Investigation of long-term behaviour of support elements in tunnelling

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Construction methods

- Project background:
  Example of the development of tunnel designs

Left: Cross section around 1900
Center: NATM double shell cross section
Right: NATM single shell cross section

10th principle of NATM: “Thin temporary and final linings” (Müller & Fecker 1978)
Procedure

Laboratory investigations
- Individual durability tests on support material

In situ tests
- Investigations on support elements on site

Evaluation of the support system
- Consideration of the mutual effects of the support elements
Subject of investigation

- Double shell tunnels
- Roadway tunnels

Object of investigations

Support elements:
- Shotcrete
- Inner lining concrete
- Rock bolts
- Membranes

In-situ measurement:
- Stress measurements in the inner lining

Left: Sampling in a cross passage, Gleinalmtunnel (2014)
Right: NATM double shell cross section, support elements

Lorenz (2014, 2015)
**Shotcrete**

- Uniaxial compressive strength (UCS)
- Shear parameters, cohesion and friction angle
- Scanning electron microscope images

**Uniaxial testing of shotcrete samples**

![Graph showing UCS values for different tunnels](image)

- Ganzsteintunnel: 44.7 N/mm²
- Katschbergtunnel: 43.7 N/mm²
- Tanzenbergtunnel: 69.5 N/mm²
- Gleinalmtunnel: 82.2 N/mm²
- Arlbergtunnel: 44.7 N/mm²

(1) Austrian Society for Concrete- and Construction Technology (OEVBB), (2009), Guideline „Sprayed Concrete“

**Left:** 360 [d] hydrat, sharp needles with up to 2 µm long C-S-H-phases

**Right:** View of shotcrete from the Bosrucktunnel under scanning electron microscopy

Wicht, Stark (2000)
Inner lining

- Uniaxial compressive strength (UCS)
- Shear parameters, cohesion and friction angle

Left: Cracks in the inner lining, Gleinalmtunnel
Right: Drilled core samples and uniaxial test

Uniaxial testing of inner lining samples

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© Austrian Society for Concrete- and Construction Technology (OEVBB), (2012), Guideline, Concrete for Inner Linings

Ganzsteintunnel 34,1 36,2 36,2 36,3 47,7
Katschberg tunnel 40,1
Tanzenberg tunnel 33,1
Arlberg tunnel 40,1
Bosruck tunnel 33,1

UCS [N/mm²]

Ganzsteintunnel Katschberg tunnel Tanzenberg tunnel Gleinalmtunnel Arlberg tunnel Bosruck tunnel

Subsurface Engineering (2014)
Lorenz (2014)
Lorenz (2014)
Rock bolts

The properties of the rock bolts in a tunnel were compared with unused ones.

Performed investigations:

- Mechanical tests
- Chemical analyses
- Structural observation
- Failure pattern analyses

Left: Extracted rock bolt

Right: Tensile specimen B10x50
Rock bolts

- Analysis of rock bolts: significant local corrosive attacks on the surface of the bolts
- No deterioration: according to strength, hardness and microstructural investigations

- Water:
  Analysis of mountain water samples: concentration too low for attacks of the supporting material

Left: New bolt, tempered steel  
Right: Used bolt, ferritic-perlitic steel; Bosrucktunnel
Membrane

The extracted sheet membranes were used for about 30 years and examined for changes of typical polymer properties.

- Microscopic examination
- Thermal analysis
  - Differential scanning calorimetry
- Tensile test
  - Young’s modulus, tensile strength
- Infrared spectroscopy

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Tanzenberg</th>
<th>Ganzstein</th>
<th>Katschberg</th>
<th>Roppener</th>
<th>Bosruck</th>
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Determination of the residual load bearing capacity of the shotcrete lining

Stress measurement of the tangential stress in the inner lining by flat-jack test

Numerical simulation of the deterioration of the primary support system

Comparison of the simulated and measured stresses

Above: Performing roof measurements on the intermediate ceiling

Right: Measuring in the side wall

Lorenz (2015)
Stress measurement

**Test procedure:**

- Inner lining of the tunnel gets locally unloaded with a horizontal cut
- Caused deformations along the saw cut are measured
- Deformations are compensated by loading the inner surface of the cut with pressure from a flat-jack
- When the deformations are completely compensated, the pressure of the flat-jack equates the tangential stress of the inner lining

Lorenz (2015)
Simulation

- Outer and inner lining are simulated together
- Determination of the load transmission from the outer lining onto the inner lining
- Load transmission between the outer and inner lining is modeled with couplings

Left: Numerical model; shotcrete and inner lining
Right: Coupling linings
The testing results of the stress measurements at the inner lining and the simulations show that in rock with good geotechnical parameters only low or no stresses can be detected in the inner lining.

Only in areas with swelling rock higher stresses can be measured and calculated.

It is difficult to estimate the swelling potential of the rock mass, which leads to a higher deviation between the measured stresses and the simulation in these areas.

### Table: Measuring point Sidewall Cross-section Roof

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</table>

* calculated with swelling pressure, t no compressive stresses, - not measured
Conclusion

- It is shown that the support function of the primary support is **unaffected even after 30 years**
- The results show no reduction of the technical lifetime regarding the strength of the support elements
- The stress measurements of the inner lining indicate that the bearing capacity of the outer lining is still intact

Summary:

*Concepts, in which the outer lining is part of the permanent support elements, can be considered*
Thank you for your attention

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