

Replaces together with the Standards SIA 197 and 197/1 Sections 1 and 2 of the Standard SIA 198, Edition 1993

Projektierung Tunnel – Strassentunnel

Projet de tunnels – Tunnels routiers

Progettazione di gallerie – Gallerie stradali

## Design of Tunnels Road Tunnels

197/2



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## FOREWORD

The previous Standard SIA 198 *Underground Construction* (1993) dealt mainly with regulations concerning execution; design was only briefly mentioned.

The present Standards

- SIA 197      Design of Tunnels – Basic Principles
- SIA 197/1    Design of Tunnels – Railway Tunnels
- SIA 197/2    Design of Tunnels – Road Tunnels

close this gap. They are directed towards design engineers. Also addressed are clients (owners and operators) and those involved in site supervision and construction work.

SIA 197 presents the basic principles to be taken into consideration in the design of traffic tunnels, irrespective of the actual purpose (railways or roads). This includes the various aspects of safety and environmental impact. It also includes the regulations dealing with the design of structures executed underground following the SIA Structural Standards. The special features that need be considered in the case of road and rail tunnels are covered in the two specialists' Standards SIA 197/1 and SIA 197/2.

In order to simplify application, the three Standards have the same structure up to the titles of the 3rd level. This frequently leads, on the other hand, to the omission of text with only a cross-reference to the other Standard(s).

The regulations for the execution of underground structures are dealt with as before in the Standard SIA 198 *Underground Structures – Execution*.

Committee for SIA 197

## 0 SCOPE

### 0.1 Limitations

- 0.1.1 SIA 197/2 *Design of Tunnels – Road Tunnels* lays down the basic principles for the design of road tunnels. These are valid in addition to the regulations given in the SIA 197.
- 0.1.2 SIA 197 *Design of Tunnels – Basic Principles* lays down the basic principles for the design of traffic tunnels. Management aspects (use, operation and maintenance) are dealt with only insofar as they are relevant for design.
- 0.1.3 The two Standards SIA 197 and 197/2 apply to the design and layout of the tunnel (infrastructure concept) irrespective of whether the tunnel is constructed by a mined or a cut-and-cover construction method.
- 0.1.4 SIA 198 *Underground Structures – Execution* details the requirements for the construction materials and the most important regulations regarding execution (underground structures excluding interior finish).
- 0.1.5 SIA 197, 197/2 and 198 may be applied analogously for changes to existing traffic tunnels.

### 0.2 References

#### 0.2.1 Technical requirements

See SIA 197.

In addition reference is made to the following Standards, recommendations and guidelines. These apply in full or in part, in the general sense of the reference.

SN 640 070	Projektierung, Grundlagen; Geschwindigkeit als Projektierungselement
SN 640 090	Projektierung, Grundlagen; Sichtweiten
SN 640 100	Linienführung; Elemente der horizontalen Linienführung
SN 640 105	Verbreiterung der Fahrbahn in Kurven
SN 640 110	Linienführung; Elemente der vertikalen Linienführung
SN 640 120	Linienführung; Quergefälle in Geraden und Kurven, Quergefälleänderung
SN 640 200	Geometrisches Normalprofil
SN 640 201	Geometrisches Normalprofil, Grundabmessungen
SN 640 324	Dimensionierung Strassenoberbau
SN 150 915	Öffentliche Beleuchtung: Strassentunnel, -galerien und -unterführungen

#### 0.2.2 References to legal requirements

See SIA 197, Appendix A.

#### 0.2.3 ASTRA Guidelines

Further regulations may be found in the guidelines of the Federal Office for Roads (ASTRA). These are mentioned in the corresponding Clauses in the Standard.

- Guidelines and Recommendations for Cable Duct Systems
- Ventilation of Road Tunnels
- Marking of the Safety Provisions in Tunnels
- Fire Detection
- Radio Systems in Tunnels
- CCTV Traffic Monitoring

**0.3 General contract conditions**

See SIA 197.

**0.4 Exceptions**

See SIA 197.

# **1 TERMINOLOGY**

1.1 The present Standard employs the technical terms already defined in SIA 197.

1.2 Technical terms that are not defined in SIA 197 are explained in the present Standard at their first occurrence.

# **2 BASIC PRINCIPLES**

See SIA 197.

# **3 GROUND**

See SIA 197.

## **4 SAFETY**

### **4.1 Basic principles**

See SIA 197.

### **4.2 Hazards**

See SIA 197.

### **4.3 Design procedure**

See SIA 197.

### **4.4 Safety planning**

#### **4.4.1 General**

4.4.1.1 Safety in road tunnels depends on the following four groups of influential factors:

- Road users
- Operation (operation and servicing of the operating and safety plant, use in emergencies)
- Infrastructure (structures, operating and safety plant)
- Vehicles (type, condition and transported goods).

4.4.1.2 The present Standard deals primarily with the design of the infrastructure and only provides limited information on the use and operation of the tunnel.

It contains the requirements for structures and the operating and safety plant intended to limit the effects of incidents.

4.4.1.3 Suitable infrastructure and its unlimited serviceability are the prerequisites to prevent or limit the effects of incidents (breakdown, accident, fire, etc.). The correct behaviour of the user (traveller) and the state of readiness of the emergency services (police, fire, ambulance and maintenance services) are also of importance when an incident occurs.

4.4.1.4 The construction, operational and organisational measures shall be planned so as to allow swift intervention at the location of the incident, first by the road users and then by the emergency services.

#### **4.4.2 Procedure, health and safety analyses and safety measures**

See SIA 197, Clauses 4.4.2 to 4.4.6.

## **5 ENVIRONMENT**

See SIA 197.

## **6 MANAGEMENT**

See SIA 197 and Appendix A.

## **7 STRUCTURAL DESIGN**

### **7.1 Basic principles**

See SIA 197.

### **7.2 Structural analysis**

See SIA 197.

### **7.3 Dimensioning**

See SIA 197.

### **7.4 Accidental actions and corrosion**

#### **7.4.1 Fire**

7.4.1.1 The main structural elements shall be designed for a specific fire load.

Information on the procedure is given in the Standards SIA 261, Clause 15, and SIA 262, Clause 4.3.10.

7.4.1.2 Fire load is defined in terms of a temperature–time curve. Relevant information and explanations are given in Appendix B.

7.4.1.3 The structural components and the fastenings for plant shall be designed such that failure does not occur in the first fire phase. This phase is defined by a temperature of 450 °C over a period of half an hour (limiting load for protected persons).

#### **7.4.2 Explosion**

7.4.2.1 The tunnel shall be assigned to Category 1 (see SIA 261, Clause 17). If a higher value is assigned, then this shall be specified in the Required Duty Agreement.

7.4.2.2 The intermediate slab shall be assigned to Category 2.

7.4.2.3 The following values shall be assumed for fire load from an explosion of petrol fumes with the following load–time variation:

- sudden increase ( $t = 0$ ) of the overpressure within the traffic corridor of 0 to 100 kN/m<sup>2</sup>
- linear decrease of the overpressure from 100 kN/m<sup>2</sup> to 0 kN/m<sup>2</sup> within a millisecond.

7.4.2.4 The requisite verification shall form part of the Safety Plan. The results form the basis of the Safety Plan and shall be documented in the Safety Report.

#### **7.4.3 Earthquake**

See SIA 197.

#### **7.4.4 Corrosion**

See SIA 197.

## **7.5 Particular structural components**

### **7.5.1 Lining Segments**

See SIA 197.

### **7.5.2 Unreinforced concrete lining**

See SIA 197.

### **7.5.3 Fastenings**

See SIA 197.

### **7.5.4 Intermediate slab**

7.5.4.1 The Intermediate slab shall be designed for:

- dead and superimposed loading (e.g., components of the ventilation system)
- live loading (persons, goods)
- overpressure and underpressure due to the ventilation
- exceptional actions (fire, explosion).

7.5.4.2 A downwards-directed live load of 2.0 kN/m<sup>2</sup> acting in the most unfavourable position shall be taken into consideration.

7.5.4.3 Any constraints due to the deformation of the lining (rock mass) shall be taken into consideration.

### **7.5.5 Internal finishes and support facilities**

7.5.5.1 Additional structural components shall be determined for on a project-specific basis and described in the Basis of Design.

7.5.5.2 The following may be present within the tunnel:

- Suspended carriageway slab
- Service duct
- Seepage drainage channel
- Particular structures for the drainage system
- Internal wall lining.

7.5.5.3 The following may be present within the support facilities:

- Buildings
- Roads and parking areas.

## **7.6 Construction inspections and monitoring**

See SIA 197.

## **8 CONSTRUCTION WORKS**

### **8.1 General**

Basic principles for the design of tunnels are given in SIA 197. The present Standard deals with the special requirements for the design of road tunnels.

### **8.2 Alignment**

#### **8.2.1 Horizontal alignment**

8.2.1.1 The ventilation system and the concept for emergency escape routes can influence the choice of alignment.

8.2.1.2 The dazzle effect at the portal shall be taken into consideration by means of a curved alignment in the case of long tunnels if possible.

8.2.1.3 Straight stretches with a length exceeding 3 km shall be avoided in the case of long tunnels.

8.2.1.4 Tunnels with a length of less than 200 m shall be in a straight line for safety reasons.

8.2.1.5 SN 640 090 "Projektierung, Grundlagen: Sichtweiten" and SN 640 100 "Linienführung: Elemente der horizontalen Linienführung" shall be taken into consideration.

#### **8.2.2 Vertical alignment**

8.2.2.1 The consequences of a change of direction of the longitudinal gradient (crests, dips in the road) on the drainage or the tunnel ventilation shall be taken into consideration. Dips shall if possible be avoided.

8.2.2.2 The maximum longitudinal gradient shall not exceed 5% due to increased danger (accident frequency, spread of smoke).

8.2.2.3 SN 640 110 "Linienführung: Elemente der vertikalen Linienführung" shall be taken into consideration.

#### **8.2.3 Camber**

8.2.3.1 The camber shall be at least 2.5% and shall not exceed 5%. The minimum gradient is necessary to allow liquids that are spilt during an incident to drain away quickly.

8.2.3.2 Changes in the camber can negatively affect the design of the main drain and shall be avoided if possible.

8.2.3.3 For changes in camber, the maximum secondary longitudinal gradient can be limited to 0.5%.

8.2.3.4 SN 640 120 "Linienführung: Quergefälle in Geraden und Kurven, Quergefältsänderung" shall also be taken into consideration.

