VRC Safety Guidelines Part C

Basic Measures

Version 1.0
January 2004

Ministry of Transport, Public Works and Water Management

jklmnopq

Public Works Dept. and Water Management, Civil Engineerging Division

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Steunpunt Tunnelveiligheid

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1 Introduction

The expropriation of increasingly scarcer space is constantly growing. Building densities are still increasing and ideas concerning use of the ‘third dimension’ are already taking shape. Alongside the ‘traditional’ methods of tunnelling, new technology is being developed (including boring, deepened positionings, covering-over); more often, there are also considerations to completely cover-over motorways in order to create more room for living space, offices and housing.
In this context an integral approach to the safety issue is an absolute must. The guidelines which were set down in the past (such as the WUT guidelines) were inadequately geared for this.

The Civil Engineering Division's Center for Tunnel Safety have formulated an integral method of approach for the safety issues of the infrastructure of subterranean roads.
To summarize, this philosophy comprises 5 main sections (for further clarifications, please refer to the appendix):

A. Standards, guidelines and starting points.
B. Safety considerations.
C. Basic measures.
D. Additional measures and their safety effectiveness.
E. The safety organisation.

This compilation concerns Part C. The compilation consists of two parts that jointly constitute a complete unit. In the first part entitled ‘VRC Guidelines’ a description is given of the safety measures which *could be* applied to the subterranean and deepened positioning infrastructure. Please note: this does not mean that all the measures mentioned here actually have to be applied! The guidelines with their associated (brief) explanations are formulated for each measure. The second part entitled ‘VRC Appendices’ contains appendices for most of the chapters in the guidelines. A more extensive explanation of the guidelines is provided, as well as background information. Reference is also made to relevant literature.

The measures mentioned in this compilation are restricted purely to the safety aspects. For further designing, specifications, implementation methods and suchlike, please refer to SATO[1].

These guidelines are primarily intended for assisting the designer, but also other parties who are involved in the safety aspects, to arrive at a well-balanced package of safety measures.

Chapter 2 contains definitions with regard to the considered groups of road structures and the terminology employed.
Chapter 3 deals with the inter-relationships of the safety measures. It also contains a preferential order when taking the various safety aspects into consideration.
Chapters 4 to 21 describe the safety measures under consideration. As a fold-out sheet at the back, there is a clarification of the abbreviations used.

Suggestions for use
It should be emphasized that these guidelines should be used in conjunction with the manuals and guidelines which have been (and are being) developed for the other parts of the integral safety philosophy.

There are still all sorts of developments taking place in the field of tunnel safety; they concern both the regulations (national and international) as well as the development of new techniques and measures. Should there be reasonable cause, the VRC Guidelines will be adapted to these

[1] SATO: Dutch acronym for Specific Aspects of Tunnel Design. An overview of tunnel specifications; under management of the Civil Engineering Division of the Public Works Dept. and Water Management

developments. The current version of these guidelines can be found on the Center for Tunnel Safety website: www.tunnelsafety.nl

When being applied to projects, the designer will have to provide a clear insight into the contemplated, interrelated safety measures, whereby a thorough justification for each measure is required, based on:

- The assumption that no content will be provided for one or more measures in this compilation;
- The fact that those measures that will be employed, can be tested for their own correct value.

In order to further improve the quality of the guidelines, we request that you, as a user, report anything obscure as well as any other commentary to the Center for Tunnel Safety (www.tunnelsafety.nl)

2 Definitions

2.1 General

In this chapter, the road structures which are dealt with in these guidelines are divided into 4 groups:

1. Lengthy closed structures: tunnels;
2. Short closed structures;
3. Partially closed structures;
4. Laterally closed structures .

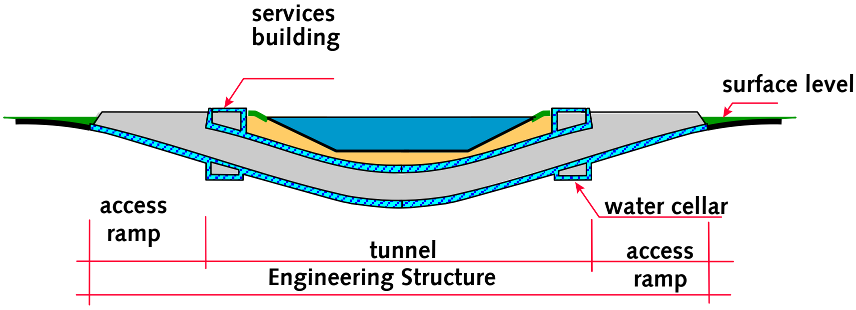
In paragraph 2.2 a definition is given per group. A number of examples are also given of structures which are part of the relevant group.
In paragraph 2.3 a number of terms and definitions are explained.

2.2 Groups of road structures

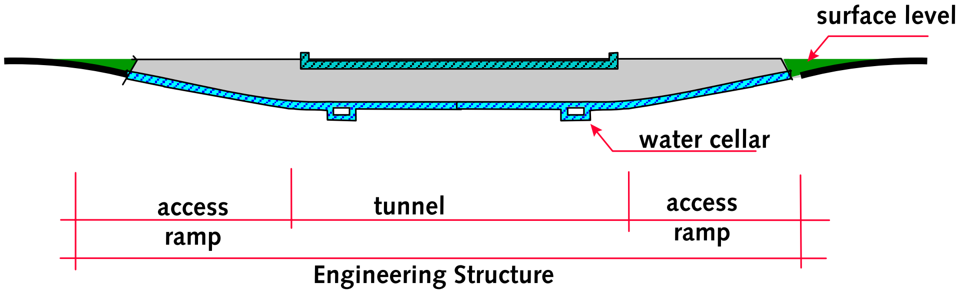
2.2.1 Lengthy closed structures: Tunnels

Tunnels are lengthy, closed, rectangular or circular engineering structures for the benefit of a roadway or railway line.
Examples are:

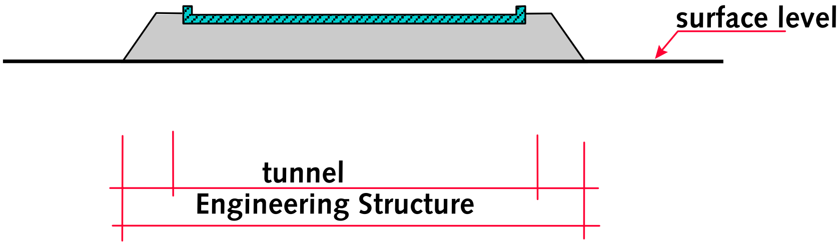
- A tunnel under a watercourse



- A tunnel under the surface level



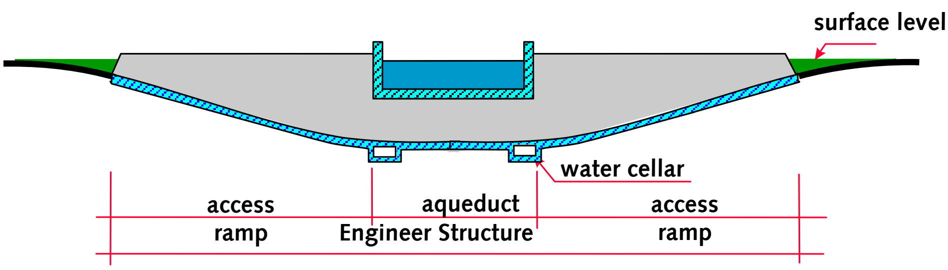
- A tunnel above the surface level



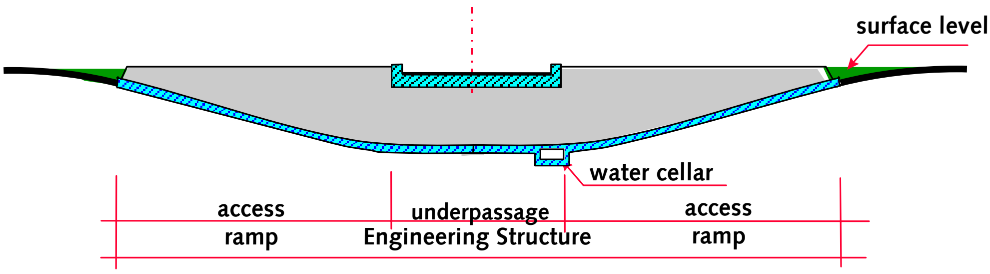
2.2.2 Short, closed structures

Short, closed structures are closed engineering structures for the benefit of a roadway or railway line of which the length of the closed section is limited.
Examples are:

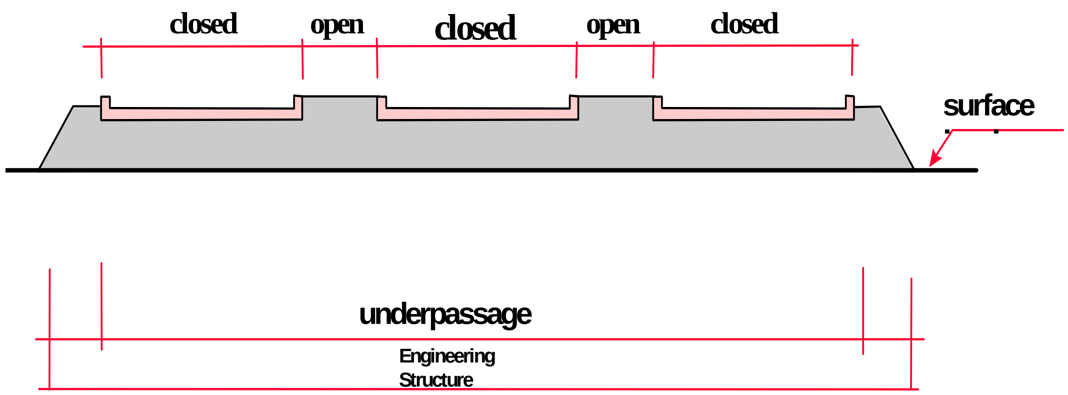
- An aqueduct: a short, closed engineering structure which carries water across a valley, a roadway or railway line.



