TBM Applications III

TBM tunnels in extremely difficult geology (shallow tunnels / mixed ground)

3. Challenges in urban infrastructure tunnelling

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Trondheim, 4th Nov 2019
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2. Type of TBM machines. To choose the right one

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1. Introduction. Increase of tunnels under urban environment
TRANSPORTATION

Key Trends

- Urban mobility demand is booming: from 30 tn passenger-km/year to 50 tn in 2050
- High-speed trains are x8 more energy-efficient than planes and x4 than cars
- 50% of the world's top 100 airports will have capacity constraints by 2025

Consequences

- Roads: capacity expansion, access to cities
- Rails: inter-city connections
- Urban transportation: Trams, LR, Metro
- Expansion of existing Airports, new airports

Saturated and congested transportation assets
Rise of energy efficient and pollution free solutions
• Global growth impacts large-scale urban regions, in particular their attractiveness.

• Land expansion occurs at the edge of existing urban areas and cities have to adapt and change by investing in transport infrastructure to strengthen inner urban development or “city-to-city” connections, despite difficult ground conditions.

• Urban tunnels are at the core of urban expansion management. That’s why tunnels under urban environment is a constant demand from clients around the world.

• TBM are one of the potential tunnel construction methodology that can be applied with a successful performance.

• Minimizing interference in surface, impact or disturbance to the communities and stakeholders along the tunnel alignment and optimizing cost and time for clients.
2. Type of TBM machines. To choose the right one
· **Main Beam**  
  (Working in open mode)

· **Single Shield**  
  (Working in open and close mode)

· **Double Shield**  
  (Working in open mode)

· **Earth Pressure Balance (EPB)**  
  (Single Shield working in close mode)

· **Slurry Shield**  
  (Single Shield working in close mode)
Challenges in urban infrastructure tunnelling

