Conventional Tunnelling in Urban Areas - General

TRAINING MATERIAL PREPARED BY

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Conventional Tunnelling in Urban Areas - General
Introduction

Definition of conventional tunnelling:

Any method of underground construction except methods using full profile TBM could be considered as conventional tunnelling

Representatives:

- New Austrian Tunelling Method (NATM)
- Shotcrete Lining Method (SLM)
- ADECO method
- Prevault method
Conventional tunnelling:

- Ground around the tunnel is considered to be load bearing element
- Type and quantity of support elements is adjusted in combination with development of ground reaction
- Stability is confirmed by frequent monitoring of ground reactions mainly by deformation measurement
- Depending on the conditions the requirement of stiff or light deformable support is identified
Conventional tunnelling

Typical support elements:

- Shotcrete lining reinforced by steel mesh or steel fibres
- Rock anchors of various types (SN, frictional, selftapping etc.)
- Steel ribs or lattice girders
- Special measures ahead of the face (pipe roofs, forepoling, face bolts etc.)

Subdivision of cross section usually depends on ground conditions, size of excavation and surface settlements control
Conventional tunnelling

Hard rock conditions:

- Drill and blast excavation, partially mechanized excavation
- Subdivision into top heading and bench
- Invert in case of poor rock conditions
- Support classes framework defines advance lengths, type and quantity of support elements
- Waterproofing system from membrane and drainage pipes on side of tunnel walls (umbrella system)
- Final lining from unreinforced or reinforced concrete
Conventional Tunnelling in Urban Areas - General

Conventional tunnelling

Soft ground conditions without special requirements:

- Without buildings on surface above tunnel
- Mechanized excavation
- Subdivision into top heading, bench and invert
- Special measures (e.g. pipe roofs, temporary invert, elephant foot)
- Shorter length of advance
- Waterproofing system from membrane and drainage pipes on side of tunnel walls (umbrella system)
- Final lining from reinforced concrete usually adjusted for full load of overburden
Conventional tunnelling

Soft ground conditions with special requirements:

1. Settlements on surface are to be restricted – urban areas with buildings or communications
2. Subdivision of cross section with rapid ring closure
3. Excavation of small sections of face with immediate support
4. Short length of advance
5. Fully tanked lining system with or without membrane without permanent drainage
6. Final lining from watertight reinforced concrete designed for the full water pressure
Conventional tunnelling

Example of tunnelling in poor rock conditions, Sitina tunnel, Slovakia
Conventional tunnelling

Example of tunnelling in soft ground conditions with deformation restriction, Sitina tunnel, Slovakia
Interrelationships of tunnel design philosophies

Conventional Tunnelling in Urban Areas - General
Special measures during tunnel driving

The chosen Special Measures should make provision for:

1. Engineering and geological conditions - usually soft ground conditions
2. Hydrogeological conditions
3. Thickness of overburden
4. Location and distance to built up area
5. Restrictions – noise, vibration, working hours etc.
6. Requirements – deformation limitations, settlement control measures
7. The size and geometry of excavating profile
The selection and design of proper excavation sequences depends on several parameters:

1. Size of tunnel
2. Type of rock or soil
3. Deformation limitations
4. Vibration (blasting) limitations
5. Equipment types and capacities
6. Experience of contractor – client
7. Construction time, schedule
Sprayed concrete linings

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Special measures – division of excavation face

Typical horizontal face division

• Top heading – Bench – Invert (done with or without shotcrete)

Combination of horizontal and vertical face division

• Top heading – vertical division with or without temporary invert
• Face division into sidewall or multiple drift technique

Special cases

• Exploration gallery (location in profile)
• Excavation in very small steps with subsequent immediate installation of at least a part of the support (ex. shotcrete sealing)
Profiles comparison – surface settlement reduction

Tunnel Lainz, Construction Lot 31, Austria
Railway link between western and southern railway line in Vienna, double track railway tunnel. Length: 1.800 m, Cross Section 130 m².

