Monitoring and safety management of tunnels in the Vienna metro network

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Tunnel network statistics

- NATM tunnels
- TBM tunnels
- cut and cover tunnels

![Chart showing tunnel network statistics for Vienna Metro Network.](chart.png)
Safety management

- during design and construction phase (basis RVS 09.01.42)
  - evaluation and interpretation of monitoring data (e.g. geotechnical measurements, survey of settlements of building, ground water table levelling)
  - definition of trigger values for warn and alert case
  - monitoring of the system behavior
  - procedures in case of deviations
- warn, alert criteria and countermeasures
  - S0: system behavior within expected range → no countermeasures
  - S1 (warn criterion): e.g. increase of shotcrete thickness and face dowels in number and length
  - S2 (alert criterion) → crisis situation → e.g. excavation stop, immediate application of shotcrete, massive strengthening of face support and completion of ring closure
  - S3: risk to public areas → crisis situation → closing off endangered area, evacuation of public if required; S2-measures + additionally: strutting of excavation (e.g. by timber)

Contour plot of surface settlements in mm for U1/10 “Troststrasse”
Monitoring sites

- during in-service life
- monitoring of geometry, displacements and stresses situated in several sections of the metro tunnel network
- fixed intervals (2-5 years)
Metro construction in the 1980’s – Lot U6/1 Pottendorfer Straße

- extension of U6 light rail to the south
- first major project in soft ground in Vienna using NATM
- no experience with NATM in Vienna’s soft ground

Geology and tunnel design U6/1

- Miocene (lower pannonian) formation; is heavily weathered and was subject to tectonic movements during the subsidence of the Vienna basin
  - clays, silts, sands and gravel
  - clays and silty clays are tectonically disturbed and show fissures up to greater depths

U6/1 measurement cross-sections

- standard measurement cross-sections
- detailed measurement cross-sections (e.g. MQ6)
- test-site for soft ground NATM
- geodetic surface monitoring

monitor the long-term development of stresses in the inner (40cm) and outer (20-30cm) lining
- 16 concrete stress cells (B)
- 4 pore water pressure transducers
- 12 radial stress cells (G)
Load case: earth pressure + water pressure + dead load

Moments
max. ~100 KNm/m

Normal forces
max. ~500 KN/m

- 400 mm cast-in-situ concrete lining was chosen to take the loads and ensure water tightness

### Load case: final (without water pressure)

#### Normal forces

<table>
<thead>
<tr>
<th>Section</th>
<th>Max. Loads</th>
<th>Max. Design Loads (e+w+d.l.)</th>
<th>Final Load Case</th>
<th>Measured Values</th>
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</table>
Tunnel inspection

- Inner lining: cracks opening size up to 1.2mm (mean value: 0.4mm)
- Concrete cover 40-65mm
- Mean values of concrete strength of 46-48N/mm² > req. 30N/mm²
- Cracks corresponding to stress measurements!

Results

- Detailed inspection every 10 years (crack detection, lab tests,...)
- Continuous systematic monitoring at certain cross-sections over tunnel lifecycle ensures safety (period: 2-5 years)
- Scientific approach from detailed monitoring sections: according to back-calculation, values remain well below the design limits (relevant standard then: Austrian Standard B 4200)
- Assumptions taken for the first NATM in soft ground in Vienna have been in the correct range

Thank you for your attention!