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SIA 197:2004 Civil Engineering

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REGISTERED CODE OF THE SWISS STANDARDS ASSOCIATION

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

Projets de tunnels – Bases générales
Progettazione di gallerie – Basi generali
Projektierung Tunnel – Grundlagen

Design of Tunnels
Basic Principles

197

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CONTENTS

FOREWORD

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

The present codes:

– 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 the execution of construction works.

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

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

The regulations for the execution of underground structures are dealt with in the code SIA 198.

Committee for SIA 197

0 SCOPE

0.1 Limitations

0.1.1 The code SIA 197 *Design of Tunnels – Basic Principles* defines the rules for the design of traffic tunnels. Management aspects (use, operation and maintenance) are treated only insofar as they are relevant for design.

0.1.2 The code SIA 197/1 *Design of Tunnels – Railway Tunnels* defines the specific rules for the design of railway tunnels including the corresponding ancillary structures.

0.1.3 The code SIA 197/2 *Design of Tunnels – Road Tunnels* defines the specific rules for the design of road tunnels including the corresponding ancillary structures.

0.1.4 The three codes apply to the design and layout of the tunnel (infrastructure concept) independent of whether the tunnel is constructed by underground excavation or by the cut-and-cover method.

0.1.5 The requirements of Section 7 apply to the design of underground structures.

0.1.6 For the design of structures by the cut-and-cover method the codes SIA 260 to SIA 267 are applicable. This is also true for the structures needed for the interior finish, provided the present code does not stipulate otherwise.

0.1.7 The code SIA 198 *Underground Structures – Execution* details the requirements for the construction materials and the most important regulations regarding execution (underground structures excluding interior finish).

0.1.8 The codes SIA 197, 197/1 197/2 and 198 may be applied analogously for changes to existing traffic tunnels.

0.1.9 The code SIA 197 may also be applied in a general sense for other underground structures, e.g.
- galleries for water and pipes
- caverns of all types
- vertical or inclined shafts.

0.2 Normative references

0.2.1 Technical specifications

0.2.1.1 For the design of cut-and-cover structures (Section 0.1.6) the present code is valid in combination with the following codes (some of which do not exist in English translation):

SIA 260	Basis of structural design
SIA 261	Actions on structures
SIA 261/1	Actions on structures – additional requirements
SIA 262	Concrete structures
SIA 262/1	Concrete structures – additional requirements
SIA 263	Steel structures
SIA 263/1	Steel structures – additional requirements
SIA 267	Geotechnical design
SIA 267/1	Geotechnical design – additional requirements
SN EN 206-1:2000	Concrete – Part 1: Definition, properties, manufacture and conformity

0.2.1.2 Reference shall be made to the codes, recommendations and guidelines listed below. These apply in full or in part, depending on the sense of the reference:

SIA 179	Fixings in concrete and brickwork
Recommendation SIA 196	Tunnel ventilation during construction
SIA 198	Underground Structures – Execution
Recommendation SIA 199	Mapping the geological conditions in underground-construction
SIA 272	Waterproofing and drainage in underground works
Recommendation SIA 430	Management of construction waste
Recommendation SIA 431	Drainage of construction sites
SIA 469	Maintenance of structures

0.2.1.3 If a code, recommendation or guideline referred to is replaced by a new publication, then from this point in time the pertinent references apply analogously for the corresponding requirements in the new publication.

0.2.2 **Legal requirements**

The most important Swiss federal regulations are listed in Appendix A.

0.3 General contract conditions

0.3.1 The code SIA 118/198 *General Conditions for Underground Construction* contains the contract conditions for underground construction works that serves as a basis for the contract between the owner and the contractor.

0.3.2 For the structures conforming with Section 0.1.6 the general conditions that are applied in a particular case are those for the specific construction method employed.

0.4 Deviations from the code

0.4.1 Deviations from the present code are permissible, provided they are justified by the existing boundary conditions and new developments or new knowledge. The structural safety and serviceability nevertheless shall be verified in all cases.

0.4.2 These deviations shall be explained and justified in the service criteria agreement and documented in the basis of design.

1 TERMINOLOGY

1.1 Technical terms

analytical model *Berechnungsmodell* *modèle d'analyse* *modello di calcolo*	Combination of physical quantities (e.g. force and deformation quantities) by means of corresponding relationships (e.g. equilibrium conditions, material laws and kinematic conditions). Sometimes referred to as the computational model.
characteristic line method *Kennlinienverfahren* *méthode convergence – confinement* *metodo convergenza – confinamento*	Method for determining the rock pressure on the basis of the stress–strain characteristics of the lining and the ground.
clearance profile *Lichtraumprofil* *gabarit d'espace libre* *sagoma limite o profilo dello spazio libero*	Space for the traffic, determined by the basic dimensions, kinematic envelope and safety margins.
conservative expected value *Vorsichtiger Erwartungswert* *valeur probale prudente* *volore probabile prudente*	A prudent value with an adequate safety margin compared to the estimated expectancy value to provide the required reliability.
continuum model *Kontinuumsmodell* *modélisation d'un milieu continu* *modello del continuo*	Model in which the ground is divided in finite elements to obtain a numerical solution.
design section *Sollprofil* *profil cible* *profilo teorico*	Minimum theoretical tunnel cross-section.
sliding mass model *Bruchkörpermodell* *modèle de blocs* *modello dei corpi disgiunti*	Numerical model consisting of blocks simulating a failure mechanism.
double-shell lining *Ausbau, zweischalig* *revêtement double coque* *rivestimento a doppio anello*	Lining consisting of the temporary support and the inner lining separated by an intermediate layer (in general the waterproofing).
drainage *Entwässerung* *épuisement des eaux* *smaltimento delle acque*	Measures to collect and discharge water and other liquids.
drainage system *Entwässerungsanlage* *système de drainage* *sistema di drenaggio*	The entirety of the measures adopted for the purpose of drainage.
equipment *Ausrüstung* *équipement* *equipaggiamento*	Equipment that is necessary for the operation and the safety of the user, including the ventilation.
geotechnical auxiliary measure *Bauhilfsmassnahme* *mesures de stabilisation* *provedimento preventivo di stabilizzazione*	Measure that is part of the excavation process, but implemented ahead of it, in order to ensure working safety and the stability of the underground opening.

ground model *Gebirgsmodell* *modèle du massif* *modello dell'ammasso roccioso*	Idealised description of the ground (rock and soil) in terms of geometrical and geotechnical values.
groundwater *Bergwasser* *eau du massif* *acqua d'infiltrazione*	Water that flows from the rock into the underground opening or acts on the lining.
hazard *Gefährdung* *menace* *pericolo*	Circumstance that presents a danger to persons, the environment or material assets.
hazard scenario *Gefährdungsbild* *situation de risque* *situazione di pericolo*	Description of a critical situation or an undesirable event for a structure and/or its surroundings.
homogeneous zone *Homogenbereich* *zone homogène* *zona omogenea*	Zone in which the rock and ground properties lie within prescribed limits.
infrastructure *Infrastruktur* *infrastructure* *infrastruttura*	Comprises the structure and its ancillary components (operating and safety equipment).
lining (inner) *Verkleidung* *revêtement* *rivestimento*	Measures additional to the temporary support or executed separately, which provide the structure (arch) with the necessary properties (bearing capacity, shape, appearance, etc.).
loosening pressure *Auflockerungsdruck* *charge de dislocation* *carico dei corpi disgiunti*	The contact pressure between the rock and the lining that results from the self-weight of broken rock and joint material.
modification *Veränderung* *modification* *modifica*	Changes made to the structure to adjust to new requirements.
single-shell lining (monocoque lining) *Ausbau, einschalig* *revêtement simple coque* *rivestimento ad anello semplice*	Lining consisting of the temporary support and the inner lining which are connected together by friction and interlocking action.
principle of resistance *Widerstandsprinzip* *principe de résister à la pression* *principio di resistenza alla pressione*	Constructional measures aimed at resisting the ground pressure and preventing ground deformation.
running surface *Fahrebene* *plan de roulement* *piano di scorrimento*	Plane defined by the top of the rails (railways) or the road surface (roads).
risk *Risiko* *risque* *rischio*	Hazard quantified by means of probability of occurrence and amount of damage.

effective ground pressure *Echter Gebirgsdruck* *pression effective du massif* *pressione efficace dell'ammasso roccioso*	Contact pressure at the rock-lining interface and the lining due to time-dependent stress redistribution resulting from inelastic ground deformations.
ground resistance *Gebirgswiderstand* *résistance du massif* *resistenza dell'ammasso roccioso*	Limit of bearing capacity of ground.
roof load *Firstauflast* *charge de sollicitation du revêtement en calotte* *carico sul rivestimento in calotta*	Surcharge on the lining due to the self-weight of the overlying rock (special case of loosening pressure).
safety analysis *Sicherheitsanalyse* *analyse de la sécurité* *analisi di sicurezza*	Method of determining the required safety measures.
traffic space *Fahrraum* *gabarit ou espace de circulation* *vano di circolazione*	Utilisable space within the design section that is not occupied by equipment.
space for (technical) equipment *Raum für Ausrüstungen* *espace pour équipement* *spazio per equipaggiamento*	Space for the arrangement of operating and safety equipment including ventilation installations, e.g. jet fas.
space for later construction measures *Raum für spätere bauliche Massnahmen* *espace pour interventions constructives ultérieur* *spazio per interventi costruttivi ulteriori*	Space for constructional measures that are implemented later (after putting into operation).
space for tolerances *Raum für Abweichungen* *espace pour écarts* *spazio per imprecisioni / deviazioni*	Space for the compensation of unavoidable deviations that may arise later.
standard cross-section *Normalprofil* *profil normal / coupe type* *profilo normale / sezione tipo*	Representation of the typical cross-section with information on the temporary support, waterproofing, drainage, lining and internal structural components, together with the usable space and the operating equipment.
structural model *Tragwerksmodell* *modèle de la structure* *modello strutturale*	Result of bounding and idealising the structural system.
structure *Tragwerk* *structure porteuse* *struttura portante*	Total system of structural elements and ground necessary to maintain equilibrium and the shape of the structure.
substructure *Unterbau (Sohle)* *infrastructure* *sottostruttura*	All the layers beneath the superstructure that transmit the loads to the ground.
superstructure *Oberbau* *voie de circulation / chaussée* *sovrastruttura*	All the layers above the substructure that support and distribute the traffic loads.

swelling pressure *Quelldruck* *pression de gonflement* *pressione di gonfiamento*	Stress developed at the contact between the ground and the tunnel lining arising in swelling rock when volume expansion is prevented.
temporary support *Ausbruchsicherung* *soutènement* *provedimenti di sicurezza*	Measures to ensure working safety and stability and to limit rock deformations in the vicinity of the excavated opening during execution.
rail track / road pavement *Gleiskörper / Strassenkörper* *structure de la voie / de la route* *sopra e sottostruttura del binario / della strada*	Comprises the superstructure and the substructure of the rail track or the road.
tunnel system *Tunnelsystem* *système des tunnels* *sistema di gallerie*	All the structures required for a particular project (rail or road tunnel) to achieve its planned use.
tunnel support *Ausbau* *soutènement et revêtement* *provvedimenti di sicurezza e rivestimento*	Measures to ensure stability and limit the deformations of the excavated underground opening during construction and use; consists of the temporary support and the lining.
type of support *Sicherungstyp* *type de soutènement* *tipo di provedimenti di sicurezza*	Pre-defined temporary support measures (proposal for execution) for different ground conditions and dimensioning situations.
usable space *Nutzraum* *espace utile* *spazio utile*	Total usable space above the running surface, which is bounded by the design section; comprises the space for traffic, constructional purposes and ventilation.
usable space for constructional purposes *Nutzraum, bautechnisch* *espace utile constructif* *spazio utile costruttivo*	Space for constructional purposes, consisting of space for tolerances and space for later constructional measures.
usable space for traffic *Nutzraum, verkehrstechnisch* *espace utile pour le trafic* *spazio utile per il traffico*	Space for traffic purposes, representing the total amount of space which is available for traffic and space for equipment.
usable space for ventilation *Nutzraum, lüftungstechnisch* *espace utile pour installations de ventilation* *spazio utile per le installazioni della ventilazione*	Space for the arrangement of ventilation ducts.
utilisation water *Betriebswasser* *eaux de l'exploitation* *acqua d'esercizio*	Water resulting from the use of the structure.
walkway *Bankett* *banquette / trottoir / chemin latéral* *banchina / marciapiede*	Strip beside carriageway (between carriageway and wall of tunnel), which serves as a walkway or escape route in the case of critical events.
waterproofing *Abdichtung* *étanchéité* *impermeabilizzazione*	Measures to prevent the infiltration of water (to protect structural components or underground facilities) or to prevent a loss of liquid from an underground chamber.

waterproofing concept *Abdichtungskonzept* *concept d'étanchéité* *concetto d'impermeabilizzazione*	The various compatible components that provide the waterproofing and drainage functions.
waterproofing system *Abdichtungssystem* *système d'étanchéité* *sistema d'impermeabilizzazione*	The various compatible components that constitute the waterproofing system.
principle of yielding supports *Ausweichprinzip* *principe de libération des contraintes* *principio di allentamento delle tensione*	Aim is to reduce rock pressure by allowing a controlled deformation of the rock using constructional measures.

