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

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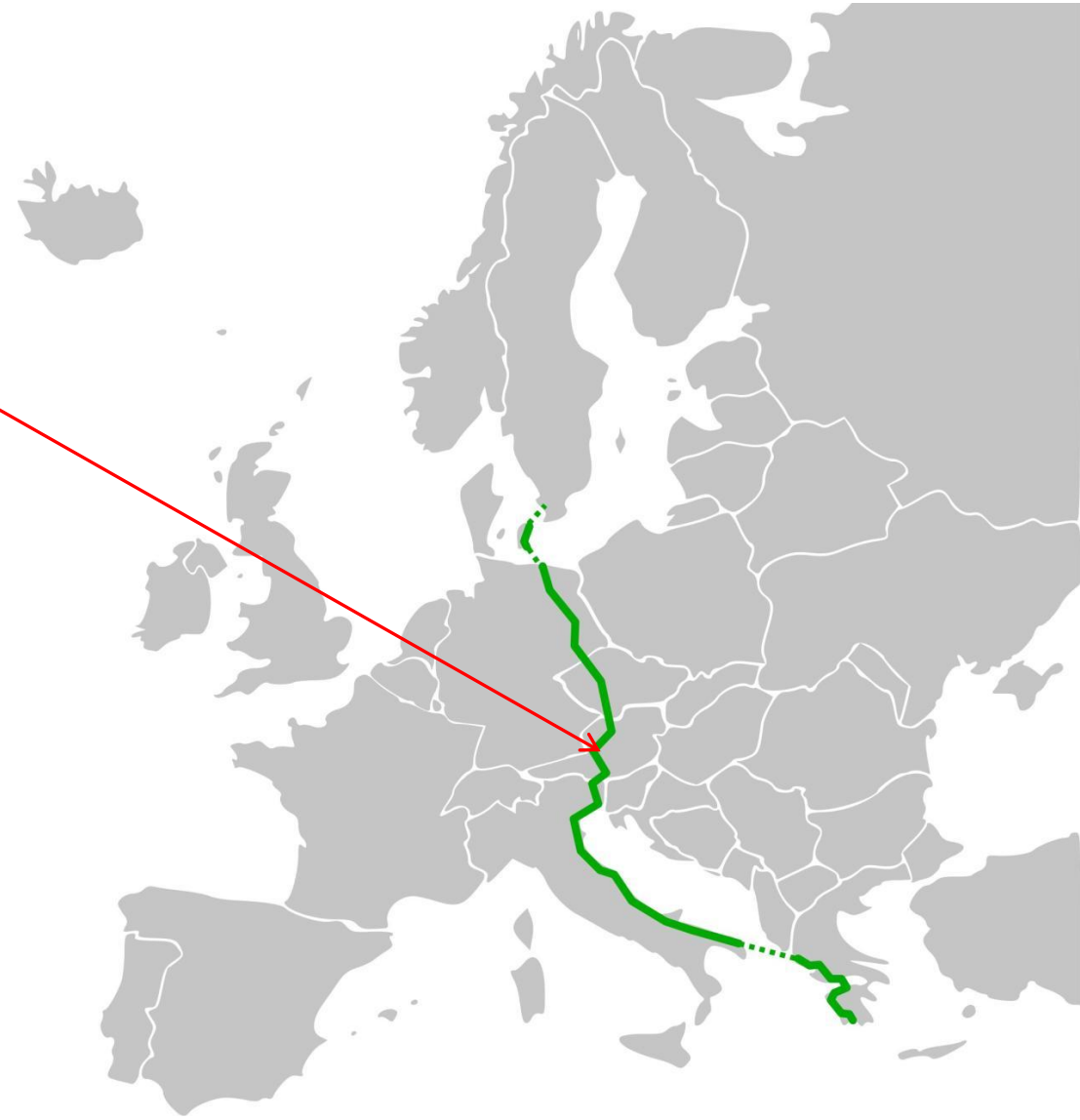
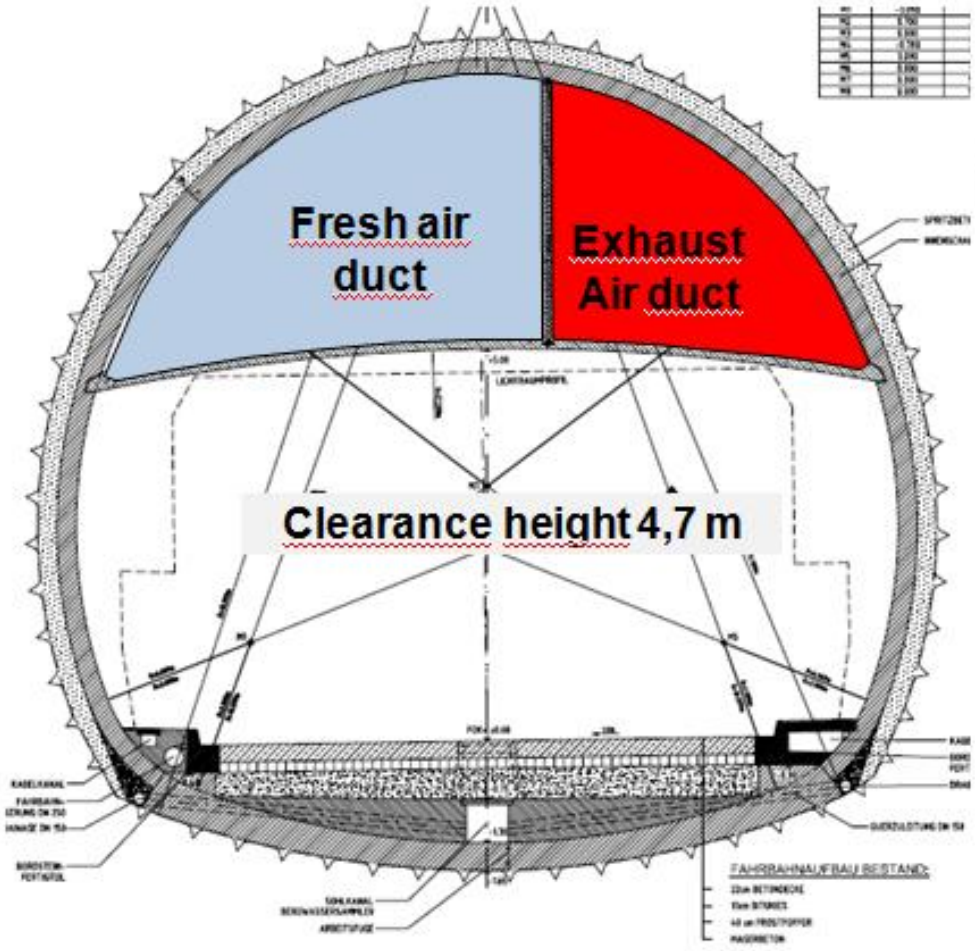
The Tauern Tunnel Fire Disaster 1999