#### **8.2.4 Junctions in tunnels**

8.2.4.1 The term *junction* denotes both slip roads and branching.

8.2.4.2 Junctions within a tunnel shall be avoided if possible.

8.2.4.3 Junctions in tunnels shall be designed so as to provide an additional carriageway.

8.2.4.4 A sufficiently long deceleration lane shall be provided in the case of branching within a tunnel.

8.2.4.5 Carriageway crossings shall be avoided in twin tunnels.

### 8.2.5 **Road junctions in the vicinity of the portals**

8.2.5.1 Road junctions in the vicinity of portals shall be avoided if possible.

8.2.5.2 The design shall ensure that there is no tailback of traffic into the tunnel on the slip road to the junction if a road junction is indispensable.

## 8.3 **Tunnel cross-section**

### 8.3.1 **General**

See SIA 197.

### 8.3.2 **Design cross-section**

8.3.2.1 The kinematic envelope required because of vehicle dynamics shall be based on the design speed, the alignment and the type of traffic according to:

SN 640 200 "Geometrisches Normalprofil"

SN 640 201 "Geometrisches Normalprofil: Grundabmessungen"

SN 640 105 "Verbreiterung der Fahrbahn in Kurven"

8.3.2.2 A hard shoulder shall generally not be provided in tunnels. Exceptions shall be justified in the basis of design.

8.3.2.3 The requirements placed on the kinematic envelope for exceptional transports shall be taken into consideration in the case of strategic supply routes.

8.3.2.4 The widening of the carriageway for the vehicles and reduced visibility shall be taken into consideration in the case of tunnels with small radii curvature.

8.3.2.5 The space requirements in the case of tunnels that also serve pedestrians, cyclists and motorcyclists shall be specified and justified in the basis of design (see also Clause 8.8.8).

8.3.2.6 The space requirements for plant comprise space requirements for the operating and safety plant located beside and above the kinematic envelope (including ventilation fans). A safety tolerance of 30 cm shall be provided above the kinematic envelope in addition.

8.3.2.7 A large accessible duct shall be installed beneath the carriageway if practicable. The accessible duct can be placed at the side of the cross-section in the case of cut-and-cover tunnels.

8.3.2.8 The operational envelope for traffic is shown in Figure 1. Some examples of standard tunnel cross-sections are given in Appendix C.



## **8.4 Lining**

- 8.4.1 Water containing salt from melting snow and ice is carried a considerable distance into the tunnel by vehicles. Reinforced linings shall be therefore avoided if possible.
- 8.4.2 The inner lining shall be at least 30 cm thick in the case of a double-shell lining.
- 8.4.3 The surface of the lining shall be as smooth as possible. This simplifies
  - the application of a covering layer to the tunnel wall (with a bright colour for lighting reasons)
  - cleaning the tunnel walls.

## **8.5 Carriageway, walkways and cable ducts**

### **8.5.1 Carriageway**

- 8.5.1.1 The carriageway superstructure shall be designed in accordance with: SN 640 324 "Dimensionierung Strassenoberbau".
- 8.5.1.2 The superstructure shall be well drained to prevent standing water. The drainage (drainage layer, drain pipe) shall be placed at the lowest point of the standard cross-section.
- 8.5.1.3 An elevated suspended carriageway slab shall be designed as a bridge structure.
- 8.5.1.4 Construction measures (e.g., crash barriers) shall not be used to split the carriageway into traffic lanes.
- 8.5.1.5 No manholes shall be placed in the traffic lanes or hard shoulder.

### **8.5.2 Walkways**

- 8.5.2.1 The walkway shall be at least 1 m wide, including the kerb.
- 8.5.2.2 The headroom above the walkway shall be at least 2 m.
- 8.5.2.3 The space requirement for traffic signals located against the tunnel walls, a square area with 0.8 m by 0.8 m, shall be kept free on both sides of the tunnel above the walkway.

### **8.5.3 Cable routes (service ducts)**

- 8.5.3.1 It is often useful to arrange the supply and drainage pipes, as well as the communications cables and safety plant in a larger service duct separated from the traffic corridor. Servicing and refurbishment can then be carried out with little disturbance to traffic.
- 8.5.3.2 The design of the service duct depends on the operations requirements and shall be designed for pedestrian access. The clear opening shall be at least 2 m high and 1 m wide except at pipe crossings.
- 8.5.3.3 Access to the service duct for single tunnels shall be arranged from the lay-by and for twin tunnels from the cross tunnels with vehicle access.
- 8.5.3.4 An independent access to the tunnel shall be provided to the traffic corridor in the vicinity of the portals.
- 8.5.3.5 The service duct may be used as a separate ventilation duct for the ventilation of the cross-passages and underground control centres.
- 8.5.3.6 The principles laid down in the ASTRA Guideline "Leitsätze und Empfehlungen für Kabel-Kanal-Systeme" shall be taken into consideration.

#### 8.5.4 **Protection from vibration and structure-borne noise**

8.5.4.1 Previous experience suggests that in the case of road traffic no special precautions are needed to prevent inadmissible actions on adjacent structures in general.

8.5.4.2 Special precautions may be needed in the following cases:

- Cut-and-cover sections of tunnel with adjacent structures directly above or in the immediate vicinity
- Tunnels that are driven just below or beside existing adjacent structures
- Joints (carriageway construction joints) in the case of suspended carriageway slabs.

### 8.6 **Waterproofing**

See SIA 197.

### 8.7 **Drainage**

#### 8.7.1 **General**

Groundwater (clean water) and operations water (polluted water) shall in general be drained away separately.

#### 8.7.2 **Sintering**

See SIA 197.

#### 8.7.3 **Collecting the groundwater (drainage)**

See SIA 197.

#### 8.7.4 **Diversion of water (seepage and drain pipes)**

8.7.4.1 The distance between flushing manholes or flushing niches shall not be more than 75 m.

8.7.4.2 Access openings to manholes and niches shall have a diameter of at least 600 mm. Openings of inspection manholes or flushing manholes shall be at least 300 mm wide (width of flushing plant including clearance).

8.7.4.3 Drain pipes intended to be inspected by maintenance personnel shall have a diameter of at least 600 mm.

8.7.4.4 Manholes shall not be placed in the carriageway.

#### 8.7.5 **Discharge in front of the portal**

See SIA 197.

#### 8.7.6 **Drainage system for operations water**

8.7.6.1 Perforated (slotted) drainage channels shall be provided for the drainage of the carriageway to allow combustible, explosive or toxic liquids to be discharged quickly from the traffic corridor.

- 8.7.6.2 The liquids shall be discharged into a closed system. The requirements for explosion protection shall be taken into consideration:
- Use of inverted siphons that prevent the return of explosive gases into the traffic corridor
  - The filling of the inverted siphons shall be ensured
  - Watertight, secured manhole covers, to avoid hazards (e.g., blowing-off of covers arising from ignition in the drainage system).
- 8.7.6.3 The seepage drainage channels shall be connected every 50 m to the collector pipe by means of inverted siphons. The intakes to the inverted siphons shall have a capacity of at least 100 l/sec.
- 8.7.6.4 Non-perforated pipes with watertight joints shall be used for the collector pipes.
- 8.7.6.5 The collector pipe shall be designed for a discharge of 100 l/sec in open channel flow. The collector pipe shall be able to discharge peak values of 200 l/sec for short periods; the collector pipe can be operated under pressure due to build-up of water during this period.
- 8.7.6.6 The amount of cleaning water to be assumed shall be 10 l/sec and that for fire fighting 20 l/sec.

## **8.8 Additional construction measures for safety purposes**

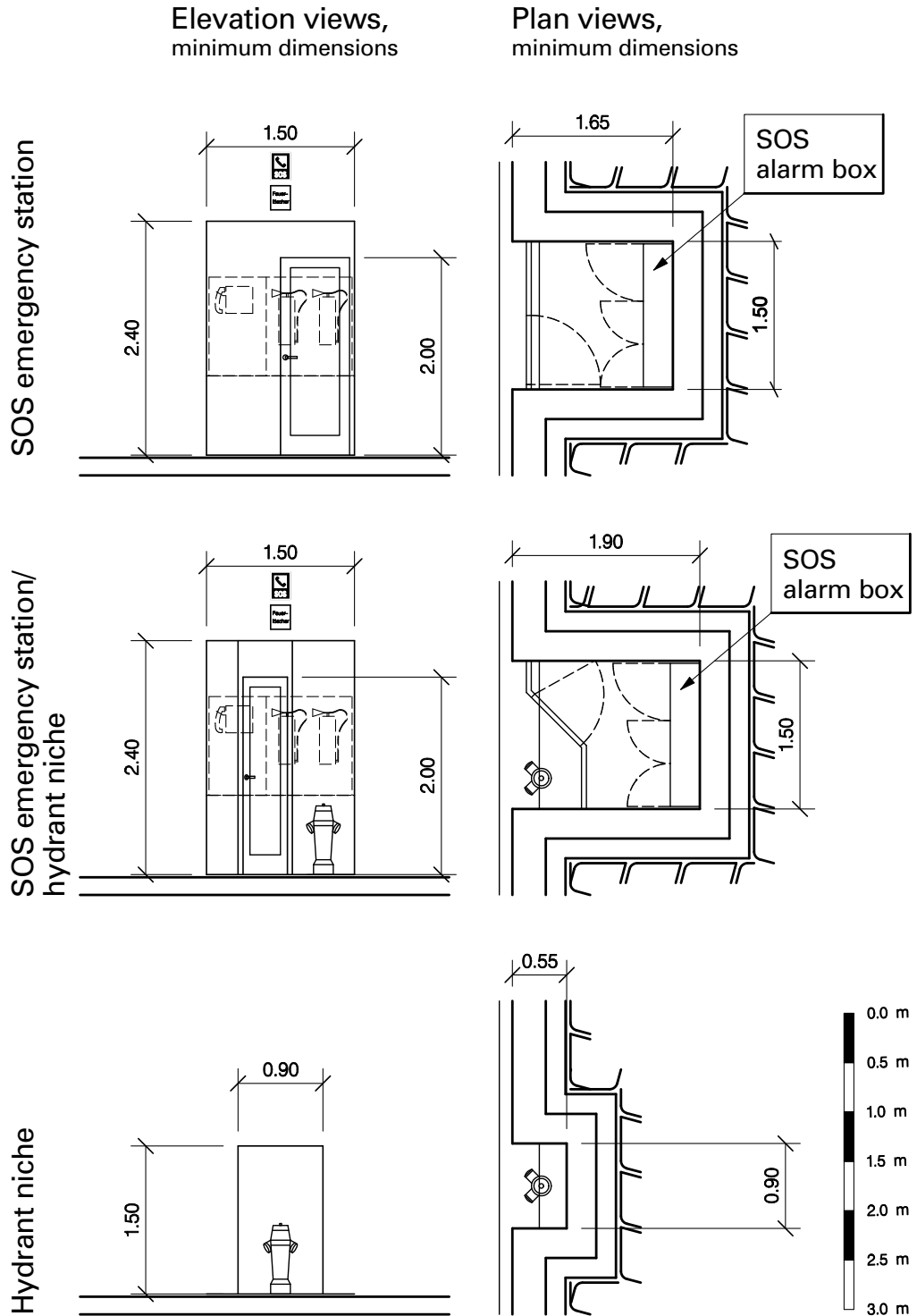
### **8.8.1 General**

- 8.8.1.1 The construction measures to ensure the safety of the user include:
- Niches
  - Lay-bys
  - Emergency escape routes from the traffic corridor
    - Cross-passages to adjacent traffic tunnels with pedestrian and vehicle access
    - Connections to the open air
    - Cross-passages to a parallel service tunnel or duct.
- 8.8.1.2 A distinction shall be made with respect to construction safety measures between single and twin tunnels.
- 8.8.1.3 The spacing of the construction safety measures along the tunnel shall be based on a grid of 150 m.
- 8.8.1.4 Construction safety measures shall be provided for tunnels with a length exceeding 300 m. Deviations (e.g., with low traffic density or a succession of short tunnels) shall be justified.