Profile with quick ring closure

Designed profile

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Special measures – Central Gallery

Excavation procedure
1 central tunnel
2 central pillar - concrete casting
3 sidewall drifts (southern tube)
4 sidewall drifts (northern tube)

Tunnel Valík, Czech Republic
Motorway D5 Prague – Norimberk, bypass Plzeň

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Excavation by single drift technique

Cross section

Longitudinal section

Plan

Excavation sequence

Conventional Tunnelling in Urban Areas - General
Excavation by multiple drift technique

**Cross section**

- I Side drift
- II Side drift
- III Central section
- Top heading
- Heading
- Bench
- Invert
- Temporary sidewalls
- Temporary backfill
- Shotcrete

**Longitudinal section**

- Shotcrete
- Temporary sidewall
- Temporary backfill
- I + II

**Plan**

- Lag
- (depending on tunnel size)
- (if required)

**Excavation sequence**

- Top heading
- Bench
- Invert

*Conventional Tunnelling in Urban Areas - General*
Excavation sequence for escalator tunnel

Vertical position of lattice girders

Conventional Tunnelling in Urban Areas - General
Special measures – Driving and Main Construction Stages

Example – Underground Station

1. Excavation and support of crown of centre drift
2. Excavation and support of bench of centre drift
3. Construction of support frames
4. Excavation and support of the two side drifts
5. Excavation and support of the two middle drifts
6. Lining construction

Conventional Tunnelling in Urban Areas - General
Excavation Sequence using pillar drifts

Conventional Tunnelling in Urban Areas - General
Excavation Sequence using Pillar Drifts

Stage 3
Construction of concrete columns

Stage 4
- Heading
- Bench
- Invert

Enlargement of platform tunnels

Stage 5
- Heading
- Bench and Invert

Excavation of concourse tunnel

Conventional Tunnelling in Urban Areas - General
Special measures – support elements

Most frequently used:

- Wire Mesh – additional layer
- Shotcrete plain or reinforced - additional layer
- Steel rib – reduced spacing, stronger profiles
- Rock bolts – change type (expansion, fully embedded, injection, self drilling etc.) and/or additional rock bolting
- Cable anchors
- Forepoling pipes or bars
- Lagging sheets, made from 3 – 4 mm steel sheets used in cohesionless material
Subsurface measures during excavation

- Shotcrete sealing – temporary support
- Supporting core
- Face bolting
- Forepoling
- Ring closure
- Strengthening - applying immediately (shotcrete, wire mesh, rock bolts)
- Shortening of length round – acc. actual conditions encountered up to 0.8 – 0.6 m
- Lagging sheets – auxiliary support (used in cohesionless material)
- Lining stress controller LSC - yielding support (used in squeezing rock)
- Compensation and permeate grouting
Subsurface measures

- Large anchor plates for better load distribution
- Supporting core
- Shotcrete sealing
- Face bolting
## Crown support – Forepoling without grouting

<table>
<thead>
<tr>
<th>Method</th>
<th>Area of utilization</th>
<th>Description</th>
<th>Plants &amp; equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driven-in rebars</td>
<td>Strongly weathered ground, consistent non-cohesive soils</td>
<td>Steel bars for ex. Ø 25mm, length 2,5 to 6m, driven-in</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steel pipes for ex. Ø 40mm, length 2,5 to 6m, driven-in</td>
<td></td>
</tr>
<tr>
<td>Drilled rebars</td>
<td>Slightly weathered ground</td>
<td>Steel bars for ex. Ø 25mm, length 2,5 to 6m</td>
<td>Drill jumbo, grout pump</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- plugged-in to pre-drilled holes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- plugged-in to pre-drilled holes filled with grout</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steel pipes for ex. Ø 40mm, length 2,5 to 6m, plugged-in to pre-drilled holes filled with grout</td>
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</tbody>
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## Crown support – Forepoling without grouting

