INFLUENCE OF CODES, GUIDELINES AND OTHER REGULATIONS ON THE TUNNEL DESIGN IN AUSTRIA

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Influence of codes, guidelines and other regulations, on the tunnel design in Austria

The Tauern Tunnel Fire Disaster 1999

The Tauern Tunnel is part of the European Transport network E55. It is one of the most important north-south transit routes through the Alps. The 1st tube was opened in 1975.
The Tauern Tunnel Fire Disaster 1999

- Tauern Tunnel is part of European Transport network E55
- A10 – Tauern Highway one of the most important north-south transit routes through the Alps
- 1st tube opened 1975
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

The Tauern Tunnel Fire Disaster 1999
The Tauern Tunnel Fire Disaster 1999

- May 29th 1999
  - Truck with paint canisters crashed into waiting queue
  - 24 cars and 16 trucks burnt out completely
  - 12 fatalities
Tunnel Damage

- debris of spalling
- intermediate ceiling:
  - partial breakdown
  - suspension intact
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

Damage of intermediate ceiling

- Additional air
- Exhaust air
- Cracks on top and bottom
- ca. 1m
- SALZBURG
- VILLACH

- SCHUTT

- BL 048 - Zwischendecke oben / Zulauf: Querpann Längsführung mit starken Höhenversatz
Refurbishment of Sidewalls

- removal of damaged concrete
- installation of reinforcement
- shotcrete lining
Refurbishment of Ceiling

- Fresh Air Duct
- Exhaust Air Duct
- PREFABRICATED SUPPORT PART
- PREFABRICATED SUPPORT PART
- CABLES
- SUSPENSION
- PARTITION WALL EXISTING
- ANGLE IRON
- PREFABRICATED SUPPORT PART
- PREFABRICATED SUPPORT PART
- SALZBURG
- VILLACH
- RECONSTRUCTED WITH SHOTCRETE
Refurbishment of Ceiling

- placing and fixing of prefabricated elements (L ~ 450 m)
- refurbishment works could be finished within 3 months
- costs ~ 6.5 Mio. US$
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

Other fire catastrophes

- March 24th, 1999
  - Mont Blanc Tunnel: L = 12 km, finalised 1965
  - Fire catastrophe, reportedly due to a cigarette, which was thrown away carelessly and lit fire on a truck
    - 39 fatalities, numerous injured people
    - Intermediate ceiling crashed over > 100 m length
  - Reopening of refurbished tunnel after 3 years

- October 24th, 2001
  - St. Gotthard Tunnel, Switzerland, L = 17 km, finalised 1980
  - Fire catastrophe due to crash of 2 trucks
    - 11 fatalities, intermediate ceiling crashed over > 300 m
  - Reopening of refurbished tunnel after 2 months
Consequences of the tunnel fire incidents

- Importance of internationally harmonized improved tunnel safety standards
  - UN/ECE report of group of experts on road tunnel safety (2001)
  - DIRECTIVE 2004/54/EC on minimum safety requirements for tunnels in trans-European road network

- Basic Objectives
  - PREVENT critical events
  - Reduce CONSEQUENCES of accidents
    - enable self rescue
    - provide measures for road users to intervene immediately
    - ensure efficient action by rescue forces
    - protect the environment and limit material damage
EC-Directive 2004/54/EC on minimum safety requirements for road tunnels

- All EU member states needed to implement the directive into national law. Austria: Road Tunnel Safety law (STSG)
- Applies to all tunnels >500m in trans-European road network
- Defines organisational structure
  - Administrative authority: link to European Commission
  - Tunnel Manager (TM): responsible for safety management and reporting of tunnel incidents
  - Safety Officer: nominated by TM for every tunnel;
    - coordinate all preventive and safeguard measures
    - takes part in design process
    - ensures coordination with emergency services
    - verifies that operational staff and emergency services are trained and tunnel is being maintained
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

EC-Directive on minimum safety requirements for road tunnels

- Defines procedures for approval of a tunnel
  - Safety documentation
    - technical description of tunnel, incl. safety measures
    - traffic forecast
    - hazard investigation, specifying conditions for dangerous goods transport
    - emergency response plan
    - risk analysis

- Demands for inspection entity
  - Regular inspection interval: 6 years
EC-Directive on minimum safety requirements for road tunnels

- Defines minimum safety measures
  - Differentiation between tunnels being in operation and tunnels being in the design stage
  - If structural requirements can only be satisfied at disproportionate cost, implementation of risk reduction measures may be accepted, provided that the alternative measures will result in equivalent protection → risk analysis

