Investigation strategies on the example of the Semmering Base Tunnel

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Project overview Semmering Base Tunnel

- 27.3 km railway tunnel
- part of „Südbahn“ railway line
- Baltic-Adriatic Axis (BAA)
Project overview Semmering Base Tunnel

- curved alignment
- double tube tunnel system
- cross passages (500 m distance)
- emergency stop
- 3 temporary access structures for construction purposes (shafts and access tunnels)
Project overview – geological setting

- eastern margin of alpine orogen
- intense thrusting and folding
- 4 major tectonic nappes (crystalline basement and sedimentary cover)
- large-scale fault systems
- complexe and heterogeneous ground conditions!!

simplified geological map of the projekt area (tectonostratigraphic units)
Geological and geotechnical investigation

Preparatory works
- Desk study
- Field inspection
- Remote sensing data

Surface investigation program
- Geological mapping
- Hydrogeological measurements
- Laboratory tests

Preliminary ground model

Subsurface investigation program
- Core drilling
- Insitu- and laboratory tests
- Geophysical investigation

Final ground model

Consistent and plausible?
- Yes
- No

Type of project
- Size of project
- Complexity

Who is the Client?

Where is the project?

Availability of investigation methods

Acceptance of the project

Contract model (BOT, DBOT, etc.)
Geological and geotechnical investigation

- investigation campaigns:
  - phase I: investigation for route selection design (2005-2007), area of 300 km²
  - phase II: investigation for preliminary design (2008 - 2009), corridor along selected alignment
  - phase III: investigation for detailed and tender design (2010 – 2014), selected alignment, 3 construction lots

- methods applied:
  - field mapping
  - core drillings
  - borehole measurements and in-situ testing
  - surface geophysical investigations
  - laboratory testing
  - evaluation of data from tunnel projects in the project area
Geological and geotechnical investigation

- methods applied:
  - external experts for satellite image analysis, seismicity and stratigraphy

*map of tectonic lineaments from satellite image analysis*

*location of earthquakes causing damages in a distance of 50 km to the Semmering area*
Geological and geotechnical investigation

- Field mapping
  - scale 1:10000, approx. 300 km² for route selection
  - scale 1:5000, along selected alignment corridor
  - detailed-scale mapping of portal areas

field mapping - outcrop

geological map
Geological and geotechnical investigation

- Core drillings
  - phase I: 82 drillings (< 450 m)
    - total 11354 m
  - phase II: 60 drillings (< 720 m)
    - total 18034 m
  - phase III: 55 drillings (< 850 m)
    - total 9219 m

grand total: 38607 m
Geological and geotechnical investigation

- Borehole testing and measurements
  - geophysical/geotechnical methods
    - deviation log
    - calliper log
    - acoustic and optical borehole imaging
    - density log
    - natural gamma log
    - vertical seismic profiling
    - dilatometer test
    - in-situ stress measurements

borehole logging: ABI, CAL, DENS, incl. interpretation of discontinuities
Geological and geotechnical investigation

- Borehole testing and measurements
  - hydrogeological methods
    - fluid conductivity and temperature log
    - flowmeter measurements
    - tracer fluid logging
    - hydraulic packer tests

borehole logging: ABI, CAL, DENS, incl. interpretation of discontinuities
Geological and geotechnical investigation

- surface geophysical investigations
  - seismic reflection
  - seismic refraction tomography
  - electrical resistivity tomography

in total 21 profiles

dolomite

geophysical investigation of the Kaltenbach anticline
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Geological and geotechnical investigation

- laboratory analyses and testing
  - geology/mineralogy (>700 samples)
    - mineralogical composition (x-ray, point-counting)
    - clay mineral content
    - microscopic analyses (thin sections)
    - abrasivity tests (Cerchar Abrasivity Index)

thin section, nicols crossed; chlorite-muscovite-quartz-feldspar-gneiss

Cerchar abrasivity index test, sericitic phyllite
Geological and geotechnical investigation

- laboratory analyses and testing
  - rock mechanics testing (>1100 samples)
    - uniaxial compression tests
    - triaxial compression tests
    - Brazilian tests
    - shear tests (discontinuities, intact samples)

uniaxial compression test
limestone
Geological and geotechnical investigation

- laboratory analyses and testing
  - swelling tests (48 samples)
    - free swelling strain
    - axial swelling stress
    - swelling strain/stress (Huder/Amberg)
  - chemical analysis for classification of muck for recycling and waste disposal planning
Evaluation and results

- highly complex and heterogeneous ground conditions
- 18 large-scale geological units
- > 60 rock types
- poor ground conditions: 12 - 15 % fault zone material, overburden up to 870 m
- water inflow ≤300 l/s: in sections with limestone, dolomite (~2000 m), hydraulic pressure ≤28 bar
- swelling rocks: anhydrite
  fault gouge material rich in clay minerals

geological longitudinal section
Evaluation and results

- Flexibility during execution of investigation program
  - investigation phase I – geol. Model: Semmering Crystalline Complex with gneiss, micaschist, and amphibolite
  - investigation phase II: unexpected: dolomite at tunnel alignment – highly water permeable
    - additional investigation: 5 core drillings (500 to 700 m each)
    - surface geophysical seismic survey (3 lines)
  - consequence: realignment of tunnel axis
Evaluation and results

■ 3D Geological Model
  - to check and ensure the plausibility and consistency of the geological and structural model
  - easy information transfer of the geological architecture
  - presentation purposes

- whole tunnel length of 27.3 km
- model width of up to 10 km
- simplifications required!
Conclusion

- The investigation methods applied represent a state of the art ground investigation program for large infrastructure tunnel projects

- Each ground investigation program has to be individually designed for each project and for each design phase

- The design of an investigation program requires a sound knowledge about the investigation aims, the requirements as well as the capabilities and limitations of each investigation method
Conclusion

- The designer and geological consultant of an investigation program needs to have a ground model in the sense of a forecast model

- This model has constantly to be compared with the actual investigation results and updated during the investigation process

- As soon as substantial divergences between expected and factual conditions are detected adjustments of the investigation program are required
Conclusion

■ In case of the Semmering Base Tunnel project the originally designed investigation program had to be modified during the execution

■ The adjustment of the investigation program allowed for an identification, assessment and characterisation of geotechnical key structures

■ Therefore short term decision processes are essential as well as a profound technical understanding by the client for the reasons of the adjustments required and consequences in case of omitting them

■ A 3D geological model is an effective tool for checking the consistency and plausibility of a geological and structural model and it provides an understandable access to complex information for all parties involved
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Semmering Base Tunnel, construction lot SBT2.1 Tunnel Fröschnitzgraben site installation area (ÖBB Webcam, 2015-03-22)