The Tauern Tunnel Fire Disaster 1999

- Tauerntunnel 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



The Tauern Tunnel Fire Disaster 1999

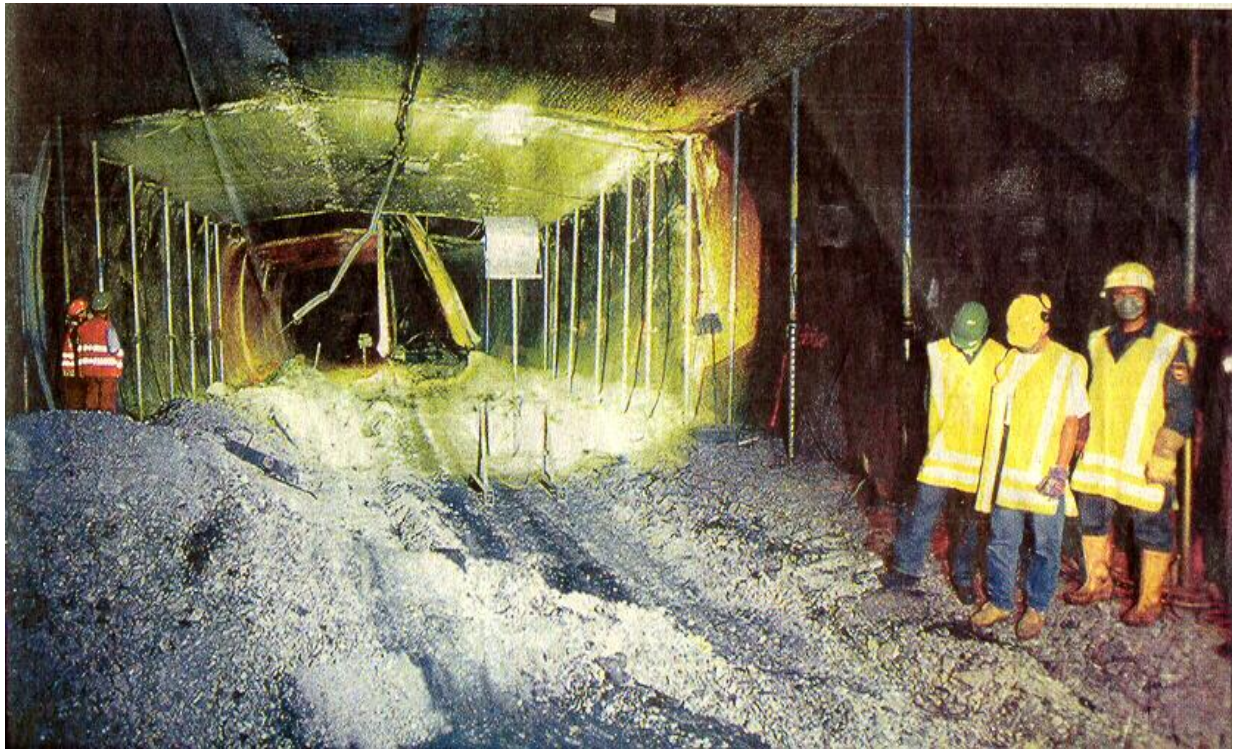


The Tauern Tunnel Fire Disaster 1999

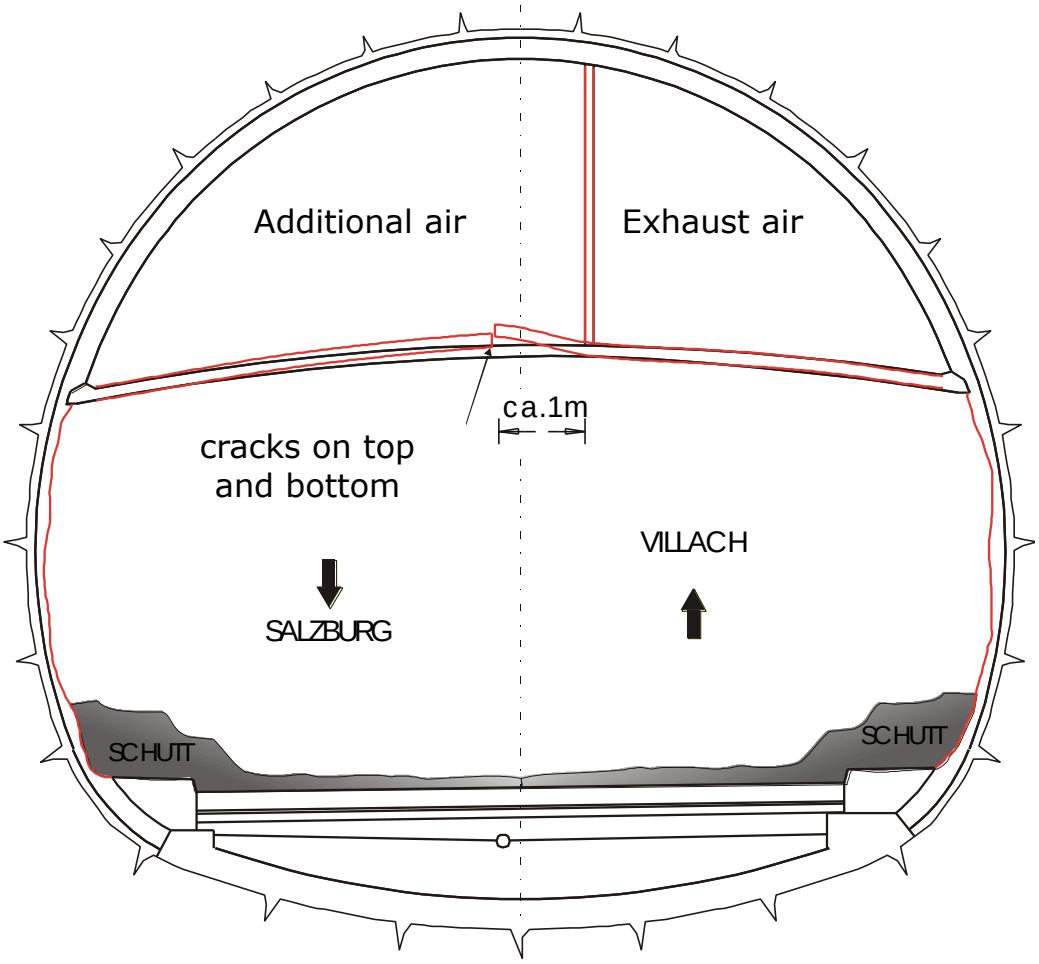
- May 29th 1999
  - Truck with paint canisters crashed into waiting queue
  - 24 cars and 16 trucks burnt out completely
  - 12 fatalities

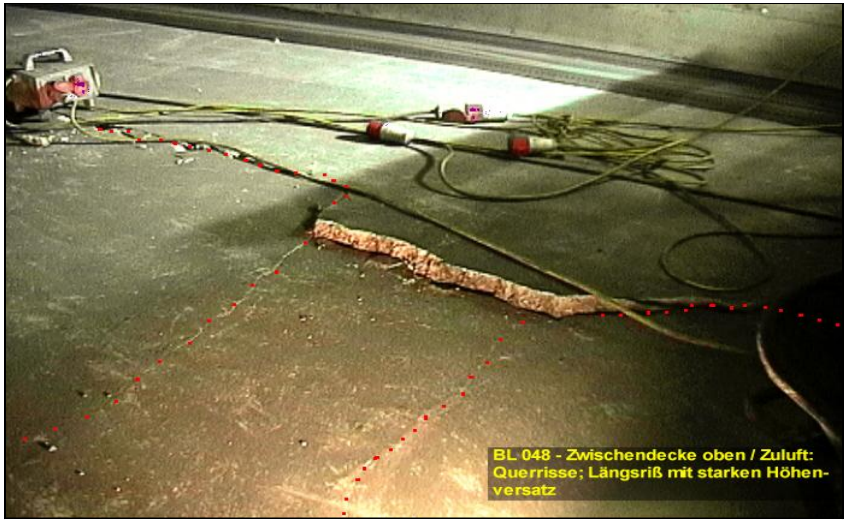
Tunnel Damage

- debris of spalling
- intermediate ceiling:
  - partial breakdown
  - suspension intact



Damage of intermediate ceiling





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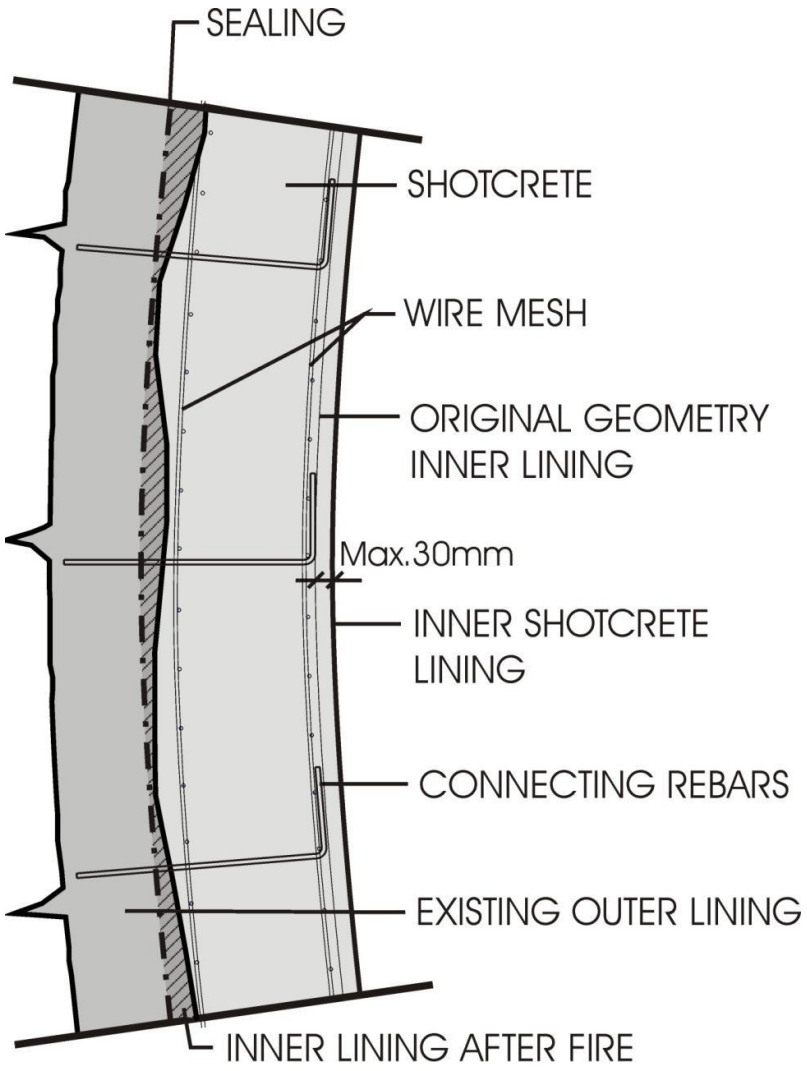
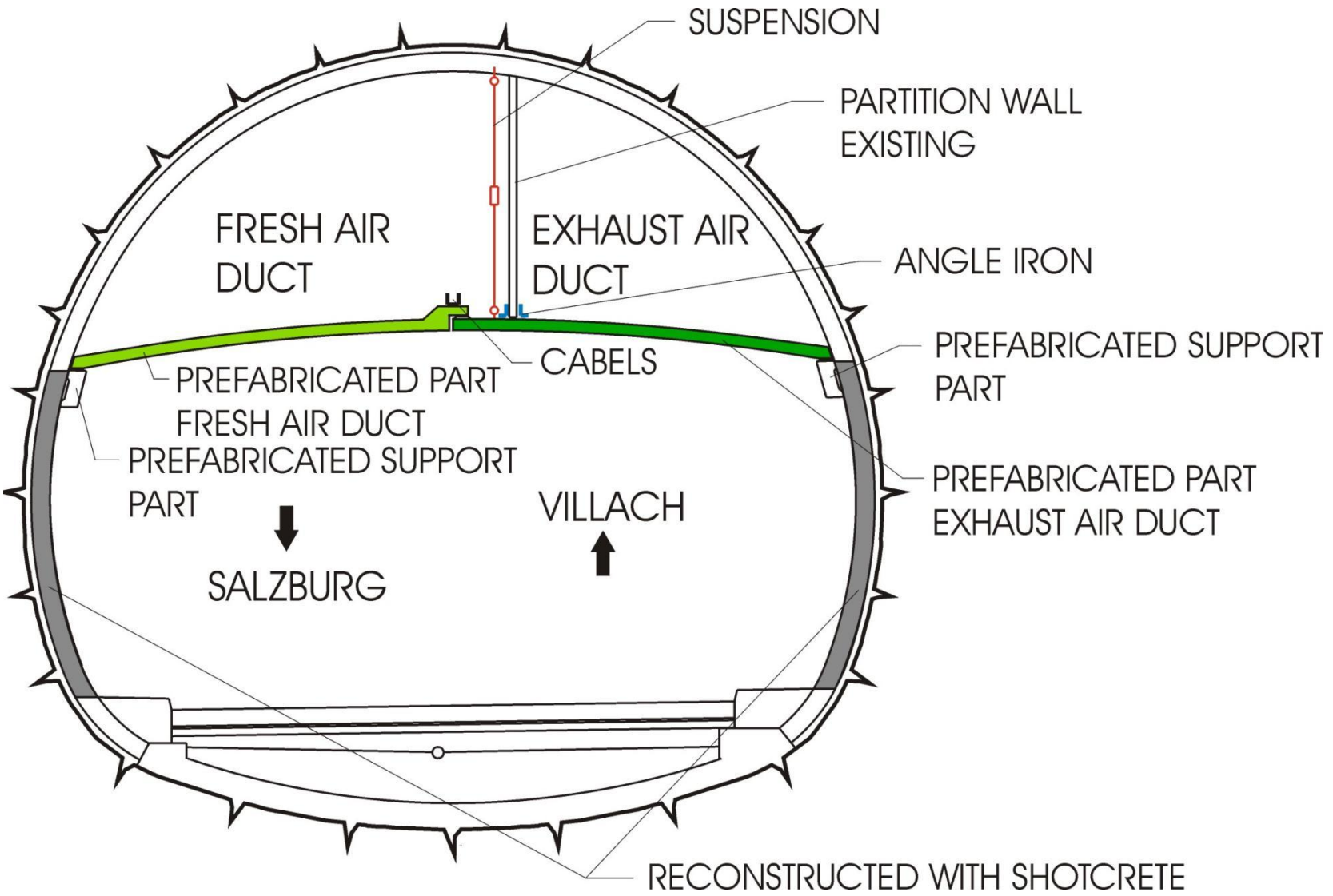
Refurbishment of Sidewalls