1.2 Technical terms for rail tunnels

ballastless track *Feste Fahrbahn (schotterloser Oberbau)* *voie de circulation fixe (sans ballast)* *binario a soprastruttura rigida*	Track system with support of tracks on a bearing slab or bearing layer without ballast.
catenary *Fahrleitung* *ligne de contact (caténaire)* *linea di contatto (catenaria)*	Support system of overhead wire or (live) conductor rail for the traction energy supply of electric railways.
contact wire *Fahrdraht* *fil de contact* *filo di contatto*	Part of the contact line (sliding wearable connector of the vehicle current collector).
earthing *Erdung* *mise à terre* *messa a terra*	Earth connections, earthing wires and other electrically conducting objects connected to one another.
free cross-section *Tunnelquerschnittsfläche, freie* *section transversale libre* *sezione trasversale libera*	Aerodynamically free cross-sectional area above the top of the rails minus the space required for constructional purposes.
track heaving reserve *Hebungsreserve* *réserve de relevage* *riserva per rincalzo*	Precautionary safety margin with regard to the height dimensions in the clearance profile to take into account lifting of the track during maintenance work (tamping in the case of ballast track, correction of track position for a fixed track).
reference line *Bezugslinie* *ligne de référence* *linea di riferimento*	Kinematic line of demarcation of rail vehicles and freight (see AB-EBV, Appendix A.3).
safety niche *Personenschutznische* *niche de protection pour le personnel* *nicchia per la protezione del personale*	Protected area for personnel who have to work in the tunnel during rail operations.
space for contact line (catenary) *Fahrleitungsraum* *espace autour de la caténaire* *spazio intorno alla catenaria*	Space above the pantograph space (see AB-EBV, Appendix A.3) for the contact line including the electrical safety gap.

space for pantograph *Stromabnehmerraum* *espace pour le pantographe* *spazio per il pantografo*	Space for pantograph (current collector) including the voltage-dependent electrical safety gap.
tolerance of track position *Gleislagetoleranz* *tolérance de l'assiette de la voie* *tolleranza della posizione del binario*	Construction and operating tolerance of the track.
top of rail *Schienenoberkante (SOK)* *niveau supérieur du rail (NSR)* *livello superiore della rotaia (LSR)*	1. Position of the running surface in the cross-section, 2. Height of the track axis in the cross-section (reference height).
track axis *Gleisachse* *axe de la voie* *asse del binario*	Geometrical axis of the rails (line in the running surface in the middle between the rails), defining the horizontal and vertical alignment of the rails.
track bearing slab *Gleistragplatte* *dalle de roulement* *piattabanda*	Base for a fixed track (ballastless track).
track position *Gleislage* *assiette de la voie* *posizione del binario*	Defined by the height (reference height), the lateral position, the cross gradient (warping) and the gauge of the track.

1.3 Technical terms for road tunnels

carriageway *Fahrbahn* *chaussée* *carreggiata*	Part of the road specifically for traffic.
drainage of the carriageway *Fahrbahnentwässerung* *evacuation des eaux de la surface de roulement* *smaltimento delle acque della carreggiata*	Lateral drainage of the carriageway surface with lateral and longitudinal gradients.
monitoring system *Erfassungsanlagen* *équipement de saisie* *equipaggiamento di rilevamento*	Comprises all technical equipment necessary for operation, such as fire warning systems, measuring systems for lighting and ventilation, etc.
surface of carriageway *Fahrbahnoberfläche* *surface de roulement* *carreggiata*	Surface of the wearing course.

1.4 Technical terms in other languages

Technical terms in several languages are to be found in the following publications:
- Code SN 640 302 "Strasse und Gleiskörper; Terminologie", Edition of June 2000
  Languages: German, French, Italian and English.
- Association mondiale de la Route (AIPCR), Multilingual Dictionary on CD-ROM
  Languages: German, French, English and Spanish.

2 BASIC PRINCIPLES

2.1 General

2.1.1 The service criteria agreement forms the basis of design. It has to be checked for every stage before each planning phase and if necessary adjusted. This also applies to documents derived from it.

2.1.2 The service criteria agreement defines:
- planned use of the structure
- requirements for the equipment (functional requirements)
- requirements for user safety
- design working life
- requirements for waterproofing
- influence of the structure on the environment
- influence of the environment on the structure.

2.1.3 Knowledge of the ground properties is of great importance in tunnelling. The properties shall be assessed according to the object-specific requirements (see Section 3).

2.1.4 The design must allow the requirements of working safety and health protection to be fulfilled and ensure user safety (see Section 4). The choice of the tunnel system is hereby of decisive influence.

2.1.5 The design must allow the requirements of environmental protection to be fulfilled during the execution and operation phases (see Section 5).

2.1.6 The design must allow the requirements of use, operation and maintenance to be taken into consideration (see Section 6). The mutual dependencies of use and maintenance or operation and maintenance shall be considered.

2.1.7 The design must allow the durability of the structure to be ensured to the required degree (see Section 7).

2.1.8 The project is the result of an optimisation process (comparison of variant designs). The aim is to determine the most economic solution for the construction, use, operation and maintenance of the tunnel for the design working life, taking into account the abovementioned aspects.

2.2 Planning phases

2.2.1 The following relationships in the construction process result when working with the service model SIA 112 and the code SIA 260:

Table 1 Planning phases and aims

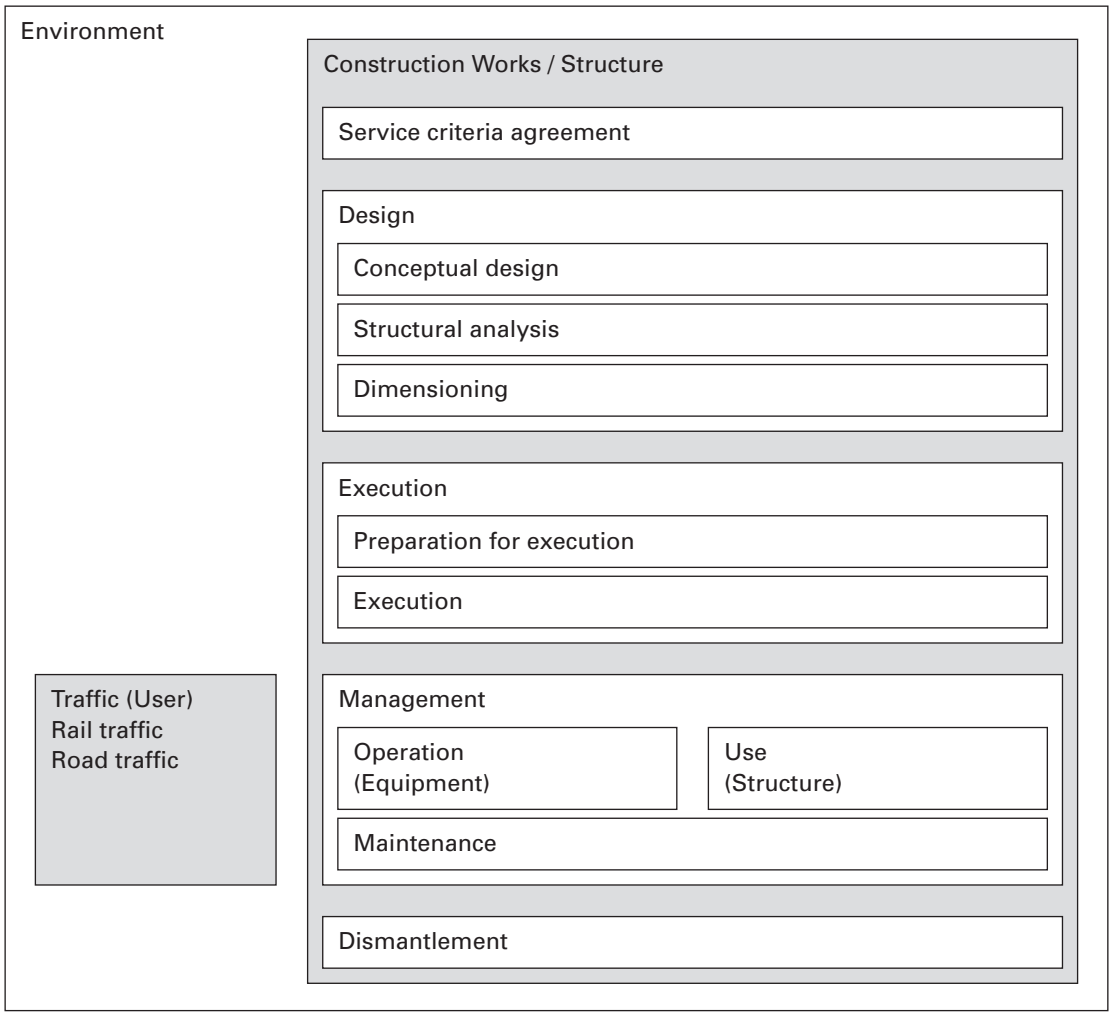
Phases	Sub-phases	Aims (project-specific)
Design	Strategic planning	Definition of the overall concept
	Preliminary studies	Proof of feasibility
	Preliminary project [1)]	Optimum constructional solution
	Submitted project [2)]	Project presented for approval
	Construction project [3)]	Project ready for construction
Execution	Tendering	Mature tendering documents
	Detailed design	Project ready for execution
Operation	Use and operation	Safe use (user and operator)
	Maintenance	Availability during the planned period

2.2.2 The partial aims for the individual phases or sub-phases shall be determined on the basis of the object-specific guidelines.

2.2.3 An overview of the performances for the individual phases or sub-phases is given in Appendix B.

[1)] For national motorway: General project
[2)] For national motorway: Construction project
[3)] For national motorway: Detailed project

Figure 1 Planning phases and design elements



2.3 Documentation

2.3.1 Basic documents and results of the design

2.3.1.1 The following documents shall be prepared and if necessary adapted to the project phases. The amount of documentation depends on the size and importance of the tunnel.

- service criteria agreement (see SIA 260)
- basis of design (see SIA 260)
- geological, hydrogeological and geotechnical reports (see Recommendation SIA 199)
- safety report
- report on environmental impact assessment
- structural analysis (see SIA 260)
- technical report (see SIA 260)
- operating concept
- utilisation concept
- service instructions (see SIA 260)
- operating instructions (see SIA 260)
- monitoring plan (see SIA 260)
- maintenance plan (see SIA 260).

2.3.1.2 The safety report documents the safety planning and its results.

2.3.1.3 The report on environmental impact describes the required project-specific measures.

2.3.1.4 The operating concept describes how the tunnel is operated under normal conditions (see Section 6.2.2) and in the case of critical events.

2.3.1.5 The intervention concept describes which emergency services are involved in the case of critical events and what their duties are.

2.3.2 Project records

2.3.2.1 For each tunnel a complete collection of construction documents is required for the project records. It has to be prepared for the completion of the design and execution phases and submitted to the operator before the start of operation.

2.3.2.2 The construction documents provide the operator with a basis for management.

2.3.2.3 The construction documents shall be clearly organised and presented so as to contain all important information on the construction work and the operating equipment:
- basic requirements and results of the design (see Section 2.3.1)
- final geological report
- record of construction, especially general and detailed plans of the executed structure
- general and detailed plans of the operating and safety equipment (including operating instructions, lists of cables, lists of signals, lists of interfaces, etc.).

3 GROUND

3.1 General

3.1.1 The geological, hydrogeological and geotechnical ground conditions have a decisive influence on the project concept and the construction methods.

3.1.2 Site investigations, which provide information on the essential geological conditions for each phase, are necessary therefore already in the earlier phases of design. The results shall be described in a manner suited to the individual phases and presented and evaluated in a suitable form (e.g. geological model).

3.1.3 In addition, all further effects on humans and the environment that influence the design, execution and operation (e.g. rocks containing asbestos, radioactivity) shall be taken into account.

3.1.4 The Recommendation SIA 199 defines the essential technical terms and describes the basic documents that are necessary for a useful documentation.

3.1.5 A clear separation between description and assessment is an essential prerequisite of the documentation to be prepared.

3.1.6 The most reliable information on the ground is given by an exploratory drift.

3.1.7 In ground with poorly predictable geological and hydrogeological problem zones preliminary explorations with boreholes and/or geophysical measurements, which are performed during driving, are a necessary addition.

3.1.8 The geological, hydrogeological and geotechnical conditions encountered during construction shall be recorded and documented in a suitable way. These documents form an essential part of the construction documents.

3.2 Geology

3.2.1 The geological report describes the geological and tectonic conditions.

3.2.2 Soil and rock shall be described in sufficient detail (see Recommendation SIA 199).

3.3 Hydrogeology

3.3.1 The hydrogeological report describes the local and regional hydrogeological conditions (see Recommendation SIA 199).

3.3.2 The water-bearing layers (soil and rock) and their possible interaction, the groundwater reservoirs, the regional groundwater flow conditions and the connections to surface waters shall be described.

3.3.3 The existing areas protected against water pollution, protected groundwater zones and areas together with the utilisation of the groundwater shall be taken into account.

3.3.4 The expected amount of water (initial and permanent quantity, range of variation) shall be given.

3.4 Geotechnical properties

3.4.1 The geotechnical properties of soil and rock shall be described in sufficient detail (see Recommendation SIA 199).

3.4.2 The results of laboratory and field tests shall be presented and evaluated.

3.4.3 It is necessary to differentiate, whether the results apply to intact rock or the rock mass as a whole.

3.5 Occurrences of gas

3.5.1 Natural gas, depending on the type and amount, can impair safety during execution and operation.

3.5.2 Therefore gas occurrences must be assessed in the geological report.

3.5.3 Gas occurrences shall be measured during excavation. The results form the basis for deciding whether or not to implement any temporary or permanent measures.

