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Sammendrag
Rapporten er en gjennomgang av tunnelstandarden i Sveits og de anbefalinger som sveitsiske myndigheter gir når det gjelder bergsikring og tunnelkledninger. Dette som en sammenligning til de forslagene til ny byggestrategi for norske vegtunneler som Etatsprogrammet har kommet fram til.

Summary

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1. Introduction

1.1 General

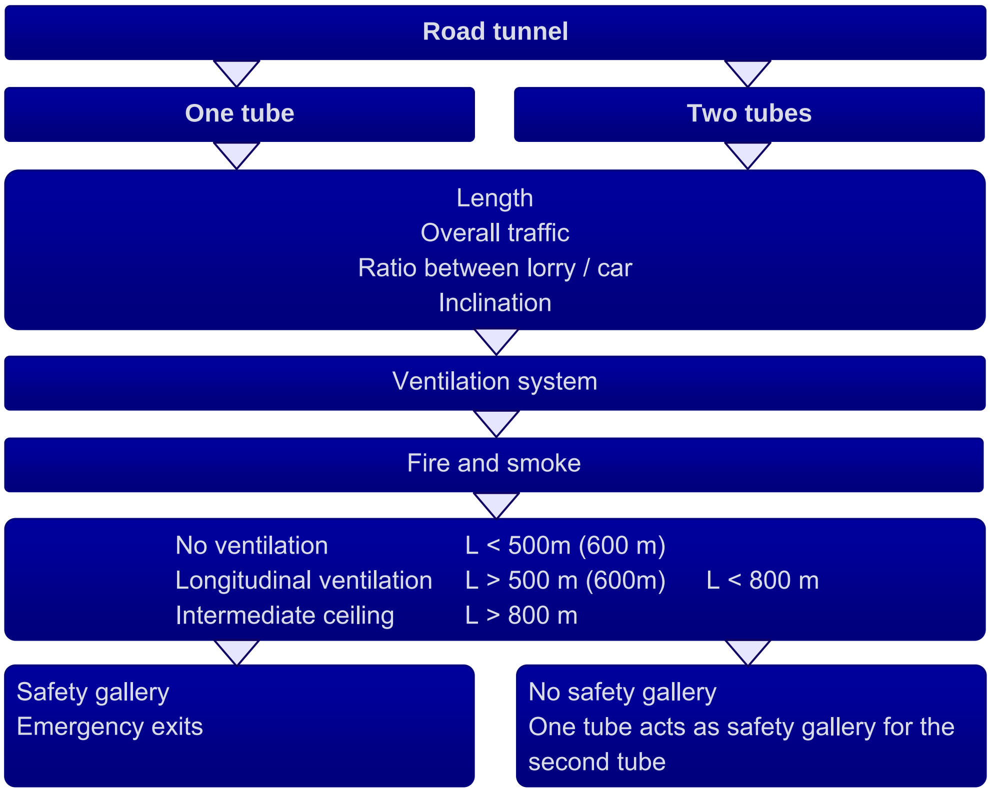
Recent incidents in existing road tunnels in Norway like damages due to frost effects or damages to the inner lining as a consequence of falling rocks have led to a reconsideration of the existing design standards. As a basis of comparison, the recommendations of the Swiss tunnel standards will be analysed. In connection with these events the following tasks will be treated:

Geology	Assessment of geological conditions Visualisation of the results
Overbreak regulations	Rules for drill and blast and for mechanised advance
Lining	Sealing with membranes or sprayed sealing Examples of solutions for final lining
Frost and Salt protection	Demands on concrete and sealing concept
Fire protection	Protection of tunnel structures Selection of design loads Measures for safe evacuation of fugitives
Ventilation	Evaluation of ventilation systems List of required data to determine the risk level
Life time	Determination of the different requirements for tunnel elements
Costs	Statement of typical costs for sealing and final shell tunnel solution

1.2 Swiss – Tunnel approach

In Switzerland tunnel design and construction base upon the Swiss Engineer and Architect (SIA) standards and upon Guidelines of the Swiss Office for road construction (ASTRA). The tragic car accidents in road tunnels with many casualties in recent years have led in Switzerland to much higher safety requirements especially concerning self rescue measures.

The decision for the adequate tunnel system, fulfilling all safety requirements, bases on the following flow chart:



1.3 Related documents

E-Mails	24. February 2010	Road Tunnel Strategy Study
	24. February 2010	Road Tunnel Strategy Study
	12. February 2010	Road Tunnel Strategy Study
	03. February 2010	Road Tunnel Strategy Study – Workshop
	04. February 2010	Road Tunnel Strategy Study – Workshop
	04. February 2010	Road Tunnel Strategy Study – Workshop
	04. February 2010	Road Tunnel Strategy Study – Workshop
	26. January 2010	E-Mail addresses
	28. January 2010	Extended agenda for the meeting
	26. January 2010	Road Tunnel Strategy Study - Agenda for Work Shop
	26. January 2010	Road Tunnel Strategy Study - Agenda for Work Shop
	18. January 2010	Road Tunnel Strategy Study – Meeting 14.01.2010
	12. January 2010	Road Tunnel Strategy Study – Proposal, CVs
	08. January 2010	Road Tunnel Strategy Study
	06. January 2010	Road Tunnel Strategy Study
	23. December 2009	Road Tunnel Strategy Study
Meetings	29. January 2010	Work Shop

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2. Geology

2.1 General

The description and the design of the geological, hydro geological and geotechnical conditions, builds the base for the assessment of the range of homogeneous areas and their classification and the modelling of possible hazard scenarios.

The aim of the bedrock description is the elaboration of a geological model which allows the development of subsoil models for the calculation and design of the tunnel construction.

Fundamentals:

- A clear differentiation between the description and the assessment of the bedrock has to be made.
- The characteristics of the bedrock and loose soil have to be summarised in a detailed diagram along a longitudinal section.
- Previous to the design phase, geological, hydro geological and geotechnical investigations must be carried out and have to be considered in the evaluation of the utilisation of the structure.

On the following page an example of a geological longitudinal section of a actual tunnel project is shown.