8.8.2 **Single tunnel: niches, lay-bys, emergency escape routes**

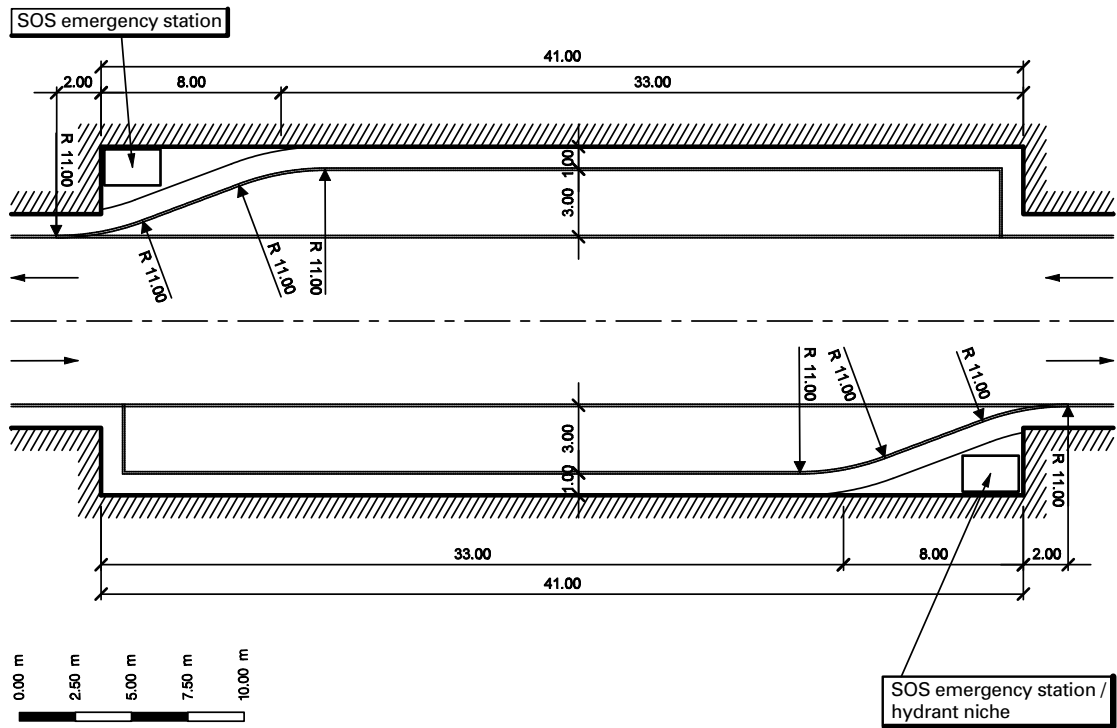
- 8.8.2.1 The niches for the SOS equipment shall be arranged every 150 m on alternate sides. The fire hydrants shall in general be spaced every 150 m on both sides. The minimum dimensions are shown in Figure 2:
- Combined SOS/fire hydrant niche
  - SOS niche
  - fire hydrant niche.

Figure 2 Niches



8.8.2.2 Alternate lay-by bays shall be provided every 600 to 900 m (Figure 3). The lay-bys can be located staggered in the case of difficult ground conditions.

Figure 3 Lay-bys

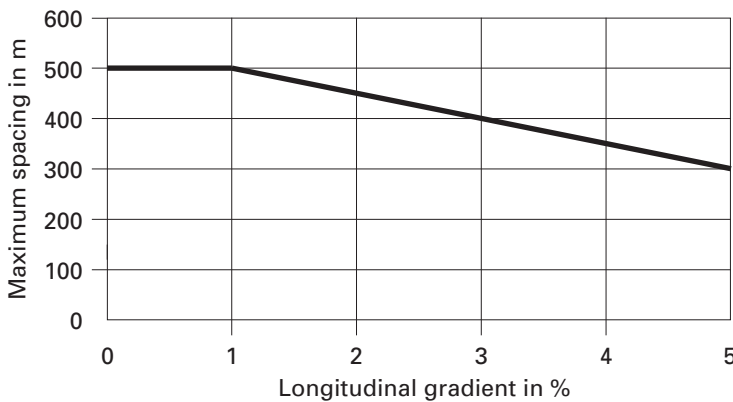


8.8.2.3 The emergency escape routes from the traffic corridor shall be placed at regular intervals along one side of the tunnel. The emergency escape routes shall in the case of an emergency, in combination with other safety plant, allow the tunnel user to escape in the shortest possible time from the danger zone.

The maximum spacing of the emergency escape routes shall be 300 m in the case of cut-and-cover tunnels.

The maximum spacing of the emergency escape routes depends on the longitudinal gradient of the tunnel in the case of mined tunnels. The value can be taken from Figure 4.

Figure 4 Maximum spacing of emergency escape routes



The decisive longitudinal gradient is the highest value of the mean longitudinal gradient over an 800 m length of tunnel.

Special measures are necessary for tunnels with a longitudinal gradient greater than 5%.

- 8.8.2.4 The following emergency escape routes are not permissible:
- Into spaces without access to the open air
  - Into a space situated above the carriageway (e.g., separated by an intermediate slab).
- 8.8.2.5 Emergency escape routes are possible that lead:
- directly into the open air for tunnels with a small depth of overlying ground (e.g., cut-and-cover tunnels) or with a suitable topography (tunnels close to a hillside)
  - to a parallel tunnel (safety tunnel), with exit to the open air
  - to a large duct, which lies within the tunnel cross-section outside the traffic corridor (e.g., the service duct below the carriageway) and leads into the open air.
- 8.8.2.6 An alternative approach can be made if it is only planned to construct a second tunnel either in the short or long term e.g., in the case of staged construction. A parallel pilot tunnel shall be constructed which can serve as a safety tunnel until the construction of an adjacent tunnel is ready.
- 8.8.2.7 The requirements of Clause 8.8.3 apply to niches and lay-bys in single tunnels with two-way traffic.

### 8.8.3 **Twin tunnels: niches, lay-bys, emergency escape routes**

8.8.3.1 The niches for the SOS plant shall be arranged at intervals of 150 m on the right-hand side of the carriageway. The fire hydrants shall be arranged at intervals of 150 m. In general they are positioned on the same side, usually the right-hand side of the carriageway. The minimum dimensions are shown in Figure 2.

*(Note: for jurisdictions with driving on the left, the words right side shall be replaced with left side.)*

8.8.3.2 No lay-bys shall to be planned except for control rooms with no access from the outside (see Clause 8.10.1.4).

8.8.3.3 Emergency escape routes shall be arranged as cross-passages with pedestrian access between the two adjacent tunnels at regular intervals of maximum 300 m.

8.8.3.4 Some emergency escape routes shall be designed to accommodate emergency services vehicles for tunnels as follows: for tunnels up to 1.2 km in length, one emergency escape route; for longer tunnels, every third emergency escape route (maximum spacing 900 m).

### 8.8.4 **Cross-passages for pedestrian access**

8.8.4.1 Cross-passages for pedestrian access shall have a design cross-section of at least 2.0 m wide and 2.50 m high.

8.8.4.2 The doors shall be at least 1.00 m wide and 2.00 m high. They shall be easy to use.

In general, double doors shall be provided. They shall be fixed to the inside of the tunnel wall and shall open into the cross-passage.

If sliding doors are provided (in justified cases), the mode of operation shall be clear to the user.

8.8.4.3 In the vicinity of cross-passages, the side of the carriageway (kerb, seepage/drainage channels) shall not be lowered.

### 8.8.5 **Cross-passages for vehicle access**

8.8.5.1 Cross-passages for vehicular access shall have a design cross-section of at least 4.20 m wide and 4.50 m high.

8.8.5.2 Gates shall be at least 4.00 m wide and 4.30 high. In addition, cross-passages shall be provided with the same doors as specified in Clause 8.8.4.2.

*(Note: the term gate means door with access for vehicles. See also fire regulations.)*

## 8.8.6 **Construction details of the cross-passages**

- 8.8.6.1 The cross-passages shall be designed as ramps, which are not too steep (maximum 15%).
- 8.8.6.2 A sufficiently large space (at least 8 m<sup>2</sup> floor area) shall be provided between the doors and steps if the cross-passages have to be designed as steps. The steps shall be at least 1.0 m wide.
- 8.8.6.3 The cross-passages shall be illuminated and separated by a door from each traffic corridor.
- 8.8.6.4 The door closers shall comply with the requirements of Clause 7.4.1. Doors and gates shall exhibit a minimum fire resistance corresponding to T30.

## 8.8.7 **Adjacent tunnels or ducts**

- 8.8.7.1 In certain cases a parallel adjacent tunnel can be provided, which may serve as an exploratory or pilot tunnel and on completion of construction can be used as a safety tunnel.
- 8.8.7.2 The design cross-section of such a tunnel shall be at least 2.00 m wide and 2.50 m high.
- 8.8.7.3 The emergency escape routes shall be arranged at distances of 300 m as accessible cross-passages to the tunnel and separated from the traffic corridor or the safety tunnel or duct by a door.
- 8.8.7.4 The parallel adjacent tunnel or duct is not to be designed for normal vehicles permitted by the road traffic laws.
- 8.8.7.5 The parallel adjacent tunnel or duct shall be provided with lighting.