- **2000**: METROSUR MADRID S-165, D=9,330mm, CH POWER: 2,800 KW
- **2002**: BARCELONA METRO S-221, D=12,060mm, CH POWER: 4,000 KW
- **1994**: VALENCIA METRO S-84, D=6,520mm, CH POWER: 800 KW
- **2005**: MADRID M30 S-300, D=15,200mm, CH POWER: 12,000 KW
- **2015**: Hong Kong (Check Lap Kok), D=17,600mm
<table>
<thead>
<tr>
<th>Start date/ Launch</th>
<th>Country</th>
<th>Project</th>
<th>TBM manufacturer</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design started</td>
<td>Russia</td>
<td>Orlovsky Tunnel, Saint Petersburg*</td>
<td>1 Herrenknecht Mixshield</td>
<td>19.00m</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td>Project on hold</td>
<td></td>
<td></td>
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<tr>
<td>2015</td>
<td>Hong Kong</td>
<td>Tuen Mun - Chek Lap Kok subsea highway link*</td>
<td>1 Herrenknecht Mixshield</td>
<td>17.60m</td>
</tr>
<tr>
<td>2011</td>
<td>USA</td>
<td>Alaskan Way highway replacement tunnel*</td>
<td>1 Hitachi Zosen EPBM</td>
<td>17.48m</td>
</tr>
<tr>
<td>2016</td>
<td>Italy</td>
<td>Santa Lucia Highway Tunnel, A1 near Firenze*</td>
<td>1 Herrenknecht EPBM</td>
<td>15.87m</td>
</tr>
<tr>
<td>2018</td>
<td>China</td>
<td>Shenzhen Chunteng Tunnel</td>
<td>1 CREG Slurry</td>
<td>15.80m</td>
</tr>
<tr>
<td>2019</td>
<td>Australia</td>
<td>West Gate Tunnel (Melbourne) A1 Sparvo highway tunnel*</td>
<td>1 CREG Slurry</td>
<td>15.60m</td>
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<tr>
<td>2006</td>
<td>China</td>
<td>Shanghai Changjiang under river highway tunnel Shanghai West Changjiang Yangtze</td>
<td>2 Herrenknecht Mixshields</td>
<td>15.43m</td>
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<tr>
<td>2011</td>
<td>China</td>
<td>Hangzhou Qianjiang Under River Tunnel</td>
<td>Ex-Shanghai Changjiang highway tunnel Project</td>
<td>15.43m</td>
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<tr>
<td>2005</td>
<td>Spain</td>
<td>Madrid Calle 30 Highway Tunnels</td>
<td>2 machines</td>
<td>15.20m</td>
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<tr>
<td>2017</td>
<td>China</td>
<td>Shantou City Su'at Subsea Highway Tunnel</td>
<td>1 CREG Slurry</td>
<td>15.03m</td>
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<tr>
<td>2013</td>
<td>China</td>
<td>Shouxhou Lake Highway Tunnel</td>
<td>1 Herrenknecht Mixshield</td>
<td>14.93m</td>
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<tr>
<td>2011</td>
<td>China</td>
<td>Weisan Road Tunnel, Nanjing* Shangai Hongmeng Road</td>
<td>2 IHI/Mitsubishi/CCCC slurry TBMs</td>
<td>14.93m</td>
</tr>
<tr>
<td>2008</td>
<td>China</td>
<td>Nanjing Yangtze River Tunnel* Jungong Road Subaqueous Tunnel, Shanghai</td>
<td>2 Herrenknecht Mixshields</td>
<td>14.93m</td>
</tr>
</tbody>
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</thead>
<tbody>
<tr>
<td>2000</td>
<td>The Netherland's</td>
<td>Greenshant double-track rail tunnel Waterview highway connection, Auckland*</td>
<td>1 NFM Technologies</td>
<td>14.87m</td>
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<tr>
<td>2009</td>
<td>China</td>
<td>Yingqian Road Tunnel, Shanghai Bund Tunnel, Shanghai</td>
<td>1 Mitsubishi EPBM Ex-Build Tunnel machine</td>
<td>14.27m</td>
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<tr>
<td>2006</td>
<td>Canada</td>
<td>Niagara Water Diversion Tunnel*</td>
<td>1 Robbins hard rock gripper TBM</td>
<td>14.40m</td>
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<tr>
<td>2004</td>
<td>Russia</td>
<td>Moscow Siberwald Highway Tunnel</td>
<td>1 Herrenknecht Mixshield</td>
<td>14.20m</td>
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<tr>
<td>2001</td>
<td>Russia</td>
<td>Moscow Lefortovo Highway Tunnel*</td>
<td>1 Herrenknecht Mixshield</td>
<td>14.20m</td>
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<tr>
<td>1997</td>
<td>Germany</td>
<td>Hamburg d6 Elbe River Highway Tunnel*</td>
<td>1 Herrenknecht Mixshield</td>
<td>14.20m</td>
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<tr>
<td>1994</td>
<td>Japan</td>
<td>Trans Tokyo Bay Highway Tunnel*</td>
<td>8 machines</td>
<td>14.14m</td>
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<tr>
<td>2010</td>
<td>Spain</td>
<td>Seville SE-40 Highway Tunnels*</td>
<td>2 NFM Technologies EPBMs</td>
<td>14.00m</td>
</tr>
</tbody>
</table>
Challenges in urban infrastructure tunnelling
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**Box Jacking Projects**

- **YULIN**: 10.12m x 7.47m (7.42m x 5.62m)
- **TIANJING**: 5.74m x 5.02m (2.87m x 5.02m)
- **ZHENGZHOU**: 10.42m x 7.57m
- **CHENGDU**: 6.02m x 4.52m
- **WUHAN**: 9.82m x 5.52m
- **GUANGZHOU**: 7.52m x 5.42m
- **HANGZHOU**: 9.82m x 5.52m
- **SINGAPORE**: 7.62m x 5.645m

**11.9 x 10.95m Horse-shoe Shape EPB TBM Railway Tunnel**
3. Common Challenges in urban infrastructure tunnels
Topics for the symposium:

- Easy tunnels are already built
- Future machines, innovations and markets
- Groundwater handling
- **Shallow tunnels**
3.1. Shallow tunnel launch portal (Dubai, UAE)
**METRO DUBAI 2020**

**CONTRACTOR:** Expolink consortium (Alstom - ACCIONA - Gülermak)

**CLIENT:** RTA- Roads & Transport Authority Dubai.

**CONTRACT VALUE:** 26 B NOK

**SCOPE:** 15 Km tram (11.8 km elevated, 3.2 km underground (TBM D=6.9 m)). – 7 stations including Expo
Reference design:
- Classic cut and cover ramp approach leading to the TBM launch site.
- 560m of below grade ramp section (300m as cut and cover)
- Two TBM supply shafts were provisioned.