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</thead>
<tbody>
<tr>
<td>Grouted driven-in rebars</td>
<td>grout able soils and rocks</td>
<td>Threaded steel bars Ø 25, 32, 38mm with head adjustment for driving-in. Grouting from the rebar’s head</td>
<td>Grout pump</td>
</tr>
<tr>
<td>Self drilled rebars</td>
<td>non-cohesive soils, unstable drilled holes</td>
<td>Threaded steel bars Ø 25, 32, 38mm with drilling bit. Grouting via rebar’s head. Drilling bit is screwed onto rebar external threading.</td>
<td>Drill jumbo, grout pump</td>
</tr>
<tr>
<td>Grouted pipe rebars</td>
<td>grout able soils and rocks</td>
<td>Threaded steel bars Ø 25, 32, 38mm with drilling bit. Grouting via rebar’s head with valve enabling secondary grouting. Drilling crown is screwed into pipe internal threading.</td>
<td>Drill jumbo, grout pump, pressure valve</td>
</tr>
</tbody>
</table>
Subsurface measures - Forepoling

1. Shotcrete sealing with or without wire mesh
2. Erection of steel rib
3. Shotcrete to nominal thickness
4. Forepoling pipes or bars
5. Second layer of wire mesh and shotcrete
Special measures - Forepoling

Rock bolts, length 6m

Rock bolts, length 4m

Forepoling bars, length 6m, Ø 25mm

Top Heading

Top Heading min. 25m ahead
Max. depends on ground conditions

Conventional Tunnelling in Urban Areas - General
### Crown support – Forepoled umbrella (pipe roof)

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</tr>
</thead>
<tbody>
<tr>
<td>Pipe roof without grouting</td>
<td>soils and rocks hardly grout able up to non-grout able</td>
<td>Horizontal predrilling, steel pipes driving-in Ø 60-200mm, length up to 30m Pipes inner concreting</td>
<td>Drill jumbo, driving equipment</td>
</tr>
<tr>
<td>Pipe roof with grouting</td>
<td>soils and rocks easily grout able up to non-grout able</td>
<td>Horizontal predrilling, iron pipes driving-in Ø 60-200mm, length till 30m</td>
<td>Drill jumbo, driving equipment, grouting unit</td>
</tr>
<tr>
<td>Pipe roof with Jet Grouting</td>
<td>heterogenetic soils with various distribution of grains</td>
<td>Horizontal predrilling, high-pressure grouting simultaneously executed with pulling out drilling rod Ø 0,5m to 1,0m, length up to 15m, overlap 3 to 5m</td>
<td>Drill jumbo, drilling platform, high-pressure equipment (pump, mixer, feeder), data monitoring equipment</td>
</tr>
</tbody>
</table>
Special measures – Pipe Roof

- Rock bolts, length 6m
- Angle app. 120°
- Length up to 30m, overlap 3 - 5m
- Driving direction
- Top Heading
- Bench
- Invert

Conventional Tunnelling in Urban Areas - General
Jet Grouting – example
injection length 9m, Ø 60cm

Top Heading – sand
Bench – silt
Invert - sand

Additionally sprayed shotcrete
Mininimum shotcrete thickness 20 cm under Jet Grouting piles

Conventional Tunnelling in Urban Areas - General
Jet Grouting – example
injection length 9m, Ø 60cm

Top Heading – sand
Bench – silt
Invert - sand

Minimum shotcrete thickness 20 cm under jet grouting piles
Tunnel settlement trough

Key:
- a - tunnel excavated radius
- Smax - tunnel maximum settlements
- i - distance to point of inflexion

Conventional Tunnelling in Urban Areas - General
Compensation grouting

Station constructed in Vienna
(compensation grouting used to control settlement)
Geotechnical Monitoring

Instrumentation and measurement programs are an integral part of tunnelling especially with NATM.