Geological longitudinal section for rock tunnel

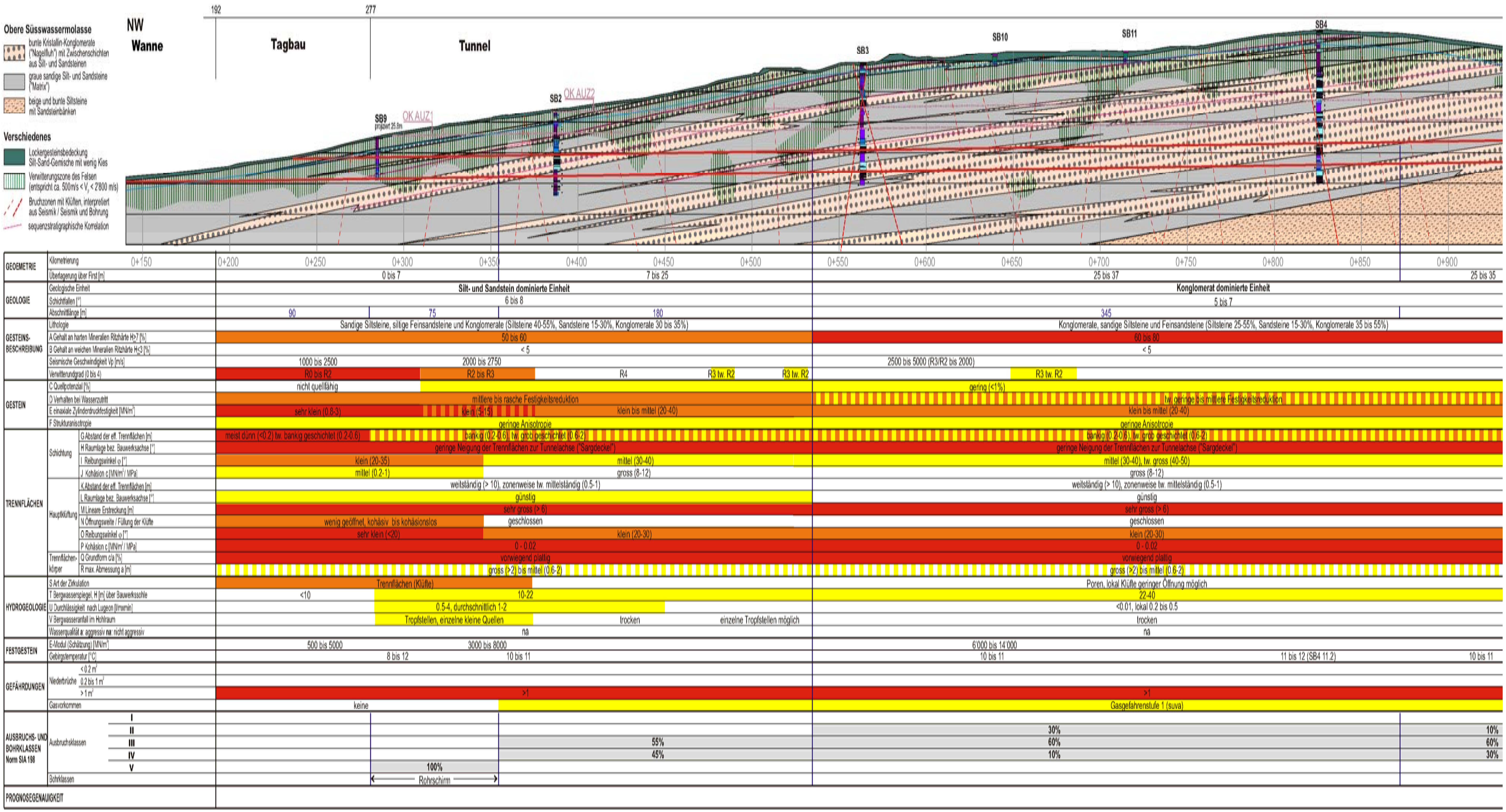


Fig. 2.1
Longitudinal geological section

2.2 Safety plan

The different safety measures implemented during design and realisation are part of a superior safety management. This plays a major role especially in urban areas, where the overburden is often very low and where buildings, roads, life lines and other infrastructures have to be crossed.

To avoid large settlements or even cave-ins all possible hazards have to be evaluated and assessed concerning possible damage and occurrence probability. The related risk, the product of these two values, then gas to be checked if it is acceptable or if special measures have to taken to avoid the risk or at least reduce it to a level where it can be accepted (residual risk). To visualize the hazards and the precautionary construction measures, a safety plan has to be developed (see fig. 2.2).

A safety committee consisting of the client, the design engineer and an external safety expert assist and supervise the implementation of the safety plan. The safety committee mainly concentrate on the following tasks:

_ Higher-ranking safety aspects
_ Type and extent of examination of identified hazards
_ Selection of the external inspection engineer
_ Modification of specified safety measures
_ Find a solution for disagreements between the inspection engineer and the design engineer

During the design phase, the inspection engineer assesses the following tasks:

_ The completeness and relevance of the hazards specified in the safety plan and the implementation of the correspondent measures.
_ The implementation of the measures decided for the realization.