- Demands for reporting to EC
  - Reports on fires and safety relevant accidents in tunnels: 2 years

- Harmonizes tunnel signing
## EC-Directive on minimum safety requirements for road tunnels

<table>
<thead>
<tr>
<th>MINIMUM REQUIREMENTS</th>
<th>Traffic ≤ 2 000 veh. per lane</th>
<th>Traffic &gt; 2 000 vehicles per lane</th>
<th>Additional conditions for implementation to be mandatory, or comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500-1 000 m</td>
<td>&gt;1 000 m</td>
<td></td>
</tr>
<tr>
<td>2 tubes or more</td>
<td>§2.1</td>
<td></td>
<td>Mandatory where a 15-year forecast shows that traffic &gt; 10 000 veh./lane.</td>
</tr>
<tr>
<td>Gradients ≤ 5 %</td>
<td>§2.2</td>
<td>*</td>
<td>Mandatory unless not geographically possible.</td>
</tr>
<tr>
<td>Emergency walkways</td>
<td>§2.3.1 §2.3.2</td>
<td>*</td>
<td>Mandatory where there is no emergency lane, unless the condition in §2.3.1 is respected. In existing tunnels where there is neither an emergency lane, nor an emergency walkway additional / reinforced measures shall be taken.</td>
</tr>
<tr>
<td>Emergency exits</td>
<td>§2.3.3 - §2.3.9</td>
<td>○</td>
<td>Implementation of emergency exits in existing tunnels to be evaluated case-by-case.</td>
</tr>
<tr>
<td>Cross-connections for emergency services at least every 1 500 m</td>
<td>§2.4.1</td>
<td>○ / •</td>
<td>Mandatory in twin-tube tunnels longer than 1 500 m.</td>
</tr>
<tr>
<td>Crossing of the central reserve outside each portal</td>
<td>§2.4.2</td>
<td>•</td>
<td>Mandatory outside twin- or multi-tube tunnels wherever geographically possible.</td>
</tr>
<tr>
<td>Lay-bys at least every 1 000 m</td>
<td>§2.5</td>
<td>○</td>
<td>Mandatory in new bi-directional tunnels &gt;1 500 m without emergency lanes. In existing bi-directional tunnels &gt;1 500 m: depending on analysis. For both new and existing tunnels, depending on extra usable tunnel width.</td>
</tr>
<tr>
<td>Drainage for flammable and toxic liquids</td>
<td>§2.6</td>
<td>*</td>
<td>Mandatory where transport of dangerous goods is allowed.</td>
</tr>
<tr>
<td>Fire resistance of structures</td>
<td>§2.7</td>
<td>•</td>
<td>Mandatory where a local collapse can have catastrophic consequences.</td>
</tr>
</tbody>
</table>
## Influence of codes, guidelines and other regulations, on the tunnel design in Austria

### EC-Directive on minimum safety requirements for road tunnels

**SUMMARY OF MINIMUM REQUIREMENTS**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Traffic ≤ 2 000 veh. per lane</th>
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<tbody>
<tr>
<td><strong>Lighting</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal lighting</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Safety lighting</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Evacuation lighting</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Ventilation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Special provisions for (semi-) transverse ventilation</td>
<td>•</td>
<td>•</td>
<td>Mandatory in bi-directional tunnels where there is a control centre.</td>
</tr>
<tr>
<td><strong>Emergency stations</strong></td>
<td></td>
<td></td>
<td>Equipped with telephone and 2 extinguishers. A maximum interval of 250 m is allowed in existing tunnels.</td>
</tr>
<tr>
<td>At least every 150 m</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Water supply</strong></td>
<td></td>
<td></td>
<td>If not available, mandatory to provide sufficient water otherwise.</td>
</tr>
<tr>
<td>At least every 250 m</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Road signs</strong></td>
<td></td>
<td></td>
<td>For all safety facilities provided for tunnel users (see Annex III).</td>
</tr>
<tr>
<td>§2.12</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Control centre</strong></td>
<td></td>
<td></td>
<td>Surveillance of several tunnels may be centralised into a single control centre.</td>
</tr>
<tr>
<td>§2.13</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Monitoring systems</strong></td>
<td></td>
<td></td>
<td>Mandatory where there is a control centre.</td>
</tr>
<tr>
<td>Video</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Automatic incident detection and/or fire detection</td>
<td>•</td>
<td>•</td>
<td>At least one of the two systems is mandatory in tunnels with a control centre.</td>
</tr>
<tr>
<td>§2.14</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Equipment to close the tunnel</strong></td>
<td></td>
<td></td>
<td>Recommended if there is a control centre and the length exceeds 3 000 m.</td>
</tr>
<tr>
<td>Traffic signals before the entrances</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>§2.15.1</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Traffic signals inside the tunnel at least every 1 000 m</td>
<td>•</td>
<td>•</td>
<td></td>
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EC-Directive on minimum safety requirements for road tunnels