- An underpassage: a short, closed engineering structure with which a roadway or railway line can be led below a roadway, railway line or surface level.



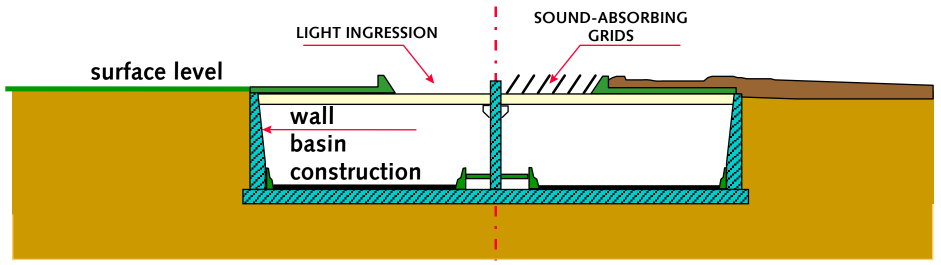
- A DODO [closed/open/closed/open = COCO] structure: an engineering structure that has alternating short, closed and open sections, with which a roadway or railway line can be led below a roadway, railway line or surface level.



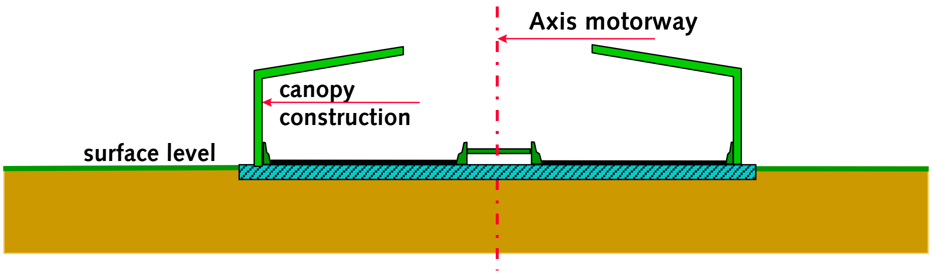
2.2.3 Partially closed structures

Partially closed structures are mainly closed, rectangular engineering structures for the benefit of a roadway or railway line.
Examples are:

- A covered-over basin construction: a roadway (subterranean) between walls and provided with a roof structure which, for the most part, is closed.



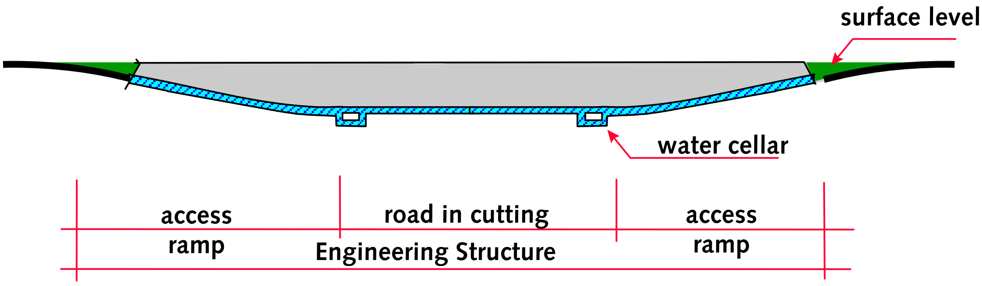
- A canopy structure: a structure at the surface level which, for the most part, screens the roadway from the surroundings in order to restrict noise pollution to the environment. The structure mainly has a closed character.

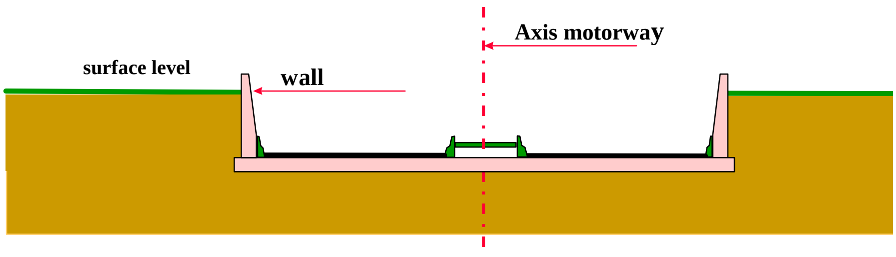


2.2.4 Laterally closed structures

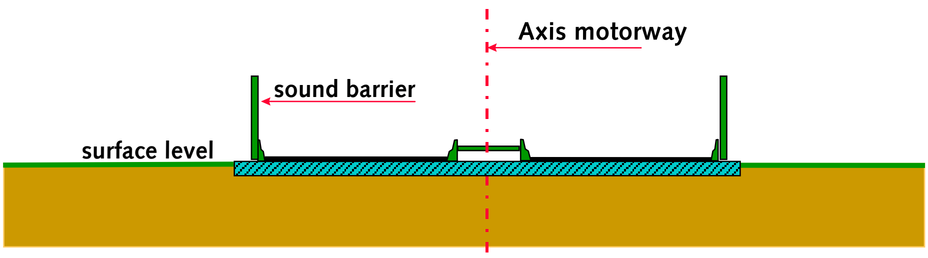
Laterally closed structures are open rectangular engineering structures for the benefit of a roadway or railway line.
Examples are:

- A road in cutting: a subterranean open road structure.





- A roadway provided with acoustic barriers: a roadway, generally at surface level, provided with screens for limiting noise pollution to the environment.



2.3 Terminology

2.3.1 Structure terms

Basin construction: A U-shaped engineering structure, which lies subterranean or not, for the benefit of a roadway or railway line.

Control Building: A building in which all the functions of the tunnel installations are controlled and monitored.

Control Centre: Operation of various objects, sometimes called traffic management office.

Services Building: A building situated at or near to an engineering structure, in which the electrical and mechanical installations of such engineering structure have been erected.

Main cellar: A water cellar of which the net storage is also determined in view of the quantity of rainwater gathered during a normative shower.

Central cellar: A water cellar in the closed section of a tunnel. Characteristic of a central cellar is that, in principle, no large quantities of rain water can end up here.

Pump room: A dry area, generally above the water cellar, which houses the facilities for the pump installation.

Access ramp: The structure which links up to the roadway at the surface level to the tunnel, aqueduct, underpassage or road in cutting.

Water cellar: A space in which rainwater, possible leak water, water used for fire-fighting and lost liquid substances are temporarily stored.

2.3.2 Safety definitions

ALARA: As Low As Reasonably Achievable. Freely translated this principle means "Use your head throughout the entire design stage and examine where you can gain added safety benefits in a practical manner without extra investments, also when the structure has undergone both a probabilistic and deterministic analysis and has been approved."

Operating: The activities whereby (from a centrally situated area) the winding up of the traffic and the operation of the technical traffic and tunnel installations are monitored by operators, and whereby, during disruptions or deviations from the normal situation, matters are interjected by means of standardized actions, whether automated or not.

Monitoring: The 'checking' activity which is initiated by an operating system in the form of a technical fault and/or fire alarm signal, possibly followed by an automatic measure without human intervention.

