SUPPLEMENTARY JET GROUTING AT METRO VIENNA LOT U1-10

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Vienna

- Currently 1.7 mio inhabitants
- 5 metro lines in operation
- various tramway and bus lines
- fastest growing city of Austria
Modal Split – Wiener Linien

Percentage of travellers using:
1993-2013

- Public transport (+10)
- Bicycle (+3)
- Car (-12)
- Pedestrians (-1)

Amount 2013

Development of the share of public transport in percent

- 900 million passengers
- 600,000 sold annual season-tickets

Photo source: © Wiener Linien

APA-graphic order
Supplementary jet grouting at metro Vienna Lot U1-10

General lay out

- Metro station shaft
- NATM platform tunnel

<table>
<thead>
<tr>
<th>U1 south extension</th>
<th>Adaption exist. bifurcation</th>
<th>Adaption existing station</th>
</tr>
</thead>
</table>

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Supplementary jet grouting at metro Vienna Lot U1-10

Cross sections

Platform tunnel (79 m²)  Cross passage

section 79,17 m³
Shotcrete Sp C20/25

section 62,95 m³
Shotcrete Sp C20/25
Station Troststraße

- Station tunnel track 1: open cut & cover tunnel with bored piles
- Station tunnel track 2: mined tunnel with jet grouting-umbrella
Geological long section

<table>
<thead>
<tr>
<th>GB</th>
<th>Length ~[m]</th>
<th>Angle of friction</th>
<th>Cohesion</th>
<th>E-Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silt</td>
<td>242</td>
<td>23°</td>
<td>0,05 MPa</td>
</tr>
<tr>
<td>2</td>
<td>Gravel</td>
<td>30</td>
<td>35°</td>
<td>0 MPa</td>
</tr>
<tr>
<td>3</td>
<td>Loess</td>
<td>495</td>
<td>25°</td>
<td>0,02 MPa</td>
</tr>
</tbody>
</table>
Alternating strata loess/loessic loam
Geotechnical design of Troststraße metro station

- standard tunnel heading could not satisfy the settlement trough criteria (max. tangent slope 1:750)

- The following scenarios for the excavation of the mined station tunnel were simulated:
  - sidewall drift
  - pipe roof umbrella
  - Jet grouting umbrella
Geotechnical design of Troststraße metro station

- standard tunnel heading could not satisfy the settlement trough criteria (max. tangent slope 1:750)

- The following scenarios for the excavation of the mined station tunnel were simulated:
  - sidewall drift
    - max. settlement ~45mm, 1:450
  - pipe roof umbrella
    - max. settlement ~50 mm, ~1:400
  - Jet grouting umbrella
    - max. settlement ~42mm, ~1:500
Artificial ground freezing

■ Cross section with freezing
Horizontal jet grouting umbrella on vertical jet grouting piles

- Cross section with jet grouting
Platform tunnel 3D FE analysis with HS model for loess

- Vertical Jet grouting piles from surface
- Horizontal jet grouting umbrella from tunnel
- Sandy gravel
Results from 3D FE

- Inclination for horizontal and vertical jet grouting < 1:750
  + max. settlements < 3 cm
Supplementary jet grouting at metro Vienna Lot U1-10

- Settlement trough on surface

![Graph showing settlement trough on surface with lines indicating different methods of jet grouting: horizontal, freezing, and horizontal + vertical.]

- Inclination on surface 1:x

![Graph showing inclination on surface with lines indicating different methods of jet grouting: horizontal, freezing, and horizontal + vertical.]

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3D view of vertical jet grout piles
3D view of lateral and vertical jet grouting
Supplementary jet grouting at metro Vienna Lot U1-10

Detailed Building Assessment

- Building inspections
- FE-analysis

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Detailed Building Assessment

- Building inspections
- FE-analysis

→ Repair works
→ Improvement of building foundations

Calculated tangent slope of settlement trough < 1:750

Max $\Delta Y = 3.18$ cm

$\Delta Y = 1.89$ cm

$\Delta Y = 3.06$ cm
# Alert and alarm criteria

## Tunnel

<table>
<thead>
<tr>
<th>Alert Level</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>System behaviour within the tolerances of the expected behaviour according to the design</td>
</tr>
<tr>
<td>S1</td>
<td>Deviation from the expected behaviour; phase of reaction</td>
</tr>
<tr>
<td>S2</td>
<td>Dangerous conditions; risk limited to the construction site, crisis situation</td>
</tr>
<tr>
<td>S3</td>
<td>Dangerous conditions, risk not limited to the construction site and public involved; crisis situation</td>
</tr>
</tbody>
</table>