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<td></td>
<td>500-1 000 m</td>
<td>&gt;1 000 m</td>
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<tr>
<td>Communication systems</td>
<td>§2.16.1</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Radio re-broadcasting for</td>
<td></td>
<td>●</td>
<td>●</td>
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<tr>
<td>emergency services</td>
<td></td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Emergency radio messages for</td>
<td>§2.16.2</td>
<td>●</td>
<td>●</td>
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<tr>
<td>tunnel users</td>
<td></td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Loudspeakers in shelters and</td>
<td>§2.16.3</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>exits</td>
<td></td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Emergency power supply</td>
<td>§2.17</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Fire resistance of equipment</td>
<td>§2.18</td>
<td>●</td>
<td>●</td>
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</tbody>
</table>

REMARKS

- Shelters without an exit leading to escape routes to the open shall not be built.
EXAMPLE: ARLBERG TUNNEL

- Overview
  - Austria’s longest road tunnel
  - one tube, opened 1978
  - Total length incl. Galleries: ca. 15.508 m
  - Parallel railway tunnel
EXAMPLE: ARLBERG TUNNEL

- Overview
  - Austria’s longest road tunnel
  - 1 tube, opened 1978
  - Total length incl. Galleries: ca. 15.508 m
  - Parallel railway tunnel

Cross passages every ~1.5-2 km
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

EXAMPLE: ARLBERG TUNNEL

- 3-D Model of emergency exit
- Max. distance of emergency exits: 500 m
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

EXAMPLE: ARLBERG TUNNEL

Cross Section Road Tunnel

- Space for E&M equipment (lighting, signage etc.)
- Exhaust air
- Escape route
- Adaptation of E&M equipment for the escape routes
- Construction of 8 lay-bys and 37 connections into the fresh air duct

South

North

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Situation in Austria

- **Laws:** Austrian Road Tunnel Safety Law
  - Safety measures according to EC directive 2004/54/EC, in cases additional national regulations (stricter than directive)
  - Refurbishment TERN tunnels: till April 2019

- **Austrian Guideline Codes for Planning, Construction and Maintenance of Roads (RVS)**
  - Austrian Society for Research on Road, Rail and Transport [www.fsv.at](http://www.fsv.at)

- **Guidelines from Austrian Society for Construction Technology ÖBV**
  - [www.bautechnik.pro](http://www.bautechnik.pro)

- **Guidelines from Austrian Society for Geomechanics**
  - [www.oegg.at](http://www.oegg.at)

- **Design Manuals from operators**
  - ASFINAG (Austrian Highway Operator) [www.asfinag.at](http://www.asfinag.at)
### RVS Guideline Codes for Tunnel Design