## 8.8.8 **Lanes for pedestrians and cyclists**

- 8.8.8.1 The design shall separate, if possible, pedestrian, cyclist and motorcycle traffic from vehicle traffic.
- 8.8.8.2 Pedestrians and cyclists, if they need to have access to the tunnel, shall be provided with their own lanes or separate paths.
- 8.8.8.3 The walkways provided on both sides according to Clause 8.5.2.1 shall serve for emergency purposes only.

## 8.9 **Tunnel portals**

### 8.9.1 **Basic principles**

- 8.9.1.1 Any reduction of the carriageway width (reduction of traffic lanes) shall be made outside of the tunnel.
- 8.9.1.2 The portals shall be designed to ensure safe traffic conditions from the open-air approach section into the tunnel and vice versa.
- 8.9.1.3 The alignment at the exit portal shall be suitably designed to reduce dazzling of drivers caused by direct sunshine.

### 8.9.2 **Accessibility of the portals**

- 8.9.2.1 The portals shall be provided with access from the normal traffic network.
- 8.9.2.2 Vehicle access shall be provided for the emergency services from one adjacent tunnel to the other in the case of twin tunnels (central reservation crossing).

8.9.2.3 The snow-clearing concept of the corresponding operating sector of the road shall be taken into consideration in the planning of the portal areas. It shall be made possible for vehicles to turn in front of the portals (at the end of the snow-clearance sections) if deemed necessary.

### 8.9.3 **Measures in front of the portals**

8.9.3.1 If the carriageway of the open-air operating sector of the road has no hard shoulder, then lay-bys shall be provided, if possible, in both traffic directions of the same size as those inside the tunnel.

8.9.3.2 An SOS cabinet with a telephone and two fire extinguishers, as well as a fire hydrant, shall be provided in front of the portals.

## 8.10 **Ancillary facilities**

### 8.10.1 **General**

8.10.1.1 The following types of ancillary facilities may be required:

- Control centres
- Ventilation ducts and shafts including the associated ventilation outlet structures for extracted air
- Accesses and entrances to these facilities.

8.10.1.2 The term control centre is used to mean all rooms and buildings required to manage the operations of the tunnel. These include control centres for ventilation and for the operating and safety plant (electrical and communications systems).

### 8.10.2 **Arrangement of the control centres**

8.10.2.1 Control centres shall be arranged, if possible, at the portals.

8.10.2.2 Control centres shall be provided, if possible, with separate accesses and entrances from outside.

8.10.2.3 It may be necessary to have the control centres in caverns without separate access in the case of long tunnels. These control centres shall be provided with access via the lay-bys or cross-passage as follows:

- Single tunnels with lay-bys on both sides (according to Clause 8.8.2.2)
- Twin tunnels without hard shoulder with a lay-by on one side (according to Clause 8.8.2.2) and a cross-passage allowing vehicle access.

### 8.10.3 **Design of control centres**

8.10.3.1 The requirements for the design of the control centres shall be analogous to the requirements that apply to the portals (Clause 8.9, SIA 197).

8.10.3.2 The design of the control centres shall also fulfil the following requirements:

- Suitable conditions for servicing the operating and safety plant
- Suitable conditions for replacing heavy or bulky components without causing much delay to traffic.

8.10.3.3 The design shall take the requirements of building physics into consideration (effects of temperature and humidity differences).

8.10.3.4 The relevant fire protection regulations shall be taken into consideration.

8.10.3.5 The fire protection concept shall contain information about the fire compartments, the fire-fighting plant and the emergency escape routes from the control centre.

8.10.3.6 The building ventilation, provided this is allowed by the fire protection concept, shall be designed for optimum operations. Complete separation of the rooms shall be avoided if possible to enable a better balance of the air (humidity, temperature).

8.10.3.7 If a connection to the tunnel exists, the control centres shall be ventilated with positive pressure to reduce the penetration of the dust or corrosive air from the traffic corridor.

8.10.4 **Intake and outlet air ducts for the tunnel ventilation**

8.10.4.1 The ventilation ducts shall be provided with pedestrian access.

8.10.4.2 The distance between the ventilation intake and outlet structures shall be made large enough to prevent discharged air from being sucked in again.

8.10.4.3 The position of the ventilation tunnels and shafts shall be fixed on the basis of meteorological, topographical and geological conditions.

## **9 OPERATING AND SAFETY EQUIPMENT**

### **9.1 General**

9.1.1 The operating and safety plant shall be selected on a project-specific basis and documented in the operations manual.

9.1.2 The following facilities shall be provided, if there are no overriding requirements for tunnels longer than 300 m. Deviations (e.g., in the case of low traffic volumes or several short, closely spaced tunnels) are admissible; they shall be specified and justified in the basis of design.

9.1.3 The operating and safety facilities comprise:

- monitoring and control plant
- lighting
- ventilation
- traffic management equipment (traffic signals and road markings)
- detectors and communications plant
- fire-fighting plant.

9.1.4 The following are necessary for the operation of the above facilities:

- Power supply
- Ancillary facilities.

9.1.5 The following are necessary for the monitoring and management control of the complete operating and safety plant:

- Master control system (including operations control system, man-machine communication)
- Traffic control system
- Emergency services and telephone control centres
- Emergency services mobilisation systems
- Master control centres or control units.

9.1.6 The facilities shall function autonomously and not be controlled by one central control system in order to prevent the simultaneous failure of several facilities should the master control system fail.

9.1.7 The coordination between the operating and safety plant relevant to safety shall be shown in an action matrix. The action matrix shows which action is automatically triggered by an alarm transmitted by a monitoring system in each of the different operating systems.

An example of an action matrix is shown in Appendix D.

9.1.8 The systematic monitoring and servicing of the plant is an absolute prerequisite to ensure high reliability during operation.

### **9.2 Main control centres**

9.2.1 Generally, 2 master control centres shall be provided:

- Traffic control centre (emergency services control centre), whose purpose is to monitor and control traffic as well as to mobilise the emergency services.
- Operations control centre (maintenance control centre), whose purpose is to monitor the technical systems and to ensure their functionality.

9.2.2 The functionality of the control centres and the corresponding equipment shall be agreed at an early planning phase.

## **9.3 Lighting**

### **9.3.1 Lighting in the traffic corridor**

9.3.1.1 The following types of lighting are differentiated:

- Traffic corridor lighting
- Adaptation lighting to help drivers to re-adjust to changing light conditions (entrance and exit lighting)
- Emergency lighting.

9.3.1.2 The traffic corridor lighting provides uniform lighting of the traffic corridor and adequate visibility.

9.3.1.3 The adaptation lighting lessens the effect of a marked change in light conditions from the outside to the inside of the tunnel and vice versa, and shall be designed such that hazards on the carriageway can be easily seen.

9.3.1.4 Detailed information on the design of the lighting is given in SN 150 915.

9.3.1.5 The emergency lighting provides lighting to the traffic corridor in case the power supply fails. The emergency lighting is a part of the traffic corridor lighting, which has a separate connection to the uninterruptible power supply. Generally, every fourth light shall be assigned to the emergency lighting.

### **9.3.2 Fire emergency lighting**

9.3.2.1 The fire emergency lighting serves the purpose of orientation in case of fire. It shall be connected to the emergency (uninterruptible) power supply.

9.3.2.2 The fire emergency lights shall be arranged every 50 m on the side of the emergency escape routes.

9.3.2.3 The fire emergency lighting shall be provided on both sides of the tunnel if there is no emergency escape route or in exceptional cases where emergency escape routes are on both sides of the tunnel.

9.3.2.4 The fire emergency lighting shall be installed at a height of 0.50 m above the walkway.

### **9.3.3 Control of the lighting**

9.3.3.1 The adaptation lighting is controlled by light density measurements taken out at the portal.

9.3.3.2 The traffic corridor lighting depends on the time of day (day, night). Ideally, the traffic corridor lighting shall be controlled as a function of traffic volume.

9.3.3.3 The traffic corridor lighting shall be set to the highest level in the case of fire and the fire emergency lighting activated.

### **9.3.4 Lights and installation of cables**

9.3.4.1 The lighting comprises:

- Light fittings and power supply feed lines
- Hangers and fastenings
- Cable ducts.

9.3.4.2 The lights shall have a corrosion-resistant casing to class IP 65.

9.3.4.3 Hangers, fastenings and cable ducts shall be corrosion-resistant.

9.3.4.4 Light casings and cable ducts shall be designed from non-inflammable or low inflammable material to class BKZ 5.3.

9.3.4.5 The cables shall be halogen-free.

## **9.4 Ventilation**

### **9.4.1 Purpose of ventilation**

9.4.1.1 Ventilation represents an important safety element, both in normal operation and in an emergency.

9.4.1.2 In normal operation the ventilation ensures an adequate air quality in the traffic corridor, as well as compliance with any environmental protection laws.

9.4.1.3 The air quality can be measured by the following parameters:

- CO content
- Impairment of visibility
- Nitrogen oxide content (NO<sub>x</sub>)
- Fine particles (PM10)

9.4.1.4 The impairment of visibility is caused by

- Traffic (exhaust from internal combustion engines, wear of tyres and brake linings, etc.)
- Possible formation of fog within the tunnel or in the vicinity of the portals (at critical air humidity values and temperatures).

9.4.1.5 The ventilation has to limit the spread of smoke or be able to influence it according to specified fire scenarios in the case of fire.

### **9.4.2 Ventilation system**

9.4.2.1 Tunnels can be ventilated by:

- Natural ventilation
- A ventilation system without air extraction in an emergency
- A ventilation system with air extraction in an emergency.

9.4.2.2 The choice of the ventilation system depends on:

- tunnel length
- longitudinal profile
- volume and composition of the traffic
- risk of traffic jams.

9.4.2.3 The ventilation concept considerably influences the conceptual design of a road tunnel.

For example:

- Size of the standard cross-section
- Ventilation control centres (number, location, size)
- Ventilation shafts and tunnels (number, diameter, length).

The design (ventilation concept and conceptual design of the structures) shall therefore be integral and carried out in close cooperation with the technical experts (HVAC consultant and civil engineer).

9.4.2.4 The choice of the ventilation system and the design of the ventilation system shall be in accordance with the ASTRA Guideline "Lüftung der Strassentunnel".

### **9.4.3 Components of the ventilation**

9.4.3.1 The following components have an important influence on the conceptual design:

- Fans including drive motors and stand-by units
- Closure elements (closure flaps/gates)
- Air expulsion flaps including motor
- Throttling elements, baffles
- Sound absorbers (silencers)
- Ducts, dividing walls.

The installation of such components can involve considerable changes to the structure if these components have to be installed later.

- 9.4.3.2 The following components are important for the operation of the tunnel, but have less influence on the conceptual design:
- Control and regulation units
  - Monitoring systems (monitoring plant).

