Statistics on Causes of Accidents

Causes of Accidents

- Design
- Construction
- Management
- Force Majeure
- Insufficient Ground Investigation

Lessons Learnt
Pre-Bidding Documents

• Geological investigation and geotechnical data as much as possible

• Full disclosure of all GG data
  – Geological model
  – GG Data Report
  – Geotechnical Base Report

• Different Ground Conditions ➔ Owner
Design Documents

- Geomechanical model
- Structural model of the tunnel
- Assumptions, completeness and type of calculations and simulations
  - Continuum media?
  - Type of model and parameters
  - 2D or 3D analysis?
- Monitoring → threshold values

Design Reviewer
Design during Construction

- Complementary investigation and mapping of all GG conditions
- Monitoring interpretation
- Design back-analysis

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Design Validation
Construction

• Faithful to the design ➔ changes in agreement

• Quality control (materials and services)

• Integrated risk and construction management ➔ contingency and emergency actions
Role of Contracts

• Keep fair balance
  – quality, schedule and costs

• Mix of technical and performance specifications → quality control

• Independent auditing and full disclosure of control parameters

Incorporate risk management and risk sharing
Conclusions

1. Urban tunnelling is a great and increasing demand worldwide

2. Urban tunnelling is challenging due to urban environment and its constraints

3. Urban tunnelling is likely dominated by limit admissible damage criteria

4. Risk management has to be incorporated in all project phases