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>RVS_09.01.11</td>
<td>Structural Engineering and Geotechnical preparatory work, General</td>
</tr>
<tr>
<td>RVS_09.01.12</td>
<td>Structural Engineering and Geotechnical preparatory work, Scope of Services</td>
</tr>
<tr>
<td>RVS_09.01.13</td>
<td>Structural Engineering and Geotechnical preparatory work, City Area</td>
</tr>
<tr>
<td>RVS_09.01.21</td>
<td>Construction Design, Alignment Regulations for Tunnels</td>
</tr>
<tr>
<td>RVS_09.01.22</td>
<td>Construction Design, Tunnel Cross-Sections</td>
</tr>
<tr>
<td>RVS_09.01.23</td>
<td>Construction Design, Interior finishing</td>
</tr>
<tr>
<td>RVS_09.01.24</td>
<td>Construction Design, Structural Equipment for Operation and Safety</td>
</tr>
<tr>
<td>RVS_09.01.25</td>
<td>Construction Design, Tunnel Portal Area</td>
</tr>
<tr>
<td>RVS_09.01.31</td>
<td>Structural Engineering and Geotechnical Works, TBM Road Tunnel</td>
</tr>
<tr>
<td>RVS_09.01.41</td>
<td>Constructive Design, Open construction method</td>
</tr>
<tr>
<td>RVS_09.01.42</td>
<td>Design Guide Lines, Tunnel in Soil underneath Built-Up Area</td>
</tr>
<tr>
<td>RVS_09.01.45</td>
<td>Structural design, Constructional fire protection in transportation buildings for roads</td>
</tr>
<tr>
<td>RVS_09.01.51</td>
<td>Safety tunnel sites, Concepts for health- and safety concepts on tunnel sites</td>
</tr>
<tr>
<td>RVS_09.02.22</td>
<td>Operation and Safety Facilities, Tunnel Equipment</td>
</tr>
<tr>
<td>RVS_09.02.31</td>
<td>Ventilation Systems, Basics</td>
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<td>RVS_09.02.32</td>
<td>Ventilation Systems, Fresh Air</td>
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<td>RVS_09.02.41</td>
<td>Lighting Engineering, Lighting</td>
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<td>RVS_09.02.51</td>
<td>Fire Extinguishing Systems, Fixed Fire Fighting Systems</td>
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<td>RVS_09.02.61</td>
<td>Tunnel Radio Engineering, Tunnel Radio Facilities</td>
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<tr>
<td>RVS_09.03.11</td>
<td>Methodology of Risk-Analysis</td>
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<tr>
<td>RVS_09.03.12</td>
<td>Risk Evaluation of Dangerous Goods Transport through Road Tunnels</td>
</tr>
<tr>
<td>RVS_09.04.11</td>
<td>Maintenance and Operation</td>
</tr>
</tbody>
</table>

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**Austrian Tunnelling Seminar Ankara, March 31st & April 1st, 2015**
RVS Guideline 09.01.22 for Tunnel Cross Sections

- Clearance Profile Tunnel
  - Clearance height 4.7 m
  - Elevated walkways on both sides
  - Lane width as a function of
    - Max. design speed
    - Average daily truck traffic intensity on working days
  - 0.25 m between lanes and walkway for drainage and road marking
RVS Guideline 09.01.24 for Structural Equipment

- Cross passages / emergency exits: Clearance Profiles
  - EQ: for rescue forces – regular distance 1000m
  - GQ: for pedestrians
    - regular distance 250 – 500 m, depending on risk analysis (to be defined together with rescue forces)

Figure 7: Clearance profile of EQ

Figure 10: Clearance gauge of GQ
RVS Guideline 09.01.24 for Structural Equipment

- Lay-by

**Figure 4:** Clearance gauge in the range of a one sided breakdown bay
RVS Guideline 09.01.24 for Structural Equipment

- Lay-bys
  - Every 1000 m for new tunnels if no emergency lane available

![Diagram of tunnel layout showing lay-bys and emergency niches.](image)

- Water supply niche
- MEP room
- Emergency niche
- Lay by / breakdown bay
- Water supply niche with rapid intervention hose reel
- Jersey wall
- Picture of lay by in unidirectional tunnel
- In bi-directional tunnels: lay-by on both sides
RVS Guideline 09.01.24 for Structural Equipment

- Emergency Stations
  - Usually situated in niches
  - regular distance 125 m (max. 150) in new tunnels
RVS Guideline 09.01.24 for Structural Equipment

- Emergency Stations
  - Emergency boxes allowed instead of every 2nd niche
  - Emergency station at tunnel portal
RVS Guideline 09.01.24 for Structural Equipment

- Water Supply Line and Water Supply Niches
  - Water supply niches with hydrants opposite of emergency niches
  - Pressure: min. 6, max 12 bar; flow: min. 20l/s for 90 mins
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

RVS Guideline 09.01.24 for Structural Equipment

- Water Supply Niches with rapid intervention hose reels
  - Located in lay-bys
  - min. hose length 60 m, equipped with foam mixing device

![Diagram of tunnel drainage system](image)
RVS Guideline 09.03.11 Tunnel Risk Analysis

- Based on statistical evaluation of incidents in Austrian tunnels
- Includes simplified analysis of hazardous goods transports; for detailed analysis → DG-QRA (Piarc)

Input: influence factors
- Tunnel length
- Traffic volume
- Truck-amount etc.