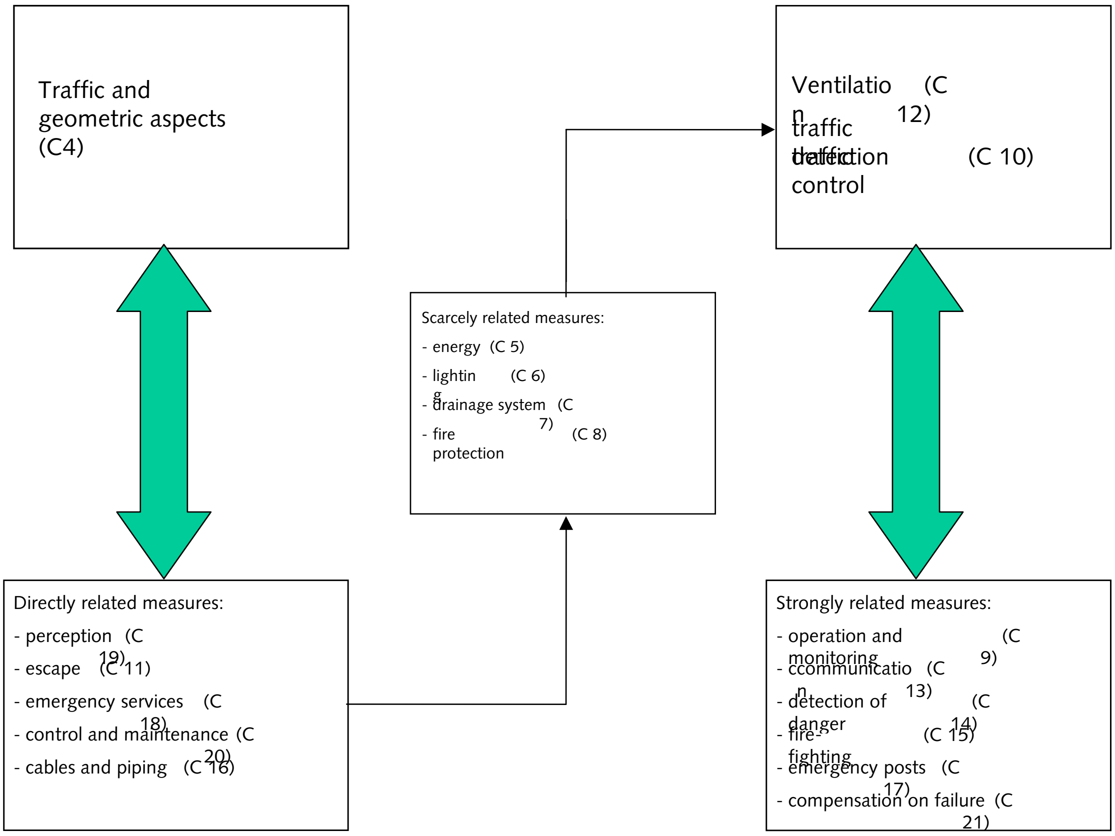
Calamity: A serious incident in the tunnel where the matter concerns: people being trapped and/or seriously injured (in such a manner, that assistance from the fire department is considered necessary), fire or the release of hazardous substances.

Emergency button:	A button (physically or on a screen) which activates a group command whereby all the necessary commands needed during a calamity are performed with a single action and thus the associated actions are activated.
Failure (of the tunnel):	A tunnel fails when it cannot be used for the safe passage of the type of traffic for which it was designed.
Failure (of the installation):	An installation fails if it's main functioning cannot be wholly fulfilled.
Escape route:	The entire route that people must follow when leaving their vehicle all the way to a safe spot outside the structure.
Escape path:	A specially constructed part of a structure along which one can escape.

3 Relationship of measures

3.1 Relationship between safety measures

There are inter-relationships between the safety measures described in these guidelines. Some measures are hardly related to one another, while there is a strong inter-relationship between other measures. These inter-relationships lead to a preferential order when taking the various safety aspects into consideration. This preferential order and the inter-relationships are reflected in the following figure.



In the first instance the main points of the geometric design of the structure must be determined. The guidelines which are relevant here, are mentioned in chapter 4: traffic and geometric aspects.
Safety measures that have a direct relationship to this, concern:

- perception (chapter 19);
- escape facilities (chapter 11);
- approachability by the emergency services (chapter 18);
- control and maintenance (chapter 20);
- the facilities for the cables and piping (chapter 16).

The measures that have relatively minor relationships with other measures should be individually determined for every structure.

It concerns:
- the power supply; (chapter 5);
- the degree of illumination (chapter 6);
- the required drainage systems (chapter 7);
- the protection against fire (chapter 8).

The remaining measures have a strong relationship with the mechanical ventilation and traffic detection and traffic control. To establish whether these two measures should be applied, a decision must first be taken in view of the guidelines set out in chapter 12 (Ventilation) and chapter 10 (Traffic detection and traffic control).
Below, the inter-relationships are examined more closely depending whether mechanical ventilation is applied or not.

3.2 Tunnels with mechanical ventilation

1. The application of ventilation implies the application of detection systems which indicate the necessity for use, followed by a reactionary definite start-up action. In this case, one should at least be dealing with a monitored tunnel.

   If, in light of that which is mentioned in chapter 12, the choice is made for mechanical ventilation, then this should be used and there would need to be something present to activate it automatically or manually. So there would have to be at least a detection in order to necessitate ventilation. It is also necessary, in whatsoever manner, that the activation actually happens once detection has occurred. It is possible that this could happen fully automatically, without their being any human observation or intervention. Possible means of detection for pollution and/or fire are described in chapter 14. The requirements for a monitored tunnel are described in chapter 9.

2. In order to determine the pollution, a system must be installed which is able to determine the concentration of pollution. When the pollution criteria is exceeded, this system should automatically activate the ventilation.

   For a description of possible systems, please refer to chapter 14.

3. If a fire detection (optional) is applied, then this must activate the ventilation.

   For a description of possible systems, please refer to chapter 14.

4. The switching off of the mechanical ventilation must be suitably organized.

   When the ventilation is activated it will have to be switched off at some time. It goes without saying, in cases of fire, that this doesn't happen automatically. Human intervention would therefore be required in order to switch the ventilation off. Theoretically, this could be possible by means of a switching facility in or near the tunnel where someone could switch off the ventilation on the spot (the tunnel operator or the fire department). However, this is not very practical! The emergency services would have to turn out for every alarm, whether false or not!

5. If a traffic detection system is applied then a traffic control system must also be applied and the tunnel must be monitored.

   When applying mechanical ventilation, basically traffic detection is also always applied. However, it is possible to have a tunnel with ventilation but without traffic detection. Normally, the choice for traffic detection is primarily motivated from the desire to be able to observe the traffic (see chapter 10). A traffic detection system only makes sense if measures can intervene. It must therefore always be interfaced to a traffic control system (see chapter 10) and operation (see chapter 9).

6. An operated tunnel must be monitored with cameras.

   If traffic detection is installed and hence its operation, then the operator must be able to observe the situation. He therefore needs sight of the situation. That is why any observation system must be linked to the traffic detection by means of CCTV monitoring (see chapter 13).

7. An operated tunnel must be provided with communication facilities.

   The influencing of traffic doesn't end by bringing it to a halt or by closing off a traffic lane. In an occurring event, communication between the operator and the road user is necessary in order to bring about a desired behaviour required from the road user. Likewise, in an occurring event, communication amongst the emergency services themselves and between the emergency services and the operator must be possible.
   Reference is made to chapter 13 for a detailed description of the possibilities.

8. Fire-fighting facilities must be installed.

   In order to provide road users with an opportunity to attempt to extinguish a fire that has started, fire-fighting equipment must be installed. In the event of mechanical ventilation, portable fire extinguishers and often also fire hose reels are provided.
   Fire-fighting facilities must also be provided for the fire department.
   Reference is made to chapter 15 for a detailed description of the extinguishing equipment and its application.

9. The communication facilities and the fire fighting equipment must be housed in the emergency posts.

   Reference is made to chapter 17 for a description of the layout of the emergency posts.

10. An analysis of compensating measures must be made in case the tunnel installations fail.

   See chapter 21.

3.3 Structures without mechanical ventilation

Due to there not being any mechanical ventilation, a detection system which could activate the start-up of the ventilators would also not be necessary.

When the structure forms part of a longer route which, as a whole is monitored and operated, traffic detection and traffic control (chapter 10) and their associated operation (chapter 9), CCTV (chapter 13) and communication facilities (chapter 13) could make up a logical package of measures. In situations where this is not the case, in certain circumstances safety observation could also lead to this conclusion.

In order to provide road users with an opportunity to attempt to extinguish a fire that has started, fire-fighting equipment must be installed. Fire hose reels are not fitted in tunnels which are not mechanically ventilated. Dependent on the length and the circumstances, extinguishing equipment must be fitted for the fire department.
Reference is made to chapter 15 for a detailed description of the extinguishing equipment and its application.

Possible communication facilities and fire-fighting equipment must be housed in the emergency posts.
Reference is made to chapter 17 for a description of the layout of the emergency posts.

4 Traffic Engineering

4.1 Introduction

This chapter deals with the road design in tunnels which form part of the:

- national arterial roads (highways);
- regional arterial roads;
- area access roads.

National arterial roads must be designed in accordance with the Guidelines stipulated for the Designing of Highways (ROA), published in the early 1990s. Regional arterial roads and area access roads must be designed in accordance with the Road Design Handbook[2].

The purpose of this chapter is to give tunnel designers an idea of the road design requirements and desires stipulated for tunnels that follow on from the road design. Reference is made to the appendix for a detailed explanation.

4.2 Plotting

1. When designing, consideration must be taken into account of the elements present in the landscape. The entrance to the tunnel and the course of the road leading up to it must stand out against the surroundings.

2. On approaching the tunnel entrance, it is important that the driver should not be hampered by the glare of the (low-lying) sun, to prevent being blinded.

3. Connections in tunnels should be avoided as much as possible because of the difficult orientation.

   In the event that connections are applied, and due to the lesser obviousness, the filtering in from the connection would require a longer 'nose' than would be normal. When driving out at a connection, there is a danger of colliding against the separating wall. That is why an impact attenuator must be fitted. So too does the timely visibility of the direction signage often cause a problem.

4. Ensure there is adequate visibility distance.

   It appears to be advantageous if drivers could anticipate the entering of the tunnel. The best way to achieve this is by constructing the access ramps with a broader horizontal curvature, whereby the distance to the tunnel portal (and vehicles ahead) can be properly estimated. In the tunnel itself, there must be an adequate visibility distance[3] *present. For sharp curves it may be necessary to increase the distance from the edge lane marking to the wall. For lengthy tunnels, it is desirable that the driver does not have sight of the exit portal too far in advance in order to prevent him from fixating his attention too much on it.*
   For vertical curves, the visibility distance must be seen as the normative criterion when determining the minimum lower and upper radii. In existing tunnels, there is a minimum lower radius of R = 2,500m and an upper radius of R = 10,000m. Until such time as more detailed research data can be made available, this 'best practice' measure can be maintained.