Alternative design proposed:
- Shallow launch of the TBM
- Cut and cover section replaced with a bored tunnel constructed with minimum cover requirements
Reference design:

Opportunities:
- Construction ahead of TBM delivery possible although on the critical path
- Final structure provides more space for Mechanical, Electrical and Plant equipment (MEP)
- Reduced geotechnical risk profile

Risks:
- Multiple stakeholder approvals required
- Three major utility diversions
- Large construction area required close to residential buildings
- Complex construction works that lie on the critical path of the project
- Complex dewatering requirements
- Utility corridor largely compromised for future development (major utility corridor crossing alignment)
Reference design:

Opportunities:
• Major utility diversions can be avoided
• Reduced stakeholder approval risk
• Utility corridor remains available for future developments
• Start of the open cut works and the provision of the required protection works for the TBM launch provides more float on critical path of the project
• Reduced soil subsidence from tunnelling compared to cut and cover and decrease in influence zone of settlement

Risks:
• Water mains running close to tunnel crown (require diversion)
• Increased geotechnical/tunnelling risk due to shallow cover
• Increase duration of TBM tunnelling works due to additional length of 391m to replace the cut and cover length present in the original design.
Challenges in urban infrastructure tunnelling

- **Mitigation measure (Structural and Geotechnical design)**
- Soil Improvement
- Construction of an inclined structural concrete slab to remain as a permanent structure
- Diaphragm walls
- Geotechnical protection works - concrete slab - temporary works for protection purposes only
Challenges in urban infrastructure tunnelling
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Challenges in urban infrastructure tunnelling
The additional 391m of tunnel drive require additional 1.5 months on the TBM Tunnel construction schedule.

TBM construction program, improved by 1.5 months.

TBM productivity achieved as planned:

- First 353m @ 7.4m/day = 48 Days
- Next 646m @ 11.5m/day = 56 Days
- Next 709m @ 12.9m/day = 55 Days
- Last 680m @ 12.6m/day = 54 Days
CONCLUSIONS:

The rigorous risk management approach that was implemented led to a successful completion of the shallow TBM launch alternative on R2020 project.

Structural and qualitative mitigation measures were designed and implemented in order to ensure a fully controlled construction environment.

All decisions were carried out in a highly collaborative manner between the Client, the Contractor and the Designer. All parties were mindful of the drivers of each other and everybody in the management team had a similar understanding of the risks.

This success demonstrates that with a collaborative work model, innovative solutions can be applied and executed in a structured and safe manner that can lead to benefits for the Client and the Contractor alike.
3.2. TBM Tunneling under buildings in bad geological conditions
(Gijón, Spain)
METRO TREN (GIJON, SPAIN (2003))

**CONTRACTOR:** ACCIONA

**CLIENT:** Ministry of Public Works and Transport (Spanish Government)

**CONTRACT VALUE:** 1.4 B NOK

**SCOPE:** 3.9 Km of single tunnel (EPB D=10.55m) 2 stations
• Main alignment of the tunnel under streets, avoiding buildings

• Some mitigation measures for settlement in buildings (steel micropiles from surface)

• Change in design in order to minimize tunneling under buildings

• Challenge in an specific area.
Geological profile:

- Main TBM excavation in marls and dolomitized limestone, with some clay inclusions. Water level at surface.

- Due to change in alignment, some buildings on the top of tunnel with presence of silt, potential settlements.

- It required specific design and treatment: **Soilfrac compensation grouting**. Soilfrac® is a process used to control or reverse the settlement of structures. It consists of the injection of material into the soil between the foundation to be controlled and the tunnel that can cause the settlement.
Soilfrac compensation grouting:

A. Evaluate and quantify potential settlements
B. Before the tunnel is executed, the material is previously injected into fractures, thereby causing an expansion (vertical movement in affected buildings have to be controlled under very sensitive electronic survey).
C. Tunnel excavation occurs and provisional settlement takes place.
D. Simultaneous compensation grouting is executed, counteracting the settlement that occurs or producing a controlled heave of the foundation.
E. Final assumable settlement
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TBM Applications III
Challenges in urban infrastructure tunnelling
• **FINAL CONCLUSIONS:**

  • TBM Urban tunnels are coming...

  • TBM providers market is mature for any complex tunnels request.

  • Open for innovation. EASY TUNNELS ARE ALREADY BUILT!

  • Client, Contractor and Designer have to be one team and have a similar understanding of the risks.

  • Cannot only be Contractors problem. Changes and innovations normally becomes a win - win situation.