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

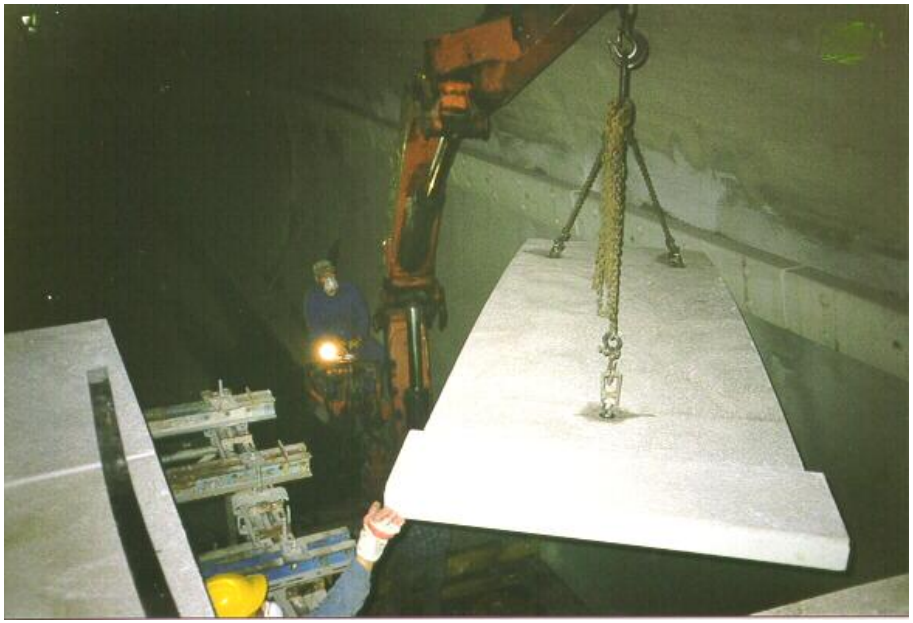


Refurbishment of Ceiling



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$

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 fatalilties, 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
  - PIARC: Report on fire and smoke control in road tunnels (1999)
  - 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

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



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EC-Directive on minimum safety requirements for road tunnels

● mandatory for all tunnels
* mandatory with exceptions
❍ not mandatory
☯ recommended

SUMMARY OF MINIMUM REQUIREMENTS		Traffic ≤ 2 000 veh. per lane		Traffic > 2 000 vehicles per lane			Additional conditions for implementation to be mandatory, or comments
		500-1 000 m	>1 000 m	500-1 000 m	1 000-3 000 m	>3 000 m	
2 tubes or more	§2.1						Mandatory where a 15-year forecast shows that traffic > 10 000 veh./lane.
Gradients ≤ 5 %	§2.2	*	*	*	*	*	Mandatory unless not geographically possible.
Emergency walkways	§2.3.1 §2.3.2	*	*	*	*	*	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.
Emergency exits at least every 500 m	§2.3.3 - §2.3.9	❍	❍	*	*	*	Implementation of emergency exits in existing tunnels to be evaluated case-by-case.
Cross-connections for emergency services at least every 1 500 m	§2.4.1	❍	❍ / ●	❍	❍ / ●	●	Mandatory in twin-tube tunnels longer than 1 500 m.
Crossing of the central reserve outside each portal	§2.4.2	●	●	●	●	●	Mandatory outside twin- or multi-tube tunnels wherever geographically possible.
Lay-bys at least every 1 000 m	§2.5	❍	❍	❍	❍ / ●	❍ / ●	Mandatory in new bi-directional tunnels >1 500 m without emergency lanes. In existing bi-directional tunnels >1 500 m: depending on analysis. For both new and existing tunnels, depending on extra usable tunnel width.
Drainage for flammable and toxic liquids	§2.6	*	*	*	*	*	Mandatory where transport of dangerous goods is allowed.
Fire resistance of structures	§2.7	●	●	●	●	●	Mandatory where a local collapse can have catastrophic consequences.

AUSTRIAN SOCIETY FOR GEOMECHANICS

EC-Directive on minimum safety requirements for road tunnels

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			500-1 000 m	>1 000 m	500-1 000 m	1 000-3 000 m	>3 000 m	
Lighting	Normal lighting	§2.8.1	●	●	●	●	●	
	Safety lighting	§2.8.2	●	●	●	●	●	
	Evacuation lighting	§2.8.3	●	●	●	●	●	
Ventilation	Mechanical ventilation	§2.9	❍	❍	❍	●	●	
	Special provisions for (semi-) transverse ventilation	§2.9.5	❍	❍	❍	❍	●	Mandatory in bi-directional tunnels where there is a control centre.
Emergency stations	At least every 150 m	§2.10	*	*	*	*	*	Equipped with telephone and 2 extinguishers. A maximum interval of 250 m is allowed in existing tunnels.
Water supply	At least every 250 m	§2.11	●	●	●	●	●	If not available, mandatory to provide sufficient water otherwise.
Road signs		§2.12	●	●	●	●	●	For all safety facilities provided for tunnel users (see Annex III).
Control centre		§2.13	❍	❍	❍	❍	●	Surveillance of several tunnels may be centralised into a single control centre.
Monitoring systems	Video	§2.14	❍	❍	❍	❍	●	Mandatory where there is a control centre.
	Automatic incident detection and/or fire detection	§2.14	●	●	●	●	●	At least one of the two systems is mandatory in tunnels with a control centre.
Equipment to close the tunnel	Traffic signals before the entrances	§2.15.1	❍	●	❍	●	●	
	Traffic signals inside the tunnel at least every 1 000 m	§2.15.2	❍	❍	❍	❍	☯	Recommended if there is a control centre and the length exceeds 3 000 m.

EC-Directive on minimum safety requirements for road tunnels

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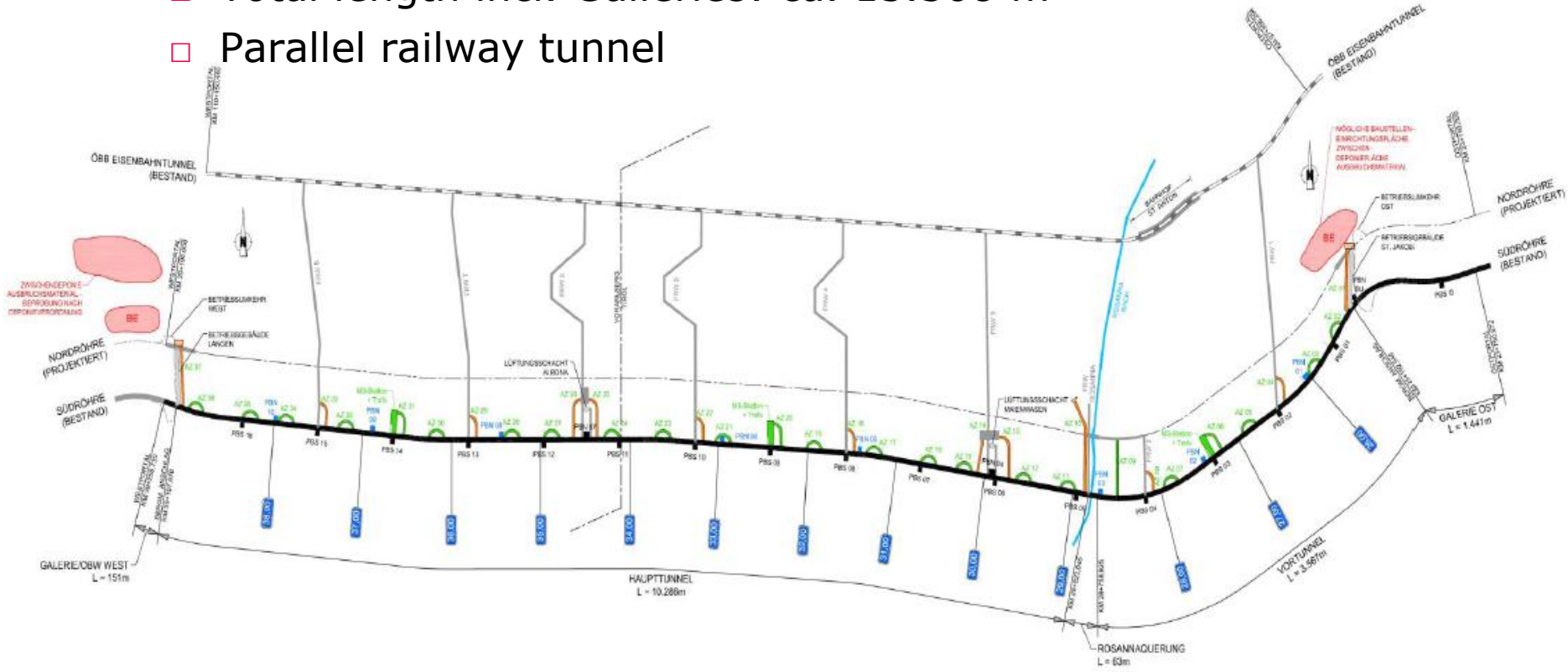
			500-1 000 m	>1 000 m	500-1 000 m	1 000-3 000 m	>3 000 m	
Communication systems	Radio re-broadcasting for emergency services	§2.16.1	❍	❍	❍	●	●	
	Emergency radio messages for tunnel users	§2.16.2	●	●	●	●	●	Mandatory where radio is re-broadcasted for tunnel users and where there is a control centre
	Loudspeakers in shelters and exits	§2.16.3	●	●	●	●	●	Mandatory where evacuating users must wait before they can reach the outside.
Emergency power supply		§2.17	●	●	●	●	●	To ensure the functioning of indispensable safety equipment at least at during evacuation of tunnel users.
Fire resistance of equipment		§2.18	●	●	●	●	●	Shall aim to maintain the necessary safety functions.