Safety plan

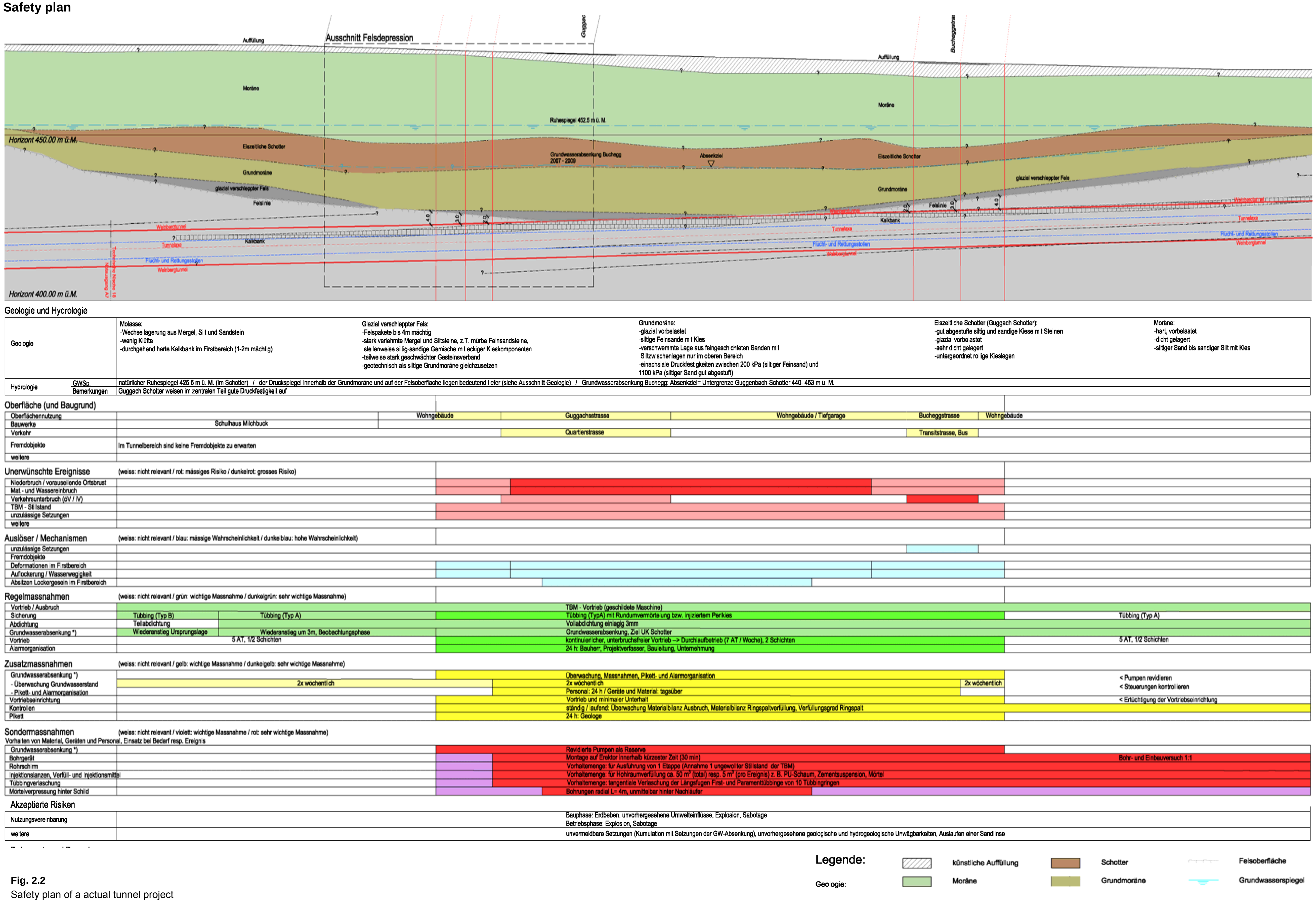


Fig. 2.2
Safety plan of a actual tunnel project

2.3 Swiss Tunnel Standards

_ SIA 199
Chapter 1.2 Lockergestein
Chapter 1.3 Fels
Chapter 1.4 Hydrogeologie

_ Chapter 2: Beschreibung des Gebirges
Chapter 2.2 Geologische Verhältnisse
Chapter 2.3 Hydrogeologische Verhältnisse
Chapter 2.4 Geotechnische Verhältnisse
Chapter 2.5 Gasvorkommen

_ Chapter 3: Beurteilung des Gebirges
Chapter 3.2 Verhalten des Gebirges
Chapter 3.3 Gefährdungsbilder
Chapter 3.4 Planung von Massnahmen
Chapter 3.5 Beurteilung des Ausbruchmaterials

_ Chapter 4: Geologische, hydrogeologische und geotechnische Berichte
Chapter 4.2 Herkunft, Genauigkeit und Vollständigkeit der Daten
Chapter 4.3 Vorschläge für ergänzende Untersuchungen
Chapter 4.4 Aufbau der Berichte
Chapter 4.5 Schlussbericht

3. Overbreak regulations for Drill and Blast and TBM advance

3.1 General

In drill and blast tunnel advance, the shape of the excavation does not match the theoretical cross section but rather larger e.g. due to rock fall. In TBM advance, especially with gripper TBMs, this phenomenon can also occur. Therefore a special regulation has to be fond to take the overbreak into consideration.

Unless otherwise stipulated in the contract for services, the excavation is paid for according to the theoretical quantities involved.

The heading face is the exposed surface area of the tunnel face following excavation. This applies to full-face or partial excavation.

3.2 Overbreak

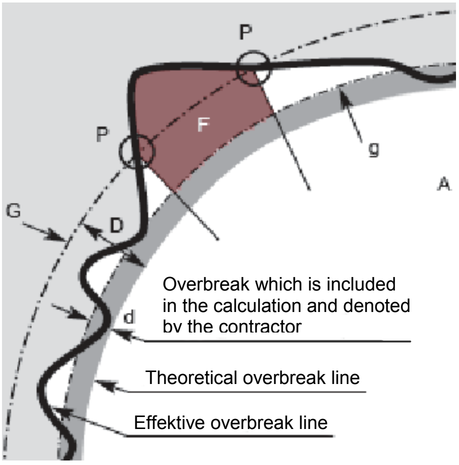
Overbreak due to the chosen construction method

The overbreak d shown in Figure 3.1 results from working methods is included in the unit prices for excavation and mucking. This calculated overbreak has to be declared in the contractors bid.

Overbreak due to the geological conditions

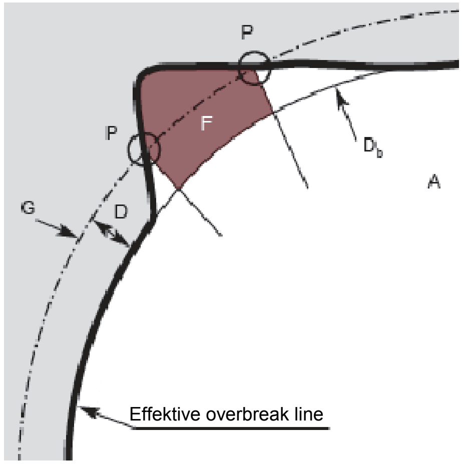
An overbreak resulting from geological conditions is a local collapse not caused by carelessness on the part of the contractor (e.g. through overcharging, as well as the overbreak in the invert which has to be excavated for geological-geotechnical reasons).

In the case of geological overbreak to Figure 3.2, loading and transport of muck to the temporary dumpsite as well as the measures necessary for grouting of the cavity and for support are paid for the entire profile area F.



- Limitation of the geological overbreak in drill & blast tunnel-driving and mechanically-assisted tunnel-driving in rock and in soft ground
- A: Theoretical excavated surface area
- D: Distance between the theoretical excavation line and the boundary line G
- d: Distance between the theoretical excavation line and the boundary line g
- g: Up to this line, the overbreak is calculated into the excavation price
- G: Boundary line, dependent on D
- F: Surface area for which the geological overbreak will be paid for

Fig. 3.1
Overbreak regulation for drill and blast



- Limitation of the geological overbreak in TBM tunnel-driving with or without shield
- A: Theoretical excavated surface area
- D: Distance between the theoretical excavation line and the boundary line G
- Db: Bore diameter with worn tool
- G: Boundary line, dependent on D
- F: Surface area for which the geological overbreak will be paid for
- P: Point of intersection between the boundary line G and the effective excavation line
- P: Point of intersection between the boundary line G and the effective excavation line

Fig. 3.2
Overbreak regulation for TBM advance

Regulation

Unless otherwise stipulated in the contract for services, the value D for vault and invert is determined according the following formulas, where A equals the theoretical excavated surface area:

- Drill & blast tunnel-driving:
  $D = 0.07 \cdot \sqrt{A}$, but $D_{min} = 0.40$ m
- Mechanically-assisted tunnel-driving in rock or in soft ground
  $D = 0.05 \cdot \sqrt{A}$, but $D_{min} = 0.40$ m
- Tunnel-driving with systematic stabilisation measures *auxiliary constructional measures*, shield or blade shield:
  $D = 0.03 \cdot \sqrt{A}$, but $D_{min} = 0.25$ m

_ Tunnel-driving with TBM or shield tunnelling machine:
  $D = 0.03 \cdot \sqrt{A}$, but $D_{min} = 0.20$ m

The surface area of the partial excavation in m^2 counts as the theoretical excavated surface area A.

3.3 Swiss Tunnel Standards

_ SIA 118/198 Chapter 8.5 Ausmassbestimmung

4. Lining methods

4.1 General

In the sixties for the final lining the method with the prefabricated concrete lining elements were also used in Switzerland. Today the final lining of new tunnels is made exclusively of in situ cast concrete.

During the refurbishing of existing tunnels with a final lining of prefabricated concrete elements, these elements will be reassembled in the upper area of the tunnel. In the lower part of the tunnel, with a high of approximately two meters a concrete wall is constructed, which serves as a protection against de-icing salt as well as a protection against damages caused by car crashes.