3.6 Hazards

3.6.1 The geological, hydrogeological and geotechnical reports serve as a basis for the assessment of the ground. The reliability of the descriptions and any deviations to be considered shall be presented.

3.6.2 The recognition of hazards that can occur during the execution and operation of the tunnel form an essential addition to the descriptions. The consequences of possible deviations from the descriptions shall be taken into account.

3.6.3 The probable combinations of possible hazards lead to the hazard scenarios. These provide the basis for determining the measures to be implemented in order to control the hazards.

3.7 Material management

3.7.1 A concept shall be prepared for material management (utilisation, treatment and storage of the spoil material). The basis is provided by the geological report. The concept is part of the report on the environmental impact assessment.

3.7.2 According to the Recommendation SIA 199 the spoil material (muck) can be divided into four classes.

3.7.3 The guideline for the exploitation, treatment and storage of cut and stripped overburden and spoil material with a mineral content (“Richtlinie für die Verwertung, Behandlung und Ablagerung von mineralischem Aushub-, Abraum- und Ausbruchmaterial” (Aushubrichtlinie) of BUWAL (in 2006 changed to BAFU, English FOEN: Federal Office for the Environment) shall be taken into account.

4 SAFETY

4.1 Basic principles

4.1.1 The safety of persons, the environmental resources and material assets shall be adequately ensured during the execution (new construction works) and management (use, operation and maintenance) phases. The required measures must be economic and correspond to the state-of-the-art.

4.1.2 The required measures shall be determined by those participating in the design phase. They shall be described in the basis of design and documented in the relevant project records.

4.1.3 The measures include:
- constructional measures (infrastructure concept)
- operational measures (operating concept)
- organisational measures (intervention concept).

4.1.4 The measures to ensure safety shall be reappraised if new information becomes available.

4.2 Hazards

4.2.1 Hazards arising from the ground and the construction process

4.2.1.1 Hazards connected with the ground or ground behaviour and with execution shall be limited.

4.2.1.2 These hazards may concern:
- persons, above all the contractor's personnel
- environmental resources, above all water and soil
- material assets, above all the contractor's machinery and equipment, the infrastructure itself, as well as property belonging to a third party (buildings and facilities in the vicinity).

4.2.2 Hazards arising from the tunnel system

4.2.2.1 Hazards arising from an insufficient reliability of the structure or the equipment during the operating phase shall be avoided.

4.2.2.2 These hazards may concern:
- persons who use the tunnel (travellers/passengers)
- persons who maintain and operate the infrastructure (personnel)
- material assets, above all user's vehicles (rail and road traffic), as well as the tunnel itself and the property of third parties.

4.2.3 Hazards arising from the user

4.2.3.1 Hazards arising from events (accident, fire, etc.) shall be limited.

4.2.3.2 These hazards may concern:
- persons who use the tunnel (travellers, passengers, rail personnel)
- persons who carry out maintenance work (personnel belonging to the operator or contractors)
- persons who intervene in critical events (personnel belonging to the emergency services)
- environmental resources, above all water and soil
- material assets, above all user's vehicles (rail and road traffic) and the tunnel system itself.

4.3 Design procedure

4.3.1 In the case of hazards arising from the ground and the construction process

4.3.1.1 The risks can be reduced by suitably specifying:
- concepts for the tunnel system and construction methods, which also include appropriate measures to protect the environment
- measures for working safety and health protection.

4.3.1.2 The concepts and the construction methods shall be prepared within the framework of the conceptual design, structural analysis and dimensioning (see Sections 3, 7 and 8). The results shall be documented in the basis of design and the structural analysis and in the report on the environmental impact assessment.

4.3.1.3 The measures for working safety and health protection shall be presented in a concept. This is prepared in two steps as part of the planning and design and of the execution (see SIA 198).

All measures that influence the tunnel concept (e.g. additional construction works that are necessary for execution) and the construction method (e.g. minimum size of a tunnel cross-section, ventilation measures) shall be dealt with in the first step.

4.3.2 In the case of hazards arising from the tunnel system

4.3.2.1 The risks can be reduced by:
- maintaining the bearing capacity of the structure
- ensuring the functionality of the operating and safety equipment during the design working life.

4.3.2.2 Structural safety and equipment functionality shall be taken into account in the design (see Sections 7, 8 and 9). The results shall be documented in the basis of design and in the service and operating instructions.

4.3.2.3 Durability shall be ensured by the operator through maintenance. The basic requirements shall be treated in the design and documented in the monitoring and maintenance plans.

4.3.3 In the case of hazards arising from the user

4.3.3.1 The risks can be reduced by:
- preventing critical events (limiting hazard potential during use, reducing the probability of occurrence)
- limiting the effects of damaging occurrences.

4.3.3.2 The measures to reduce these risks shall be included in the safety planning (Section 4.4). The results shall be documented in the basis of design and in the safety plan.

4.3.3.3 Measures to ensure the safety of personnel (operator or the commissioned contractor) and the traffic safety in the narrow sense (rail and road traffic) are the responsibility of the operator and not the concern of this code.

4.4 Safety planning

4.4.1 General

4.4.1.1 The design shall specify a concept for the infrastructure and the operating measures in which the safety requirements are taken into account during use and operation.

4.4.1.2 Moreover, in the design the organisational measures (intervention concept) that have to be implemented to deal with critical events shall also be specified.

4.4.1.3 The infrastructure concept together with the operational and the organisational measures are greatly influenced by the choice of the tunnel system. It shall be determined according to the specific use (type and intensity of traffic).

4.4.1.4 The primary aim is to avoid critical events that endanger persons and environmental resources or material assets.

4.4.1.5 Secondarily, measures to reduce the extent of damage shall be planned in the case of a critical event. They should provide optimum conditions, in order to achieve the following aims (in order of importance):
- promote self-rescue of those involved
- enable self-help of those involved
- enable efficient use of emergency services
- protect the environment (soil, water, air)
- limit damage to the infrastructure.

4.4.2 Procedure

4.4.2.1 Within the project organisation an authority has to be designated that is responsible for safety planning and defines the list of duties of those involved (owner, commissioned engineers and specialists, operator, emergency services) regarding questions of safety.

In addition, it shall be decided how conflicting demands of the required measures can be dealt with (settlement of disputes).

4.4.2.2 With the help of a safety analysis it shall be checked if user safety requirements are fulfilled. The type and extent of the safety analysis are governed by:
- size and complexity of the tunnel
- use
- design phase.

4.4.2.3 The type and extent of the safety analysis shall be determined by the authority responsible for safety planning in consultation with the owner. For projects subject to the regulation dealing with prevention of technical faults (StFV, see Appendix A), the requirements of this regulation shall also be taken into account.

4.4.2.4 The tunnel shall not be considered in isolation, but as part of the corresponding rail or road section.

4.4.2.5 The safety analysis is based on the following:
- conditions relating to the user (rail and road traffic). These comprise the regulations that deal with traffic flow and the type of transported goods
- conditions relating to the tunnel. These comprise the actual tunnel project (structures and equipment) and the planned organisational safety measures
- list of events to be considered (e.g. accident scenarios).

4.4.2.6 The safety analysis must be carried out in the earliest possible project phase and checked in the subsequent phases. If necessary, the required measures have to be adapted.

4.4.2.7 The results of safety planning shall be described in the safety report.

4.4.3 Qualitative safety analysis

4.4.3.1 The qualitative safety analysis is suitable for checking projects, in which the tunnel system and important design elements (infrastructure) have been fixed.

4.4.3.2 With the qualitative safety analysis it is checked qualitatively whether the measures planned for the project are adequate to reduce as far as is possible the risks due to the critical events. If the checks reveal a safety deficiency, additional safety measures must be planned.

4.4.3.3 For a qualitative safety analysis the following steps have to be carried out:
- defining the most important factors relating to use (volume of traffic, conditions of admission for vehicles and goods, etc.)
- defining critical events
- listing the planned measures
- checking whether the planned measures satisfy code requirements.

4.4.4 Quantitative safety analysis

4.4.4.1 The quantitative safety analysis is suitable above all for checking:
- variants that differ in their concept (e.g. tunnel system) or in important design elements (in general in earlier project phases)
- complex projects in the sense of Section 4.4.4.3.

4.4.4.2 With the quantitative safety analysis the risks due to critical events are determined quantitatively and compared with quantitative protection aims. If the measures specified in the project are inadequate to fulfil the protection aims, additional measures shall be planned.

4.4.4.3 In the case of complex projects the following criteria – usually in combination – may be sufficient reason for carrying out a quantitative safety analysis:
- very long tunnels
- large volume of traffic
- high proportion of dangerous goods in the case of freight traffic
- high conflict potential of the traffic regime (oncoming traffic or one-way traffic, admissible maximum speed, type and quantity of dangerous goods transported).

4.4.4.4 For a quantitative safety analysis the following steps shall be carried out:
- define the critical use (volume of traffic, conditions of admission for vehicles and goods, etc.)
- define the objects to be protected (persons, environmental resources and material assets) and the quantitative protection aims
- define the critical events
- define the necessary measures
- quantitative analysis of the risks with regard to probability of occurrence and extent of damage
- compare the calculated risks with the quantitative protection aims.

4.4.5 Constructional and operational measures

4.4.5.1 The required measures shall be included in the infrastructure and operating concepts. They comprise:
- measures inside the tunnel
- measures outside the tunnel (in the region of the portals).

4.4.5.2 Detailed information is given in Sections 8 and 9.

4.4.6 Organisational measures

4.4.6.1 This involves an intervention concept for the activation of the emergency services and the detailed planning of their operations. It shall be suitably prepared for each phase and discussed with the responsible persons in the emergency services.

4.4.6.2 The interception concept may affect the infrastructure concept and require appropriate constructional measures.

5 ENVIRONMENT

5.1 Basic principles

5.1.1 Following the principle that prevention is better than cure, in the project all necessary measures to minimise as far as possible the effect of the tunnel on the environment shall be planned in advance.

5.1.2 The design shall take into account environmental effects, especially with regard to management aspects (use, operation and maintenance). Insofar as they are necessary, environmental effects that arise during execution also have to be considered in the design.

5.1.3 The required measures include:
- constructional and operational measures (tunnel infrastructure concept)
- organisational measures (activities of maintenance and operational personnel).

5.1.4 The environmental effects due to execution and operation, for which no constructional or operational measures are necessary, are the responsibility of the contractor or the operator. They are not dealt with in this code.

5.2 Implementation in the design

5.2.1 In some circumstances measures are required that take into account environmental effects arising from the operation of the tunnel:
- air pollution caused by the traffic
- noise (emissions) caused by the traffic and the tunnel equipment (e.g. ventilation system)
- vibrations caused by the traffic
- pollution of ground and surface waters caused by waste water from the tunnel (utilisation water and, possibly, groundwater)
- impairment of water-bearing layers, water intake structures or springs
- negative effect of the construction works (tunnel and other structures) on the landscape and the natural environment
- incidents arising from the transport of dangerous goods.

5.2.2 In some circumstances measures are required that take into account environmental effects arising from the construction of the tunnel:
- air pollution caused by exhaust fumes and dust (machines, vehicles)
- noise (emissions) caused by construction work (blasting, machines, transportation)
- vibrations caused by construction work (blasting, machines, transportation)
- pollution of ground and surface waters caused by waste water from the construction site (see Recommendation SIA 431)
- temporary changes of the hydrogeological conditions (flow reduction, lowering of the water table, impairment of the water intake structures)
- negative effect on the landscape and the natural environment as a result of site development, e.g. access roads and site installations (type and extent)
- damage to the soil due to compaction or harmful substances
- effects of material management and the handling of site waste, including disposal sites for contaminated material (see Recommendation SIA 430)
- incidents arising from the transport of dangerous goods
- hazard due to harmful waste deposits that are disturbed during construction.

5.2.3 These effects and the required countermeasures shall be documented in a report on the environmental impact.

5.2.4 Larger tunnels are subject to the legal requirement of an environmental impact assessment according to the law governing environmental impact (see Appendix A.1). Depending on the type of structure, the method of investigation to be adopted is specified by the federal government or the cantonal authorities. The specific instructions for performing an environmental impact assessment shall be complied with.

6 MANAGEMENT

6.1 Basic principles on use and operation

6.1.1 The project shall include all necessary measures that are a prerequisite for optimum management.

6.1.2 The various parts of the structure as well as operating and safety equipment have different design working lives that are specified therefore for each project. As guide values the following apply:

- tunnel structure without finishing, but including control rooms 80–100 years
- internal finishing 40–60 years
- operating and safety equipment 20–40 years
- measurement, signalling, control and communication systems 10–20 years

The planned design working life is only achieved if the required maintenance measures are carried out.

6.2 Service and operating instructions

6.2.1 The service instructions describe the determinant conditions for the use of the structure.

6.2.2 The operating instructions describe the determinant conditions for the proper functioning of the equipment. They shall include the following service situations:

- normal traffic conditions
- special traffic conditions e.g. during the execution of maintenance measures
- critical event.

This document is also called the operating manual.

6.3 Basic principles for maintenance

6.3.1 The maintenance of the structure and the equipment is an absolute necessity for the unlimited use of the tunnel and for ensuring reliable rail or road traffic.

6.3.2 The primary maintenance aims – in relation to the planned design working life – are:

- preserving structural safety
- ensuring serviceability of the structure
- ensuring proper functionality of the operating and safety equipment.

6.3.3 A secondary maintenance aim is state-of-the-art upgrading.

6.3.4 The maintenance measures include:

- monitoring (observation, inspection, control measurements and functionality tests)
- checks (condition survey, condition assessment, recommendation of measures)
- planning of measures
- maintenance (structures) and servicing (equipment)
- rehabilitation.