- 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



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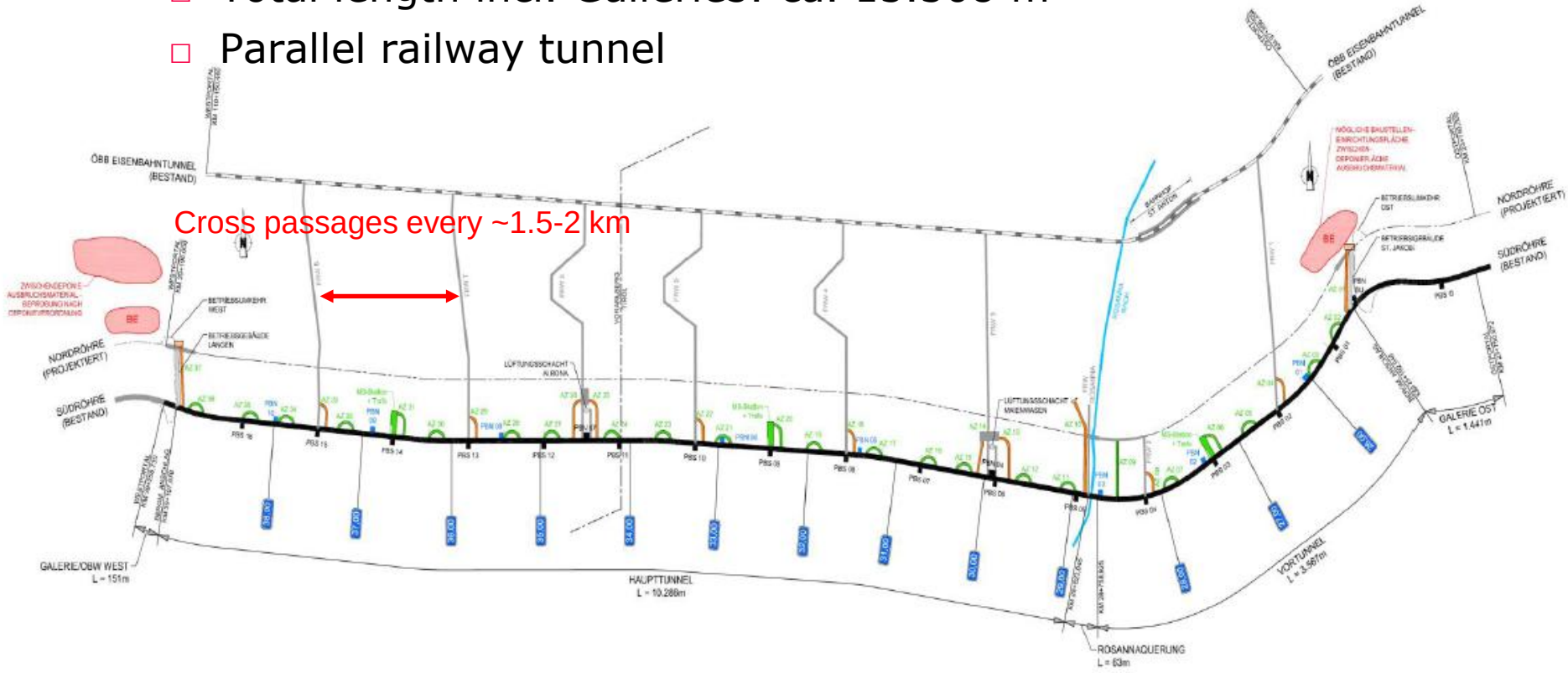
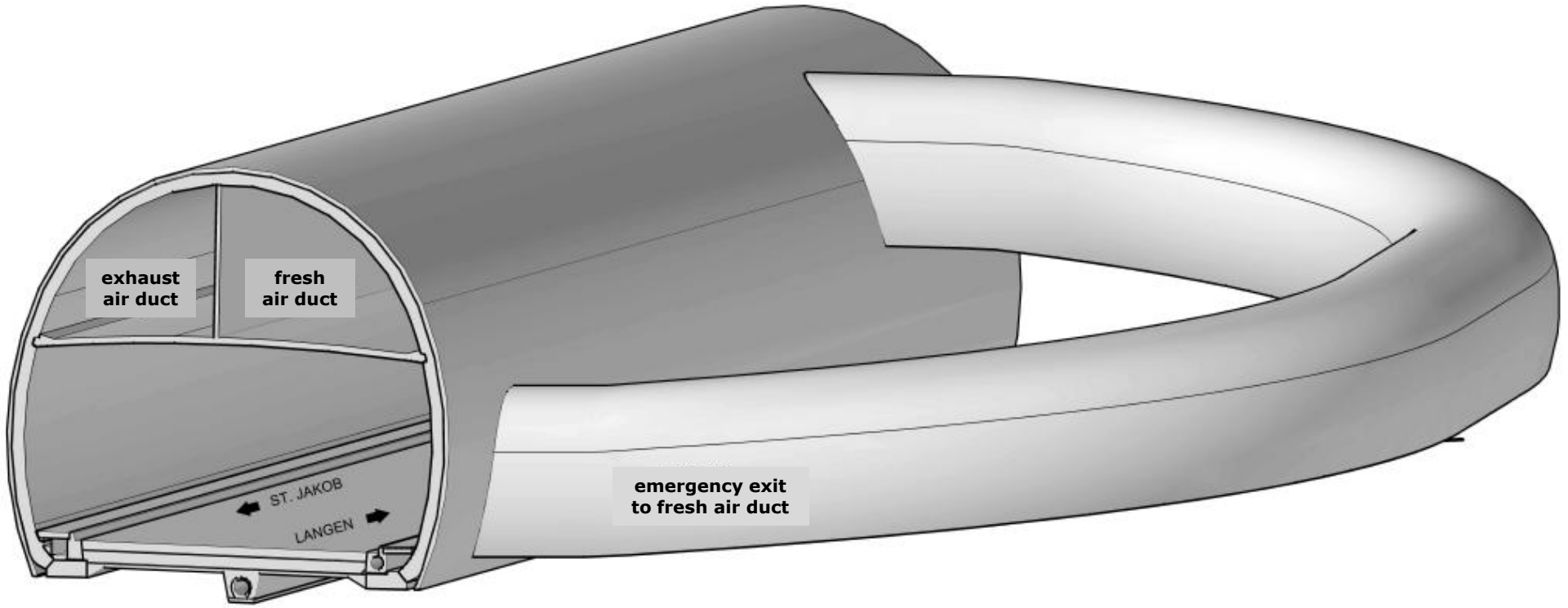