## **9.5 Traffic management (signals and road markings)**

### **9.5.1 Signalling**

- 9.5.1.1 The following traffic signals can be installed in a tunnel:
- Fixed signals (stipulated signals, informative signals)
  - Active signals
  - Lights (traffic lights, lane signals)
  - Signposts
  - Road signs
  - Electronic text displays.
- 9.5.1.2 The signalling system comprises the signals, the fastenings and the feed cables for the power supply and control.
- 9.5.1.3 The signals are fixed to the support structures and hangers. The requirements of operational maintenance shall be taken into consideration.
- 9.5.1.4 Reducing the number of lanes, e.g., for maintenance, shall be carried out outside the tunnel. The signalling shall be arranged accordingly.
- 9.5.1.5 Signals shall comply with the regulations (see Appendix A, SIA 197).

### **9.5.2 Road marking**

- 9.5.2.1 Traffic lanes in opposing directions shall be separated by a double white safety line in tunnels with two-way traffic.
- 9.5.2.2 Traffic lanes shall be separated by a single white line in one-way traffic tunnels.
- 9.5.2.3 Visibility of the edge of the carriageway shall be aided by edge lines on both sides (in the case of one-way and two-way traffic).
- 9.5.2.4 Road markings shall comply with the regulations (see Appendix A, SIA 197).
- 9.5.2.5 Optical guidance shall be arranged at the side of the walkways to improve guidance of traffic. Detailed information is given in the ASTRA Guideline "Signalisierung der Sicherheitseinrichtungen in Tunneln".

### **9.5.3 Marking the safety equipment**

- 9.5.3.1 Important installations for the safety of users (travellers) shall be marked conspicuously.
- 9.5.3.2 Marking of the safety installations comprises:
- Signals in the SOS niches (signal SSV 4.81 "telephone" with in addition "SOS" and signal SSV 4.92 "fire extinguisher")
  - SOS alarm cabinets (coated orange, RAL 2004, with SOS and labelled with the symbols for a telephone and fire extinguisher)
  - Signalling of the emergency escape route in the traffic corridor (pictogram for the escape direction, supplemented with distance information)
  - Emergency exit (pictogram, signal AFNOR "safety installation").

- 9.5.3.3 Detailed information is given in the ASTRA Guideline "Signalisierung der Sicherheitseinrichtungen in Tunneln".

## **9.6 Monitoring and communication**

### **9.6.1 Overview of the system**

The following form part of the monitoring and communication systems:

- Emergency telephone (SOS alarm cabinet)
- Fire detectors
- CCTV traffic cameras
- Walkie-talkie (radio handset), radio and mobile telephone
- Measuring systems
- Traffic monitoring
- Weather detectors.

### **9.6.2 Emergency telephone**

- 9.6.2.1 The emergency telephone (SOS telephone) shall be installed in a cabinet together with 2 fire extinguishers (SOS alarm cabinet).

- 9.6.2.2 SOS alarm cabinets are located as follows:

- In the SOS niches
- In front of each portal (1 cabinet).

### **9.6.3 Fire detectors**

- 9.6.3.1 Tunnels provided with a ventilation system as well as tunnels with high traffic volumes and/or a high proportion of transport with dangerous goods shall be equipped with automatic fire detectors (e.g., line fire detectors in the traffic corridor).

- 9.6.3.2 Detailed information is given in the ASTRA Guideline "Branddetektion".

### **9.6.4 CCTV traffic system**

- 9.6.4.1 Tunnels over 600 m in length shall be equipped with a CCTV traffic system.

- 9.6.4.2 The CCTV traffic system serves the following purposes:

- Visual assessment of the current traffic situation
- Detection of incidents (accidents, tailback, persons driving on the wrong side of road or carriage-way, etc.)
- Archiving the data (pictures) in case of an incident.

- 9.6.4.3 Detailed information is given in the ASTRA Guideline "Verkehrsfernsehen".

### **9.6.5 Walkie-talkie, radio and mobile telephone**

- 9.6.5.1 Tunnels over 600 m in length shall be equipped with a radio system.

Checks shall be made whether a radio connection is guaranteed for tunnels of shorter length. If a radio connection cannot be guaranteed, then a radio communication system has to be installed.

- 9.6.5.2 The radio communication system shall ensure an interruption-free radio connection for the following emergency services:

- Traffic police
- Fire service (technical assistance)
- Ambulance service
- Maintenance service.

- 9.6.5.3 The radio communication system shall also be able to transmit programmes of public and private VHF stations including traffic radio (ARI).
- 9.6.5.4 Separate antenna systems shall be provided for communication with mobile telephones, if necessary.
- 9.6.5.5 Detailed information is given in the ASTRA Guideline "Funksysteme in Tunneln".

#### 9.6.6 **Measuring systems**

- 9.6.6.1 The following parameters are important for the operation of the ventilation and shall be monitored by measurements in the tunnel:
- Concentration of harmful substances (CO) of the air in the traffic corridor
  - Impairment of the visibility in the traffic corridor (especially due to the production of soot particles from diesel engines)
  - Velocity and direction of air flow in the traffic corridor.
- 9.6.6.2 The location of the measuring points shall be determined in relation to the ventilation system.
- 9.6.6.3 Measurement of poor visibility can also serve the early detection of vehicles on fire.
- 9.6.6.4 The light density shall be measured in front of the portal to control the adaptation lighting for each situation.

#### 9.6.7 **Traffic monitoring**

- 9.6.7.1 The volume of traffic shall be monitored for each traffic lane distinguishing between passenger cars and lorries provided the necessity is justified.
- 9.6.7.2 It may be beneficial in certain cases to monitor the height of vehicles. This plant shall be placed in front of the portal.

#### 9.6.8 **Weather detection**

Systems for weather detection shall be installed, which e.g., allow an early warning of ice on the road surface in the vicinity of the portal, provided this is found to be necessary.

### 9.7 **Fire-extinguishing plant**

#### 9.7.1 **Hand fire extinguishers in the SOS niches**

- 9.7.1.1 Each SOS alarm cabinet contains two hand fire extinguishers with at least 6 kg AB powder.
- 9.7.1.2 The support for the fire extinguishers has a contact, which triggers a fire alarm in the emergency services control centre when the fire extinguisher is removed from its support and switches the pictures of the CCTV traffic cameras to the sector in question.

#### 9.7.2 **Water supply pipe and fire hydrants**

- 9.7.2.1 The water supply pipe shall be designed for a discharge of at least 20 l/s. The minimum pressure at the fire hydrants shall not fall below 6 bar (0.6 mpa). The static pressure shall not exceed 15 bar (1.5 mpa).
- 9.7.2.2 The water supply pipe shall be replaceable. It shall not be cast into the concrete if placed under the walkway.

- 9.7.2.3 Electrical effects on the water supply pipe shall be taken into consideration:
  - Water supply pipes shall not be used for earthing or as electrical conductors,
  - If necessary, measures shall be taken to protect against leakage currents,
  - Earthing points shall be located in the niches.
- 9.7.2.4 Anti-freezing measures shall be considered for water supply pipes endangered by frost.
- 9.7.2.5 The position of the fire hydrants is specified in Clauses 8.8.2 and 8.8.3.
- 9.7.2.6 The detailing of the fire hydrants and the associated water supply pipe connections shall be agreed upon with the emergency services.
- 9.7.2.7 The water shall be correspondingly renewed or connected to a permanent flow to comply with hygienic regulations.

### 9.7.3 **Fire-fighting water supply**

- 9.7.3.1 The fire-fighting water supply shall be provided with a reservoir of at least 250 m<sup>3</sup> capacity. If it is possible to connect to a reservoir with a fire-fighting water reserve of 250 m<sup>3</sup> specifically for the tunnel, then a separate reservoir is not required.
- 9.7.3.2 The minimum equipment for the reservoir comprises:
  - Normal overflow
  - Water level indicator with an alarm system if the level is too low.
- 9.7.3.3 The empty reservoir shall be designed so that it can be refilled in 6 to 8 hours.

## 9.8 **Power supply**

- 9.8.1 The tunnel shall be supplied by two independent, local, electrical power supplies. In addition, an uninterruptible emergency power supply shall be provided.
- 9.8.2 The power supply comprises:
  - HV and LV switchgear
  - transformers
  - LV distribution boards (normal and emergency power supply)
  - measuring, protection and control plant
  - emergency power supplies including batteries (emergency power supply)
  - compensation plant.
- 9.8.3 The emergency supply shall ensure the uninterrupted operation of the following plant:
  - Control plant
  - Emergency lighting
  - Fire emergency lighting
  - Signalling
  - Traffic TV monitoring system
  - Emergency telephone.
- 9.8.4 The independent supply shall last one hour.  
The design shall take the age-dependent reduction of efficiency of the batteries into consideration.
- 9.8.5 The regulations governing electrical plant of different voltage levels shall be taken into consideration.

## **9.9 Ancillary tunnel facilities**

### **9.9.1 Installations**

9.9.1.1 Building Services are generally required in ancillary tunnel facilities, in particular in the control centres. The following may be required:

- Heating, ventilation and air-conditioning HVAC Plant
- Sanitary Installations
- Electrical plant
- Fire alarm systems.

9.9.1.2 The building services systems shall be designed to comply with the relevant regulations for building services.

### **9.9.2 Operating plant**

9.9.2.1 Further plant may be required for operations and maintenance of the tunnel in certain cases, such as:

- pumping plant
- passenger and goods lifts
- lifting plant
- shaft lifts.

9.9.2.2 The relevant Regulations shall be specified on a case-by-case basis in the Basis of Design.



## APPENDIX A DESIGN LIFE (informative)

### A.1 Remarks

The following data supplies nominal values.

Maintenance of the structures and adequate servicing of the operating and safety plant is presupposed.

Generally, the lower value for the design life shall be adopted for the calculation of economic viability.