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[2] Handboek Wegontwerp [Road Design Handbook], ISBN 90 6628 354 8, CROW, February 2002

[3] Reference is made to the ROA 1991, chapter II, Alignment, paragraph 4 for the definition of the required visibility distance

5. Allow the design to be subjected to testing by experts.

For the final design, it is recommended that advice be sought from the Road Design Department of the Civil Engineering Division. It is possible to establish whether the design meets with the requirements by using a simulation.

4.3 The number of traffic lanes per tube

In general, it has been determined that two-way traffic is undesirable in a single tunnel tube.

6. When making the choice for the number of traffic lanes per tube, the road function must be taken into consideration. Tubes that have single traffic lanes may be selected if the function of the road is categorized as an area access road type II or as a regional arterial road.

7. No traffic lane reduction is allowed inside a tunnel and (shortly) after a tunnel.

To prevent tailbacks occurring in the tunnel.

8. The choice for the number of traffic lanes must be a permanent one for the future.

Permanence for the future coincides with the expected traffic flow and the nature and scope of the freight hauliers.

9. When the choice is made for a tube with a single traffic lane then the width between the barriers must be wide enough.

It is recommended that a minimum width be maintained in which two trucks can pass each other if there is a breakdown. In addition, the emergency services equipment must be adequately accommodated.

4.4 Cross-section

10. The cross-section of a tunnel must be at least as high as the structure gauge plus the (possibly) required extra margins.

11. From a traffic flow and road safety point of view, the dimensions for the widths of the traffic lanes must be maintained as reflected in table 4.2[4]. The width of a traffic lane is defined as the distance between the inner edge of the edge lane marking and the center of the dividing line (or between the center of two dividing lines).

Table 4.2: The traffic lane width (in m); dependent on the design speed

Road type	Design speed				
	120 km/h	100 km/h	90 km/h	< 90 km/h	80 km/h
national arterial road (motorway)	3.50	-	3.25	-	-
regional arterial road (2 traffic lanes)	-	-	3.25	3.10	-
regional arterial road (1 traffic lane)	-	-	3.00	3.00	-
area access road I	-	3.25	-	-	3.10
area access road II	-	3.00	-	-	2.75

[4] See: ROA chapter III Cross-sections 1993, [2] Handboek Wegontwerp [Road Design Handbook], ISBN 90 6628 354 8, CROW, February 2002

12. As a deviation to the ROA, the dimensions reflected in table 4.3 may be maintained for object distances in closed structures.

Table 4.3: Dimensions for object distances in closed structures

Road type	Design speed					
	120 km/h	100 km/h	90 km/h	< 90 km/h	80 km/h	60 km/h
National arterial road (motorway)	1.00	-	0.60	-	-	-
Regional arterial road	-	-	0.60	-	-	-
area access roads I and II	-	0.60	-	-	0.60	0.50

According to the EU Tunnel Safety Guideline, tunnels without a hard shoulder must be provided with foot paths which are either raised or not. This is complied with in the object distances mentioned in table 4.3.

13. Make a decision as to whether hard shoulders will be applied or not.

In general, hard shoulders are not constructed in tunnels for cost-effective reasons, unless expected traffic flow intensities in the future would justify this. Use can possibly be made of the BeslissingsOndersteunend Model Vluchtstroken In Tunnels (BOMVIT[5]).

14. In the closed section of tunnels no longitudinal gradients greater than 4.5% may be applied.

[5] BOMVIT: Dutch acronym for Decision Support Model for hard shoulders in tunnels

5 Power Supply

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5.1 General

Taking the variety of the nature and size of objects such as tunnels into consideration, it is desirable that a variations study be undertaken regarding concepts for the power supply. This study should incorporate the entire energy transportation system in the object, the desirability and location of internal sources and the extent of capabilities. Here, matters such as the reliability of the mains connection at higher levels in the electricity mains and protection of cable routes are important details.
When deciding on the application of a double mains connection, financial considerations will have to be taken into account in order to compare them with the construction of an own emergency power supply.
The costs of construction, the breakdown of standing charges and operating costs during the life span of the object are also deciding factors in the eventual choice.
A detailed explanation concerning possible sources of energy, the consequences of a power failure and the classification based on operational management can be found in the appendix.

5.2 Starting points for the dimensioning

Table 5.1 gives an overview of external sources of energy (subdivided as interruption intervals) and the supplements required per operation type.

Table 5.1: Overview of external sources of energy and required supplements

EXTERNAL SOURCE OF ENERGY	**ENERGY REQUIREMENTS**		
	BASIC LOAD		**PEAK LOAD**
Interruption interval	**Normal operation**		**Operation during calamity**
	Critical	**Non-Critical**	
<1x per 3 years	Supplement with no-break + emergency power	Supplement with emergency power	No supplementation
<1x per 6 years	Supplement with no-break + limited emergency power	No supplementation	No supplementation
<1x per 10 years	Supplement with no-break	No supplementation	No supplementation

Table 5.2 gives an overview of operation types set out according to the functions and systems which can be applied in closed structures.

Table 5.2: Overview of operating types and systems. X means the relevant system is present

OPERATING TYPE	NORMAL OPERATION			CALAMITIES OPERATION	
Functions / Systems	Critical		Non-Critical		
	Traffic guidance	Control, operation and monitoring	All other functions, except fire-fighting and escape	Fire fighting and escape	Explanation
Tunnel Lighting	X		X		Distributed see chapter 6
Other lighting			X		
Pump installations and suchlike.			X		Incl. ventilation of pump area
Tunnel ventilation			X	X	Distributed see chapter 12
Escape route ventilation				X	
Measuring and detection systems		X			
Traffic signage	X				
Traffic detection (SDS, SOS)		X			
Barriers		X			
Other traffic facilities			X		
Fire extinguishing system				X	Including heating systems
Communication systems		X			
Lighting, heating of building			X		
Monitoring of building		X			
Control, operation		X			Including transmission systems
Escape route lighting	X				According to safety standard

6 Lighting

6.1 General

This chapter deals with the lighting aspects in the traffic areas of (mainly) closed structures. Areas in a tunnel that are not part of the traffic areas must be lit in accordance with the legally stipulated regulations and standards. The lighting of escape routes is described in chapter 11.

Lighting of traffic areas in (mainly) closed structures has the following aims:

- the guaranteeing of a safe situation while travelling on the roadway that runs through the structure;
- the providing of an adequate level of light for the road users and emergency services during an incident or calamity;
- the providing of an adequate level of light during maintenance.

Reference is made to the appendix for a detailed explanation.

1. The lighting of (partially) closed structures must be designed in light of the NSVV Recommendation 'Lighting in tunnels and underpassages' 2003.

2. The lighting must be designed for the intended usage: safe passage through a tunnel.

   The luminance during normal usage which is adequate during calamities in the tunnel tube, is also adequate for the fleeing road users as well as for the emergency services (on the smoke-free side of the fire) to be able to observe the situation and to orientate themselves. Supplemental lighting will possibly be necessary for specific emergency service activities. It can reasonably be assumed that the emergency services always have portable lighting equipment at hand because of the variety of night-time situations in which they must operate.
   Maintenance situations are also not determinative for the design of a lighting situation, let alone specific circumstances.

3. The lighting installation must be structured as such, that if the cables of one section of the installation melt or come loose during a fire, the entire installation does not break down. The lighting installation must therefore be structured in sections. The cable route should, as far as possible, be installed outside the traffic area or at least be protected against fire and violence from outside (see chapter 16).

7 Drainage system

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7.1 General

In this chapter 'drainage system' means: The facilities which are required for the suitable drainage, collection and pumping away of excess water and other liquid substances from the (closed) structure and/or connected open basins and possible adjacent grounds.
The drainage system is divided into the following: The road surface, the sewerage system, the water cellars and the pump installations. Reference is made to the appendix for a detailed explanation.

It is recommended that the preventative measures be taken in order to avoid the spread and ignition of hazardous substances described in this chapter, notwithstanding the category assigned to the relevant tunnel. The costs relevant to the measures to be taken here, are limited.

7.2 The road surface

1. Avoid the creation of (petrol)puddles larger than 500m^2. In the closed section of a tunnel that has a longitudinal gradient, do not apply any open-textured asphaltic concrete (OTAC) as a top layer.

   It is strongly advised not to apply OTAC as a top layer in the closed section of a tunnel with longitudinal gradients because, when OTAC is applied as a top layer, in the possible event of petrol gushing out of a tanker:
   - *due to the clearly deviating flow behaviour, a substantially larger spread of the puddle comes about, than is the case with DBM (dense bituminous macadam) or concrete;*
   - *more evaporation occurs per unit of surface area, than is the case for DBM (also dependent on the degree of saturation in the OTAC);*
   - *the length of stay of a possibly explosive mixture of gas in the tunnel tube is far greater than is the case with DBM or concrete;*
   - *only a limited quantity of petrol reaches the sewers; a lot stays in the OTAC.*

   For structures in which the length of the closed section is short (like aqueducts) the application of OTAC is acceptable because the surface area of a possible puddle of petrol remains limited (smaller than 500m^2).