The objectives of measurements may comprise the following:

- Verification of the design assumptions including the design model and design parameters
- Adjustment of the construction methods, support systems, and supplementary measures to the actual ground conditions
- Minimization of construction hazards
- Prevention of harmful impact to the environment
Conventional Tunnelling in Urban Areas - General

Geotechnical Monitoring - Parameters

1

2 Considering the specific requirements and stages of construction the following fields with parameters must be observed:

3

• Ground water
• Ground deformation
• Soil – structure interaction
• Observation of environment (adjacent buildings and structures)

4

• Progress monitoring

5

Conventional Tunnelling in Urban Areas - General
Geotechnical Monitoring in Urban Areas

1. Survey of building conditions before start of construction
2. Measurement of settlements and heave
3. Horizontal displacement
4. Tilt measurement
5. Vibration due to blasting
6. Noise due to blasting, ventilation etc.
## Geotechnical Monitoring in Urban Areas

### Location of Tunnelling Face relative to Instrumentation Cross Section

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Monitoring Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface settlement reference points</td>
<td>d &gt; 50m Initial reading</td>
</tr>
<tr>
<td>Extensometer</td>
<td>d &lt; 30m Once a day</td>
</tr>
<tr>
<td>Inclinometer</td>
<td>e &lt; 30m Once a day</td>
</tr>
<tr>
<td>Piezometer</td>
<td>e &gt; 30m Once a week</td>
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</tbody>
</table>
## Geotechnical Monitoring in Urban Areas

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<tr>
<th>Location of Tunnelling Face relative to Instrumentation Cross Section</th>
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</thead>
<tbody>
<tr>
<td>3D-Monitoring Pins</td>
<td>Initial reading immediately after installation at each subheading</td>
<td></td>
</tr>
<tr>
<td>Pressure Cells (real time)</td>
<td>e &lt; 30m Once a day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e &gt; 30m Once a week</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
The monitoring frequencies may be adjusted as required acc. to actual ground conditions.

Monitoring frequency for real time pressure cells must be adjusted to the compensation grouting programme (if applied) as required.
Geotechnical Report

Must include at least:

- Introduction
- Site information provided at the time of tender
- Ground conditions encountered during excavation
- Comparison between the expected and encountered ground conditions
- Conclusions
Waterproofing and final lining

Protection against groundwater – waterproofing

- Open (umbrella system) – waterproofing membrane from PE or PVC protected with geotextile with pipe drainage (usually on sides of tunnel walls)
- Fully tanked system – waterproofing layer without permanent pipe drainage in case when groundwater level should not be affected by tunnel
- Double waterproofing divided into the sections by cross and longitudinal waterstop profiles especially for tunnels under groundwater level
Final (secondary) lining

- Unreinforced concrete – usually for hard rock conditions and for vault shape and circular cross sections
- Reinforced concrete – for soft ground conditions, poor rock conditions and for special shape cross section (niches, laybies etc.)
- Reinforced watertight concrete with protection of working joints (e.g. waterstops) – for tunnels under groundwater level
Example of road tunnel with unreinforced final lining and open waterproofing system with side drainage pipes (Branisko Tunnel, Slovakia)

Example of rail tunnel with reinforced final lining (Zurich - Thalwill Tunnel, Switzerland)

Conventional Tunnelling in Urban Areas - General
Final lining from the fire protection point of view

Final lining is load – bearing element with permanent function. Fire in tunnel with very high temperatures could cause collapse of lining. This could be very dangerous in case when buildings are situated above the tunnel. Various protective measures should be done for lining protection:

- surface protection of lining using special plates
- sufficient cover of steel reinforcement
- polypropylene fibres added to the concrete mixture
Conclusions and references

Conventional tunnelling methods are widely used virtually in all types of ground conditions. The application of sprayed concrete primary support in soft ground tunnelling is relatively recent compared with its use in hard rock tunnelling. For tunnels in urban areas limiting settlements is of high importance to avoid damage to overlying structures. To achieve the essential limitation of settlement, the following principal measures must be undertaken:

- Excavation stages must be sufficiently short, both in terms of dimensions and duration.
- Completion of primary support - in particular, closure of the shotcrete ring must not be delayed.