### A.2 Structure

Table 1 Design life of components

Component	Design life Years									
	20	30	40	50	60	70	80	90	100	
Support lining (unreinforced concrete)							X	X	X	
Support lining (reinforced concrete)							X	X	X	
Waterproofing							X	X	X	
Intermediate slab					X	X	X			
Carriageway support slab					X	X	X			
Lining (prefabricated elements)			X	X	X					
Seepage/drainage pipe (slotted pipe)					X	X	X			
Kerb					X	X	X			
Carriageway surfacing	X	X								
Surface protection (tunnel walls)	X	X								
Service duct in fill							X	X	X	
Drain pipes					X	X	X			
Fire hydrant pipe			X	X	X					
Ventilation duct (reinforced concrete)							X	X	X	
Ventilation duct (steel)			X	X	X					
Cable tray in the traffic corridor		X	X							
Cable tray in the service duct					X	X	X			
Miscellaneous metalwork (steel)		X	X							
Metal doors, etc. (traffic corridor)		X	X							

### A.3 Operating and safety plant

Table 2 Design life of services (components)

Installation component	Design life									
	Years	10	15	20	25	30	35	40	45	50
<b>Control Plant</b>										
Primary (overriding) control system		X	X							
Traffic control system		X	X							
Control points			X	X						
<b>Lighting</b>										
Lights					X	X				
Ballast devices			X	X						
Control systems		X	X							
<b>Ventilation</b>										
Jet fans				X	X					
Axial fans					X	X				
Control systems		X	X							
CO-measuring plant				X	X					
Visibility measuring plant				X	X					
Ventilation flaps			X	X						
Sound absorbers						X	X	X		
<b>Controlling traffic</b>										
Fixed signals				X	X					
Active signals, mechanical and electro-optical				X	X					
<b>Monitoring and communication</b>										
Emergency telephone (SOS cabinet)				X	X					
Fire alarm plant				X	X					
CCTV traffic camera		X	X							
Radio plant			X	X						
Height control, electrical		X	X							
Operating telephone plant			X	X						
<b>Fire-fighting plant</b>										
Hand fire extinguisher (SOS niche)		X	X							
Fire hydrants								X	X	X
<b>Power supply</b>										
HV and LV switchgear					X	X				
Transformers						X	X	X		
LV distribution panels					X	X				
Uninterruptible power supply plant				X	X					
Batteries (with acid filling)			X							
Batteries (with gel filling)		X								
<b>Cabling</b>										
Copper (Cu) cable						X	X			
Fibre optic cable				X	X					

## APPENDIX B FIRE LOAD (informative)

### B.1 Initial situation

A fire can develop quickly, even within a matter of minutes, with heat (very high temperatures) and smoke (with toxic gases) being developed.

Heat and smoke quickly make it impossible for unprotected persons to remain in the tunnel. Protected persons (fire service personnel with special fire-fighting clothing and breathing apparatus) can endure these effects much longer. The resistance of structures suffices in general for a strong fire action of longer duration.

The fire resistance of the structural components shall correspond to the risk to which they are subjected. The requirements shall be specified for each structural component.

### B.2 Basic safety principles in the case of fire

The safety aims in the case of fire are given by the following principles:

- Persons who are in the tunnel at the outbreak of fire should be able to save themselves.
- The intervention of the emergency services shall take place under safe conditions.
- Excessive damage shall be prevented by means of suitable measures.

### B.3 Limiting conditions for protected persons

The limiting conditions for the employment of protected fire-fighting personnel correspond to a temperature of 400 to 450 °C and a thermal radiation of 5 kW/m<sup>2</sup>.

### B.4 Fire load of vehicles

B.4.1 The possible fire load and the temperatures reached under different boundary conditions have been investigated by carrying out tests in tunnels.

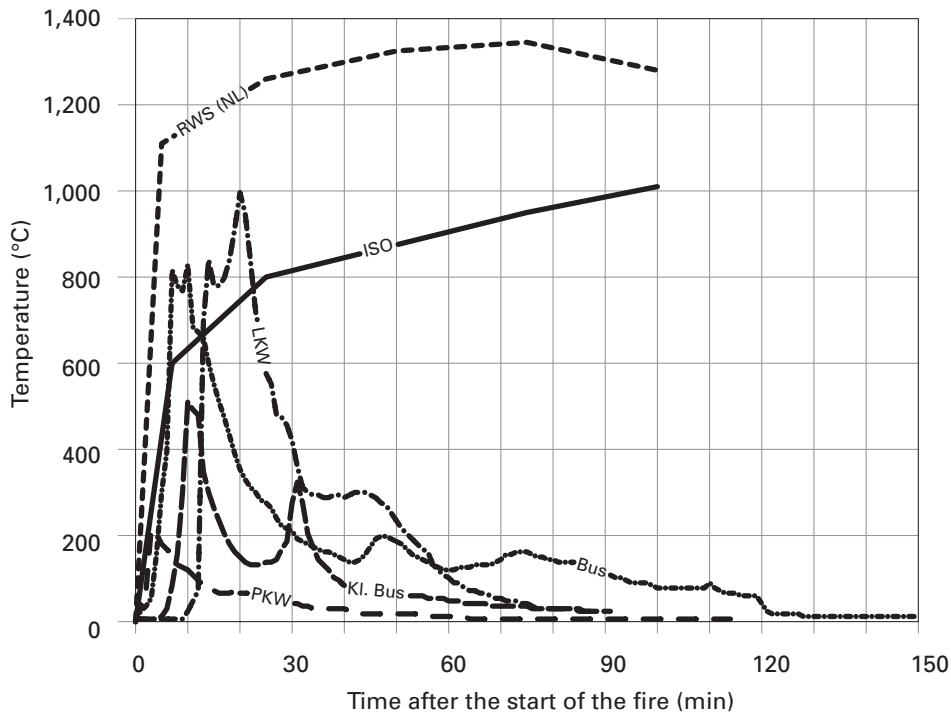
The fire energy and the corresponding fire temperature are given in Table 3.

Table 3 Fire energy and fire temperature, summarised from [1]

Type of Vehicle	Approximate fire energy released MJ	Maximum fire temperature reached °C
Private car	3,000–6,000	200
Vehicles made of plastic	7,000	500
Minibus/van		700
Bus	41,000	820
Hazardous material transport (TIR)	65,000	1,000
Heavy lorry	88,000	1,200
Tanker with 50 m <sup>3</sup> petrol not escaping into the drains	1,500,000	1,400

The temperature–time curve obtained from the EUREKA tests is shown in Figure 4 for different vehicles in comparison with two well-known standard fire curves.

Figure 5 Temperature–time curve from EUREKA tests [1]



#### B.4.2 Explanation of the results

The fire spreads very quickly (5 to 10 min) after the start of the fire. The temperature rise is steeper than the ISO curve for almost all vehicle types.

The maximum temperature reached and the duration of the fire depend on the vehicle type (see also Table 3).

The Dutch fire scenario takes into consideration tunnels that cross a waterway (e.g., tunnels floated into place). Therefore a worst-case scenario is assumed for the effects of the fire.

The Dutch design curve (RWS) is based on a tanker with a capacity of 50 m<sup>3</sup> hydrocarbons (petrol or kerosene) catching fire. Assuming that the tanker is filled to 90% capacity, this corresponds to 45,000 l with a density of 720 kg/m<sup>3</sup>, this gives a weight of 32.4 t petrol. The specific combustion energy of petrol is 43.5 mj/kg; thus this produces total fire energy of 1,409,000 mj.

The RWS curve was determined in a large-scale model test (length = 8 m, width = 2 m, height = 2 m), in which the petrol is assumed to burn in 4 tanks. Maximum temperatures of 1,350 °C were measured. Such temperatures (over 1,300 °C) were also measured in in-situ fire tests in the Ofenegg Tunnel (1965) in Switzerland, in the Zwenberg Tunnel (1975) in Austria und in the Memorial Tunnel (1993–1995) in the USA.

### B.5 Design curves (temperature–time curve)

B.5.1 The design (i.e., dimensioning) curves are practically the same for the short-term loading. The temperature increases quickly in the first few minutes, partly independent of the size of the vehicle and the fire energy. This rise is responsible for the development of heat and smoke and determines the period during which people can stay in the tunnel.

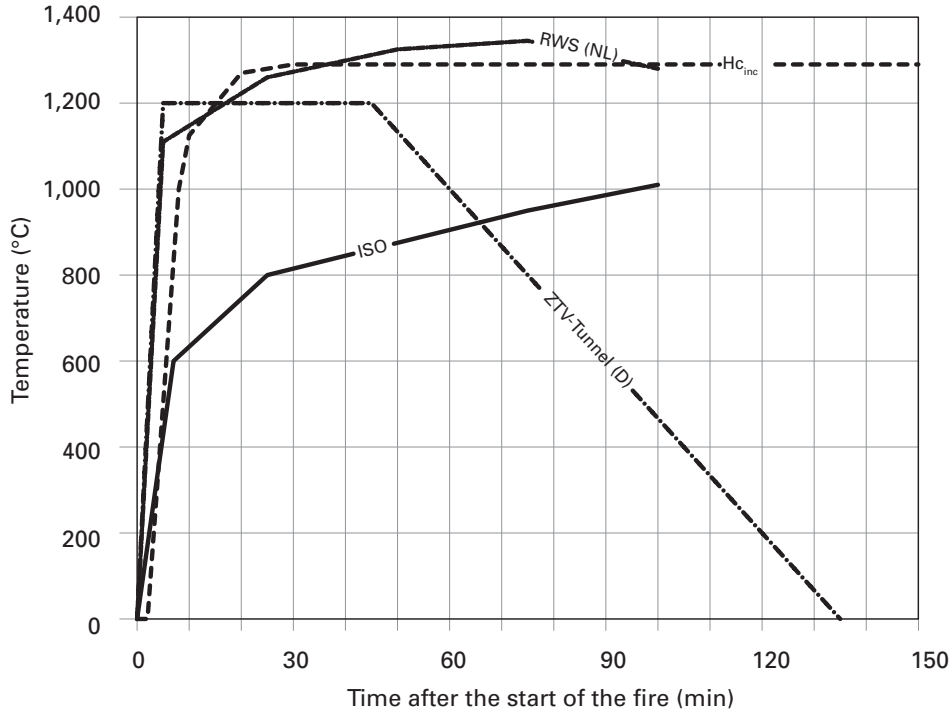
The subsequent development is important for the structure and other structural components of the tunnel, especially if there are special risks.

B.5.2 The following design curves are shown in Figure 6:

- ISO 834
- Dutch design curve RWS (Rijkswaterstaat)
- Modified hydrocarbon curve  $HC_{inc}$
- German regulation ZTV-Tunnel.

The modified hydrocarbon curve is the curve given in Eurocode EC1 increased by a factor 1,300/1,100. The design curve in EC1 only reaches a maximum temperature of 1,100°C.

Figure 6 Design curves



## B.6 Design recommendations

B.6.1 The actions depend on

- the type of vehicle (above all proportion of heavy transport) and thus the possible fire load.
- the consequences of damage caused by the fire (e.g., collapse of a substantial part of the structure).

B.6.2 For dimensioning purposes, the design curves listed in Table 4 shall be used, adapted to the AIPCR Recommendation.