In Switzerland all road tunnels are sealed (approx. 90% partially sealed, 10% fully sealed).

4.2 Primary support

_ Mechanized excavation:	Prefabricated concrete segments (tubbbings) Quality requirements: The stowage of the lateral and longitudinal joints between the prefabricated segments shall be less than 2 cm, otherwise it must be evened.
_ Drill and blast	Support with anchors, wire mesh, steel rips and shotcrete Quality requirements: If the surface is too rough it has to evened with shotcrete (gunit).

4.3 Sealing

Partial sealing	_ Without water pressure	Thickness of the membrane: d = 2mm Material: PVC / PE / FPO Fleece: 500 g/mm^2 , underlay as a protection for the membrane due to uneven surface of the primary lining
Full sealing	_ With water pressure	Single layer: - Thickness of the membrane: d = 3mm - Material: PVC / PE / FPO - Fleece: 500 g/mm^2 , underlay as a protection for the membrane due to uneven surface of the primary lining Double layer sealing: - The sealing is subdivided into enclosed sector which can be injected individually - Thickness of the membrane: d_1 = 3 mm d_2 = 3mm - Material: PVC / PE / FPO

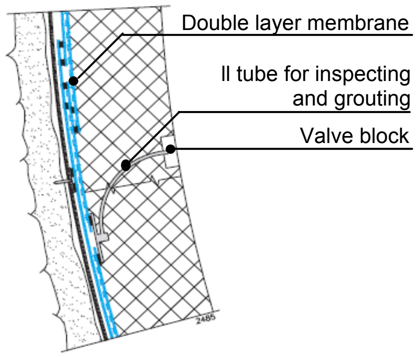


Fig. 4.1

Detail of a double layer membrane

Sprayed sealing

In cases, where the geometry of the tunnel surface is very complicated and where the patchwork sealing might become leaky, a solution with a sprayed sealing may have important advantages.

This is the case with the SBB railway tunnel "Adler", Basler & Hofmann is refurbishing during the year 2010. To reduce the uplift of the tunnel due to swelling rock, several niches have to be excavated on both sides of the tunnel to place anchors and micro piles. These niches have to be sealed against the tunnel lining. For this solution the sprayed sealing system has been chosen (Masterseal® 345).

Consumption of Masterseal® 345 per m^2 with a lamination strength of 3 mm:

_ 4 mm surface roughness ca. 3.5 kg / m^2
_ 8 mm surface roughness ca. 4.5 kg / m^2
_ 16 mm surface roughness ca. 6.5 kg / m^2

The following picture shows the solution at the Lausanne Métro tunnel M2, where a sprayed sealing has been chosen because of a gain in time and of cost-effectiveness.

Fig. 4.2
Application of sprayed sealing

This type of sealing has been executed only in the last few years. For the restoration of the Adler railway tunnel which is still going on, as an example, a sprayed sealing has been chosen to guarantee the water tightness around the technical niches.

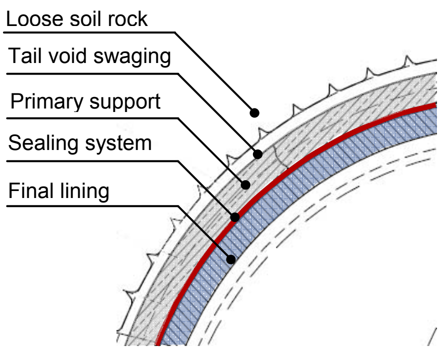
4.4 Final lining

In most of the cases, in Swiss road tunnels the following system is applied:

_ Lining thickness: d ≥ 30cm
_ Cast in place concrete
_ No reinforcement

In the case of fully sealed tunnels, the final lining is designed to withstand the existing water pressure.

Mechanized excavation



Drill and Blast

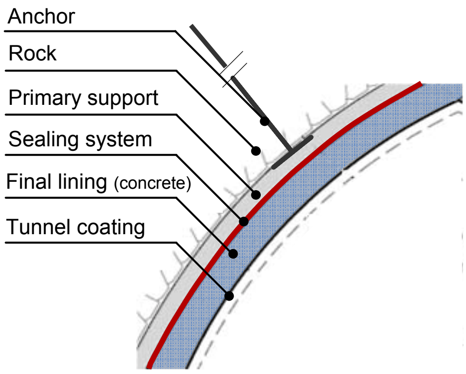


Fig. 4.3
Support, sealing and final lining

Construction methods for final lining

_ Two formwork cars	Step-back procedure
_ Length of concrete sections	10 m – 12 m
_ Duration of the curing process	One Day → Performance = 50 m/week
_ Striking	At a compression strength of ≥ 10 N/mm^2
	Test with concrete hammer
	Careful removing the formwork
	Coating to avoid adherence of the concrete

Curing of concrete

The requested quality of the concrete lining after the striking shall be ensured with adequate measures to avoid dehydration and a development of unwanted fractures. These measures and the composition of the concrete have to be optimised to each other.

4.5 Examples

Drained tunnels

_ Partial sealing

Most of the Swiss road tunnels have been realized according to the ''umbrella'' principle.

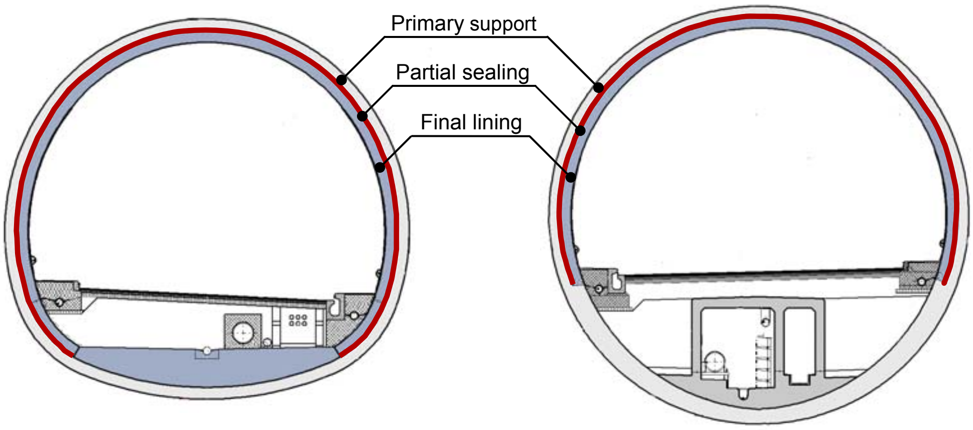


Fig. 4.4
Partially sealed tunnels

Watertight tunnels

_ Full sealing, tunnels in groundwater
_ Segment arrangement

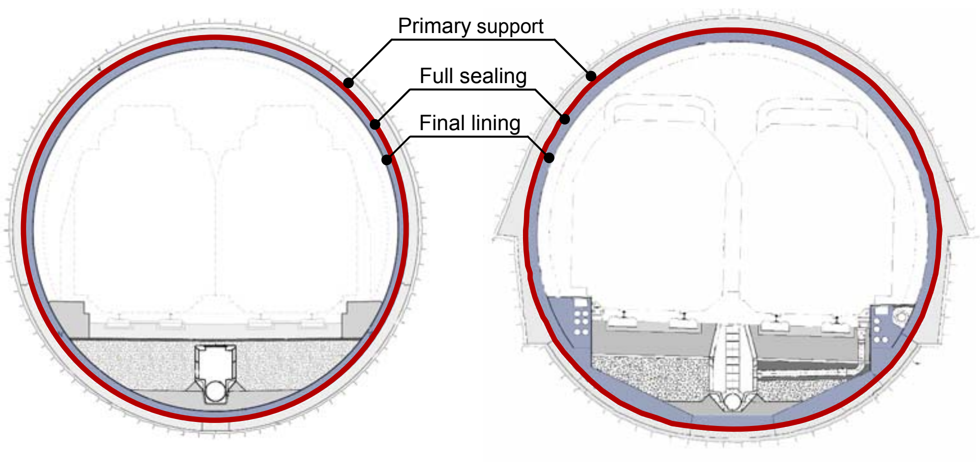


Fig. 4.5
Fully sealed tunnels

Arrangement of the prefabricated concrete elements for drained and watertight tunnels:

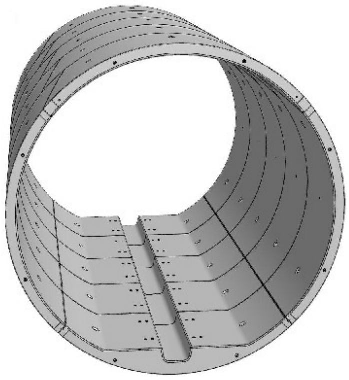


Fig 4.6
Drained tunnel: Cross joints for subsoil without groundwater

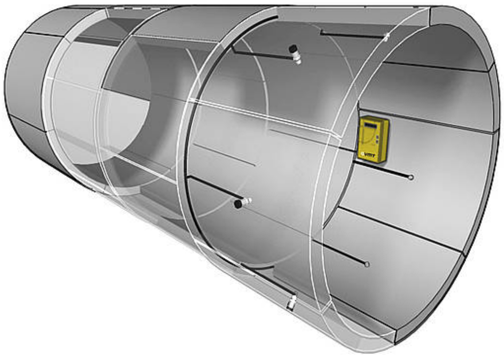


Fig 4.7
Watertight tunnel: T- shaped joints with gaskets for subsoil with groundwater (water tight)

4.6 Swiss Tunnel Standards

_ SIA 197	Chapter 8.6 Abdichtung
_ SIA 197/2	Chapter 8.4 Ausbau
_ SIA 198	Chapter 2.1 Anker Chapter 2.2 Betonstahl, Netze, Faserbewehrung Chapter 2.3 Spritzbeton Chapter 2.4 Stahleinbau und Verzug Chapter 2.5 Tübbinge Chapter 2.8 Entwässerung Chapter 2.9 Beton Chapter 2.10 Polymerbeton Chapter 3.4 Ausbruchsicherung Chapter 3.6 Vorabdichtung Chapter 3.10 Verkleidung

5. Frost and Salt protection

5.1 General

The measures against damages on tunnel lining as a consequence of frost and de-icing salt are standardized in the SIA standards. No special solutions are required for areas with low temperatures (e.g. mountains regions). The same applies to the construction of the tunnel entrance. Frost depth for water pipes in Switzerland (midland) is > 80 cm, for the higher regions the value increases.

The following procedures and measures for frost and salt protection measures are based on the SIA-Standards.

5.2 Frost protection

One method to protect the concrete lining against frost and de-icing salt is to use chemical additives to generate air voids. Water inside the concrete can expand into the voids and spalling can be avoided.

5.3 Salt protection

In certain cases also the final lining has to be reinforced. This is normally the case in the area of niches, crossways, etc. To obtain a optimal combined protection of the reinforcement against frost and de-icing salt, the final concrete lining has to fulfil special conditions:

_ Concrete with a high impermeability to prevent salt and water from penetrating into the concrete.
_ This can be achieved by the following measures:
    − Low water cement coefficient
    − Addition of micro cement, micro silicate or fly-ash
    − Chemical admixtures

Alternative solutions

_ No reinforcement to avoid damages caused by rust
_ Painting to seal the surface for protection and easy cleaning
_ Protection of the sidewalls with ceramic tiles
_ Protection of the sidewalls with ceramic tiles
    − Sealed surface
    − Easy cleaning
    − Longevity, durability
    − Expensive

5.4 Ice pressure

In Switzerland no problems with ice pressure concerning final lining and inner shell construction are known. Some of the tunnels are located in the mountain area with low temperatures in wintertime. The portal of the Gotthard road tunnel is situated on 1150 m above sea level and the portal of the Vereina railway tunnel on 1200 m above sea level. Nevertheless the solution with prefabricated inner shell concrete elements is no longer used in Switzerland.

An explanation for the fact, that no damage due to frost is known in Switzerland can be shown by the following consideration:

Ice pressure in a double shell tunnel construction

_ Sealing between support structure and final lining
  - Thickness of the fleece = ca. 3 mm → Thickness ice = ca. 3mm
  - Expansion: 10% of 3 mm → 0.3 mm

Based on this small expansion, no significant pressure will be applied on the final lining and no damage due to frost has to be expected.

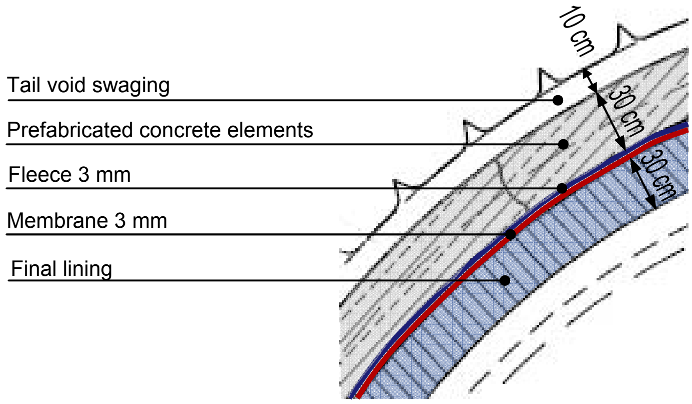


Fig 5.1
Cross section trough double shell construction

Tunnel with prefabricated concrete lining elements

As mentioned in chapter 4 in some cases of older tunnels the prefabricated concrete lining elements have been reassembled in the upper area of the tunnel. In the lower part of the tunnel, an impermeable concrete wall was constructed, which serves as a support for the prefabricated concrete lining elements and as protection against de-icing salt as well as against damages caused by car crashes.