2. When applying OTAC at the access ramps, then attention should be paid at the transition from OTAC to DBM or concrete at the entrance of the tunnel in respect of the dispersion of water. To this end the OTAC must continue to approximately 20m into the closed section of the tunnel.

3. A cross-fall of at least 2% must be applied.

   In general a cross-fall of 2% is adequate for the drainage of the road surface not to be normative in respect of the (inlet capacity of the) sewers. When applying steep longitudinal gradients (> 4.5%) or a combination of a gradient with a greater width, then a greater cross-fall is recommended.

4. The road markings which are on slanted, longitudinal gradients must be provided with broad draining grooves.

   The draining grooves are necessary, because the thermoplastic material of the road surface markings, despite its minor thickness, still forms an obstacle in the drainage of the road surface (causing liquid to stream away over a long distance on the road surface side of the road markings).
   Road rutting can influence the drainage disadvantageously!

7.3 The sewerage system

5. The dimensioning of the sewerage system at the access ramps must be based on rainwater drainage. The application of an open gutter is preferable. The drainage system at the access ramps need not be dimensioned for explosions, because both the chances as well as the consequences of an explosion at the access ramps are far smaller than in the closed section of a tunnel.

   If a drainage system with embedded piping and catchpits is applied at the access ramps then it must be investigated whether an explosion in the piping could lead to failure of the floor. Extra ventilation possibilities must also be taken into account at the entrance to the cellar.

6. The sewers in the closed section should preferably consist of sewer pipes and catchpits. The capacity of the sewers is based on a minimum of $4m^3$ per minute; the pipe diameter must be at least 200mm. It is recommended that the distances between the catchpits are not greater than 20m and that the inlet capacity is doubled on inclining gradients.

   Opening size 2 is maintained for the normative quantity outflow of petrol (an average of $1.8m^3$ per minute, see appendix). Seeing as only an averaged outflow rate could be given for the classification of the opening size, in connection with the limited amount of data available, it was decided to base the capacity of the sewers on $4m^3$ per minute; this is considered to be more than adequate to take up the outflow rate associated with opening size 2[6].
   The required pipe diameter is dependent on the gradient.

7. If a drainage system with sewer pipes is applied in a closed section without ballast concrete, then it must be proven that an explosion in the piping cannot lead to failure of the floor.

   In the event of an explosion in a closed section where ballast concrete is present, only the ballast concrete will be damaged (not the structural concrete), which is considered acceptable given the fact that the damage can be repaired within an acceptable period.

8. At the spot of the inlet to the water cellars, extra inlet grids with an opening of at least $0.25m^2$ in total, must be applied.

   In the deepest section of the tunnel (at the central cellar) extra inlet grids must be fitted because, in the event of a possible explosion in the sewers, such additional ventilation substantially reduces the chance of the flames shooting through to the central cellar. Besides, the chance of a puddle being formed in the deepest section of the tunnel is thus reduced.

7.4 The water cellars

9. The minimum target value for net storage in a central cellar is $30m^3$ (to be calculated from the 1st activation level to the highest permissible level).

   The purpose here, is that the maximum quantity of petrol released (taken as $30m^3$) can be stored in its entirety in the cellar. This guideline provides a built-in safety due to the fact that it actually concerns the prevention of a puddle on the road surface.

10. The minimum target value for net storage in a main cellar is $240m^3$ (to be calculated from the 1st activation level to the highest permissible level).

    Based on the storage of polluted water which was used for fire-fighting. In most cases the normative net storage is, however, determined by the quantity of rain water after a normative shower.

11. The vaporizing surface in the water cellars must be kept restricted.

    Although the chance of an explosion in the cellar is already kept to a minimum through other measures, it must be avoided that the liquid surface spreads unnecessarily.

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[6] *A further investigation will be undertaken into the desired capacity of the sewerage system and the catchpits.*

12. De-aeration/aeration at main cellars must preferably not end up in the closed section of the tunnel and most certainly not in the central channel. The de-aeration must be fitted as high as possible, or at the surface level. If the de-aeration/aeration ends up in one of the tunnel tubes, then it must be equipped with a flame douser.
De-aeration/aeration for the central cellar must be fitted to one of the tunnel tubes and equipped with a flame douser. The de-aeration/aeration to be fitted as high as possible in the tunnel tube.

    If the cellar fills up then an excess pressure will come about. In order to prevent that this pressure reaches such a level that the cellar does not fill up (fast enough), it must be deaerated. The de-aeration/aeration must not end up in the central channel (escape route). If possible, the de-aeration/aeration must end up above the wall lining in the tunnel tube (there is no break in the wall lining; no influence to the maintenance of the wall lining). Where the de-aeration ends up in a tunnel tube, then it must be equipped with a flame douser.

13. A water seal must be fitted between the sewerage system and the cellar. At the central cellars the height of the water seal must be a minimum of 200mm and a maximum of 1,000mm. Maintain a throughflow surface of at least $0.3m^2$. At the main cellars the height of the water seal must be a minimum of 500mm and a maximum of 1,000mm. Maintain a throughflow surface of at least $1m^2$.

    The water seal acts as a vapourless segregation between the tunnel tubes and the water cellar. The minimum height of the water seal at the main cellars is set at 500mm, due to it being possible to do so at main cellars (mostly in contrast to that for the central cellars) without any major objections. The height of the water seal is set at a maximum of 1,000mm because petrol is lighter than water and therefore a surplus height of petrol would be required in order to activate the water seal.
    Maintain a throughflow surface of at least $0.3m^2$ (keeping pollution in mind) in order to prevent that the inlet to the water cellar would become normative for the coming about of a puddle on the road surface at the water cellar. For main cellars, a very safe limit of $1m^2$ has been maintained.
    A sand trap will often be necessary for maintenance purposes (to be arranged with the manager).

14. The cellar must have a vapour-proof segregation from the central channel and the tunnel tubes.

    This prevents the vapours from spreading away from the water cellar and thus the chance of ignition from outside is restricted to a minimum. Obviously the de-aeration/aeration which has been equipped with a flame douser is a necessary exception to this measure.

15. The cellar must be well separated from the pump room. A vapour-proof segregation is not desired because it cannot provide an adequate guarantee and is not required in connection with excess pressure and explosion-safe equipment.

    In connection with the maintenance of the pumps and suchlike, a fully vapour-proofed segregation between the cellar and the pump room cannot be guaranteed.

16. In connection with the cleaning, the water cellars should be passable while walking in an upright position.

17. In connection with the regulations governing the working conditions, at least 2 independent access hatches must be installed in the cellar.

18. In order to prevent possible deterioration of the joint structure by certain hazardous substances, a cellar must not be erected across an expansion joint.

19. It must be possible to dispose of liquids from the cellar to a tanker.

    After a calamity has occurred, the emptying of a cellar must occur in a safe manner; for this purpose, a connection point for a tanker (possibly a tankship) must be fitted.

7.5 Pump installations

20. Between the first activation level and the switch-off level, the highest of the following must at least be maintained:
    - 100mm height of the water;
    - $6m^3$;
    - (for central cellars) the contents of 1 discharge pipe + $2m^3$.

    A minimum of 100mm and $6m^3$ is maintained in order to limit the number of pump starts. In order to make the drawing off of water possible in the winter, the central cellars must also be able to store the contents of 1 discharge pipe (+ $2m^3$ extra) between the activated and switched-off levels. (Obviously it would be handy to draw off from the longest piping first and then from the shortest!)

21. The discharge capacity of the pump installation of a water cellar must be at least $2m^3$ per minute. There must be at least 2 pumps fitted per cellar. For main cellars, the discharge capacity must be achievable with the number of pumps installed minus one.

    Capacity must be at least $2m^3$ per minute so that, in case of an event, the maximum extinguishing capacity can be drained. During maintenance only 1 pump may be out of order.

22. Equipment in a cellar must be suitable for use in zone 1.

    The cellar is considered to be zone 1. Zone 1 is an environment where, under normal circumstances, there is a major chance of an explosive mixture; so this is an exaggeration.

23. Equipment in a pump room must be suitable for use in zone 2.

    Although the chances of vapours penetrating from the cellar are very small because of the previously mentioned measures, the pump room is categorized as zone 2. Zone 2 is an environment where the chance of an explosive mixture is minor and that this mixture is present for only a short period.

24. It is preferable not to install switching equipment in the pump room.

25. HDPE pressure stage 10 must be applied to continuous discharge piping. The discharge piping must be replaceable.

26. In order to avoid ignition through static electricity of a possible explosive mixture which can come about in the cellar, the discharge piping of the central cellar must end up below the switching-off level of the pumps in the main cellars.

    An alternative is to earth the outflow opening of the discharge pipe. The discharge pipe must not end in the sand traps.

27. In the event of a calamity, the central cellar pumps must be stopped immediately. In order to prevent an overflowing of the cellar, the pumps however, must automatically start up at the highest permissible level. Fit a discharge pipe to both main cellars. It must be possible to close off the discharge pipe to one of the main cellars from within the control room (in calamity cases, to pump away from the spot where the traffic has come to a standstill).