The specific technical terms are defined in the code SIA 260. A detailed description of the measures is not dealt with in this code.

6.3.5 It is recommended to plan and execute the maintenance work following the procedures described in the code SIA 469.

6.3.6 The maintenance measures can greatly influence the use of the structure and the operation of the equipment. Therefore the requirements and the resulting dependencies shall be considered already in the design (e.g. in a maintenance concept).

6.3.7 The tunnel, including the auxiliary structures, shall be designed such that optimum maintenance conditions are given. Hereby the following shall be taken into account:
- cost/benefit ratio of the maintenance measures themselves
- resulting costs for rail and road traffic operations.

6.3.8 The positioning of the operating rooms and organisation of motorised or pedestrian access shall permit servicing and replacement of the operating and safety equipment without any significant restriction of rail or road traffic.

6.4 Monitoring and maintenance plans

6.4.1 The monitoring plan contains all project-specific instructions for monitoring and checking the structure and equipment that are necessary to ensure a reliable utilisation (use and operation).

6.4.2 The maintenance plan contains all project-specific instructions for the maintenance of the structure and servicing the different installations.

6.4.3 Within the maintenance plan it shall be specified for which components of a particular installation spare parts have to be kept in store. Hereby the following shall be taken into account:
- availability of the spare parts (existing, not existing)
- delivery times (from store-room, from factory)
- required availability of the installations (no, partial or complete redundancy).

6.4.4 In the case of operating and safety equipment, the monitoring and maintenance plans are frequently presented in summary form in the servicing manual.

7 STRUCTURAL DESIGN

7.1 Basic principles

7.1.1 General

7.1.1.1 The requirements of Section 7 apply to the design of structures constructed underground. For the design of structures by the cut-and-cover method and of the structural elements for the finishing work the codes SIA 260 to SIA 267 apply.

7.1.1.2 By structure is understood the totality of the structural elements together with the ground, which are required to maintain the equilibrium and the shape of the structure.

7.1.1.3 The basic principles and requirements for the subsequent design, execution and operation that derive from the conceptual design shall be described in the basis of design.

7.1.1.4 As far as possible the structural concept, the dimensioning and the construction methods shall be checked and assessed from experience gained on comparable projects. Substantial divergences from normal construction practice shall be analysed and substantiated.

7.1.1.5 If a prediction of structural behaviour based on previously carried out site investigations, structural analysis and comparable experience is not possible to a sufficient degree of reliability, the observational method shall be employed for the design, execution and, if necessary, for the use of the structures.

If the observational method is employed, the information gained during execution on the ground properties and the behaviour of the structure shall be included in the current process of design and execution.

The conditions and measures needed for the use of the observational method are given in the code SIA 267, Sections 2.2 and 2.3.

7.1.2 Structural requirements

7.1.2.1 The structure shall, with sufficient reliability, be economic, robust and durable.

7.1.2.2 Specifying the required reliability shall be based on experience augmented by theoretical considerations. If possible, one should take as a starting point the verification concept given in the code SIA 260.

7.1.2.3 Depending on the limit state and the reference period, the required reliability may be different for the structure as a whole or its individual parts.

7.1.2.4 Specifying different degrees of reliability may depend on:
- the type and consequences of failure
- the extent of acceptable damage
- the importance of the structure in dealing with the catastrophe after a critical event
- the expenditure required to reduce risks
- the possibilities of monitoring, maintenance and repair, together with the corresponding expenditure.

7.1.2.5 Ensuring adequate reliability involves in particular:
- consideration of uncertainty in determining the ground properties and the actions in the structural modelling as well as in the determination of the effects of actions
- quality assurance measures during design, execution and operation.

7.1.2.6 Ensuring durability during the design working life involves in particular:
- determining relevant actions
- estimating possible damage to the structures and the structure
- appropriate measures during the design, execution and operation, especially constructional and material-technological measures to protect materials and structural elements, professional execution as well as a well planned monitoring and maintenance.

7.1.3 Conceptual design

7.1.3.1 The conceptual design consists of elaborating different structural alternatives taking into consideration the relevant boundary conditions, checking the feasibility and assessing the execution possibilities with regard to fulfilling the design requirements.

7.1.3.2 In the conceptual design the most important actions shall be considered that can occur during execution and the planned use of the structure, including the interaction of the ground with the lining.

The possible hazard scenarios shall be analysed and, depending on the situation, suitable measures shall be specified in order either to avoid hazards, to bring them under control or limit them to an acceptable amount.

7.1.3.3 The following events or influences can cause a hazard in the phases of execution or operation, e.g.
- roof collapse, collapse up to the ground surface, rockburst, unstable working face, sudden inrush of large quantities of groundwater
- genuine rock pressure, swelling pressure, internal erosion, water pressure, ice pressure
- deviations from the assumed values of the properties of the ground and the soil or rock
- deviations from the assumed values of actions
- reduction of stiffness and loss of shear strength of the ground due to water absorption, stress relief or loosening
- impairing the structural resistance as a result of corrosion, brittleness and other chemical or physical actions
- impairing the structural resistance as a result of fire, explosion, impact, pipe burst or earthquake
- deviations from the design values of structural resistance.

7.1.3.4 Hazards can be mitigated by avoidance, prevention or reduction of the hazard, for example:
- choice of a different alignment
- choice of a structure with less susceptibility with respect to the considered hazards
- choice of a structure that is able to sustain local damage and the loss of an individual structural element or a whole section of the structure without total failure
- choice of a structure that does not fail without prior warning
- choice of suitable geotechnical auxiliary measures
- choice of suitable construction materials
- appropriate structural analysis and dimensioning
- careful detailing of the structural elements including waterproofing and drainage
- execution carried out as planned and with due care
- appropriate execution checks and warning systems (monitoring with instruments)
- special protective measures for neighbouring structures and facilities
- measures to deal with critical events
- appropriate monitoring and maintenance.

7.1.3.5 The planned service situations shall be analysed and appropriate measures shall be specified to ensure serviceability.

7.1.3.6 The following influences can impair the serviceability in the phases of execution and operation, e.g.
- stress- and time-dependent ground deformations
- time-dependent stress redistribution in the ground
- influence of groundwater
- creep and swelling of rock.

7.1.3.7 An impairment of serviceability due to inadmissible deformations and displacements of the structure can be overcome by implementing one or more of the following measures, e.g.
- a different alignment or location
- appropriate method of excavation
- a suitable lining and waterproofing concept
- modifying the ground properties by means of geotechnical auxiliary measures
- a structure that can be subsequently strengthened or modified
- execution checks and monitoring with instruments.

7.1.3.8 In assessing the different possibilities of execution, special attention shall be paid to simplicity, insensitiveness to unavoidable execution inaccuracies or possible errors in execution and the ability to adapt to possible changes in ground behaviour and in execution and operation.

7.1.4 Structural concept and basis of design

7.1.4.1 The structural concept includes in general the following information:
- ground and construction material properties
- shape and dimensions of temporary support and lining
- waterproofing concept
- information on the planned construction methods
- type of excavation, ring closure distance and time
- geotechnical auxiliary measures
- important construction details
- design working life of the different structural elements
- measures to ensure durability.

7.1.4.2 The basis of design includes:
- the design working life
- the considered service situations
- the assumed properties of the soil or rock mass
- the assumed groundwater conditions
- the considered hazard scenarios and the acceptable risks
- the requirements of structural safety, serviceability including waterproofing and durability as well as the measures planned to ensure them, including processes, execution checks and correction mechanisms
- the most important assumptions for the structural and analytical models
- aspects to be considered during execution and operation
- other conditions relevant to the project.

7.1.4.3 The scope and content of the basis of design shall correspond to the importance of the structure and the associated hazards.

7.2 Structural analysis

7.2.1 General

7.2.1.1 The goal of the structural analysis is to determine the behaviour of the structure in the considered dimensioning situations taking into account the decisive influence factors.

7.2.1.2 The methods of structural analysis should be based on established engineering practice and, if necessary, experimentally verified theory. The analysis shall be based on structural models that also comply with the basic principles of soil and rock mechanics and closely approximate the real structural (i.e. load-bearing) and deformational behaviour of the structure. The chosen analytical model may differ according to the planning phase, in order to provide a depth of treatment appropriate for the various phases.

7.2.1.3 The influence of individual parameters, e.g. the thickness, stiffness or strength of a ground layer, on the results of the structural analysis should be checked by means of a parametric study. Attention shall be given to parameters exerting a large influence.

7.2.1.4 The influence of the ground in endangering structural safety and impairing serviceability needs to be assessed. If risks are accepted, then the observational method shall be foreseen in the design and applied in the execution (Section 7.1.1.5).

7.2.1.5 The results of the structural analysis shall be checked for plausibility.

7.2.1.6 The basic principles and the results of the structural analysis shall be given in the structural analysis and in the technical report. The dimensioning situations, the computational assumptions, the analytical models and the verifications of structural safety and serviceability shall be clearly documented.

7.2.1.7 If changes are made to the structural concept, the execution or the structure's boundary conditions, then the basic principles and assumptions employed in the structural analysis shall be checked. The consequences of the changes in relation to the structural behaviour shall be assessed and reported in the basis of design and, if necessary, also in the service criteria agreement.

7.2.2 Characteristic values of the properties of the ground

7.2.2.1 The characteristic value of a geometrical or geotechnical quantity is the representative value for the chosen structural model and the considered dimensioning situation.

7.2.2.2 The characteristic value of geometrical or geotechnical quantities needed to describe the ground model according to Section 7.2.5.2 including the level of the water table and the hydraulic head shall be determined according to the code SIA 267.

7.2.3 Actions imposed by the ground

7.2.3.1 The actions arising from the ground include:
- self-weight of soil and rock
- earth pressure
- loading on tunnel roof
- loosening pressure
- genuine rock pressure
- actions due to groundwater
- creep and flow pressure
- swelling pressure
- shear forces, displacements and deformations of the ground
- seismic forces.

7.2.3.2 The actions imposed by the ground shall be determined on the basis of characteristic values according to established soil and rock mechanics methods. Their determination in underground construction is based on the dimensioning situations deemed to be critical in the design (Section 7.3.2).

7.2.3.3 The magnitude, direction and distribution of the actions imposed by the ground depend on both the geological and hydrogeological conditions and on the interaction of the ground with the lining. These dependencies shall be taken into account in the structural analysis.

7.2.3.4 The effect of water can manifest itself as water pressure, seepage force, pore water pressure or capillary force (inducing negative pore water pressure).

7.2.3.5 In order to limit the uncertainty in the magnitude of the actions imposed by the ground, empirical values based on experience with similar structures shall be considered.

7.2.3.6 In the case of tunnel structures in soil the characteristic values for the actions shall be determined by taking into account the stiffness of the lining, the reconsolidation of the soil and the ability of the soil to redistribute the stresses.

In the case of shallow structures, for the roof loading the full overburden pressure shall be assumed. To qualify as shallow underground structures the corresponding soil cover can be assumed to be less than 1.5 to 2 times the width of the cross-section of the excavation.

7.2.3.7 In the case of shallow structures in highly loosened rock or in rock of low stiffness the characteristic values of roof loading shall be determined in the same way as in soil.

7.2.3.8 Actions imposed by possible future structures that could influence the tunnel structure, e.g. those located over a shallow tunnel, shall be specified for each individual case.

7.2.4 Ground resistance

7.2.4.1 Ground resistance includes the following:
- resistance of the ground as a reaction to the displacement of the lining
- bearing capacity or sliding resistance as a reaction to the loading from the foundation or abutment
- frictional resistance as a reaction to the relative displacement of the lining and the ground
- shear resistance of the soil or rock as reaction to a displacement within the ground.

7.2.4.2 The characteristic value of the ground resistance shall be determined as a conservative expected value according to the code SIA 267 on the basis of a representative ground model using established methods of analysis or on the basis of tests, empirical values or back-calculation. The reliability of the determination of this value shall be checked and taken into account.

7.2.4.3 In the case of structural analysis that takes into account ground resistance it must be verified that the resistance assumption is compatible with the admissible ground deformation or the admissible displacement and deformation of the lining for the limit state under consideration. Otherwise the ground resistance shall be correspondingly reduced or taken into account by means of a deformation analysis.

7.2.5 Structural model

7.2.5.1 The structural model comprises the entire structure i.e., the ground surrounding the opening, the lining and any structural elements to improve the bearing capacity of the ground, such as anchors or jet-grouted columns. It connects actions, geometrical quantities and the properties of the construction materials and the ground for the purpose of structural analysis. The structural model must be suitable for predicting the structural behaviour in the dimensioning situations under consideration.

7.2.5.2 The ground model is part of the structural model. In an idealised way, according to the Recommendation SIA 199, it comprises:
- the geological structure of the ground subdivided into homogeneous zones with information on special features like bedding, joints, anisotropy, etc.
- the properties of the ground in the homogeneous zones.

7.2.5.3 Depending on the dimensioning situation different structural and ground models may be decisive for the structural analysis.

7.2.5.4 The interaction between the lining and the ground shall be considered by means of suitable modelling, e.g. the influence of the waterproof seal by reducing the shear transfer between the temporary support and the lining partially or to zero.

7.2.5.5 For the structural analysis the behaviour of the structure can generally be idealised by a simple model, e.g.
- the complex deformational behaviour by simple stress–strain laws
- complex failure processes by simple failure mechanisms
- the stress- and time-dependent properties of the construction materials and the ground by an appropriate choice of material parameters
- the three-dimensional structural action by a two-dimensional (plane-strain) model.