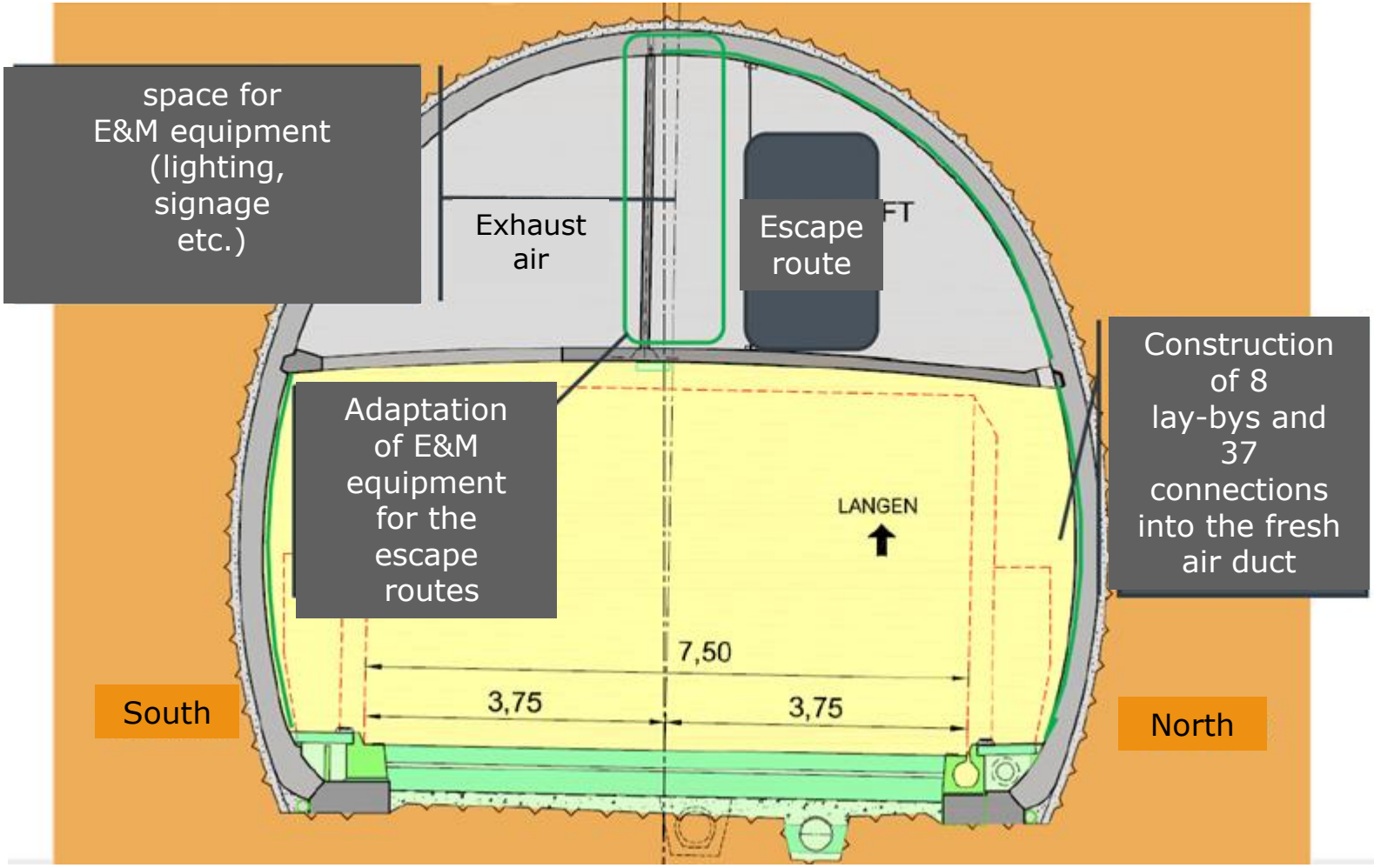
EXAMPLE: ARLBERG TUNNEL

- 3-D Model of emergency exit
- Max. distance of emergency exits: 500 m



EXAMPLE: ARLBERG TUNNEL

- Cross Section Road Tunnel



Situation in Austria

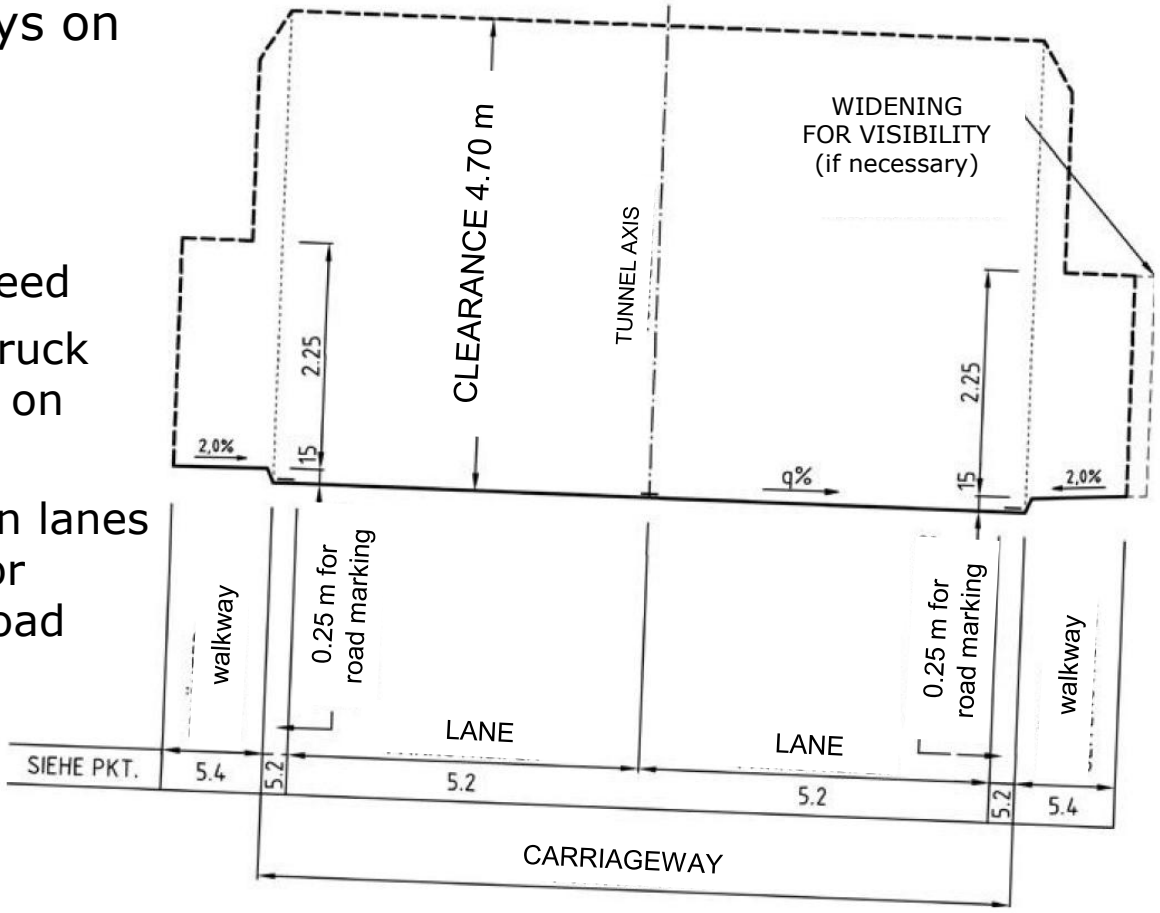
- Laws: Austrian Road Tunnel Safety Law
  - Safety measures according to EC directive 2004/54/EC, in cases additional national regulations (stricter than directive)
  - Refurbishment TERN tunnels: till April 2019
- Austrian Guideline Codes for Planning, Construction and Maintenance of Roads (RVS)
  - Austrian Society for Research on Road, Rail and Transport www.fsv.at
- Guidelines from Austrian Society for Construction Technology ÖBV
  - www.bautechnik.pro
- Guidelines from Austrian Society for Geomechanics
  - www.oegg.at
- Design Manuals from operators
  - ASFINAG (Austrian Highway Operator) www.asfinag.at

RVS Guideline Codes for Tunnel Design

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

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)