Table 4 Choice of design curve and fire load duration

	Tunnel (Structure)				Secondary components
<b>Tunnel</b>	Tunnel floated into place, tunnel below or through a building	Tunnel in weak or unstable rock	Tunnel in firm rock	Cut-and-cover tunnel	Ventilation ducts and intermediate slab
<b>Vehicle</b>					
Cars and vans	ISO 60 min	ISO 60 min	ISO <sup>2)</sup> 60 min	ISO <sup>2)</sup> 60 min	ISO 30 min
Lorries and tankers	RWS/HC <sub>inc</sub> <sup>1)</sup> 120 min	RWS/HC <sub>inc</sub> <sup>1)</sup> 120 min	ISO <sup>3)</sup> 120 min	ISO <sup>3)</sup> 120 min	ISO 120 min

Comments on Table 4:

- <sup>1)</sup> For a high proportion of tankers with combustible liquids AIPCR recommends a fire duration of 180 min.
- <sup>2)</sup> The structural resistance is generally not critical.
- <sup>3)</sup> The structural resistance is generally not critical. In case of special risks, e.g., with a shallow tunnel running just below a building, a higher fire load specified for each object shall be taken into consideration if necessary.

#### References

- [1] AIPCR/PIARC; Association mondiale de la route, *World Road Association* (1999); *Maîtrise des incendies et des fumées dans les Tunnels routiers, Fire and Smoke Control in Tunnels*. 288 pages
- [2] PIARC Technical Committee C-5 (2003); Design criteria for Structure resistance to Fire.
- [3] SN EN 1991-1-2: 2003; Einwirkungen auf Tragwerke, Teile 1–2

## **APPENDIX C    EXAMPLES OF STANDARD CROSS-SECTIONS** (informative)

- C.1        The examples below show the different standard cross-sections for a:
- cut-and-cover tunnel of rectangular cross-section without longitudinal ventilation (Figure 7)
  - mined tunnel without invert with removal of extracted air (Figure 8)
  - mined tunnel with invert and axial ventilation (Figure 9)
  - mined tunnel with service duct and removal of extracted air (Figure 10).
- C.2        The examples are intended to show various possibilities for the arrangement of the plant and the pipes following the regulations laid down in this Standard. The standard cross-sections have to be adapted to the project-specific requirements for each individual case.
- C.3        The service pipes (cable duct block, fire hydrant pipe) shall be carefully coordinated with the concept for the drainage structures (seepage pipe for groundwater, drainage pipe for groundwater and operations water).  
The following should be noted here:
- Space requirements for control and flushing ducts as well as cable ducts
  - Space requirements for crossing pipes and branching
  - Structural requirements in the vicinity of the arch abutment.
- C.4        No seepage or drainage pipes are shown in the drainage layer. Their necessity depends on the size and permeability of the drainage layer.
- C.5        A large part of the cross-section is not used for traffic corridor equipment in a circular cross-section, at the base of the tunnel, and can be used to accommodate the service duct.
- C.6        The carriageway camber can be obtained by:
- Rotation of the whole design cross-section about its centre (effective centre in the case of circular sections, fictitious centre for other shapes of cross-section).  
The distance between the tunnel axis and the carriageway axis is variable.
  - Rotation of the running surface about the middle of the carriageway without changing the design cross-section.  
The distance between the tunnel axis and the carriageway axis is constant (often equals zero).

Figure 7 Cut-and-cover tunnel of rectangular cross-section without axial ventilation

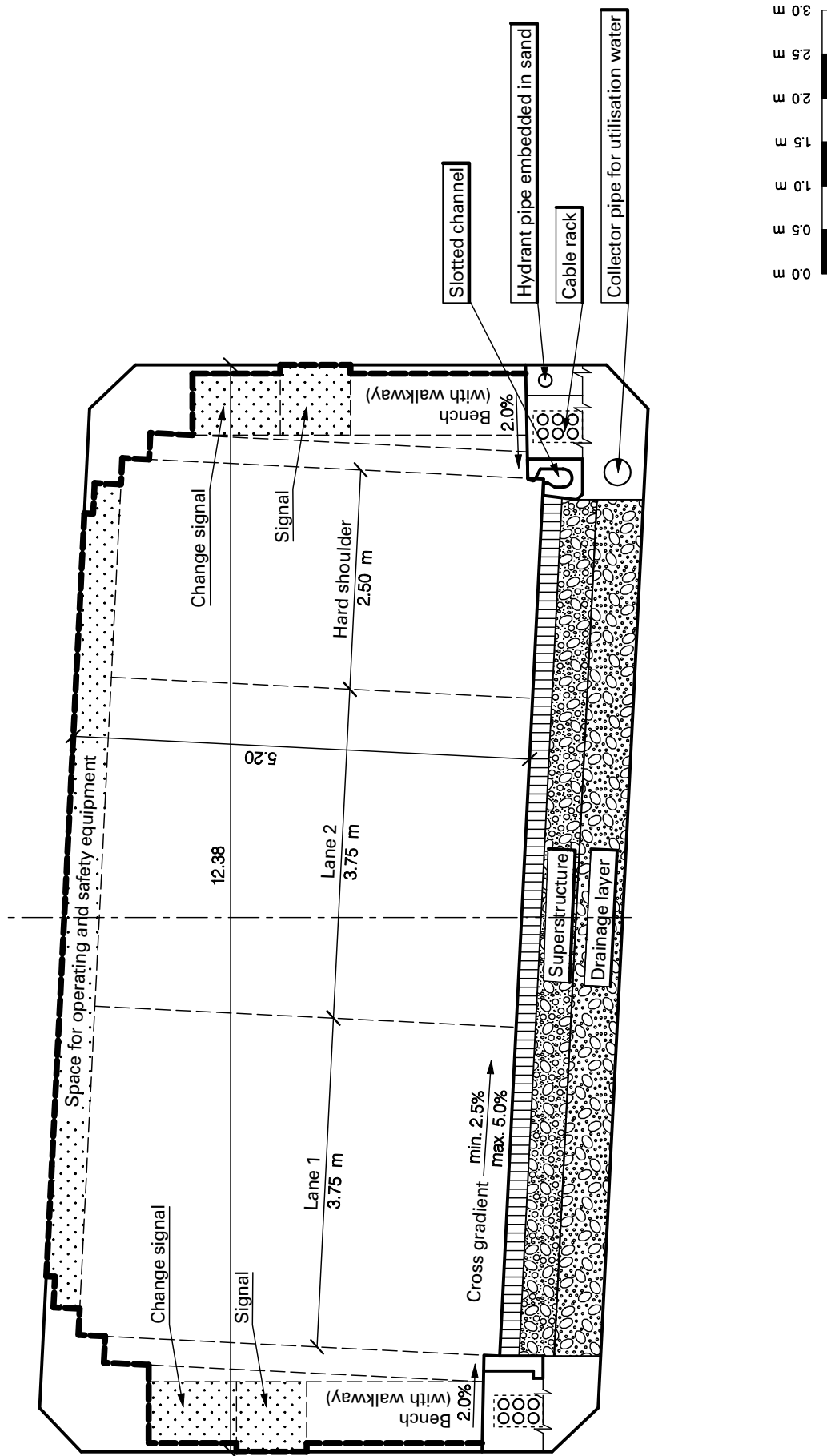


Figure 8 Conventionally excavated tunnel without invert but with removal of extracted air

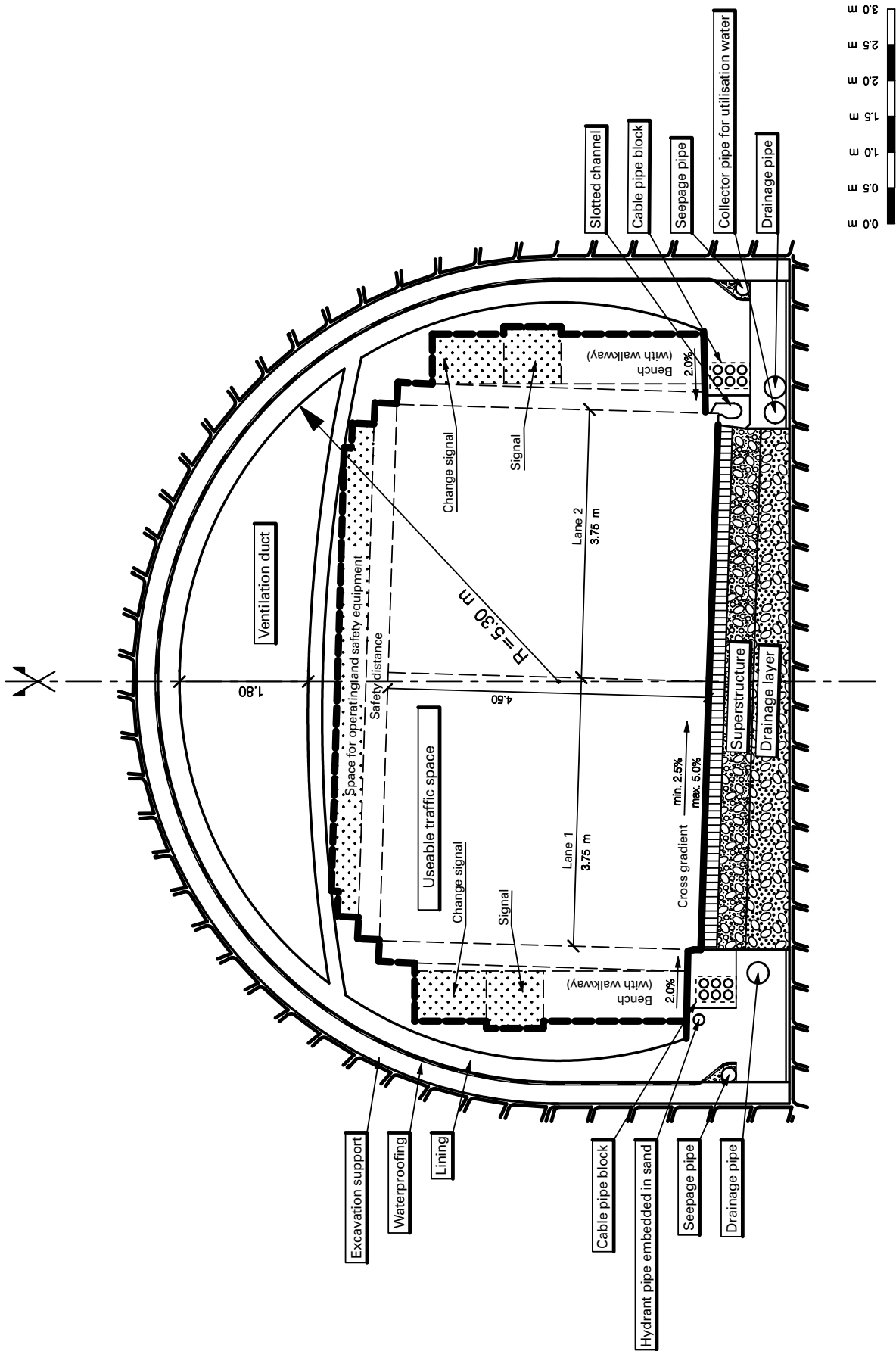


Figure 9 Conventionally excavated tunnel without convert but with removal of extracted air