7.2.5.6 The permissibility of the simplified model assumptions has to be checked.

7.2.6 Analytical model

7.2.6.1 The chosen analytical model must describe the structural behaviour in the limit state under consideration with sufficient reliability.

7.2.6.2 In the case of simplified analytical models, with the choice of the model (taking into account the uncertainty in each case) it shall be ensured that the results of the analysis lie on the safe side.

7.2.6.3 When analysing three-dimensional structures using two-dimensional structural models the simplifications of the three-dimensional actions and the influence of the three-dimensional stress redistribution have to be taken into account, especially for the resulting stress redistribution in the analysis of construction states (heading excavation, subsequent excavation of the benches, etc.).

7.2.6.4 In special cases the method of analysis may consist of a direct empirical relationship between measurement or test results and dimensioning criteria e.g., the characteristic line method to analyse swelling pressure and genuine rock pressure. There must be a clear correspondence with the conditions of the considered dimensioning situation.

7.2.6.5 The choice of the analytical model shall correspond to the dimensioning situation and the limit state under investigation. The following analytical models are considered to be suitable, e.g.
- silo theory and wedge- and block-type models to analyse the roof loading for underground structures in soil or loosened rock
- wedge- and block-type models to analyse the loosening pressure in the case of layered and/or jointed rock
- beam on elastic foundation model to analyse the effects on the lining in the case of shallow underground structures in soil or loosened rock (method of subgrade reaction)
- continuum models to analyse genuine rock pressure, loosening pressure, deformations of the ground and the structure as well as the effects of excavating the underground opening on neighbouring structures
- the empirical characteristic line method to analyse swelling pressure and genuine rock pressure.

7.3 Dimensioning

7.3.1 General

7.3.1.1 The dimensioning determines the dimensions, the construction materials with their properties, the structural detailing and the measures to ensure design requirements.

7.3.1.2 The dimensioning must ensure that no impairment or damage that was not agreed upon beforehand is caused to neighbouring structures and facilities as a result of the construction work.

7.3.1.3 In the case of underground construction the structure can be dimensioned as follows:
- dimensioning according to limit states (Section 7.3.6)
- dimensioning on the basis of experience gained with constructional measures (Section 7.3.7)
- dimensioning supported by tests (Section 7.3.8).

If possible, the dimensioning shall be performed according to limit states.

7.3.1.4 Dimensioning according to limit states requires:
- the preparation of suitable structural and action models
- the choice of an appropriate analytical model
- specifying the critical dimensioning situations
- verification that the relevant limit states are not exceeded.

7.3.1.5 If the conditions imposed on the observational model are complied with, then within the framework of the present code regulations the specified safety values may be reduced accordingly and geotechnical risks may be accepted.

7.3.2 Dimensioning situations

7.3.2.1 The considered dimensioning situations should include all foreseeable conditions that can occur during the execution and operation of the structure.

7.3.2.2 Dimensioning situations are subdivided into transient, persistent and accidental situations.
- transient dimensioning situations relate in general to the construction phases
- persistent dimensioning situations relate in general to the service situation
- accidental dimensioning situations relate to situations with exceptional events.

7.3.2.3 In the case of construction states that last for several months it shall be checked whether they must be considered as persistent dimensioning situations in the sense of the code SIA 260.

7.3.3 Transient dimensioning situations

7.3.3.1 The stability of the excavated opening is closely related to the properties of the surrounding ground. It shall be endeavoured to preserve the properties of the ground during execution, both from the technical and economic point of view.

7.3.3.2 The stability of the excavated opening including the working face shall be verified for each phase of excavation (partial and full-face) as required in the basis of design. The required support and geotechnical auxiliary measures shall be specified taking the critical dimensioning situations into consideration.

7.3.3.3 If the basis of dimensioning is uncertain, the stability of the opening shall be ensured using the observational method. The control values determined numerically or from experience – in general the deformations and displacements of the opening and its surroundings – form the basis for specifying alert and alarm values. The planned control measurements and the critical values for intervention and giving the alarm shall be specified in the control plan and if necessary in the monitoring plan.

7.3.3.4 Hazards, which
- cannot be dealt with reliably by analysis or detected and localised in time by observations,
- can lead to sudden or uncontrollable failure, e.g. roof collapse or rockfall, shall be mitigated by means of constructional measures and suitable types of support, paying attention to the relative importance. In these cases the observational method may not be employed.

7.3.4 Persistent dimensioning situations

7.3.4.1 Persistent dimensioning situations have to include all foreseeable physical circumstances and conditions (hazards, critical service situations) that can occur in the service phase of the structure.

7.3.4.2 Geotechnical auxiliary measures, that are necessary to ensure structural safety and serviceability during construction, can be considered in the persistent dimensioning situations, provided their contribution to the bearing capacity of the structure acts over the whole of the design working life.

7.3.5 Accidental dimensioning situations

7.3.5.1 Accidental dimensioning situations, when dimensioning according to limit states, shall be mitigated in general by a conservative choice of ground model and not by an increase in the safety factors relating to the ground.

7.3.5.2 Accidental dimensioning situations can, according to Section 7.3.1.3, be mitigated by means of constructional measures or suitable types of ground support. Experience from comparable dimensioning situations with other underground structures should be made use of.

7.3.6 Dimensioning according to limit states

7.3.6.1 In dimensioning according to limit states it shall be verified for the critical dimensioning situations that the limit states of structural safety and serviceability shall not be exceeded during the corresponding period.

7.3.6.2 In the verification of structural safety it shall be taken into account that the bearing capacity of individual structural elements (e.g., the sprayed concrete lining), or ground zones, may be exceeded before that of the structure as a whole.

7.3.6.3 The support types allow temporary support in different ground conditions and dimensioning situations. The bearing capacity and the behaviour of the different types of support shall be checked, assessed and recorded within the framework of the structural analysis, taking into account the critical influence factors.

7.3.6.4 The verification of serviceability relates in general to the limit states in the service phase. They concern:
- the functionality of the structure and its equipment
- user comfort
- the appearance of the structure.

Possible dimensioning criteria for serviceability are mentioned in the code SIA 260.

7.3.6.5 In dimensioning according to limit states the structural safety and the serviceability shall be verified according to the requirements of the codes SIA 260 to SIA 267. The safety values specified there shall be applied analogously.

7.3.6.6 For the analysis of the effects of actions using computational models, e.g. with use of the finite element method, in the dimensioning of the structural elements the corresponding safety values specified in the code SIA 260 shall be considered. A conservative value shall be adopted for the partial factor to take into account the uncertainty of the model.

7.3.6.7 The basis and results of dimensioning shall be recorded in the structural analysis and in the technical report. The dimensioning results shall be checked for plausibility.

7.3.7 Dimensioning on the basis of experience with constructional measures

7.3.7.1 Verification of structural safety or serviceability according to Section 7.3.6 may be dispensed with if the requirements of structural safety and serviceability can be adequately ensured with well-proven constructional and/or execution measures.

7.3.7.2 Some actions imposed by the ground, e.g. creep pressure, consolidation or settlements due to a lowering of the water table can often be counteracted better with constructional measures or by eliminating the action than by dimensioning according to limit states. The selected procedure shall be described in the basis of design.

7.3.7.3 In order to ensure that the limit states of structural safety and serviceability are not exceeded during the execution and service phases, different constructional or execution measures may be employed singly or in combination e.g.
- suitable and well-proven types of support
- established geotechnical auxiliary measures (long face anchors, drainage, jet-grouting, etc.)
- well-proven construction and other materials
- established construction methods
- well-proven structural design and detailing.

7.3.7.4 In order to assess the effectiveness of such measures, reliable, comparable and transferable experience must be available. The constructional and execution measures should exhibit a degree of reliability comparable with that for dimensioning according to limit states.

7.3.7.5 The type of support be used is generally decided upon on site, based on the assessment of the ground behaviour, ground properties and groundwater conditions.

7.3.8 Dimensioning based on tests

7.3.8.1 Some structural elements can be dimensioned on the basis of model tests, load tests or back-calculation from the current state. This is particularly meaningful if a large number of identical structural elements such as anchors or lining segments are used.

7.3.8.2 If the dimensioning of structural elements is based partly or entirely on tests, the conditions laid down in the codes SIA 260 and SIA 267 shall be complied with.

7.3.8.3 Tests on soil and rock anchors to determine the bearing capacity shall be carried out according to the code SIA 267/1. The differences in ground properties and in ground behaviour between the location of the tests and the actual location of the anchors shall be taken into account, as also time-dependence in the case of short-duration loading and in ground exhibiting pronounced creep behaviour.

7.4 Accidental actions and corrosion

7.4.1 Fire

7.4.1.1 The lining shall be designed such that no damage occurs in the case of fire,
- which could cause failure of the tunnel and substantial consequential damage or
- limits the serviceability of the tunnel permanently.

7.4.1.2 Past experience indicates that with a lining in close contact with firm ground and sufficient depth of cover over the crown no special precautions are necessary to prevent failure of the structure.

7.4.1.3 Special precautions are sometimes necessary in the following cases:
- cut-and-cover tunnel stretch with overlying structures or facilities
- tunnels in unstable ground beneath structures or facilities
- tunnels situated in the groundwater (soil of high permeability).

7.4.1.4 In the case of tunnels situated below the water table possible effects on the waterproofing need to be considered.

7.4.1.5 Progressive damage shall be prevented by means of appropriate detailing of the structural elements.

7.4.1.6 Special attention shall be given to structural elements that are important for the rescue of persons (self rescue or by others) or for the function of the fire ventilation.

7.4.1.7 The fire resistance can be increased through one or more of the following measures:
- increased concrete cover for the reinforcement
- more fire-resistant concrete
- passive fire protection measures (protective layers).

7.4.1.8 The required fire resistance shall be verified. The results provide a basis for safety planning and shall be documented in the safety report.

7.4.2 Explosion

Information is given in the codes SIA 197/1 and SIA 197/2.

7.4.3 **Earthquake**

7.4.3.1 Basic information on seismic effects is given in the codes SIA 261 and SIA 267.

7.4.3.2 An increased sensitivity to the effects of earthquakes may be given in the following cases:
- tunnels in soil
- shallow tunnels
- stretches of tunnel in fault zones
- stretches of tunnel in the transition soil/rock or cut-and-cover/underground construction.

7.4.4 **Corrosion**

7.4.4.1 In tunnels one has to reckon with an increased aggressiveness of the atmosphere that accelerates corrosion.

7.4.4.2 Locally very high corrosion can occur as a result of:
- direct corrosive action (e.g. through splashing, water spray)
- deposition of harmful substances (e.g. pollution)
- accumulation of salt on the intrados (ingress and vaporising of groundwater)
- formation of condensed water.

7.5 Special structural elements

7.5.1 **Lining segments**

7.5.1.1 In the case of tunnels (generally with circular cross-sections) the following segment types are used:
- segments as temporary support and as lining (single-lining)
- segments as temporary support (double-lining)
- invert segments (protection of excavated surface, substructure can be loaded immediately).

The combination of a single lining in the invert and a double-lining in the arch may also arise.

7.5.1.2 For the design, provided that after that there is no other requirement, the codes SIA 260 to SIA 263 apply. The actions imposed by the ground shall be determined, depending on the type of use, in accordance with Sections 7.1 to 7.3.

7.5.1.3 The following need to be determined in the design:
- shape and dimensions of the segments
- surface properties
- type and shape of joints (ring and longitudinal joints)
- type and position of connecting elements
- reinforcement (bar, mesh and/or fibre reinforcement)
- requirements for the construction materials (concrete, steel, waterproofing profiles).

The assumed values for the actions occurring in the production, transport, erection and during driving shall be taken into account.

7.5.1.4 Before starting with the production, information must be provided by the contractor regarding the forces acting on the segments caused by the driving equipment as well as the effective actions during production, storage, transport and erection. With this information, the dimensioning shall be checked and if necessary adapted.

7.5.1.5 If installed segments are partly or completely removed in order to install other structural elements e.g. niches, enlarged profiles, cross passages, shafts, connecting adits and ventilation control rooms, the required additional measures shall be specified in the design and dimensioned.

7.5.2 Lining consisting of unreinforced concrete

7.5.2.1 Unreinforced concrete is mainly suited to solid structural elements primarily under compression, which are not subjected to any significant constraints or seismic and dynamic loading.

Linings consisting of unreinforced or steel fibre reinforced cast in situ or sprayed concrete, which are installed after the ground deformations have largely or completely ceased, fulfil these conditions.

For the verification of structural safety according to the code SIA 262 the dimensioning value of the concrete compressive strength

7.5.2.2 f_{cd} shall be reduced by 20%.

7.5.2.3 If the lining does not fulfil the conditions of Section 7.5.2.1, then dimensioning shall be carried out according to the code SIA 262 or the Recommendation SIA 162/6, taking into consideration the deformations imposed by the ground. If a sufficient structural safety cannot be obtained (brittle failure behaviour, lack of rotational capacity), then adequate reinforcement is required.

7.5.3 Fastenings

7.5.3.1 Fastenings shall be determined according to technical criteria, such as the functional principle, structural behaviour, corrosion resistance, type of failure and the compatible interaction with other structural elements.

7.5.3.2 The code SIA 179 applies for fastenings, whose failure can present a hazard to persons or users (rail and road traffic) or result in serious damage.

7.6 Execution checks and monitoring

7.6.1 For each structure the execution checks and monitoring measures required to ensure structural safety and serviceability shall be specified for execution and operation.

If the observational method is employed, the special requirements for monitoring laid down in the code SIA 267 shall be taken into account.