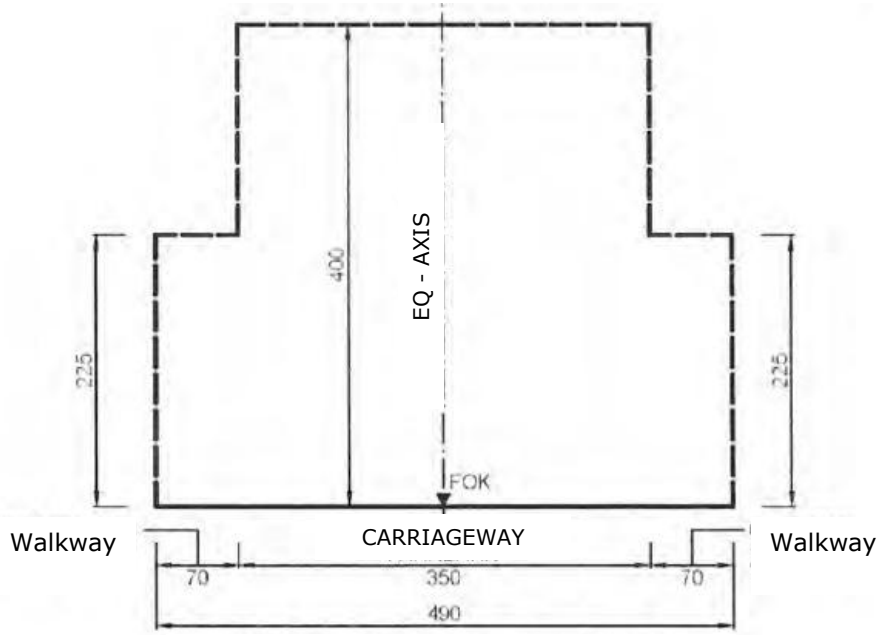


Figure 7: Clearance profile of EQ

Figure 10: Clearance gauge of GQ

RVS Guideline 09.01.24 for Structural Equipment

- Lay-by

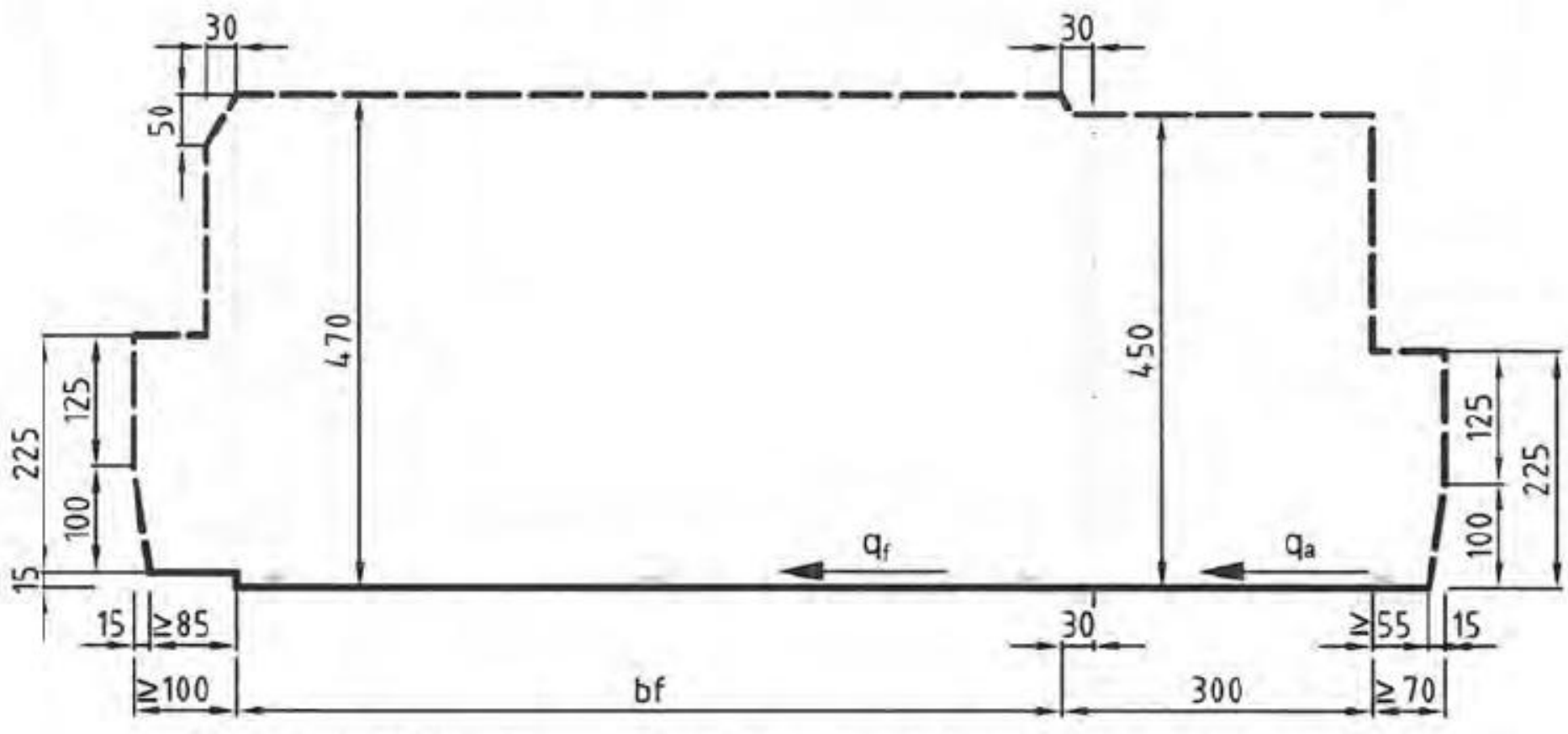
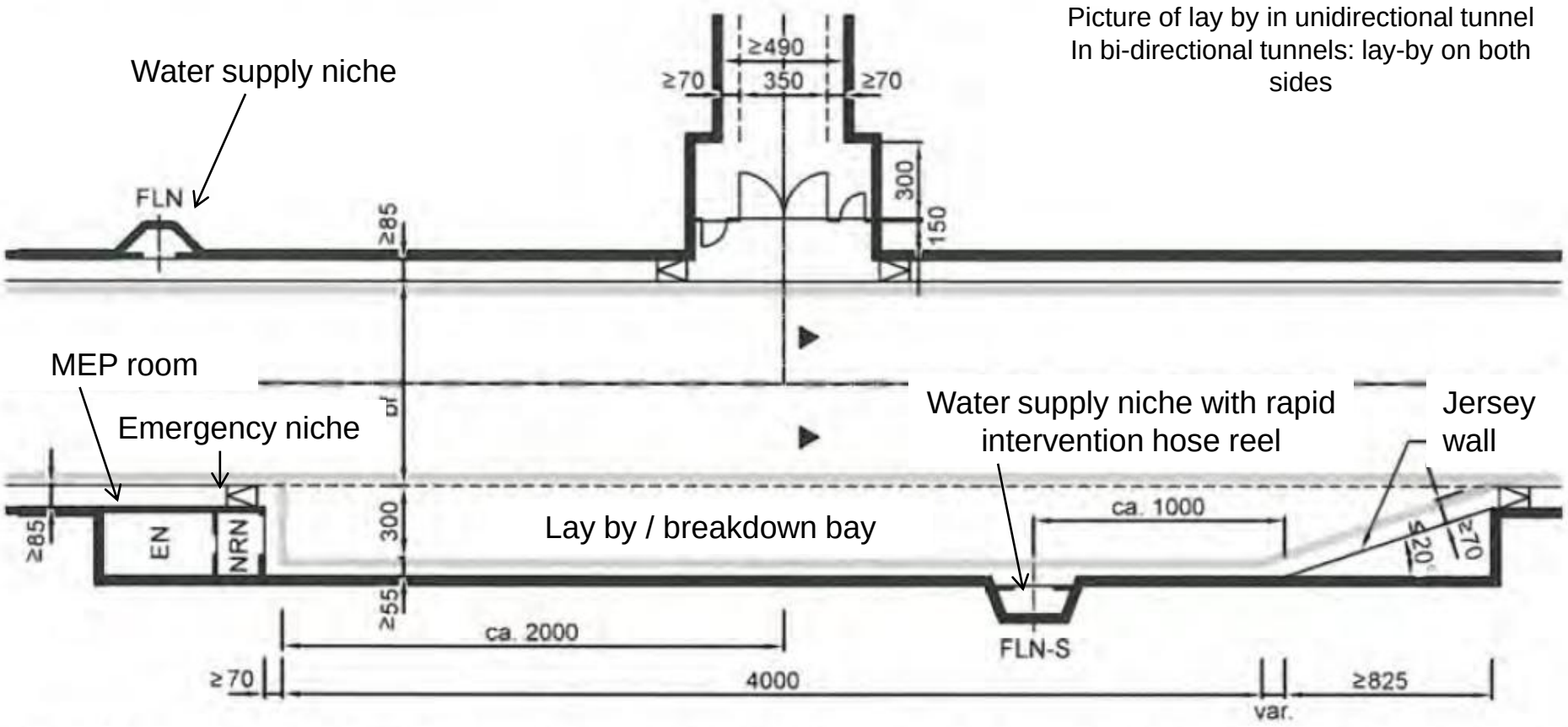


Figure 4: Clearance gauge in the range of a one sided breakdown bay

RVS Guideline 09.01.24 for Structural Equipment

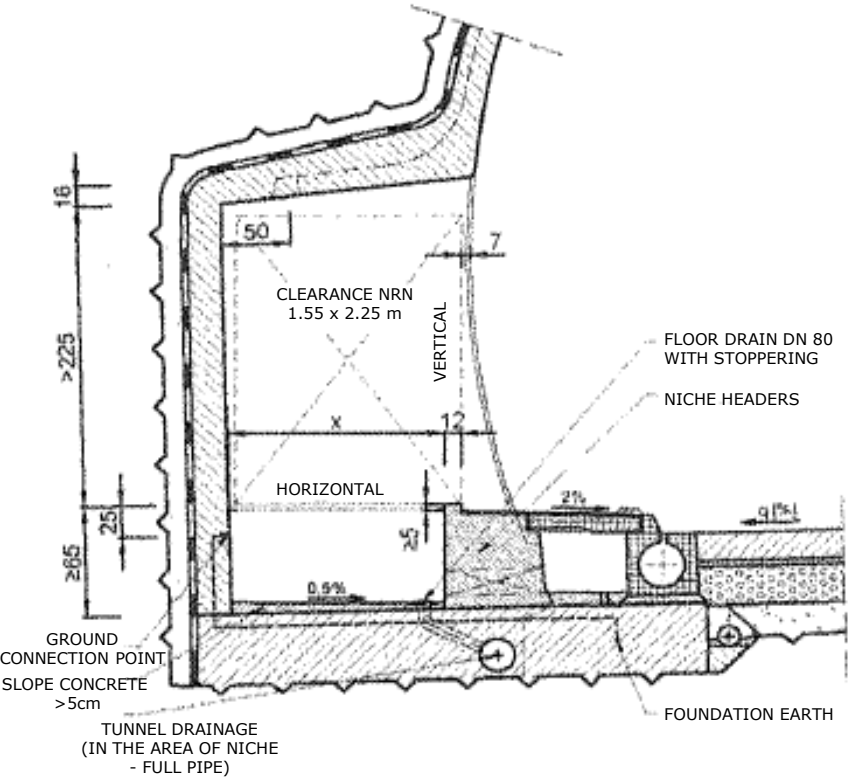
- Lay-bys
  - Every 1000 m for new tunnels if no emergency lane available



Picture of lay by in unidirectional tunnel
In bi-directional tunnels: lay-by on both sides

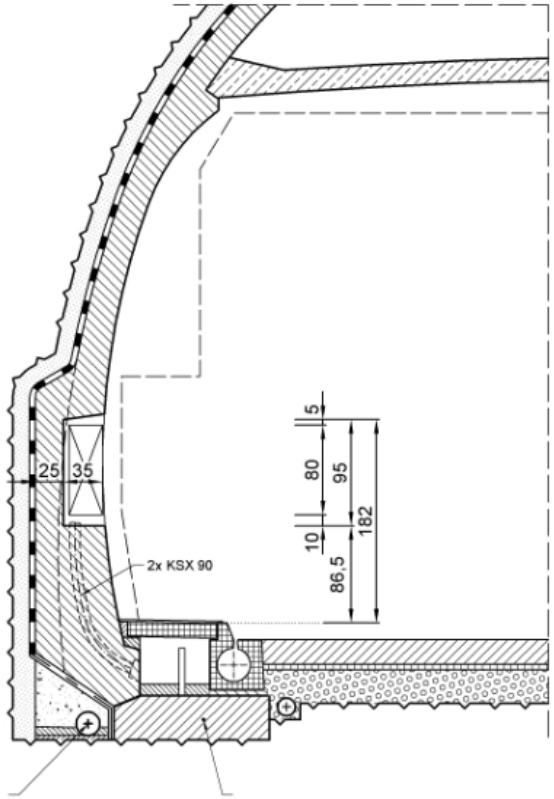
RVS Guideline 09.01.24 for Structural Equipment

- Emergency Stations
  - Usually situated in niches
  - regular distance 125 m (max. 150) in new tunnels