    The choice has been made **not** *to pump automatically to both main cellars as a standard procedure, because a number of substances (such as coagulating liquid substances), should preferably not be pumped, and to prevent as much spread as possible to other areas (the main cellars). If pumping occurs anyway, then preferably pump to the main cellar where the smallest number of people are present, this is often the cellar which is situated at the exit of the tunnel tube in which the disaster has occurred. The seals of the discharge piping may never both be closed.*

28. In the event of a calamity, the main pumps must be stopped immediately. In order to prevent an overflowing of the cellar, the pumps must start up automatically on time and must then be stopped automatically on time.

The pumps must be stopped in order to prevent hazardous substances from getting into the environment. Overflowing of the main cellar must however never occur, otherwise the hazardous substances could flow into the tunnel; to this end, the pumps must start up automatically on time. To reduce the possibility of hazardous substances getting into the environment anyway (it is assumed that it mostly concerns substances that are lighter than water) then after the automatic start up, the pumps must stop again on time. Obviously, it could also be considered to pump from the central cellar to the other main cellar if the one threatens to overflow.

29. In order to prevent hazardous vapours reaching the pump rooms from the tunnel tubes and/or the cellars during a calamity, the situation in the pump rooms must have a prevalent excess pressure in respect of the pressure in the relevant tunnel tube (and the cellars); in this respect, a maximum pressure of 50Pa must be assumed in the tunnel tubes.

    In the absence of sufficient data being available about the pressures which occur during the ventilation of a tunnel tube, the maximum pressure in the tunnel tube is set at 50Pa. When calculating the excess pressure, no consideration need be taken into account of a brief increased pressure in the cellar as a result of it filling up.

30. The pumps must be connected to the emergency power supply facility.

    In tunnels that are provided with emergency power by means of a generator, the pumps must be connected to the emergency power supply. Hence it will be avoided that, on failure of the public network in combination with rainfall, (eventual) flooding will come about in the tunnel and the tunnel would therefore have to be closed.

31. The pump room must be well segregated from the central channel and/or other surrounding areas (ducts to be closed off and door-closers placed on the doors).

    The closing off of ducts and the fitting of door-closers onto the doors are relatively inexpensive measures which reduce the likelihood of vapours penetrating via the pump room into the central channel; this does not necessarily apply in calamity cases (then there is excess pressure in the central channel as well as in the pump rooms), but for situations where the hazardous substances have unnoticeably ended up in the cellar.

8 Fire Protection

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8.1 General

Whether tunnel(like) structures should be protected against the possible effects of a fire, is particularly dependent on the question as to what the economic consequences of the (partial) loss of the structure would be. The taking of protective measures can be seen as a form of 'insurance' against costs which cannot or are difficult to bear. On this basis, protection will (almost) always be chosen for structures situated under watercourses and only in exceptional situations for viaducts. See the extensive explanation in the appendix for this.

8.2 Area of application

1. Take protective measures for structures situated under watercourses.

   Research has shown that protective measures in structures situated under watercourses (application of heat-resistant cladding) are a justified investment, notwithstanding whether the transportation of hazardous substances is permitted or not.

2. Take into consideration whether or not to apply protective measures for structures that are not situated under watercourses.

   Generally, no protective measures are taken for viaducts, underpassages and suchlike, because repair of the (mains) connection can be realized relatively quickly. However, it is possible that the economic importance may be so great, that protection is desired (for example, the intersection of a roadway with a runway at Schiphol).

3. When applying protection to rectangular tunnels, the ceiling and the upper section of the walls (pressure zone) must be protected in any event.

   Here it concerns the protection of the flexural zone (reinforcement) of the roof and the zone with high compressive stress where damage can lead to permanent damage or the loss of the structure. Closer examination has shown that no excessive spalling damage occurs to the remaining wall sections (some damage is acceptable here) in the concrete qualities commonly used up to now for immersed tunnels.

4. When applying protection to circular tunnels, the entire upper section of the structure (from road surface to road surface) must be protected.

   Such a structure is particularly subjected to pressure loads. Spalling damage at any spot (which can happen to concrete that is sensitive to spalling), can eventually lead to the loss of the tunnel. In this, special attention must be paid to the protection of the lining just above the road surface; a concrete barrier profile (step barrier) is often applied there. After a while, continuous spalling of the barrier could also lead to spalling of the lining. Possible solutions to this problem are, for example: the application of polypropylene fibres in the concrete of the barrier or the continuation of the heat-resistant cladding behind the barrier.

5. Sealing rubbers at the joints to be protected adequately.

   It is preferable not to permit temperatures above 80°C.

8.3 Measures

6. Protective measures could be:
   External measures:
   a) the application of heat-resistant cladding;

b) cooling down of the outer surface of steel structures;
c) cooling down by means of a sprinkler system;
d) the application of a double wall.

Internal measures:

e) the application of polypropylene fibres as an additive to the concrete mixture;
f) the application of steel fibre concrete.

For a. *the application of heat-resistant cladding*
Sheet materials as well as sprayed materials qualify. Basically, materials which are poured in the formwork also qualify. Reference is made to the appendix for a detailed explanation.

For b. *cooling down of the outer surface for steel structures*
From fire tests carried out on steel sheet piling it appeared, that if gravel and water end up at the back of the sheet piling, then the temperature of the steel does not exceed 100 °C; in a test with sand and water at the back, the temperature of the steel became so high that very little of the residual strength remained. For steel (tube)tunnels which are situated under watercourses, application of a gravel layer along the sides and above the tunnel seem possible as long as the water vapour which forms, remains free-flowing.

For c. *cooling down by means of a sprinkler system*
There are a number of disadvantages to a sprinkler system, which is why the Public Works Dept. and Water Management have never applied same to traffic tunnels. The tunnels along the Betuwe Route on the other hand, have been provided with a sprinkler system. It was proven by means of a test, that a sprinkler system is able to cool concrete down to such a degree, that the temperature of the unprotected concrete surface clearly remains less than 100 °C, whereby the reinforcement remains cool and no spalling occurs. A great deal of attention must be paid to the reliability of the sprinkler system.
In principle, the same can be achieved with (automatic) extinguishing systems being able to prevent a major fire from occurring. However, when applied, there are high demands set on the effectiveness and reliability.

For d. *the application of a double wall*
When applying an extra (facing) wall, it is possible that this wall may be lost, as long as the second wall (main structure) remains intact.

For e. *the application of polypropylene fibres as an additive to the concrete mixture*
It appeared from fire tests carried out, that on application of polypropylene fibres in the concrete, dependent on the fibre content, the degree of spalling can significantly be restricted. How it works in principle, is based on the melting of the fibres (at approximately 150 °C) whereby small little channels are formed; the vapour created can thus escape with the result that no major tensile stresses come about. The good performance of the fibres is influenced, to a major degree, by the combination of the quantity and the diameter of the fibres applied. Very fine fibres restrict the spalling more so than course fibres; it appears that when sufficient fibres are applied, the spalling can be prevented almost entirely. Some research has shown that the application of polypropylene fibres does not disadvantageously influence the sustainability of the structure. The application of polypropylene fibres could possibly provide a solution for structures where the reinforcement is not of importance to the permanently constructive function (for example, bored tunnels).

For f. *the application of steel fibre concrete*
Steel fibres have a limited beneficial influence on the spalling behaviour.

7. Heat-resistant cladding must comply with and be tested in accordance with the procedure described in the most recent version of the document ‘Fire protection for tunnels’, document number GT-98036 (98-CVB-R1161).

   In broad terms this means:
   - *proof of the suitability of the material at 1,350 °C;*
   - *proof of an adequate bonding of the material during the fire test (minimum requirements are also set out for the fastening);*

- *for concrete that has a higher density than the concrete used to date by the Public Works Dept. and Water Management in the construction of immersed traffic tunnels, there must be proof that no spalling occurs;*
- *for concrete that has a density equal to or lower than the quality of concrete used to date for immersed traffic tunnels, there must be proof that the temperature of the concrete (and steel) does not exceed the set limit.*

9 Operation and monitoring

9.1 General

Reference is made to the appendix for a detailed explanation.

9.2 Area of application

1. For tunnels that are only monitored, the operating system for the monitoring must be geared for:
   - Tunnel engineering installations (pumps, tunnel ventilation, tunnel lighting, et cetera).
   - Building engineering installations (for the control buildings at the tunnel).

2. For tunnels which are monitored and operated, the operating system must be geared towards the monitoring and – where not automatically operational – the operating of:
   - Traffic systems.
   - Tunnel engineering installations (pumps, tunnel ventilation, tunnel lighting, et cetera) and communication systems (such as CCTV and intercom).
   - Building engineering installations.

3. If the tunnel is centrally operated (from an operating centre situated outside the tunnel where a number of objects are monitored and operated), then a transmission system must be installed in order to transmit all the relevant information pertaining to the monitoring and operation, from the tunnel (environment) to the operating center and vice versa.

   A number of systems are possible, the most important of which are:
   - *A system which can only be operated centrally and there are no supervisory functions present at the tunnel location. Failure of the central operation system would lead to a total loss of the operation and monitoring of the tunnel. In order to limit the chances of this occurring, the data transmission must be implemented redundant. This system is currently (2003) applied in North Holland.*
   - *A system in which a (plain) local operation is installed other than the central operation. In this case, the data transmission can be of a simple type and personnel must be available for operating locally in cases of emergency. This system is currently (2003) applied in South Holland*.