7.6.2 The planned structure, the surrounding ground as well as existing structures and facilities shall, if relevant, be included in the execution checks and the monitoring.

7.6.3 For the execution checks and the monitoring the requirements of the code SIA 198 apply and, in a general sense, those also of SIA 267.

8 CONSTRUCTION WORKS

8.1 General

8.1.1 The tunnel system designates the structures that are necessary to achieve the planned use and ensure the safety of persons, the environment and material assets. The tunnel system may comprise:
- tunnel tubes
- cross-passages as escape routes (see Section 8.8)
- adits and shafts as separate escape routes (see Section 8.8)
- ancillary structures (see Section 8.10).

8.1.2 The tunnel system shall be determined as a function of the type and intensity of use (type and volume of traffic).

8.2 Alignment

8.2.1 If possible, the alignment should be adapted to the ground conditions in an early design phase.

8.2.2 In the case of long tunnels, for technical reasons involving execution or operation and safety, the choice of the alignment can be influenced, e.g. by
- undertaking intermediate attacks
- tunnel ventilation plant.

8.2.3 The longitudinal section should be chosen so as to allow the water in the tunnel to drain away to the portals.

8.2.4 For technical reasons involving the drainage, a longitudinal gradient of at least 0.5% shall be aimed at.

8.2.5 The ground conditions shall be taken into account when specifying the distance between two adjacent parallel tunnel tubes. In special cases (e.g. branching, portal area) other criteria may be decisive.

8.3 Tunnel cross-section

8.3.1 **General**

8.3.1.1 The typical cross-section of the tunnel with information on the support, waterproofing, drainage, lining and finishing together with usable spaces and equipment shall be shown in the standard cross-section.

8.3.1.2 The following points shall be considered in the design of the standard cross-section:
- required design section
- waterproofing and drainage concept (see Sections 8.6 and 8.7, and the code SIA 272)
- required lining
- technical requirements due to execution (e.g. circular section with machine excavation).

8.3.1.3 If different construction methods seem to be equivalent but necessitate different standard cross-sections, it may be better to plan and invite tenders for different projects.

8.3.2 **Design section**

8.3.2.1 The space beneath the running surface is determined by the space required for the drainage system and cable ducts, as well as the constructional and the technical execution requirements.

8.3.2.2 The space above the running surface is determined by the required usable space (Figures 2 and 3), as well as the constructional and the technical execution requirements.

8.3.2.3 The usable space consists of the elements listed below:
- usable space for traffic
- usable space for constructional purposes
- usable space for ventilation (if required).

8.3.2.4 The usable space for traffic consists of the following elements:
- clearance profile (usable space for passage through the tunnel above the running surface)
- abutment with space for walkway (service or emergency way)
- space for equipment including any free space (safety margin).

8.3.2.5 The space for constructional purposes *(t)* consists of the following elements:
- space for tolerances *(a)*
  The space for tolerances takes into account the deviations due to execution errors (see Section 8.3.3).
- space for later constructional measures *(b)*
  The space for later constructional measures is reserved for measures (e.g. thickening of the lining, noise-insulating lining), which may be necessary during the service phase.

  The two values *a* and *b* are combined in a different way for rail and road tunnels.

8.3.2.6 The usable space for ventilation provides space for a ventilation duct, separate from the running tunnel space (one or more parts).

8.3.3 Deviations from design dimensions (execution errors)

8.3.3.1 The following deviations shall be differentiated:
- deviations in the cross-section or individual construction elements from the design dimensions and the planned shape
- deviations in the cross-section (axis) or individual construction elements from the planned position.

The deviation is the difference between the actual value and the corresponding design value. The planned position is based on the theoretically calculated axis.

8.3.3.2 In underground construction, deviations from the design values occur due to:
- deformation of the structure (ground)
- inaccuracies in execution
- deviations in the axis (surveying errors).

8.3.3.3 Due to the stress redistribution in the ground – depending on the ground properties, the construction process and the temporary support – the shape of the structure can change. Thus deviations from the design dimensions may arise that are independent of the execution inaccuracies and deviations in the position of the axis.

8.3.3.4 Execution inaccuracies refer to all the deviations that occur in the execution (e.g. inaccuracy in the setting out, deviation of the drive from the design axis, different shape of the excavated cross-section, inexact position and shape of the temporary support and the lining).

8.3.3.5 Deviations in the axis are given by unavoidable, random measuring errors. They consist of the inaccuracy in the position of the basic surveying network (plan view and vertical section) and the underground network determined as excavation proceeds. In the case of long tunnels this may be in the range of several centimetres to decimetres.

8.3.3.6 The real deviation of the driving axis from the design position can only be determined after the breakthrough. Beforehand the checks on the setting-out by the client may be taken as a reference. However, due to the accumulation of random measuring errors this already exhibits deviations with respect to the design position.

Figure 2 Definition of the usable space (rail tunnels)

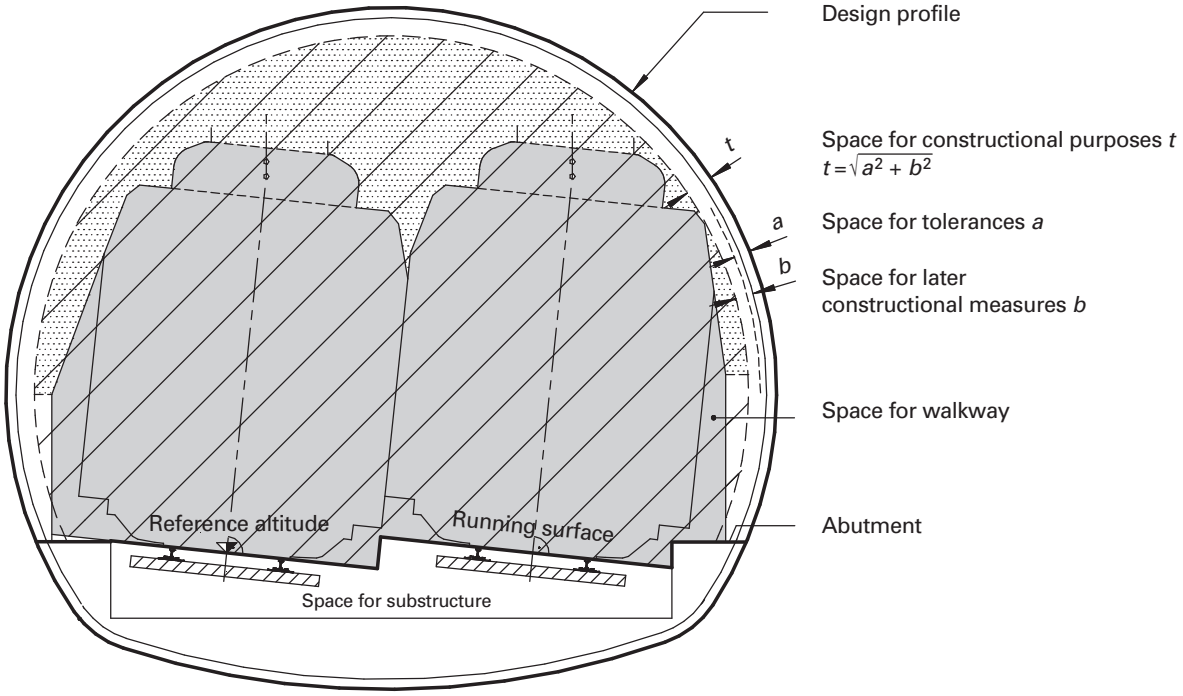
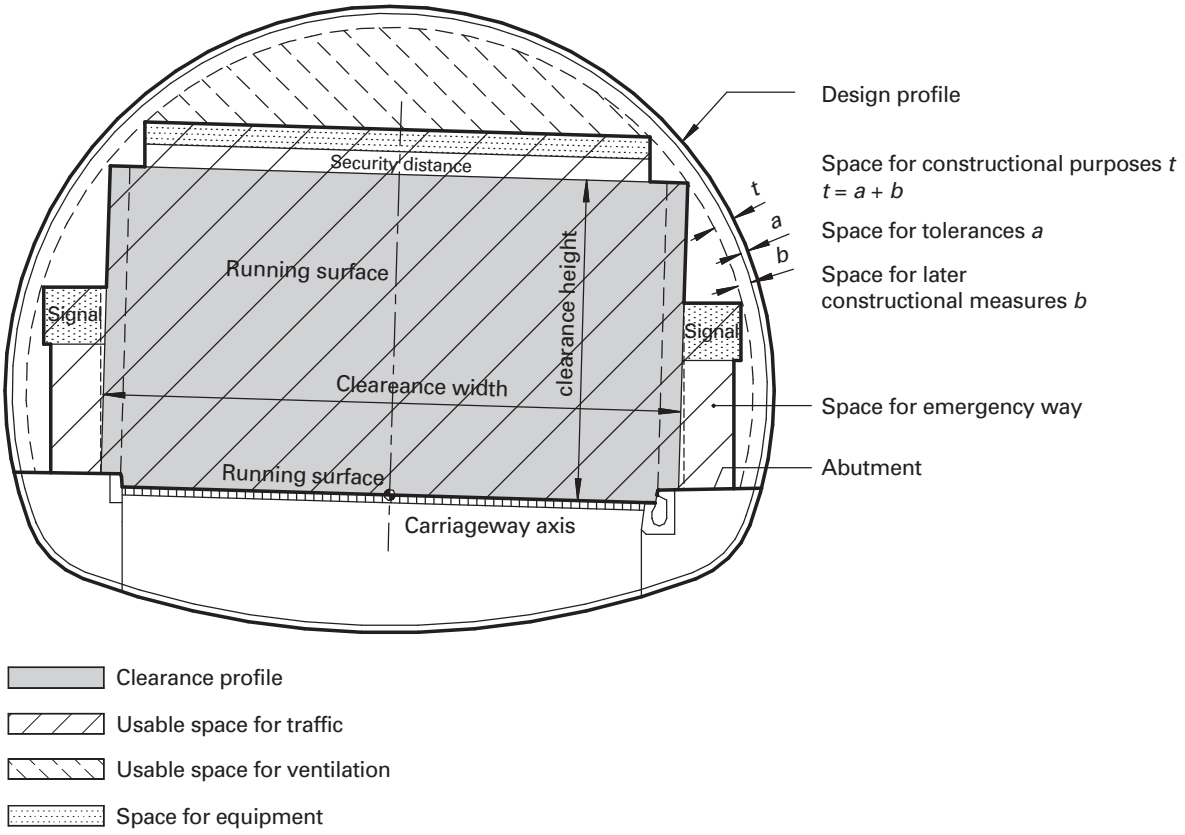


Figure 3 Definition of the usable space (road tunnels)



8.3.3.7 If the construction of the lining starts before the tunnel breakthrough has taken place, the tunnel axis deviations – depending on the size of the maximum foreseeable breakthrough error – shall be compensated by appropriate measures (enlarging the excavated cross-section, modifying the dimensions of the inner lining, etc.).

8.3.3.8 For the vectors of the deviations from the design values, due to execution inaccuracies and deviations of the tunnel axis, the following apply:
- they only reach their maximum value in the same place very rarely.
- they usually do not exhibit the same direction at the same time.

Thus the probable total deviation to be considered can be determined by means of a law of error propagation.

8.3.3.9 If no exact information is available to take into account the execution inaccuracies, the following nominal values for deviations shall be specified.

Table 2 Space to accommodate execution inaccuracies

Method of excavation (see code SIA 198)	Recommended values in cm (measures as radius)	
	Excavation width ≤ 5 m	Excavation width > 5 m
Drill and blast	5	10
Mechanised excavation in rock	5	10
TBM – excavation in rock	15	15
Mechanised excavation in soil		
– without shield	10	15
– with shield	15	20

8.3.3.10 The deviations with respect to the design values, planned shape and planned position of the design cross-section can be taken into account as follows:
- in the tunnel cross-section by increasing the design section
- during execution by adjusting the cross-section on the basis of the actual deviations (modifying the cross-section of excavation, modifying the lining, reprofiling)
- after driving or breakthrough by specifying a new theoretical tunnel axis
- by a combination of these solutions.

The procedure shall be specified in the service criteria agreement.

8.4 Lining

8.4.1.1 The choice between a single or a double-lining depends on the ground, the construction method, the required waterproofing, operational requirements and economic aspects (execution and conservation). The optimum solution and the type of lining shall be specified for each project.

8.4.1.2 For a single-shell lining, the lining supplements the temporary support, except for the case of single-pass segments. Between the temporary support and the lining there is a frictional and an interlocking connection. In the basis of design it shall be specified whether the structural resistance of the temporary support shall be fully or partially considered in determining the bearing capacity of the lining during the service phase.

8.4.1.3 For a double-shell lining between the temporary support and the lining there is no guaranteed frictional connection. The two linings are separated by an intermediate layer (e.g. waterproofing membrane, drainage layer). The temporary support exhibits in general a temporary load-bearing function. In the basis of design it shall be specified to what extent the structural resistance of the temporary support shall be considered during the service phase to determine the bearing capacity of the lining.

8.4.1.4 The thickness of the lining is governed by structural requirements, the minimum thickness being given by the technical execution requirements.

8.4.1.5 In the following cases in general a double-lining should be chosen:
- if the groundwater is aggressive with regard to concrete, requiring a durable inner ring, protected by waterproofing, as the permanent inner lining
- in the case of mechanised excavation (TBM), if extreme loading is caused by non-uniformly distributed rock pressure or high swelling pressure and the segments alone do not provide the necessary structural reserves
- in the case of simultaneous high water pressure and high water ingress, if the required waterproofing can no longer be permanently ensured with a single lining.