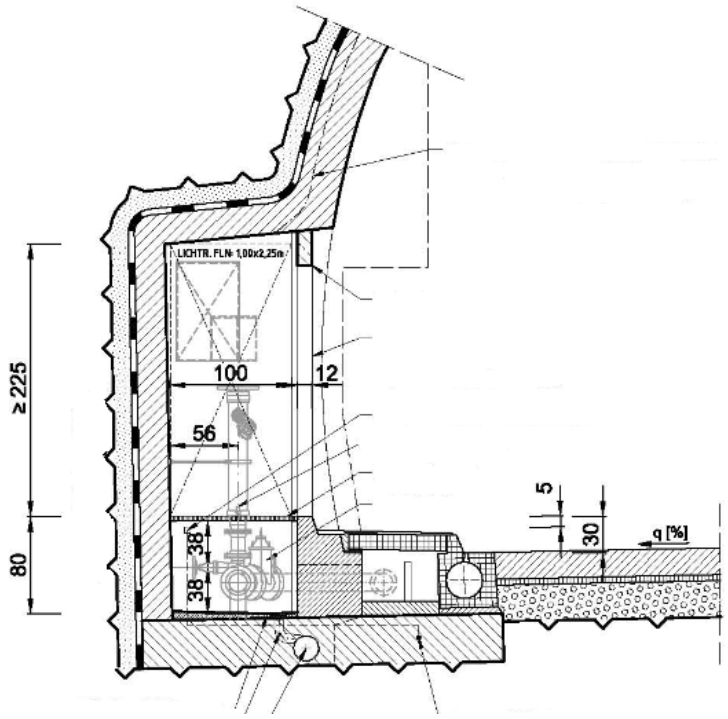
RVS Guideline 09.01.24 for Structural Equipment

- Emergency Stations
  - Emergency boxes allowed instead of every 2nd niche
  - Emergency station at tunnel portal



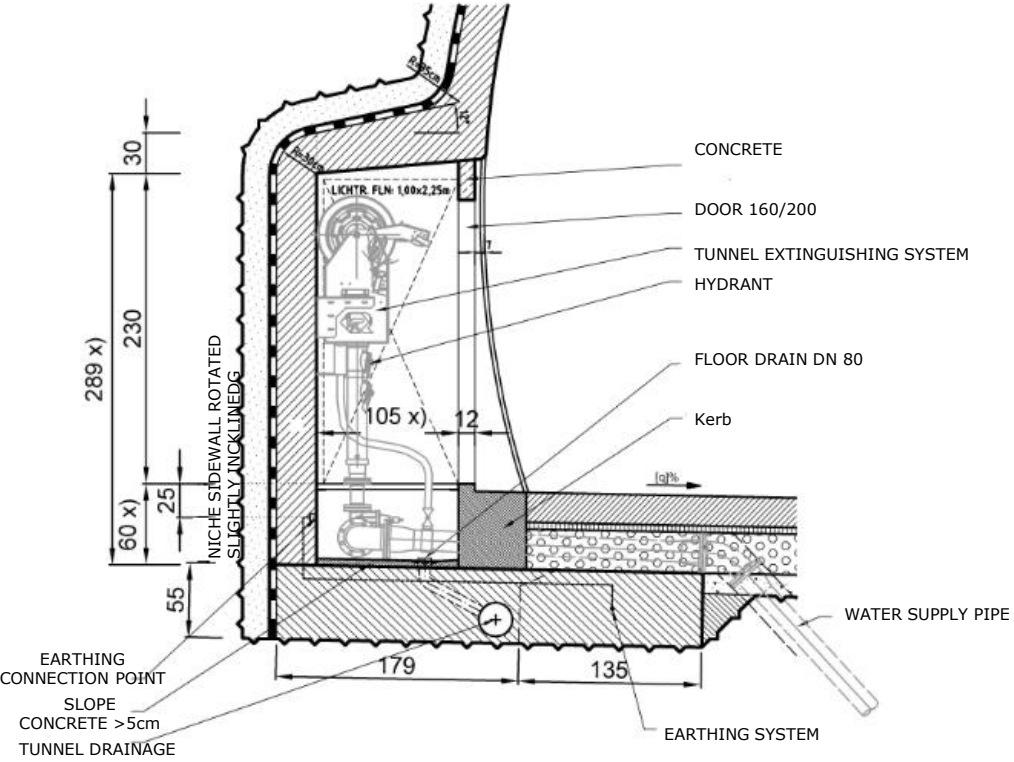
RVS Guideline 09.01.24 for Structural Equipment

- 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



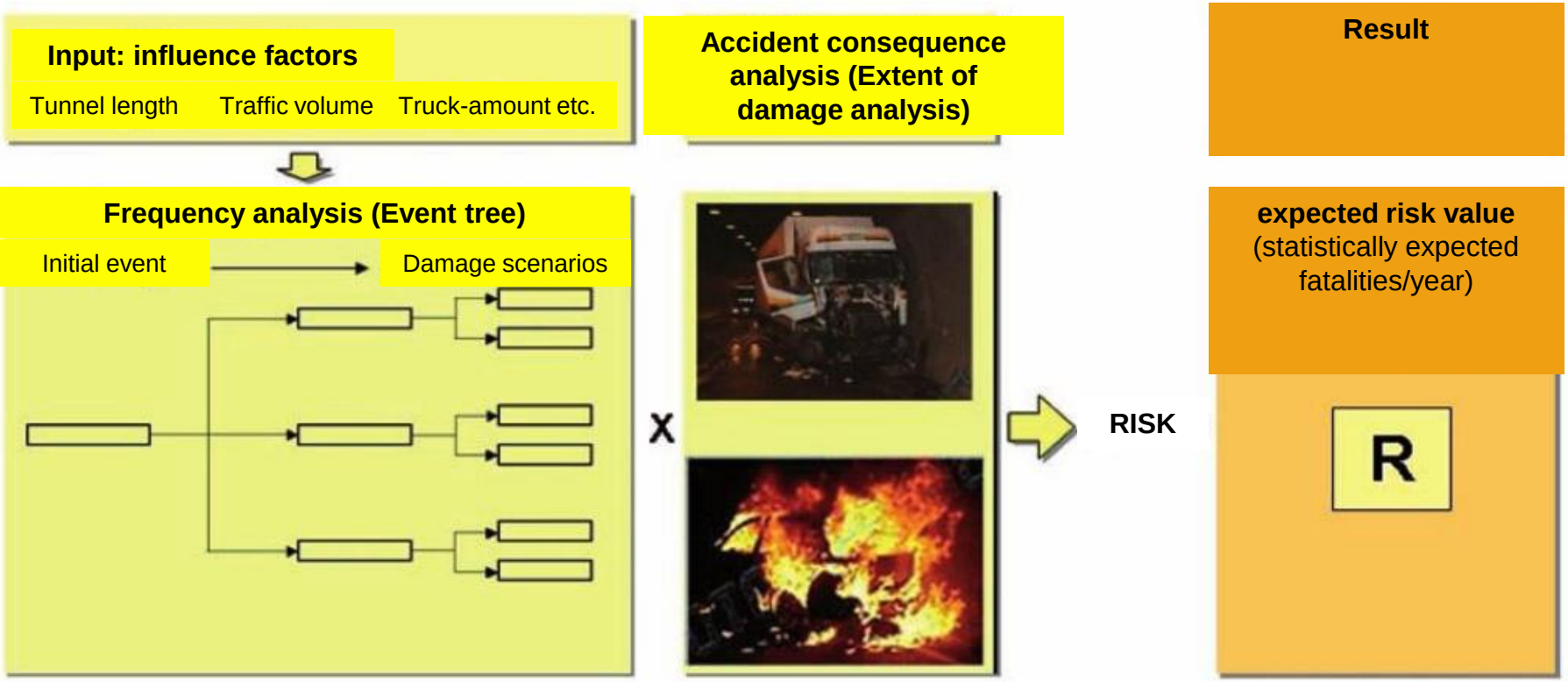
RVS Guideline 09.01.24 for Structural Equipment

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



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)

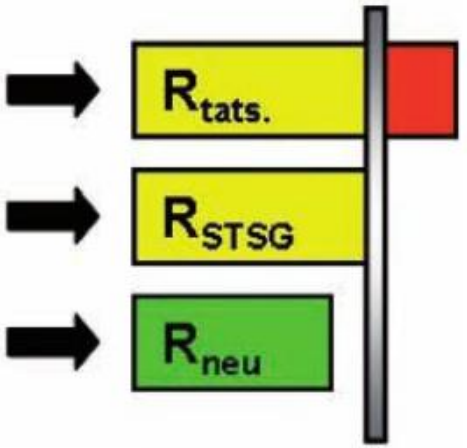


Basic structure of the tunnel risk analysis (©RVS)

RVS Guideline 09.03.11 Tunnel Risk Analysis

- Result: expected risk value
- Enables the comparison of safety measures
- Allows classifiaction 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

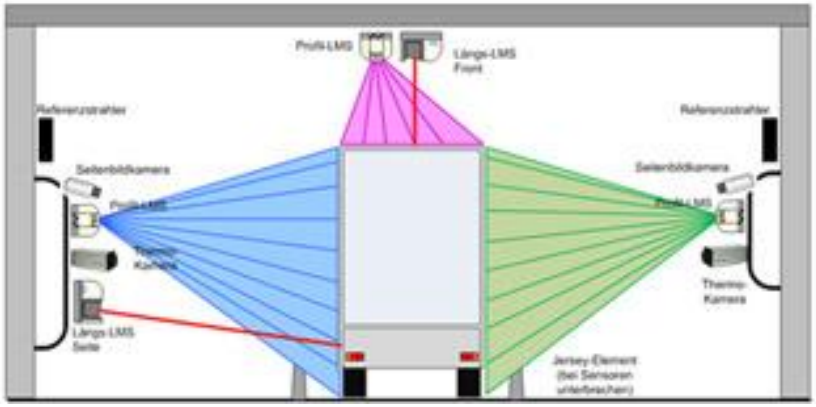
- Determination of safety facilities
  - Definition of surveillance and operation concept (central station for operation and surveillance 24/7, separate locations for operation and surveillance e.g. by police)
  - Selection of safety facilities according to min. requirements defined by hazard classes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

