Application of Micropiles for Uplift Control and Foundation of Large Access Ramps of an Underwater Road Tunnel in Gdańsk

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Scope of presentation

- General Project overview
- Geotechnical conditions
- „WET” vs. „DRY” excavation pit protection
- Design aspects of anchoring systems
- Quality control and monitoring
- Conclusions
General Project overview - Gdańsk (North Poland)
General Project overview - main information

- First Road Tunnel ever done by TBM in Poland
- Polish record TBM shield Ø 12.6 m (2 tubes)
- Total volume of extracted spoil (~1.0 mln m³) big enough to fill up the Wembley Stadium full
- Over 3,300 micropiles installed (ca. 38.5 km)
General Project overview - longitudinal cross section

<table>
<thead>
<tr>
<th>No.</th>
<th>Section</th>
<th>Length, [m]</th>
<th>Max. excav. depth, [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>U section in open pit</td>
<td>147.5</td>
<td>8.5</td>
</tr>
<tr>
<td>2.</td>
<td>Tunnel in open pit (eastern bank)</td>
<td>192.5</td>
<td>20.5</td>
</tr>
<tr>
<td>3.</td>
<td>TBM section (2 x Ø12.56 m)</td>
<td>1 072.5</td>
<td>--</td>
</tr>
<tr>
<td>4.</td>
<td>Tunnel in open pit (western bank)</td>
<td>112.5</td>
<td>22.0</td>
</tr>
<tr>
<td>5.</td>
<td>Tunnel in open pit and roundabout</td>
<td>630.0</td>
<td>13.2</td>
</tr>
</tbody>
</table>
Geotechnical conditions – TBM launching chamber

GL=1,5 ASL

Fine Sand
$q_c = 10\text{MPa}$, $\phi = 33^\circ$, $\gamma = 20\text{kN/m}^3$

Organic
$c_u = 20\text{kPa}$, $\phi = 10^\circ$, $\gamma = 14\text{kN/m}^3$

Medium Sand
$q_c = 15\text{MPa}$, $\phi = 34^\circ$, $\gamma = 20.5\text{kN/m}^3$

Silty clay
$c_u = 150\text{kPa}$, $\phi = 15^\circ$, $\gamma = 21.5\text{kN/m}^3$

GW=0,5 ASL

Coarse Sand
$q_c \geq 15\text{MPa}$, $\phi = 40^\circ$, $\gamma = 21\text{kN/m}^3$
Construction phases – Primary solution („WET”)

GL=+1,5m ASL

GW=+0,5m ASL

Sand
Organic
Sand
Clay
Sand
GW=+0,5m ASL

Anchoring elements

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Construction phases – Adopted solution („DRY”)

Construction phases:
- GL = +1.5 m ASL
- GW = +0.5 m ASL
- Sand
- Organic
- Sand
- GW = +0.5 m ASL
- GW = -3.0 m ASL

Anchoring elements

- GL = +1.5 m ASL
- GW = +0.5 m ASL
- Sand
- Organic
- Sand
- GW = -3.0 m ASL
- GW = -10.5 m ASL

Clay
Construction phases – Adopted solution („DRY”)
Construction phases – Adopted solution („DRY”)
Design aspects of anchoring systems

1. Structural capacity of an anchoring element

- DYWI-Drill hollow bar T76 (steel class 28 Mn 6)
- Steel deduction due to corrosion (3.25 mm / 100 years)
  - $A_{\text{nom}} = 24.68 \text{ cm}^2$  
  - $A_{\text{corr}} = 17.57 \text{ cm}^2$

- Allowable tensile capacity
  - $P_{\text{allow}} = f_{yd} \cdot A_{\text{nom}} = \textbf{968 kN}$ (temporary stages) 
  - $P_{\text{allow}} = f_{yd} \cdot A_{\text{corr}} = \textbf{689 kN}$ (permanent stage) 
  - $R_{\text{max}} = \textbf{791 kN}$
  - $R_{\text{max}} = \textbf{589 kN}$
Design aspects of anchoring systems

2. Bond capacity

- Ultimate bond stress tested on trial elements on site
  - $f_1 = 1.05 \text{ MPa}$   $f_2 = 0.63 \text{ Mpa}$

- Length and circumference of hallow bar / encapsulated part
  - $L_{\text{pile}} = 10.0 \text{ m}$   $C_{\text{pile}} = 0.239 \text{ m}$
  - $L_{\text{encap}} = 3.5 \text{ m}$   $C_{\text{encap}} = 0.503 \text{ m}$

- Allowable pull-out capacity
  - $P_{\text{allow}} = f_1 \cdot C_{\text{pile}} \cdot L_{\text{pile}} = 2509 \text{ kN}$
  - $P_{\text{allow}} = f_2 \cdot C_{\text{encap}} \cdot L_{\text{encap}} = 1109 \text{ kN}$

  $> R_{\text{max}} = 791 \text{ kN}$
Design aspects of anchoring systems

3. External capacity of an anchoring element (jet grouting column)

- **Ultimate bearing capacity**
  \[ R_{sk} = \sum \left( \frac{q_{ci}}{k_{si}} \cdot t_i \right) \cdot \pi D \]
  \[ R_{sk} = \left( \frac{2.5}{40} + \frac{20}{150} \right) \cdot \pi \cdot 1.0 = 3297 \text{ kN} \]

- **Allowable bearing capacity**
  \[ P_{allow} = \frac{3297}{2.0} = \mathbf{1640} \text{ kN} \]
  \[ > R_{max} = 791 \text{ kN} \]

4. Bearing plate capacity

- **Allowable loading (max. contact pressure)**
  \[ P_{allow} = f_{cd} \cdot A_{sp,eff} = 20000 \cdot 0.058 = \mathbf{1160} \text{ kN} \]
  \[ > R_{max} = 791 \text{ kN} \]

- **Allowable loading (punching)**
  \[ P_{allow} = f_{ctd} \cdot C_m \cdot h = 1330 \cdot 2.2 \cdot 0.4 = \mathbf{1170} \text{ kN} \]
  \[ > R_{max} = 791 \text{ kN} \]
5. Global stability against uplift (UPL)

- Temporary stage 1a (decisive)
  \[ V_e \cdot \gamma_{dst} \leq (G_e + 2T_e + G'_b + 2T_b) \cdot \gamma_{stb} \]

where:
- \( V_e \) – uplift forces (destabilising actions)
- \( G_e, G'_b, T_e, T_b \) – dead weights and friction forces (stabilising actions)
- \( \gamma_{dst/stb} \) – partial safety factors (acc. to EC7 \( \gamma_{dst}=1.0, \gamma_{stb}=0.9 \))
Quality control and monitoring

- **QC prior to production on site:**
  - Trial jet grouted columns (diameter)
  - Tests of strength and permeability (samples)
  - Pull-out tests of anchoring elements (hollow bars)

- **QC while production on site:**
  - Positioning control system utilising local GPS
  - Inclinometer measurements of every jet grouting column
  - Automatic printouts
  - Constant verification (3D visualizations)
  - Lab tests of used materials (cement grout, steel)

- **Monitoring:**
  - Precise geodesic monitoring of jet grouting plug
  - Measurements of GW (in / out of excavation)
Conclusions

- Main challenges:
  - High GW levels
  - Poor ground conditions
  - Very deep excavations
  - Extreme drilling depths
  - Decoupling hollow bars
  - Complex geotechnical solutions demanding 7 technologies

- Benefits of „DRY” method:
  - Safe
  - Cost effective
  - Time efficient

Are there any limits for geotechnique?
Thank You…

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