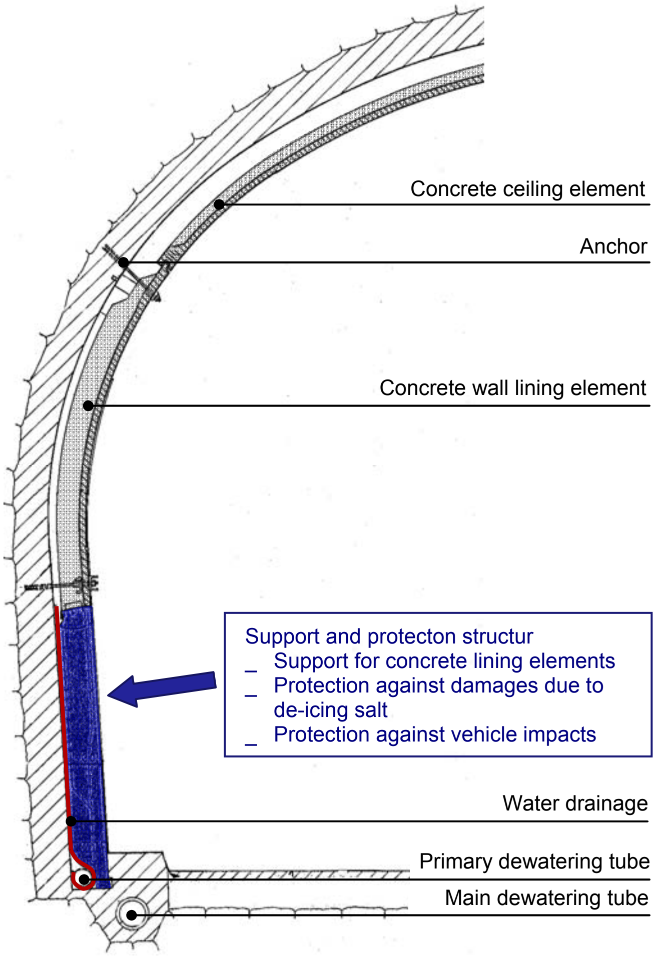


Fig 5.2
Restoration of a road tunnel with prefabricated concrete wall lining elements

5.5 Temperature comparison

To compare Swiss and Norwegian annual temperature, the following diagrams show two examples for comparable climate conditions. For tunnels in these areas the requirements concerning frost and de-icing protection are quite similar. As an example the towns of Zurich and St. Moritz (Switzerland) have been compared with Bergen and Oslo (Norway).

Zurich [408 m altitude] in comparison with Bergen [0 m altitude]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Zurich [°C]	**-3**	**-2**	**1**	4	8	12	14	13	11	**6**	**2**	**-2**
Bergen [°C]	**-0.5**	**-0.5**	**0.4**	3	6.6	10.1	11.5	11.4	9	**6.5**	**2.7**	**0.8**

Zurich (408 m above sea level) **Bergen (at sea level)**

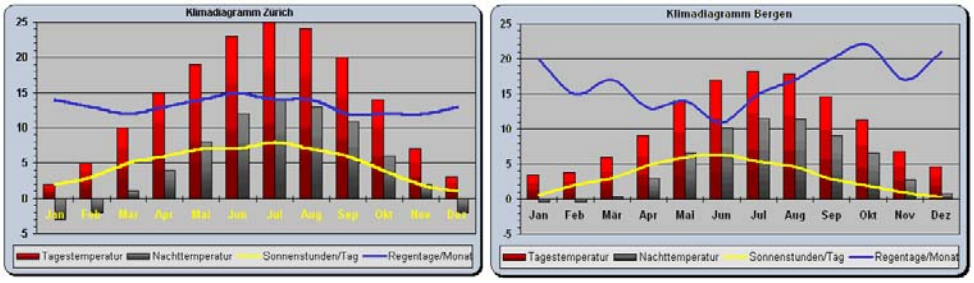


Fig. 5.3
Temperature charts Zurich / Bergen

St.Moritz [1800 m altitude] in comparison with Oslo [1 m altitude]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
St. Moritz [°C]	**-11**	**-10**	**-6.3**	-2	2	5.2	7	6.9	4.4	**-0.1**	**-4.6**	**-9**
Oslo [°C]	**-7.4**	**-7.2**	**-4.3**	0.7	5.7	10	12.8	11.8	7.7	**2.9**	**-1**	**-4.4**

St. Moritz (1800 m above sea level) **Oslo (1 m above sea level)**

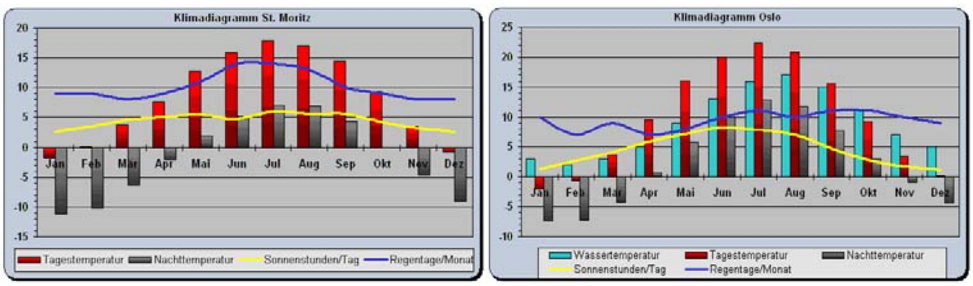


Fig. 5.4
Temperature charts St. Moritz / Oslo

5.6 Swiss Tunnel Standards

Frost	_ SIA 198	Chapter 2.9 Beton
	_ SIA 162	Chapter 4.1 Expositionsklassen, bezogen auf die Umweltbedingungen Chapter 4.2 Frischbeton Chapter 5.2 Grundanforderungen an die Zusammensetzung des Betons Chapter 5.4 Anforderungen an Frischbeton Chapter 7.2 Informationen vom Betonhersteller für den Verwender
Salt	_ SIA 197	Chapter 7.4 Aussergewöhnliche Einwirkungen und Korrosion
	_ SIA 197/2	Chapter 8.4 Ausbau
	_ SIA 198	Chapter 2.9 Beton

6. Fire protection of Road Tunnels

6.1 General

Fatal fire incidents in the Montblanc-, Tauern- and Gotthard-Tunnel resulted in much higher safety measures in road- as well in railway tunnels.

The main tasks to increase safety in case of fire was to enable a rapid self rescue by means of construction, special facilities as well as of precise information about rescue possibilities:

_ Self rescue facilities (second tube, emergency galleries, etc.)
_ Save access for rescue teams to the place of the accident. The maximal temperature to allow specially equipped firemen to fight a fire amounts 400 to 450 °C and a thermal radiation of 5 kW/m^2.
_ Special equipment to limit the extension of the fire (hydrants, water hoses, sprinkler, etc.).
_ The tunnel construction (intermediate ceiling, etc.) has to withstand a minimal fire load to enable the fugitives to reach the rescue areas.

6.2 Structure

Assessment graph

The assessment graphs for the design of the tunnel and its safety related constructions are for short-term fire loads (10 minutes) nearly identical. In the first minutes the temperature rise rapidly, partly independent of the type of vehicle and the fire energy. This rise is essential for the progression of the heat and the smoke and is decisive for the time in which the affected persons can reach a safe area.

It has to be guaranteed that the structure in the vicinity of the fire source can withstand a collapse to allow self rescue for the fugitives.

If there are risks like groundwater or low overburden in urban areas, especially in loos soil, further measures have to be taken to avoid damages to third parties.