8.4.1.6 The invert must resist the actions that result from traffic (during both construction and operation), the ground, the groundwater and the utilisation water. The invert (substructure) and the superstructure shall be considered as a single interacting system.

8.4.1.7 The invert is in general not accessible. It must be able to resist long-term actions permanently (without maintenance). The provision of an invert arch may be useful.

8.4.1.8 If an invert arch is necessary, the structural and the constructional requirements of force transmission between the substructure and the arch shall be considered. The arrangement of the pipes, cable ducts and, if required, a service gallery must also comply with these requirements.

8.4.1.9 The lining shall be designed such that, at the earliest, a complete rehabilitation is required on reaching the design working life specified in the service criteria agreement.

8.4.1.10 If reinforcement is necessary (e.g. in the case of niches, at the intersection with cross-passages), measures to protect the reinforcement must be implemented (adequate concrete cover, high-density concrete, surface treatment, etc.).

8.5 Carriageway, walkways and cable ducts

8.5.1 Carriageway

8.5.1.1 The term “carriageway” does not have the same meaning for railways and roads.

8.5.1.2 In the case of railways the term “carriageway” denotes the whole of the track, which is subdivided into substructure and superstructure.

8.5.1.3 In the case of roads the term "carriageway" denotes the part of the road serving the traffic (geometrical quantity). The term "road structure" comprises the whole of the body of the road (as a structural component), which is subdivided into substructure and superstructure.

8.5.1.4 Further information on the carriageway in rail or road tunnels is given in the codes SIA 197/1 and 197/2.

8.5.2 Walkways

Information is given in the codes SIA 197/1 and 197/2.

8.5.3 Cable systems

8.5.3.1 The cables of the different operating and safety equipment are housed in cable ducts, etc. These include high- and low-voltage cables, cables for current of low-amperage and fibre-optic cables.

8.5.3.2 The cable systems comprise the following components:
- cable pipe blocks with pulling-in and connecting shafts
- cable pipe crossings
- cable channels including supports
- earthing plant
- distributor cabinets.

8.5.3.3 The need for any third-party pipes and reserve pipes must be clarified beforehand.

8.5.4 Protection against vibrations and structure-borne noise

Information is given in the codes SIA 197/1 and 197/2.

8.6 Waterproofing

8.6.1 Actions

8.6.1.1 The following physical actions due to groundwater shall be considered:
- water penetration may damage the lining and the water may freeze in winter (forming ice in the usable space). Enclosed frozen water can cause further damage due to ice pressure.
- groundwater can influence the behaviour of the ground during execution and also later. Especially in the case of coarse- and fine-grained cohesionless soil (gravely sand, sand, fine sand, silt) measures have to be taken to prevent material from being washed into (and clogging up) the drainage layers.
- groundwater can exert pressure on the lining. The magnitude of the water pressure depends on the height of the relevant water table, which may fluctuate locally and over time. The lining shall be dimensioned for the highest possible water pressure.

8.6.1.2 The following chemical actions due to groundwater shall be considered:
- potential of chemical aggressiveness of the groundwater (soft water, aggressive water) on the construction materials and the sintering potential in the choice of material. Higher water temperature can increase the potential of chemical attack.
- the possibility of strongly mineralised groundwater discharging from a jointed structure in formations generally exhibiting low permeability (groundwater at depth).
- dissolved minerals being deposited in the pipes. The combined effect of the solution and the deposition of minerals shall be considered in the design of the drainage system.

8.6.1.3 In specifying the critical amount of water it shall be taken into account that:
- the amount of groundwater may vary considerably according to the geological and hydrogeological conditions.
- the amount of water penetrating the underground opening may be affected by constructional measures e.g.
  - application of sprayed concrete as temporary support, installing an invert arch directly on the ground, etc.
  - specific pattern of grouting to improve and seal the ground.

The possible consequences of constructional measures in relation to sintering potential shall be taken into account.

8.6.1.4 The place where groundwater flow occurs is influenced by the construction of the tunnel:
- water may flow from water-bearing layers to dry areas via drainage layers or by circulation along the tunnel.
- with the water-resisting concept the restrained groundwater can be distributed over the entire length of the tunnel.

If possible, these effects should be avoided by means of suitable measures (e.g. sealing off some sections, dewatering). Water circulation must be eliminated in the case of swelling rock.

8.6.1.5 In the case of waterproofing that is intended to prevent the outflow of liquids from the tunnel, the resulting actions and the requirements shall be determined for each specific object.

8.6.2 Requirements for waterproofing

8.6.2.1 Measures shall be taken to avoid the influences of the water on the structure and prevent damage to the operating and safety equipment and impaired operation, caused either by dripping and splashing water or by the formation of ice.

8.6.2.2 Special requirements apply in the portal areas to prevent ice formation or ice pressure. The length of this stretch of tunnel shall be fixed by the local climatic conditions.

8.6.2.3 The waterproofing is described by the following classes:

Table 3 Waterproofing classes

Waterproofing class	Description
1	Completely dry No damp areas permitted on the dry side of the structure's surface.
2	Dry to slightly damp Some damp areas permitted. No dripping water permitted on the dry side of the structure's surface.
3	Damp Locally limited damp areas and some dripping spots permitted on the dry side of the structure's surface.
4	Damp to wet Damp areas and dripping spots permitted.

8.6.2.4 The critical surfaces of the structure and the corresponding waterproofing classes shall be specified and described in the plans (standard cross-section, longitudinal section). In this way the boundaries and the interfaces are shown.

8.6.2.5 By specifying the required waterproofing it is not ensured that the structure's surface does not become wet due to possible condensation.

If there are special requirements concerning climatic conditions, this question has to be investigated separately.

8.6.3 **Waterproofing concept**

8.6.3.1 The waterproofing concept is influenced by the following conditions:
- in general waterproofing cannot be renewed.
- conservation measures are usually only of limited application and promise of success.
- waterproofing may fail during the design working life (leaks, by-passed, water pressure).
- the drainage may fail during the design working life (sintering, silting-up, biological deposits).

8.6.3.2 If necessary, suitable precautions shall be taken to be able to drain away leaking water.

8.6.3.3 The following points shall be considered when preparing the concept:
- hydrogeological conditions (amount, pressure, chemistry and distribution of water)
- utilisation-dependent aspects (conservation possibilities, design working life)
- ecological boundary conditions
- economic boundary conditions.

It shall also be ascertained which waterproofing systems (see Sections 8.6.4, 8.6.5 and 8.6.6) are suited to the planned concept.

8.6.3.4 Drainage concept

The inflowing groundwater is passed through the drainage layer under atmospheric pressure to one or more selected places in the cross-section and discharged there to a seepage water drain pipe that allows infiltration. To prevent a build-up of water pressure, one drain pipe must be located at the lowest point of the cross-section.

The drainage layer must have a sufficiently large flow section. The drainage function must be permanently ensured.

The waterproofing system shall be designed as a measure for water-under-zero pressure either with partial waterproofing in the arch or with full waterproofing around the whole of the tunnel profile (non-pressure-resisting waterproofing).

8.6.3.5 Resistance concept

The infiltrating groundwater is not drained away but held back.

The waterproofing system shall be designed as a measure to restrain water under pressure with full waterproofing around the whole of the tunnel profile (pressure-resisting waterproofing).

8.6.3.6 Partial drainage

Partial drainage may occur in the case of drainage not covering the entire surface, e.g. by means of drainage "half-shell" in the case of the sprayed concrete method, weep slits in the invert or drainage boreholes. A complete reduction of the water pressure is not ensured in these cases.

The waterproofing system shall be designed according to the requirements, in particular the required waterproofing class.

8.6.3.7 Partial resistance in the ground

In special cases (e.g. large quantities of water and high water pressure) additional measures may be necessary.

By means of grouting (filling-up and closing seepage channels in the ground) a zone of ground with low permeability can be produced. By means of drainage boreholes a drained zone is created around the tunnel. The inflowing groundwater is drained away and thus a build-up of the full water pressure is prevented.

The waterproofing system shall be designed as for the drainage concept.

8.6.4 Flexible waterproofing systems

8.6.4.1 In the case of flexible systems generally single- or double-layer built-in sealing strips are used. A different structure of the waterproofing layer is also possible.

8.6.4.2 In the drainage concept the system comprises the sealing strip, the drainage layer (e.g. drainage membrane, dimple membrane, layer of gravel) and the ground. The drainage layer may also serve to protect the sealing strips from the ground.

8.6.4.3 In the resistance concept the system comprises the sealing strip, the provisions for the subsequent sealing, the protective underlay (e.g. geotextiles) next to the ground and the ground.

8.6.4.4 The requirements for these systems (e.g. compression-shear behaviour, deformation behaviour under pressure) shall be specified for each object.

8.6.5 Rigid waterproofing systems

8.6.5.1 Rigid systems consist of an impermeable reinforced lining (in situ concrete, sprayed concrete) or of segments with sealed joints.

8.6.5.2 In the drainage concept, drainage layers and/or drainage channels shall be provided to drain away the water permanently.

8.6.5.3 In the resistance concept, if necessary, pre-waterproofing and load reductions are necessary to be able to ensure the quality of the impermeable lining. These measures only have a temporary function.

8.6.5.4 The requirements for these systems (e.g. admissible joint and crack widths) shall be specified for each object.

8.6.6 Additional measures

8.6.6.1 No additional measures are required in the drainage concept, if it is ensured that no inadmissible water pressure can build up in the drainage layers.

8.6.6.2 In the resistance concept additional measures are required:
- provisions for draining away water from leaks
- provisions for subsequent waterproofing with system-compatible (flexible) grouting
- sealing of weak spots (cracks, pockets of gravel) with system-compatible grouting.

8.6.6.3 If the sealing strip is mechanically stressed (e.g. in temporarily used tunnel sections, by re-inforced structural elements, stopend formwork, construction joints and supports), additional protection measures shall be planned.

8.7 Drainage

8.7.1 General

8.7.1.1 The drainage system serves to collect and discharge different kinds of water:
- water flowing from the ground (groundwater)
- water and liquids that collect in the traffic space (utilisation water).

8.7.1.2 The drainage system for the groundwater is part of the waterproofing concept (see Section 8.6.3).

8.7.1.3 With respect to the expected ingress of groundwater possible annual fluctuations (amount, pressure) shall be taken into account.

8.7.1.4 Generally, the utilisation water comprises the following:
- meteoric water that is carried by vehicles into the tunnel
- dirty water that is produced when cleaning the tunnel
- fire-fighting water that is needed in emergencies
- liquids that escape in the case of accidents.

8.7.1.5 The expected amount of utilisation water shall be specified for each object. Generally, the cases of maintenance work (cleaning water) and of emergencies (fire-fighting water) are critical.

8.7.2 Sintering

8.7.2.1 The causes of the sintering (hard deposits) and the available measures to influence this effect shall be considered in the design of the drainage system.

8.7.2.2 Causes of sintering

The origin of sintering in the drainage system is highly dependent on the infiltrating groundwater and the type of lining. It can be traced back to a change in the carbonic acid–calcium carbonate equilibrium of the groundwater on entering the tunnel, which among other things depends on the mineralisation, CO_2 content, temperature, pressure and pH value.

The carbonic acid dissolved in the groundwater can outgas in contact with the air in the tunnel (CO_2 partial pressure equalisation). This can lead to the precipitation of calcium carbonate, which forms hard deposits.

Due to groundwater containing carbonic acid or to soft-groundwater calcium carbonate can be leached out of the cement in the temporary support or in grouted zones, which is precipitated in the drainage system in greater strength.

8.7.2.3 Determination of the sintering potential

To estimate the sintering potential the expected amount, the chemistry and the temperature of the groundwater have to be quantified in the individual zones. Hereby the possible interaction of the groundwater and the substances it contains with the construction materials (e.g. sprayed concrete, grout) shall be taken into account.

The results form the basis for the dimensioning of the drainage system including the necessary drainage space.

8.7.2.4 Measures to reduce sintering potential:
- reduce the contact of groundwater with the concrete (especially sprayed concrete), e.g. by collecting the groundwater by means of drainage boreholes
- use concrete, porous concrete, mortar and grout with a smaller leaching tendency.

8.7.2.5 Measures to reduce sinter formation:
- allowing water to build up in the drains as far as possible
- siphoning the pipes including the airtight drainage system
- avoidance of turbulent currents
- conditioning of water.

8.7.2.6 Principle of siphoning

The pipes, up to the point where they feed into the main pipe, should be sealed from the outside air and the water built up in regular intervals. It should be aimed to have a siphoning height > 0.3 m above the top of the pipe.

It should be observed that the build-up of water creates a corresponding water pressure in the area of the substructure and abutments and at the same time can increase the contact with the construction materials containing cement.

8.7.2.7 Principle of water conditioning

By adding a hardening stabiliser one can influence the crystallisation behaviour during precipitation and a large part of the undissolved materials is held in suspension.

The correct dosage of the conditioning agent must be checked regularly taking into consideration possible changes in the chemistry of the groundwater.

The hardening stabiliser can also be added in a solid form, e.g. to reduce sintering in drainage layers.

8.7.2.8 Discharge concept

The drainage pipes and the control shafts shall be designed such that the groundwater – depending on the amount and the sintering potential – is either piped away or discharged into the drainage pipes.

8.7.2.9 Operation of the drainage system

The sintering increases the maintenance work and due to the necessitated intensive cleaning it can lead to a greater wear of the drainage system.