   Due to the adequate reliability (0,999) it is preferable to have a simple transmission connection combined with a plain local operation. Then at least the following facilities must be present locally:
   - *TV monitor system.*
   - *Telephone.*
   - *Intercom.*
   - *Audio operation (HF, loudspeaker system).*
   - *Video operation: 2 close-up images from selected cameras.*

9.3 Function and requirements of operating system

4. An operating system must comply with the following requirements:

Requirement	Purpose
Intrinsic availability based on time 0.999 [7]	guaranteed design practice
Feed via no-break installations	guaranteed monitoring and control
Similar equipment	resolving faults quicker

5. Also, on the basis of ergonomic considerations and with regard to the actions by the operator in cases of emergency, an operating system must comply with the following limiting conditions:
   - A clear presentation of the various installations to the operator, so that the operator is able to obtain a precise feed-back of the status of all the installations.
   - Sufficient limitation in the flow of data to the operator, to prevent a 'data waterfall' which the operator can no longer deal with adequately.
   - The presence of possibilities, both automatically as well as manually, to deal with deviations in individual installations immediately.
   - A segregation of installations in traffic systems, tunnel-specific technical installations and building engineering installations.
   - A sufficient degree of reliability of the entire operating system.
   - A sufficient degree of availability of the entire operating system.
   - The design must be made as such, that on failure of system sections, a technically safe (traffic) situation is maintained at all times.

6. The following installations must be able to function under emergency control:
   - traffic lights;
   - traffic signage (if there is no MTM; MTM is not emergency operable);
   - barriers;
   - height warning.

7. In cases where the operating (and/or controlling) fails, then if possible, the installations must fall back to a pre-set safe status (fail-safe mode).
   For example, this applies to:
   - the tunnel lighting (switches to an optimum level);
   - the wastewater pumps (high water detection becomes the ultimate possibility for switching);
   - possible locking of emergency doors (automatic releases);
   - escape corridor ventilation (activates);
   - the fire extinguishing pumps (start up);
   - the tunnel's power supply (guaranteed by the switch-locking of the mains connection).

9.4 Emergency button

8. The operator should have an emergency button available on the operating desk. This emergency button must always be directly accessible and must be able to be operated in a single action.

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[7] Statistics are derived from a report called 'Options study of the Caland Tunnel' and the 'VCNH Availability Report'. Such availability, if well designed, is feasible in practice.
There is still an absence of substantiation from the safety philosophy point of view. The value mentioned here is a 'best guess', based on the following starting points:
it concerns a combination of independent events; and
for events that do possibly occur simultaneously, the systems can fall back on a 'fail-safe' status

By having an emergency button, it is possible to direct the installations into an emergency operating mode in a single action.

9. Due to the fact that the actions to be started up concern a number of tunnel tubes, there must be a separate emergency button present for each tunnel tube.

10. A dangerous situation may not possibly come about when the emergency button is pushed.

    If the pushing of the emergency button leads to serious inconvenience for the traffic or to an obscure technical situation for the tunnel operator, then there will be a psychological resistance to use it. To avoid this is an important point of attention in the design.

11. The operator must be in a position to have and to keep a proper overview of the statuses of the various installations and systems which are activated by the emergency button. Returning to the original status that was present prior to the emergency button having been pushed must simply be possible per installation.

    An overview of the situation is made easier for the operator by reflecting the actions of the emergency schedule in a separate dialogue box on the screen. This also offers an opportunity to withdraw unnecessary commands afterwards if the calamity turns out to be of a different order than was originally expected.

12. The following actions must be carried out automatically when the emergency button is pushed:
    - In order to deal with the calamity, the necessary tunnel tubes (mostly at least 2) must be closed to traffic.
      The traffic lights ahead of the tunnel tubes to change via amber to red.
      Then, as a consolidation of the closing-off measure in cases of stopped traffic, the barriers must be lowered; however, this may not happen automatically, because that is dangerous; the lowering of the barriers may only take place after the operator has been reassured that the traffic has stopped. This action is therefore not part of the emergency button activities.
      If present, being automatic or not, a detour route can be established (aided by DRIPs or other dynamic signalling devices).
    - The escape path must be prepared.
      Dependent on the situation, it concerns matters such as (see chapter 11):
      Possible unlocking of the closed emergency doors.
      If necessary, locking doors within the escape route which provide access to areas other than to the escape route.
      The activation of the mechanical excess pressure ventilation.
      Escape route lighting to be set at the correct level.
      N.B. *One of the measures in the preparation of the escape path however, is* **NOT** *to activate any special facilities in order to lure people to the emergency doors. This should happen (through a separate command) only after it is deemed to be necessary to escape.*
      In tunnels where escape takes place from one tunnel tube to another tunnel tube, additional or deviating measures must be taken (for example: The Westerschelde Tunnel and Sijtwende).
    - The lighting level in the incident tube to be switched to the optimum level (100%).
      Notwithstanding the level of light outside, switch to at least the daytime level (100%) of the interior zone in the entire tunnel. The lighting that was activated the moment the emergency button was pushed, must remain on. The time lag between the pressing of the emergency button and the switching to 100% of the tunnel tube lighting, must be as short as possible.
    - The fire extinguishing system pumps to be activated and the fire extinguishing system to be brought under pressure.
    - Tunnel ventilation to be activated.
      In tunnels that have been fitted with a longitudinal ventilation system the ventilation regime must be activated that drives smoke and toxic gases out of the incident tube, in the normal driving direction of the traffic.
      In tunnels that have transverse ventilation and/or a semi-transverse ventilation system, all ventilators to be switched to maximum extraction capacity.
    - All drainage pumps to be stopped and the activation regime to be set to the emergency mode. *See chapter 7.*

10 Traffic detection and traffic control

10.1 General

Reference is made to the appendix for a detailed explanation.

1. A traffic system must be installed:
   - for tunnels that do not have a hard shoulder;
   - if this is necessary or desired for maintenance activities;
   - if use must be made of another tunnel tube for escaping;
   - if a risk analysis indicates this.

2. With regard to the carrying out of activities, account should be taken of the CROW guidelines for working on highways (publication 96A).

   These guidelines stipulate that, for carriageways which have 3 or more traffic lanes and in connection with the setting up of blocking off markers, a fixed traffic system must always be installed. In this, it is assumed that the traffic flow on a 3-lane carriageway by definition is so great, that it is dangerous to place blocking-off markers by hand or while driving.

   The placing of blocking-off markers on 2-lane carriageways by hand or while driving, is only permitted if there is a certainty that the coming about of tailbacks on the traffic lanes which are not blocked-off, are avoided.
   Under normal circumstances, when blocking-off one driving lane of the 2-lane carriageway, tailbacks will occur if the traffic flow of more than 2,000 to 2,200 vehicles per hour across both traffic lanes are merged into a single traffic lane. In adverse conditions (for example, where there are obstacles along the sides or there's an obscure situation), when blocking-off one driving lane of a 2-lane carriageway, tailbacks will occur if the traffic flow of more than 1,400 to 1,500 vehicles per hour across both traffic lanes are merged into a single traffic lane.
   It is recommended that a permanent traffic system be installed ahead of and inside tunnels with 2-lane carriageways, where the traffic flow is expected to be more than 1,500 vehicles per hour.

3. The reduction of the number of traffic lanes for maintenance purposes or for dealing with incidents must take place ahead of the entrance to the tunnel (never inside the tunnel!). The road-narrowing must be visible to oncoming traffic from quite a distance; here consideration of visibility restrictions due to possible surrounding dykes must be taken into account.

4. Given the essential character of traffic systems, these must be connected to an UPS (Uninterrupted Power Supply) in order to prevent sudden failure of traffic indicators (for example, when traffic lanes are blocked off due to breakdowns, incidents or for maintenance).

   When the public mains fail, and after the end of the operating time of the UPS, tunnels will become powerless if they have not been provided with an alternative power supply to continue for longer periods. The operating time of the UPS in these tunnels must be selected in such a manner that a safe, continual closure of the tunnel is possible by means of the traffic system.

10.2 Traffic detection

5. Automatic traffic detection is necessary in tunnels where it is necessary to escape via a parallel traffic tube if a calamity occurs.

6. Automatic traffic detection is necessary for tailback detection systems.

7. Automatic traffic detection is desirable in tunnels which are operated.

It cannot be expected that the tunnel operator continually surveys the traffic in a tunnel. Automatic traffic detection makes it possible to react very quickly and to anticipate changes in the behaviour and the flow of the traffic in the tunnel, without the operator continually having to observe the traffic.

In tunnels that have a traffic system which is intended for traffic measures other than for maintenance, automatic traffic detection is then necessary for an intense traffic flow, so too if a hard shoulder is present.

In tunnels that have very little traffic on average, an automatic traffic detection could be omitted because in such types of tunnels, the road user can anticipate a breakdown or stopped accident vehicles in good time. Further, in tunnels that have very little traffic, there is ample opportunity for road users to warn the tunnel operators about an incident via the intercom, without bringing themselves into any danger.

11 Escaping

11.1 General

Reference is made to the appendix for a detailed explanation.

1. The necessity for constructing escape routes and the manner in which these are projected must be seen in conjunction with:
   - the degree of closeness of the construction;
   - the possible size of a fire;
   - the clearance period;
   - the presence of mechanical ventilation;
   - whether the tunnel is operated or not;
   - the gradient of the road surface (both in the longitudinal and in the crosswise direction).

   The more it is a closed structure, the more there is a necessity for escape routes for road users because the internal risk increases.