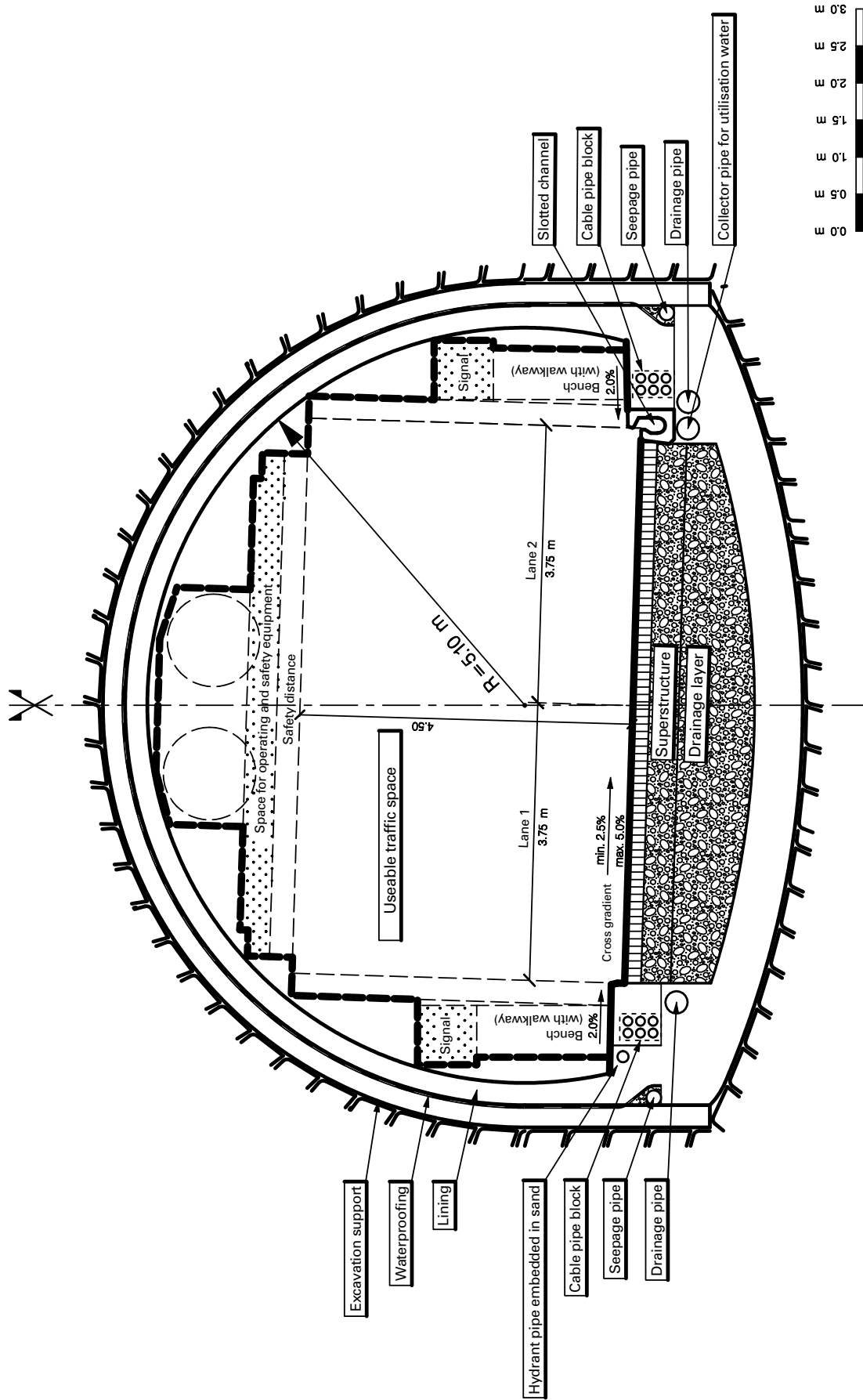
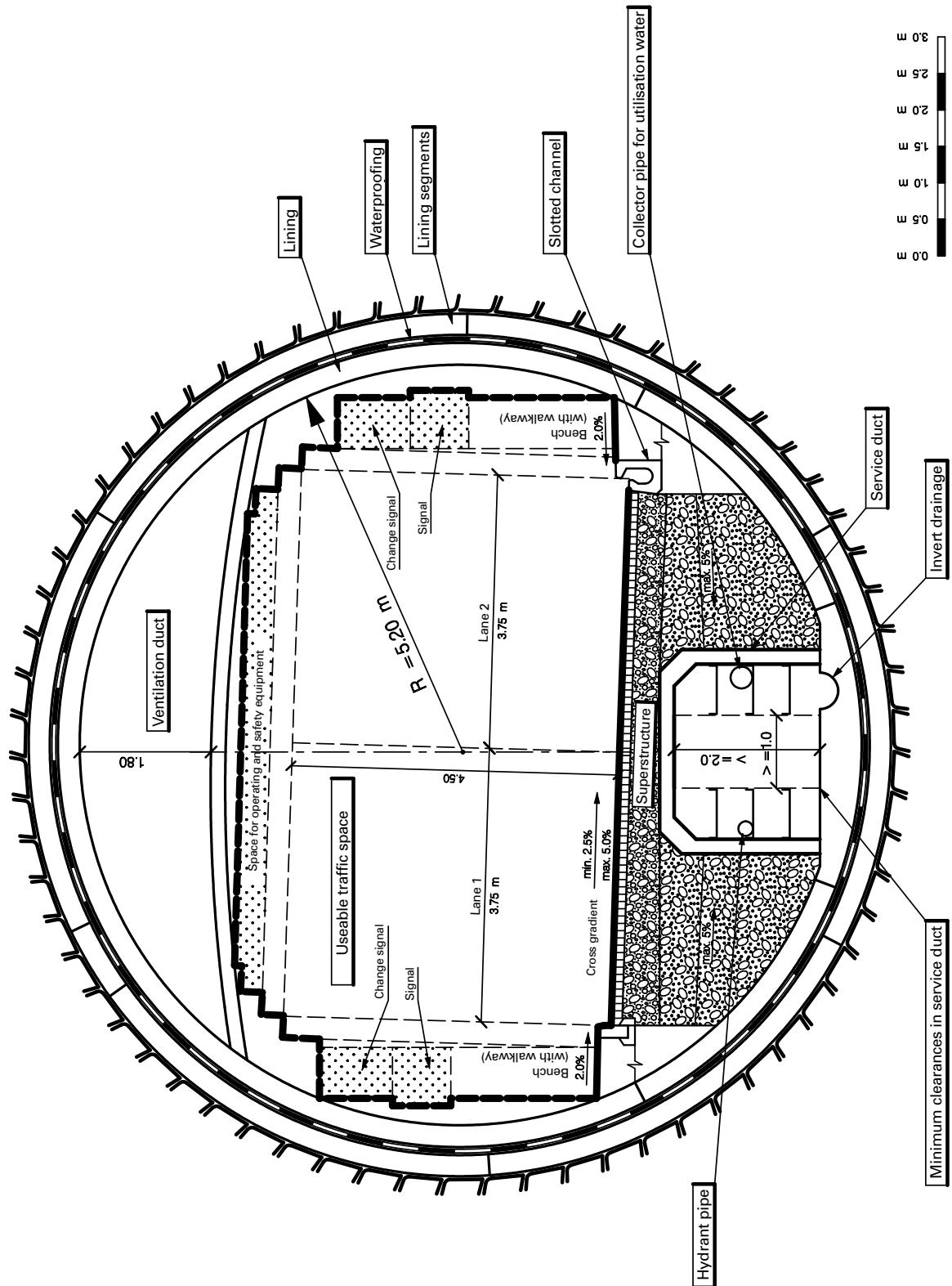


Figure 10 Conventionally excavated tunnel with service duct and removal of extracted air





## APPENDIX D EXAMPLE OF AN ACTION MATRIX FOR A TWIN-TUBE TUNNEL (informative)

<b>Monitoring system and triggering action</b>		Tunnel fire alarm plant	Building fire alarm service	Emergency telephone	CCTV traffic camera (detection of incidents)	Traffic control centre (1)	Operating control centre (2)
<b>Operating system and triggering action</b>	Tunnel ventilation	Fire alarm Switch to fire operating state	Fire alarm -	Emergency call -	Incident -	Manual command Operating state - fire - accident - maintenance (depending on manual command)	Manual command All operating states (depending on manual command)
	Traffic control centre	Alarm the emergency services control centre	Alarm the emergency services control centre	Receiving the emergency call	Alarm the emergency control centre	-	-
	Fire alarm control centre	Alarm the fire services alarm centre	Alarm the fire services alarm centre	-	-	-	-
	CCTV traffic camera	Switching on several cameras	-	Switching on several cameras	Switching on several cameras	Normal operation	Normal operation
	Tunnel lighting - through passage lighting - adaptation lighting - fire emergency lighting	Set switches to max. level - Switching on	-	-	-	Normal operation	Normal operation
	Traffic control system	Tunnels with fire: close (switch traffic lights at portals to red)	Affected tunnels: close traffic lanes	Tunnels with emergency telephone: warning (switch traffic lights at portals to blinking)	For person driving on wrong side of road or wrong carriageway: close tunnel (switch traffic lights at portals to red)	Normal operation	Normal operation
	Building ventilation	Tunnels without fire: close (switch traffic lights at portals to red)	Unaffected tunnels: -	Tunnels without emergency telephone: -	For stationary vehicle: issue warning (switch traffic lights at portals to blinking)	-	-
	-	-	Close the fire flaps	-	-	-	-

(1) Emergency services control centre = police headquarters (2) Operating control centre = central office of maintenance services



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Represented organizations in the commission SIA 197 and in the Working group SIA 197/2

ASTRA Federal Roads Office (FEDRO)

BAV Federal Office of Transport (FOT)

BUWAL Federal Office for the Environment (FOEN)

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**Acceptance and coming into force**

The central committee for Standards and Regulations accepted the present SIA 197/2 on 26/08/2004.

It comes into force on 01/10/2004.

It replaces together with the Standards SIA 197 and 197/1 Sections 1 and 2 of the Standard SIA 198, Edition 1993.

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