## Buildings (damage classification according to Kramer)

<table>
<thead>
<tr>
<th>Level</th>
<th>Kind of damage</th>
<th>Class</th>
<th>Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No damages</td>
<td>G 0</td>
<td>No damages</td>
</tr>
<tr>
<td>I</td>
<td>Architectural damages</td>
<td>G Ia</td>
<td>Light architectural damages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G Ib</td>
<td>Medium to heavy architectural damages</td>
</tr>
<tr>
<td>II</td>
<td>Construction damages</td>
<td>G IIc</td>
<td>Light to medium damages on construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G IId</td>
<td>Heavy damages on construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G IIe</td>
<td>Collapse or removal of construction</td>
</tr>
</tbody>
</table>

![Diagram showing 1/tanφ relationship with damage levels and amounts of damage]
Supplementary jet grouting at metro Vienna Lot U1-10

Vertical jet grouting

- From building basements
- From surface
Vertical jet grouting piles - construction

- Requirements:
  - pile-Ø 80 cm, minimum compressive strength 5 N/mm²
  - maximum 1% directional deviation, bore hole logging
  - Construction time: summer 2012, about 3 months duration
  - Total jet grouted piles
    - 184 piles
    - 4.200 m bore holes (max. depth 22 m)
    - 1.900 m jet grouting
Actual position of jet grouting piles (logging)
Horizontal jet grouting umbrella

- **Equipment:**
  - horizontal drilling device Casagrande PG185 with carriage length of 22.5 m
  - high pressure pump
  - batching plant
  - silo

- **Requirements:**
  - space
  - noise (residents)
  - strength development of the columns
  - surveying work
  - monitoring work
Horizontal jet grouting umbrella

- Construction time: November 2013 to April 2014
- Scope of work:
  - 11 jet grouting umbrellas with 35 pieces of Ø 600 mm piles each pile 14.8 m long and 5.5° inclination
  - 6 test piles inside the excavation section (tunnel face)
Platform tunnel horizontal jet grouting
Jet grouting umbrella

- Drilling device during the calibration

- Tunnel face with relief drillings, before start of jet grouting works
Special challenges

- Grout entries into basements
- Tearing of the soil: „fracks“
- Heave up to max. 15 mm on the surface
- Displacement of face and cracking of face
Special challenges – mitigation measures

- Increased intervals of monitoring
- Building inspections with designers and independent verifiers
- Supervision personnel in selected building basements during jetting
- Careful adaptation of alert and alarm criteria

- Adaption of the jetting parameters
- Systematic relief drillings
  - in umbrella area
  - in tunnel face
- Shortening of the secondary jet grouting piles
- Use of face bolts instead of jet grouting piles in the face
Surface settlements - overview
Conclusion

■ Horizontal jet grouting umbrella based on vertical jet grouting piles is an effective auxiliary method to limit settlement and max. tangent slopes for tunnelling in sensitive built-up areas

■ Horizontal jet grouting in fine-grained soils requires:
  □ a consistent alarm plan
  □ an experienced team
  □ a clear and open communication between all parties involved and quick decision-making

■ Despite the aforementioned challenges, the jet grouting and tunnel heading works have successfully been completed without major problems or deviations from the design criteria.
Announcement:

The journal „Geomechanics and Tunnelling“ publishes international articles about geomechanics and all aspects of tunnelling. Each issue of the journal has a special topic and is published in English and German.

■ The topic of issue 3/16 (June 2016) will be „Tunnelling in Turkey“

■ Colleagues interested to publish an article are encouraged to contact either:
  Mr. N. Ayaydin, IGT Salzburg (AT)  Mr. T. Ayten, IGT Istanbul (TR)
n.ayaydin@igt-engineering.com  t.ayten@igt-engineering.com
till 20.July 2015 with an abstract in English or Turkish.