In Fig. 6.1 the following temperature development graphs are shown: (Details from SIA 197/2)

_ ISO 834
_ Assessment graph of the Netherlands RWS (Rijkswaterstaat)
_ Modified hydrocarbon graph HC_{inc}
_ German regulation ZTV-Tunnel

The modified hydrocarbon graph is the graph in Euro code EC1 multiplied with the factor 1300/1100. The temperature development graph in EC1 reaches a top temperature of only 1100°C.

For the evaluation of the different temperature graphs, the type and structure of the vehicles have been considered.

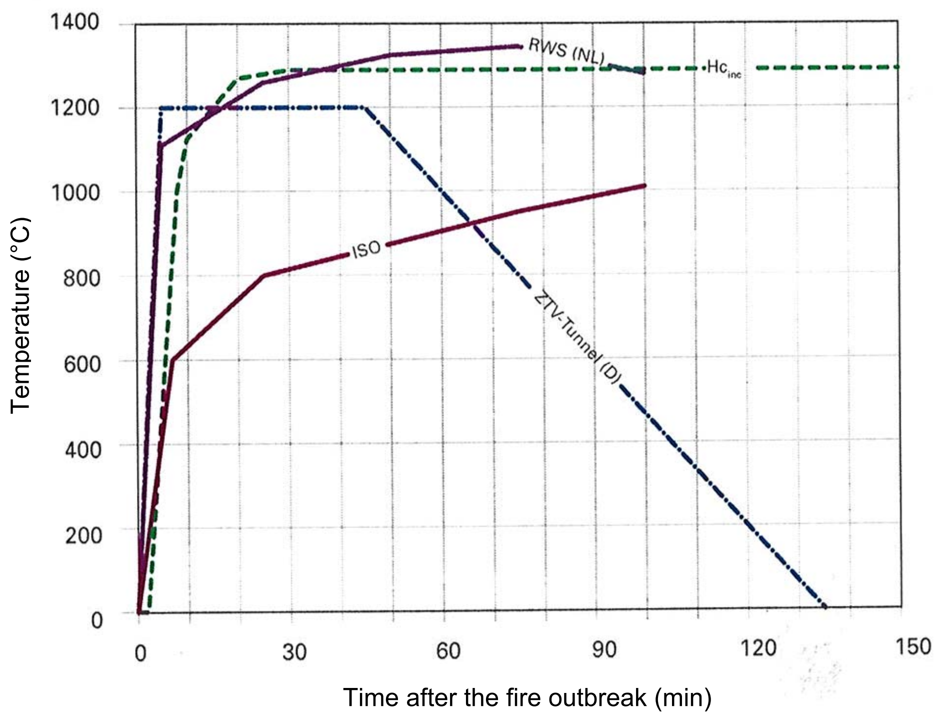


Fig. 6.1
Temperature development according different standards

Recommendation for the assessment

To come to a decision which graph has to be chosen in the above diagram, the recommendations of the Association mondiale de la Route / World Road Association (AIPCR/PIARC) shall be applied.

The decisions depend on:

_ Type of vehicle (especially the fraction of heavy traffic) which leads to the possible fire load.
_ Risk of a tunnel collapse with consequences to motorists or to above infrastructure in urban areas.

	Tunnel (Structure)				**Secondary components**
Type of tunnel / **Type of vehicle**	Immersed tunnel under or through buildings	Tunnel in unstable range	Tunnel in stable range	Cut-and-cover Tunnel	Ventilation duct and intermediate ceiling
Car and delivery van	ISO 60 min	ISO 60 min	ISO [2] 60 min	ISO [2] 60min	ISO 30 min
Lorry and road tanker	RWS/HC_{inc} [1] 120 min	RWS/HC_{inc} [1] 120 min	ISO [3] 120 min	ISO [3] 120 min	ISO 120 min

Fig 6.2
Allocation of the temperature graphs to the types of tunnel and vehicles

[1] AIPCR recommends to assume a fire duration of 180 min caused by a big tank-lorry with flammable liquid.

[2] Generally the load bearing capacity is not critical.

[3] Generally the bearing capacity is not critical. For special risks e.g. low overburden (e.g. urban areas), a higher, object specific fire load has to be considered.

6.3 User safety

In case of an event like a fire in a tunnel, most of the people normally panic. Therefore instructions in driving schools or pre knowledge cannot be applied.

The most effective and probably the only promising solution is to allow people an immediate self rescue.

In the existing Swiss and EU Standards and guidelines human needs and behaviour are not adequate cared about. This includes:

- User
- Operators and
- Rescue teams

For the future there is a high potential for improvement opportunities. To relieve people from having to take decisions in a emergency situation, optical, acoustic and structural measures have to be realised to a level of „The tunnel speaks“. This includes also the following elements:

- Signalisation (painting, signs, etc.)
- Emergency doors
- Rescue areas and
- Fire detection and automatic fire fighting

With these measures, consequences of fire incidents in tunnels can be significantly be reduced.

6.4 Swiss Tunnel Standards

- SIA 197 Chapter 7.4 Aussergewöhnliche Einwirkungen und Korrosion

- SIA 197/2 Chapter 4.4 Sicherheitsplanung
  Chapter 8.9 Tunnelportale
  Chapter 9.5 Verkehrsbeeinflussung (Signalisation und Markierung)
  Chapter 9.6 Erfassung und Kommunikation
  Chapter 9.6 Erfassung und Kommunikation

- SIA 198 Chapter 2.2 Betonstahl, Netze, Faserbewehrung
  Chapter 2.3 Spritzbeton
  Chapter 2.6 Injektionen
  Chapter 2.10 Polymerbeton
  Chapter 5.2 Sicherheits- und Gesundheitsschutzkonzept

7. Ventilation during Operation

7.1 General

A main task to achieve a high safety level in road tunnels is the ventilation system. This system depends mainly on the tunnel length, tunnel gradient, its purpose and the composition of the expected traffic.

The following graph together with the recommended evaluation of the risk degree, the required ventilation system can be chosen.

Main Groups of Ventilation Systems

The ventilation systems are structured in the following main groups:

- Natural ventilation
- Longitudinal ventilation system without off take in case of an event
- Mechanical ventilation system with off take in case of an event

At complex tunnel systems the above basic systems could be combined. There by the ventilation systems and the ventilation services have to be coordinated.