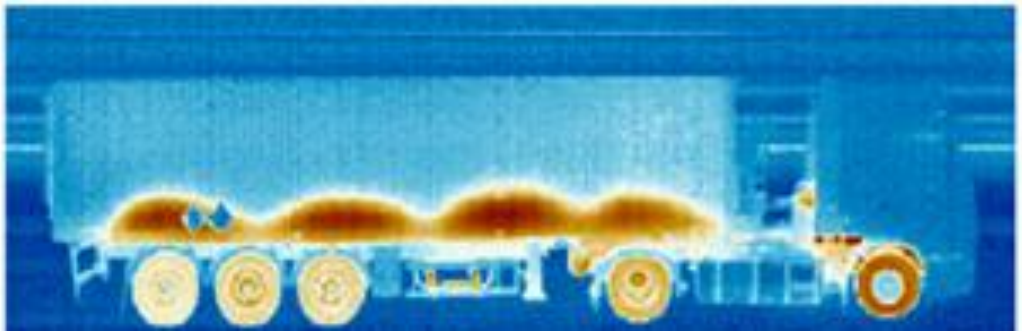
- Thermal Scanners ASFINAG
  - Thermal imaging cameras installed at separate lane ahead of tunnel portal
  - Detection of overheated heavy goods vehicles/busses (brakes, tyres, turbochargers)
  - Successful operation at Karawanken tunnel since 2012

Selected safety items – recent developments

- Thermal Scanners ASFINAG
  - 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 ASFINAG
  - Developed by ASFINAG and Joanneum research
  - Microphones installed in tunnel, max. distance 125 m
    test project Kirchdorfer tunnel
  - Software identifies unusual noises such as vehice 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

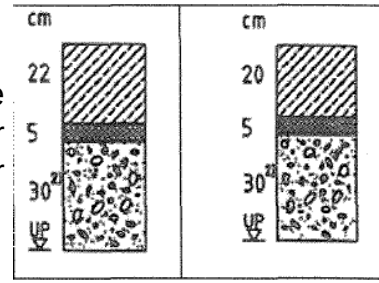
Test Run of Safety Measures – Fire smoke tests

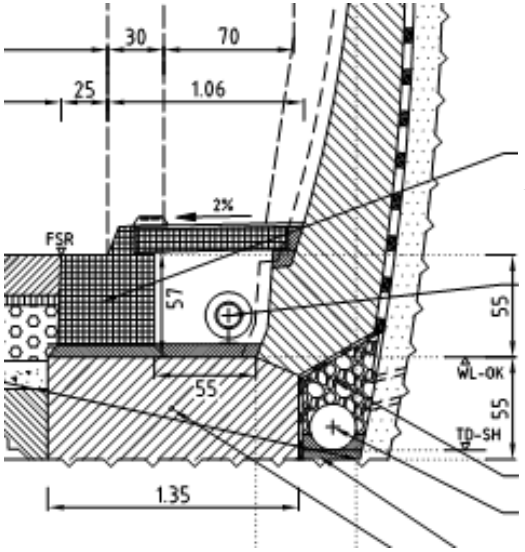
Test Run of Safety Measures – Fire smoke tests

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





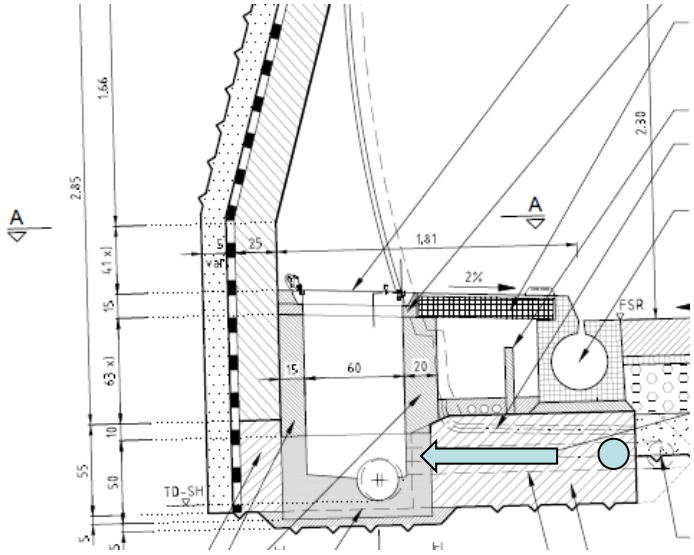
RVS Guideline 09.01.23 Interior Finishing

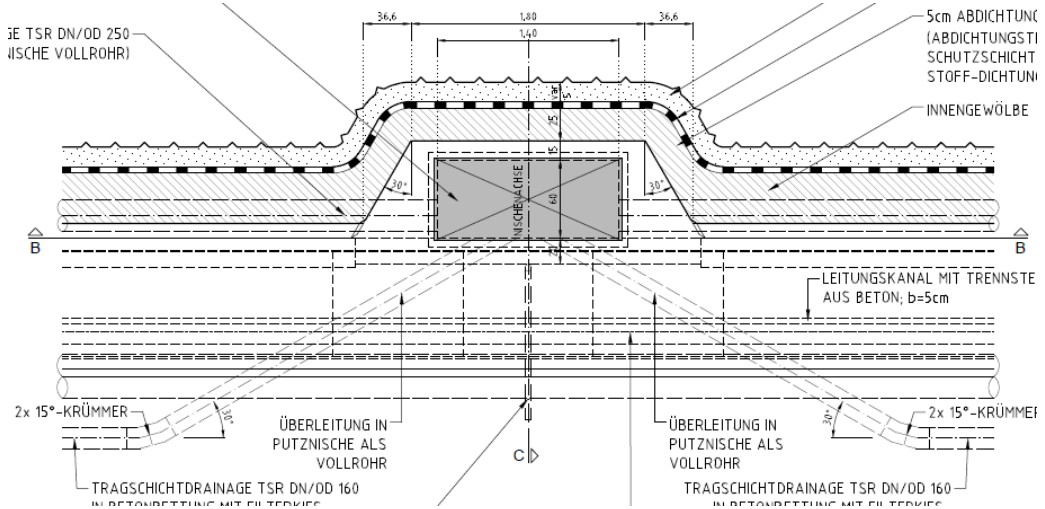
- Waterproofing
  - Standard solution: waterproofing membrane and longitudinal drainages at abutments of inner lining
    → no water pressure to be taken into account

- Drainage system
  - Carriageway drainage (polluted) → detention basin
    design capacity 100 l/s
  - Formation water drainage (clean) → river
    min. diameter DN/OD 250 or 160 (invert drainage)
    min. inclination 0.5% (0.3% at superelevation change)
    max. distance of manholes every 100 m

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

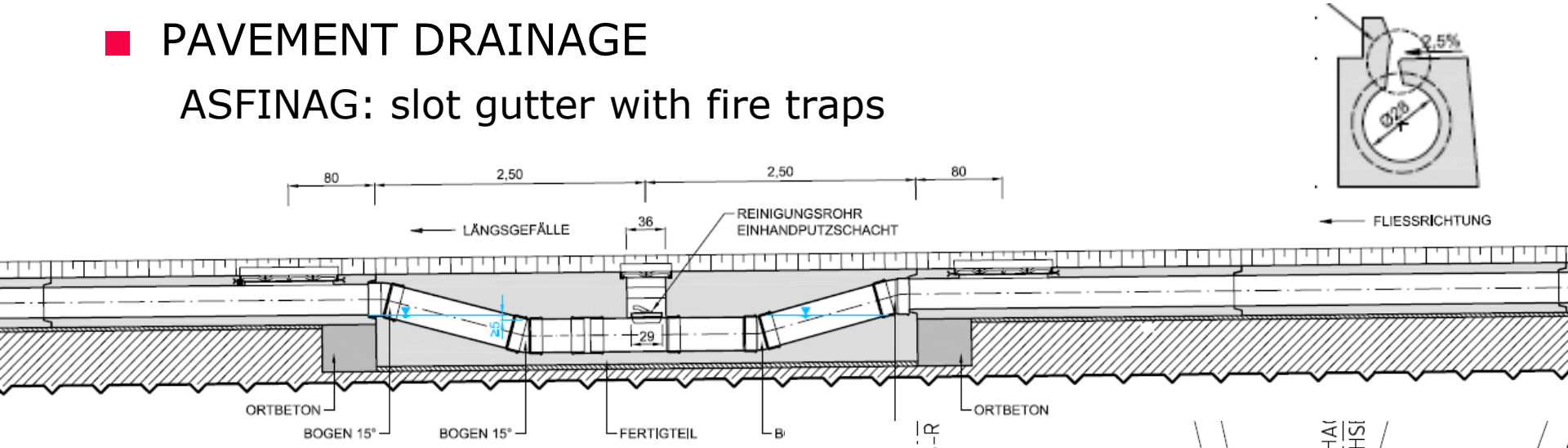




Drainage Design – specific requirements by operators

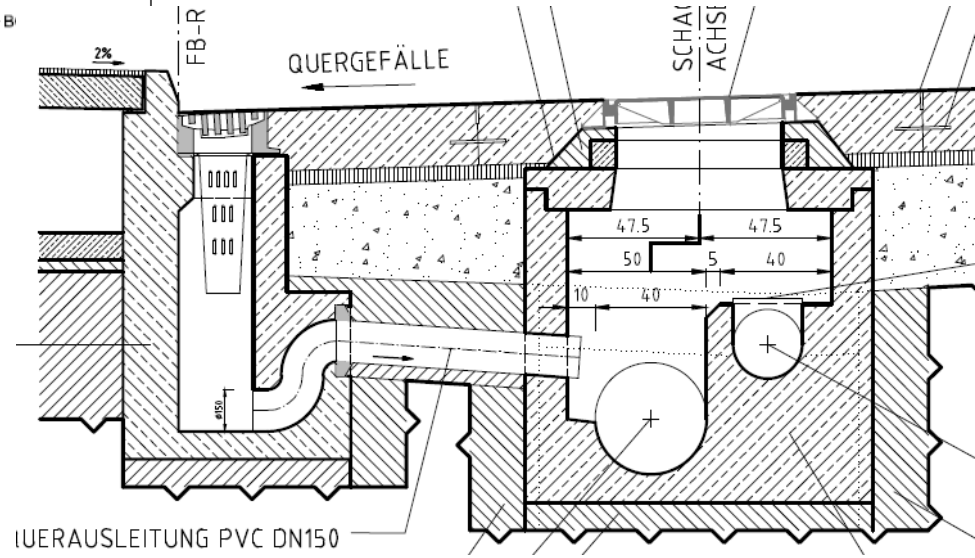
- PAVEMENT DRAINAGE

  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


THANK YOU FOR YOUR ATTENTION !