Frequency analysis (Event tree)
- Initial event
- Damage scenarios

Accident consequence analysis (Extent of damage analysis)

Result
- Expected risk value
  (statistically expected fatalities/year)

Basic structure of the tunnel risk analysis (©RVS)
RVS Guideline 09.03.11 Tunnel Risk Analysis

- Result: expected risk value
- Enables the comparison of safety measures
- Allows classification in hazard classes
- Individual tunnel is compared to a reference tunnel, which complies with safety measures according to STSG

- Tunnel with different characteristics
- Min. requirements acc. to STSG for reference tunnel
- Tunnel with alternative measures

Evaluation of the results of the tunnel risk analysis (©RVS)
RVS Guideline 09.02.22 Tunnel Equipment, Operation and Safety Facilities

■ Determination of safety facilities
  □ Definition of surveillance and operation concept
    (central station for operation and surveillance 24/7, separate locations for operation and surveillance e.g. by police)
  □ Selection of safety facilities according to min. requirements defined by hazard classes from risk analysis

■ locations of safety facilities

■ technical specifications of safety facilities
  □ Power supply
  □ Surveillance of air (visibility, CO, ...)
  □ Traffic routing and traffic control
  □ Information devices (loudspeakers etc.)
  □ Lighting and signage
  □ Emergency stations, fire alarm and fire fighting devices
  □ Data processing
  □ Cables
  □ Doors
  □ Commissioning
  □ Test runs
Selected safety items – recent developments

- Thermal Scanners
  - Thermal imaging cameras installed at separate lane ahead of tunnel portal
  - Detection of overheated heavy goods vehicles/busses (brakes, tyres, turbochargers)
  - Successful operation at Karawanken tunnel since 2012
Selected safety items – recent developments

- Thermal Scanners
  - Laser scanners measure and record the HGV from all sides
  - Thermal imaging cameras measure the external temperature of the vehicle and make critical points visible

©ASFINAG
Selected safety items – recent developments

- ACUTE – tunnel with ears
  - Developed by ASFINAG and Joanneum research
  - Microphones installed in tunnel, max. distance 125 m
  - Test project Kirchdorfer tunnel
  - Software identifies unusual noises such as vehicle collision, heavy braking, bursting tyres and triggers alarm
  - Control center can respond with good accuracy
  - Time benefit compared to standard fire alarm systems is up to 2 minutes
Test Run of Safety Measures – Fire smoke tests
Test Run of Safety Measures – Fire smoke tests
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

Test Run of Safety Measures – Fire smoke tests
RVS Guideline 09.01.23 Interior Finishing

- Pavement
  - Concrete pavement preferred; dimensions according to volume of traffic
  - Bituminous pavement is also possible

- Tunnel paint: min height 4 m

- Emergency walkways
  - +150 mm above pavement
  - Facilitate cable ducts
  - Cover slabs: regular length 1 m
RVS Guideline 09.01.23 Interior Finishing

- Waterproofing
  - Standard solution: waterproofing membrane and longitudinal drainages at abutments of inner lining
    → no water pressure to be taken into account

- Drainage system
  - Carriageway drainage (polluted) → detention basin
t    design capacity 100 l/s
  - Formation water drainage (clean) → river
t    min. diameter DN/OD 250 or 160 (invert drainage)
t    min. inclination 0.5% (0.3% at superelevation change)
t    max. distance of manholes every 100 m
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

Drainage Design – specific requirements by operators

- ASFINAG → design handbook
  - No man holes in pavement! → maintenance friendly, increased safety

- Formation water drainage
  - invert drainage → tunnel drainage at sidewalls
    maintenance and flushing of both drainages via niches

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Drainage Design – specific requirements by operators

- **PAVEMENT DRAINAGE**
  - **ASFINAG**: slot gutter with fire traps

**AUSTRIAN PROVINCES:**

- Pavement drainage inlet shafts with fire traps
- Need longitudinal drainage pipe with man holes for maintenance
Most important, tunnel related ÖBV guidelines

Contain a lot of technical specifications as well as design principles

- Sprayed concrete
  - Strength development of concrete, exposure class regulations...
- Concrete Segmental Linings
- Inner Shell Concrete
- Tunnel paint
- Formation of joints
- Tunnel drainage
- Waterproofing of tunnels
- Coatings for fire protection
- Self Compacting Concrete
- Waterproof Concrete Structures – White Tanking
Design Philosophy in Austria

■ Sprayed concrete
  □ Can be regarded as permanent, if geochemical conditions allow → in this case no decay has to be taken into account, no load transfer to inner lining

■ Inner Shell Concrete
  □ Drained tunnels: usually 250 mm non-reinforced shell C25/30
  □ Undrained tunnels: waterproof concrete is preferred over installation of waterproofing membrane special concrete properties and structural requirements are specified to create a concrete structure impervious to water
  □ Placing of concrete lining possible, if displacements < 4mm/month
Influence of codes, guidelines and other regulations, on the tunnel design in Austria

THANK YOU FOR YOUR ATTENTION!