Required database

- Portal locations
- Number of tubes
- Number of lanes
- Position of each tube
- Cross section
- Longitudinal section with gradient
- Possibilities to place ventilation operation centres
- Emergency exit locations
- One- or two-way traffic
- Averaged daily traffic in the year of commissioning and ten years later
- Percentage of lorries compared with the average daily traffic
- Meteorological data (temperature, wind, air-pressure)
- Specifications concerning environmental compatibility

7.2 Selection of the ventilation system

The field of application are defined against to the traffic type and the tunnel length:

Natural ventilation

Mechanical ventilation with smoke exhaust

Cross ventilation with intermediate ceiling and smoke exhaust

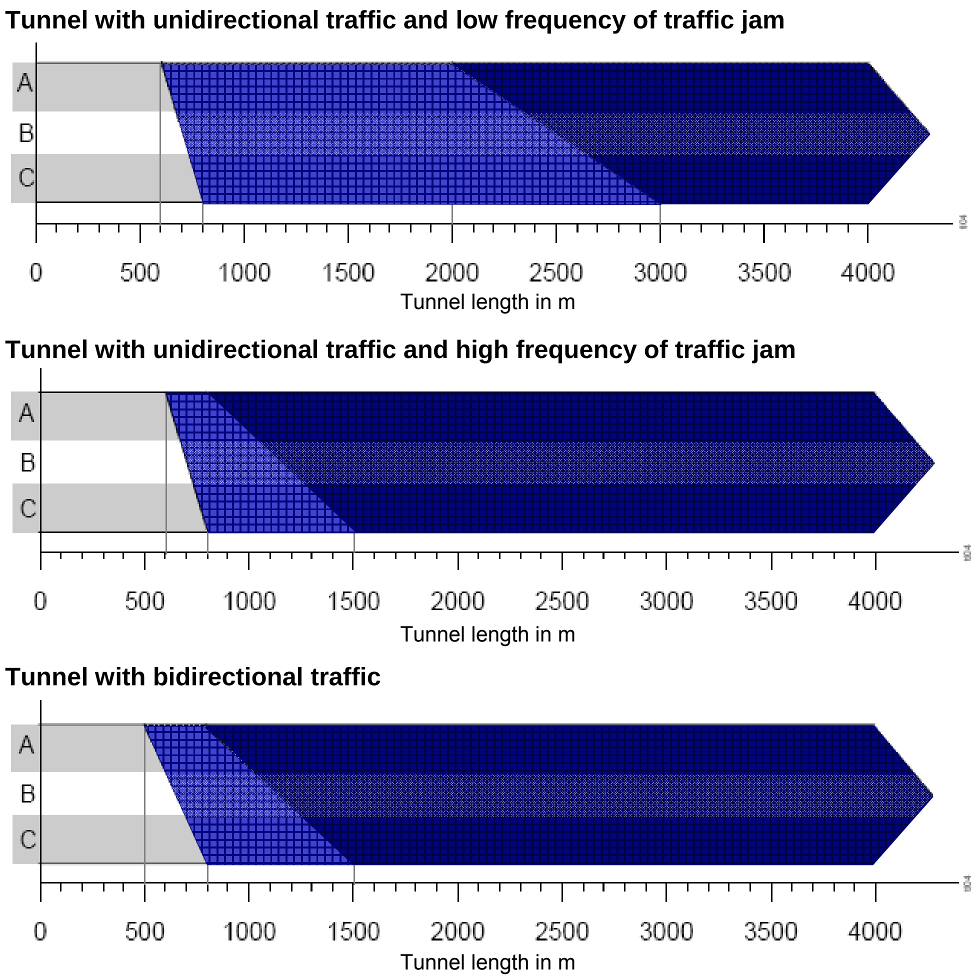


Fig. 7.1
Definition of the possible main group of the ventilation systems in safety-related aspects. The specifications are valid for tunnels with a longitudinal gradient until 5%.

If the main group of the ventilation system could not be assigning clearly, the sub-assembly groups (A, B, C) have to be evaluated according to the following criteria:

Overall traffic

Assessment of the overall traffic	Average daily traffic (ADT) divided by number of lanes	
	One way traffic	Two way traffic
O (high)	> 16’000	> 12’000
M (middle)	11’000 to 16’000	8’000 to 12’000
U (low)	< 11’000	< 8’000

Fig. 7.2
Assessment of the overall traffic

Lorry traffic

Assessment of the lorry traffic	Number of lorries during 24 h divided by the number of lanes	
	One way traffic	Two way traffic
O (high)	> 16’000	>1’200
M (middle)	800 to 1’600	500 to 1’200
U (low)	< 800	< 500

Fig. 7.3
Assessment of the lorry traffic.

Longitudinal inclination

Assessment of the longitudinal inclination	Highest value of the average inclination over a distance of 800 m in %		
	One way traffic RV1	One way traffic RV2	Two way traffic GV
O (high)	< -3	< -3 and > +3	> +3
M (middle)	-3 to +3	-3 to -1.5 and +1.5 to +3	+1.5 to +3
U (low)	> +3	-1.5 to +1.5	0 to +1.5

Fig. 7.4
Assessment of the longitudinal inclination

Overall assessment

Overall assessment	Partial assessments
A	O-O-O, O-O-M, O-O-U, O-M-M
B	O-M-U, O-U-U, M-M-M, M-M-U
C	M-U-U, U-U-U

Fig. 7.5
Overall assessment evaluated from the three partial assessments

7.3 Guideline

_ Astra_13 001

8. Life Time of Road Tunnel Elements

8.1 General

To minimise the costs for maintenance life time of the main elements of a road tunnel are defined. The longest life time is required for elements that can not replaced without extensive construction measures causing high costs and affect the traffic.

Refurbishing of elements which doesn't create unreasonable costs or time delay may have a shorter life time.

The following details are given in the SIA standard 197/2.

1) For the calculation of profitability the lower value for the serviceable will be used.

Component	Service life Years	20	30	40	50	60	70	80	90	100
Lining (without reinforcement)								X1)	X	X
Intermediate ceiling						X1)	X	X		
Wall cladding (prefabricated)				X1)	X	X				
Road surface		X1)	X							

System part	Service life Years	10	15	20	25	30	35	40	45	50
Higher ranked control system		X1)	X							
Fibre optic cable				X1)	X					
Lamps					X1)	X				
Silencer (ventilation)						X1)	X	X		
Hydrant								X1)	X	X

Fig. 8.1
Allocation of the life time for different tunnel elements.

8.2 Swiss Tunnel Standards

_ SIA 197/2 Chapter 8.3 Tunnelquerschnitt

9. Costs

9.1 General

All specifications in CHF without value added tax.

For the comparisons between Norway and Switzerland the following boundary conditions have to be considered:

_ Labour costs, different social benefits
_ Different approaches at the assessment of the installation flat-rate
_ Differences at the material procurement costs

9.2 Costs of the Swiss approach

The following chart originates from the project Rontal road tunnel. The one tube tunnel with two lanes has a diameter of 12 m, a membrane sealing and a final concrete lining.

The figures below show the typical costs for the sealing and the inner concrete lining of a Swiss two lane road tunnel.

	Quantity / m	Unit prices	Running meter
Concrete (without reinforcement)	7.06 m^3	250.-	1750.-
Formwork without base invert	1 m	330.-	330.-
Geotextile fleece (delivery /laying)	22 m^2	10.-	220.-
Sealing (PVC d = 2 mm)	22 m^2	22.-	484.-
Total			2'784.-
Equipment app. 25%			696.-
Total Swiss approach			3'480.-

Chart 9.1
Typical running meter tunnel for sealing and final lining

10. Final remarks

In this report the Swiss code of practice based on standards and guidelines is presented. A lot of these rules and practice can easily be adapted to Norwegian conditions. In the details individual adaptations for each task have to be made in cooperation with the Norwegian road authorities.

A combination of the existing Norwegian and Swiss standards will lead to an optimal solution. Chances are that Norwegian experience can make a contribution to the Swiss way of tunnelling.

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