8.7.3 Collecting the water (drainage)

8.7.3.1 The drainage layer (seepage strip, seepage packing or gravel layer, etc.) must permanently carry the ingress of groundwater. It shall be dimensioned for:
- actions imposed by the ground (pressure, temperature)
- actions imposed by the groundwater (amount, chemistry, sintering, silting-up).

8.7.3.2 The following need to be taken into account in the detailing:
- the drainage layer is in general not accessible and cannot be maintained.
- the actions, above all sintering, may reduce the effective surface area and the flow cross-section and thus impair the functioning of the drainage layer long-term.

8.7.3.3 Cemented drainage layers shall be avoided.

8.7.3.4 The properties of the drainage layer and the flow pipes shall be consistent with each other, e.g.
- the grain size distribution of the material in the drainage layer and size of the intake openings (width of slit, diameter of hole)
- the flow cross-section of the drainage layer and of the intake opening.

8.7.3.5 For other drainage measures (e.g. drainage boreholes, sealing carried out beforehand) the above regulations apply in a general sense.

8.7.4 Discharging the water (seepage and drain pipes)

8.7.4.1 The drainage system shall be designed for easy maintenance and so that its function is ensured over the design working life. It should be ensured that
- all parts should be well accessible and allow inspection.
- maintenance works should not hinder the traffic.
- servicing and repair works should cause as little expenditure as possible.
- the replacement of worn parts (covers, valves, syphons, etc.) does not require any constructional changes.

8.7.4.2 The drainage system shall be designed so that the use of mechanical means (flushing equipment, etc.) is possible.
- the seepage and drainage pipes must have a minimum diameter of 200 mm.
- tight curves and branching shall be avoided.
- the pipes shall be made as straight as possible.

8.7.4.3 The detailing (materials, wall thickness of the pipes, bedding, etc.) shall be specified such that the drainage system can permanently resist the expected actions. Attention shall be given to:
- physical and chemical actions of the groundwater and the utilisation water (e.g. ageing, external water pressure)
- actions imposed by the ground (e.g. swelling pressure)
- stresses occurring during execution (e.g. bedding of the pipes) and operation (e.g. flushing equipment or flushing pressure)
- actions due to critical events (e.g. fire).

8.7.4.4 Attention shall be paid to the danger of sintering (see Section 8.7.2). Suitable materials and pipes with as smooth a wall surface as possible shall be provided.

8.7.4.5 If a permanent penetration of natural gases into the drainage system is expected, suitable protective measures shall be taken (risk of accident).

8.7.5 Discharge in front of the portal

8.7.5.1 In the area of the portal additional system components are necessary that are compatible with the selected drainage system. These should fulfil all relevant requirements during execution and operation.

8.7.5.2 The outflowing groundwater and utilisation water shall be discharged according to the requirements of the environmental impact report. The regulations governing the prevention of water pollution and the discharge conditions shall be complied with.

8.7.5.3 In general special measures shall be taken to be able to ensure the observance of the discharge conditions, such as
- inspection manholes for taking samples and to measure the amount of flow
- storage possibilities (e.g. multiple storage basins) for the retention of the utilisation water
- purification plant for the utilisation water.

8.7.5.4 In the concept for storing the water the following shall be observed:
- critical storage volume compatible with Section 8.7.1.5
- requirements for protection against explosion.

8.8 Additional structures for safety

8.8.1 The tunnel usually includes auxiliary structures that are suitable for limiting the danger to users in the case of critical events, e.g. in the case of a breakdown, after fire breaks out or after an accident with the release of dangerous substances.

8.8.2 The type and amount of these structures to enhance safety depends very much on the tunnel system (position, length, number of tunnel tubes). Detailed information is given in the codes SIA 197/1 and 197/2.

8.9 Tunnel portals

8.9.1 The portals determine the appearance of the tunnel and have to fulfil aesthetic, technical and safety requirements.

8.9.2 The portals shall be carefully designed. In the process the following points shall be considered:
- the surroundings up to some distance from the tunnel
- geographical, topographical and meteorological boundary conditions
- natural hazards (rockfall, snow, etc.)
- other structures (retaining walls, operating rooms, roads, etc.).

8.9.3 The position of the portal and the size of the approach cutting (length and depth, boundary conditions for the excavated portal) shall be adapted to various circumstances, e.g.
- ground
- topographical boundary conditions
- possible driving methods for the tunnel
- technical requirements for the execution.

8.9.4 Tunnel sections constructed above ground (cut-and-cover tunnel, rockfall and avalanche galleries) should have the same design cross-section as that of the tunnel.

8.9.5 If the slope of the ground above the tunnel portal is greater than 2:3, an easily accessible intercepting area of at least 3.0 m length with a wall should be included as a protection against rockfall and for the safety of workers. Accumulating surface water shall be collected and properly drained away.

8.9.6 In the case of tunnels with more than one tube the recirculation of contaminated air or exhaust fumes (smoke) shall be prevented as far as possible by means of design measures.

8.10 Ancillary structures

8.10.1 By ancillary structures are understood structures that are needed for the use and operation of the tunnel, e.g. structures for tunnel ventilation, rooms for technical equipment.

8.10.2 The type and number of ancillary structures depends primarily on the tunnel system (position, length, number of tunnel tubes).

8.10.3 In the area of the portals, if necessary, structural measures shall be implemented for critical events, such as:
- access and exit routes as well as turning possibilities for vehicles belonging to the emergency services
- landing place for rescue helicopters.

9 OPERATING AND SAFETY EQUIPMENT

Information is provided in the codes SIA197/1 and 197/2.

APPENDIX A LEGAL REQUIREMENTS (informative)

The following list is not exhaustive. English is not an official language of the Swiss Confederation. The translations are provided for information purposes only and have no legal force.

A.1 In connection with the environment

- *Bundesgesetz über den Umweltschutz* (*Umweltschutzgesetz* USG), SR 814.01: Environmental Protection Act, EPA
- *Verordnung über die Umweltverträglichkeitsprüfung* (UVPV), SR 814.011: Ordinance on environmental impact assessment
- *Verordnung über den Schutz vor Störfällen* (*Störfallverordnung* StFV*)*, SR 814.012: Major Accidents Ordinance, MAO
- *Bundesgesetz über den Schutz der Gewässer* (*Gewässerschutzgesetz* GSchG), SR 814.20: Water Protection Act, WPA
- *Gewässerschutzverordnung* (GSchV*), SR 814.201:* Water Protection Ordinance, WPO
- *Lärmschutz-Verordnung* (LSV), SR 814.41: Noise Abatement Ordinance, NAO
- *Verordnung über den Schutz vor nicht ionisierender Strahlung* (NISV), SR 814.71: Ordinance on protection against non-ionising radiation

A.2 In connection with electrical installations

- *Elektrizitätsgesetz* (ELG), SR 734.0: Electricity Act
- Verordnung über die elektrischen Starkstromanlagen (*Starkstromverordnung* StV), SR 734.2: Ordinance on high voltage plants
- *Verordnung über elektrische Niederspannungserzeugnisse* (NEV), SR 734.26: Ordinance on low voltage electrical products
- *Verordnung über elektrische Niederspannungsinstallationen* (NIV), SR 734.27: Ordinance on low voltage electrical installations
- *Verordnung über elektrische Leitungen* (*Leitungsverordnung* LeV), SR 734.31: Ordinance on electrical transmission lines

A.3 In connection with railways

- *Eisenbahngesetz* (EBG), SR 742.101: Railways Act
- *Eisenbahnverordnung* (EBV), SR 742.141.1: Ordinance on the construction and operation of the railways
- *Ausführungsbestimmungen zur Eisenbahnverordnung* (AB-EBV): Regulation governing execution requirements for the railways
- *Verordnung über das Plangenehmigungsverfahren für Eisenbahnanlagen* (VPVE), SR 742.142.1: Ordinance on the planning approval procedure for railways
- *Verordnung über elektrische Anlagen von Bahnen* (VEAB), SR 734.42: Ordinance on electrical equipment for railways
- *Ausführungsbestimmungen zur Verordnung über elektrische Anlagen von Bahnen* (AB-VEAB): Execution requirements for the ordinance on electrical installations for railways

A.4 In connection with roads

- *Strassenverkehrsgesetz* (SVG), SR 741.01: Road Traffic Act
- *Verkehrsregelnverordnung* (VRV), SR 741.11: Ordinance on traffic regulations
- *Signalisationsverordnung* (SSV), SR 741.21: Ordinance on signalisation

APPENDIX B OVERVIEW OF ACTIVITIES (informative)

B.1 In Tables 4 and 5 the services are listed that occur in the different planning phases (sub-phases). The information given therein is purely informative. The activities shall be determined on the basis of the specific targets for the object.

B.2 The requirements with regard to the accuracy of costing – based on legal requirements – shall be specified.

B.3 In Tables 4 and 5 the following abbreviations are used:

BSA	Operating and safety equipment
UVB	Environmental impact report
QM	Quality management

Table 4 Services (Part 1)

Design phases / Activity	Preliminary study	Preliminary project [1]	Submitted project [2]	Construction project [3]	Tendering	Detailed design
Organisation (project management)	Present appropriate project organisation and lists of duties	Fix project organisation and lists of duties Determine QM concept	Lead and monitor progress of design Support public relations work	Lead and monitor progress of design	Accompany tendering	Lead and monitor progress of design
Quality management	Prepare service criteria agreement	Analyse project risks and if necessary adapt service criteria agreement	Analyse project risks and possibly adapt service criteria agreement	Analyse project risks and possibly adapt service criteria agreement Prepare Q-control plan	Determine suitability and acceptance criteria Prepare construction inspection plan	Analyse project risks and possibly adapt service criteria agreement Implement QM
Ground	Prepare geological, hydrogeological and geotechnical reports on the basis of existing documents Propose site investigations	Revise geological, hydrogeological and geotechnical reports on the basis of actual results Propose additional site investigations	Revise geological, hydrogeological and geotechnical reports on basis of actual results If necessary, propose additional site investigations	Prepare summary of geological, hydrogeological and geotechnical reports If necessary, propose special site investigations	–	Investigate and assess actual conditions If necessary, update geological, hydrogeological and geotechnical reports
Safety planning	Prepare basis for safety analysis	Prepare general safety analysis Specify constructional, operational and organisational measures	Check safety analysis and measures and adjust if necessary Prepare safety report	Check utilisation concept and measures and adjust if necessary Update safety report	–	Implement measures according to safety report Adjust utilisation concept
Environment	Specify relevant actions on the environment Prepare general UVB	Check actions Prepare material management concept Prepare UVB	Specify actions and measures Adjust concept for material management Adjust UVB	Include facilities affecting the environment in the project	–	Implement measures according to UVB Implement concept for material management
Operation	Prepare basis for operation concept	Specify BSA in general terms Specify operation concept	Specify BSA Adjust operation concept Prepare service instruction Prepare operation instructions	Dimension BSA Check operation concept Check service instruction, Check operation instructions	–	Check and approve basic documents of the contractors

[1] For national motorway: general project [2] For national motorway: execution project [3] For national motorway: detailed project

Table 5 Services (Part 2)

Design phases / Activity	Preliminary study	Preliminary project [1]	Submitted project [2]	Construction project [3]	Tendering	Detailed design
Basis of design	Clarify technical and economic possibilities	Prepare conceptual design Prepare general static analysis (structural analysis and dimensioning) Specify concept for waterproofing and drainage	Refine conceptual design Prepare static analysis (structural analysis and dimensioning) Check concept for waterproofing and drainage	Complete conceptual design Prepare and if necessary complete static analysis (structural analysis and dimensioning) Check concept for waterproofing and drainage	Prepare bill of quantities (structure and BSA) Check tenders	Prepare detailed plans Modify static analysis (structural analysis and dimensioning) if necessary for the effective conditions
Construction methods	Determine possible construction methods	Evaluate and assess possible construction methods	Specify construction methods	Check and if necessary modify construction methods	Check tenders	Adjust construction method according to effective conditions
Design specification	Describe general solution possibilities Present essential aspects in basis of design	Highlight optimum solution(s) Prepare basis of design	Describe planned solution If necessary, modify basis of design	Describe planned solution If necessary, modify basis of design	List special requirements (structure and BSA) Check tenders	Extend and complete relevant documents
Special regulations for execution	–	–	Determine and describe aspects which are relevant for the public Fix site concept (spaces, access and services, etc.)	Include imposed conditions in relation to execution in the project Check construction site concept and if necessary modify it	Describe requirements specific to the object Specify conditions for contractor-proposed variants	–
Costs (accuracy)	Prepare cost estimate on the basis of costs of similar existing works (± 40%)	Prepare cost estimate on the basis of costs of comparable existing structures (± 30%)	Determine cost estimate on the basis of predicted quantities and values drawn from experience (± 20%)	Check cost estimate and adjust it if necessary (± 10%)	Determine realistic predicted quantities	Cost control (comparison of estimated and actual costs)
Construction programme	Prepare general programme on the basis of similar works (experience)	Prepare general programme on the basis of similar structures (experience)	Prepare overall programme on the basis of the project specification and definitive studies	Prepare programme for the individual construction lots and adjust overall programme	Determine basis for planned time schedule Specify deadlines (start/end) for execution	Monitor deadlines (comparison of estimated and actual)

[1] For national motorway: general project [2] For national motorway: execution project [3] For national motorway: detailed project

Abbreviations of the organisations represented in the Committee SIA 197

ASTRA	Bundesamt für Strassen (Federal Office of Roads, FEDRO)
BAFU	Bundesamt für Umwelt (Federal Office of the Environment, FOEN)
BAV	Bundesamt für Verkehr (Federal Office of Transportation, FOT)

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