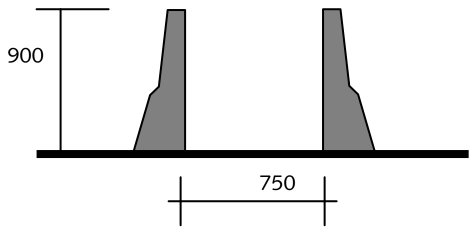
2. The scope of the escape facilities must be determined in view of the risk analysis (see VRB [8]).

11.2 Planning of escape routes

Laterally closed structures

3. In laterally closed structures that don't have a hard shoulder, maintain a gap in the central reservation between the crash barriers, with a clearance space of at least 0.75m, or create a clearance space of at least 0.75m along the side, on the outside of the guide profiles.

Escape path in the central reservation



4. For carriageways that have the same driving direction, apply crash barriers with a clearance space of at least 0.75m inbetween.

Partially closed structures

6. If smoke cannot exhaust adequately, then the same applies as for closed structures.

7. In a partially closed structure the distance between the exits must not be greater than 400m.

Closed structures

8. The mutual distance between emergency doors to be determined in view of the risk analyses.

   For risk analyses refer to Safety Guideline Part B (VRB).

[8] VRB: Dutch acronym for Safety Guideline Part B

11.3 Accessibility of escape routes

Accessibility for the user

9. No crash barriers to be fitted where they would obstruct access to the emergency doors. In such situations step barriers must be applied as guide profiles.

10. Where possible, the guidelines for accessibility by function restricted persons must be complied with; where these are contradictory to the safety requirements and safety guidelines, the safety requirements must prevail.

Accessibility for the emergency services

11. Take into account the usage of the emergency doors by the emergency services. In order to facilitate the emergency services, it is highly recommended that the emergency doors, which lead to a single central corridor between adjacent tunnel tubes, be placed opposite each other.

11.4 Design aspects

Escape routes

12. When designing escape routes, assume that all the people in the tunnel make use of the escape routes.

13. Escape routes must be free of obstacles as much as possible. Essential installation sections must be fitted in such a manner that no sharp edges occur.

    It must be avoided that the fleeing people can injure themselves on (sharp) protruding objects, and thus disrupt or even obstruct the escape process.

14. The width of the escape routes must be geared towards the number of people and on the usage of stretchers, whereby account must be taken of the width of the stretcher as well as the nursing staff walking alongside. In closed areas, the clearance space must be at least 1,200mm. A narrowing of the escape routes must be avoided as much as possible. Where narrowing is unavoidable, the clearance space must be at least 850mm.

15. Once one has escaped from the danger zone via the emergency door, the connecting escape path should not bring forth any new hazards:
    - Ensure there are clear indicators for the direction of escape.
    - An escape corridor must have an exit at both ends.
    - The opening of the doors at the exits of the escape corridors must be as wide as possible.
    - Exits must lead to the outside air.
    - There must be adequate (passable) space outside the exits of the escape corridor. The (passable) space between the guide profiles must be at least 50m long. At the end, on both sides, there must be a possibility to disembark to the road surface.
    - The escape path may not have a dead end. Dead-end corridors or areas prohibited to unauthorised persons which are connected to the escape routes must be closed off with doors or gates.
    - If there is a stairhead which leads to the services building which is not part of the escape route, then same should not be visible from the escape path.
    - If there is a stairhead which leads to the top which does form part of the escape route, then same must be fitted with escape route signage including level indicators.

15. The thoroughfare of the escape routes must be free of obstacles to prevent stumbling. Therefore thresholds and edging must not be applied.

16. Levels which are situated lower must be reachable via ramps with a gradient smaller than 1:16. Do not apply descending stairs due to the risk of falling.

17. Do not apply ascending stairs which only have 1 or 2 treads due to the risk of falling. Minor ascending level differences must be resolved by means of ramps with a gradient less than 1:16.

    A necessary exception to this, is the step up to the emergency doors from the tunnel tubes.

18. Avoid ascending stairs, it is preferable to have horizontal or slightly rising escape routes. If the choice is made for an ascending stairwell, then same must comply with the conditions stipulated in the Building Decree.

19. Lifts are not permitted in escape routes.

20. The lighting level in escape routes must be at least 100 lux along the floor.

21. Escape routes must be finished-off in light shades.

22. The escape path must be kept smoke-free, if necessary by means of a mechanical excess pressure ventilation.

23. Escape corridors must be protected in such a manner from the tunnel tube, that the escape path is not obstructed during a fire, and that within 30 minutes from the start of the fire, the escape corridor can still be used safely.

24. The floor of the escape corridors must have a closed antislip finish.

Emergency doors

25. Apply sliding doors as the access to an escape corridor.

    These are less sensitive to the excess pressure in the escape corridor and do not restrict the thoroughfare width in the escape corridor.

26. The emergency door opening must be at least 850 x 2,100mm.

27. The operating strength for opening the door must not be more than 100N, so too if the excess pressure ventilation is in operation.

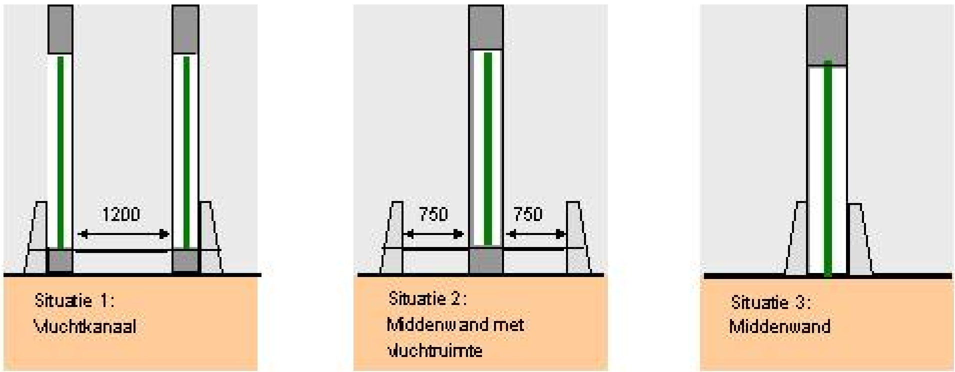
28. Handles must be fitted at a height between 0.9 and 1.2m above the threshold.

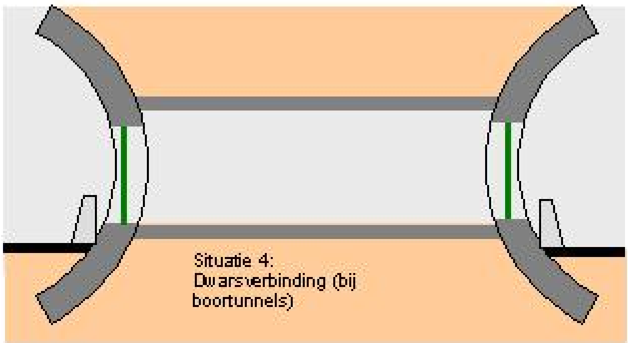
29. Emergency doors must be self-closing. The contact on the closing side must be tempered.

30. In operated tunnels, the opening of an emergency door must automatically be reported to the tunnel operator.

31. For the step up from the road surface to the threshold, do not make the riser more than 300mm and the tread no less than 250mm.

32. With regard to the locking of emergency doors, the following must be taken into account:





Nederlands	English
Situatie	Situation
Vluchtkanaal	Escape corridor
Middenwand met vluchtruimte	Central wall with escape space
Middenwand	Central wall
Dwarsverbinding (bij boortunnels)	Cross-connection (for bored tunnels)

- In situation 1, the emergency doors must not be locked in the direction towards the escape corridor. It must be avoided that fleeing people unintentionally walk through to the other tunnel tube.
  Emergency doors must be able to be opened from both sides without the use of special tools by the emergency services.
- In situation 2, the emergency doors must not be locked.
- In situation 3, lock the emergency doors in combination with operation. On activation of the emergency button the emergency doors must be automatically unlocked with such a time delay that, at the time of unlocking, it may be assumed that there is no moving traffic in the non-incident tunnel tube.
- In situation 4, the emergency door to the cross connection must not be locked. Lock the emergency door to the tunnel tube in combination with operation. On activation of the emergency button the emergency doors must be automatically unlocked with such a time delay that, at the time of unlocking, it may be assumed that there is no moving traffic in the non-incident tunnel tube.
- Locks must be unlocked in powerless situations.

33. Emergency doors that lead to outside the tunnel structure must be able to be opened from the inside by means of a so-called panic bar, and from the outside with a key that fits in

the key schedule of the tunnel or with a triagonal key. The inner surface of these emergency doors to be finished in the colour green RAL 6024.

34. Emergency doors to other areas within the tunnel structure must have a 2 hour fire-resistance in case of fire, according to the RWS curve. Emergency doors leading to outside must have a 1 hour fire-resistance according to the ISO curve.

11.5 Indication of the escape path

General

35. In escape routes, pictogram signs must be fitted which clearly indicate the direction to be followed.

36. The following standards are applicable:

ISO 16069:	Graphical symbols - Safety signs - Safety way guidance systems (SWGS)
ISO 7010:	Graphical symbols - Safety colours and Safety signs used in workplaces and public areas
NEN-EN 1838:	Applied lighting technology - emergency lighting

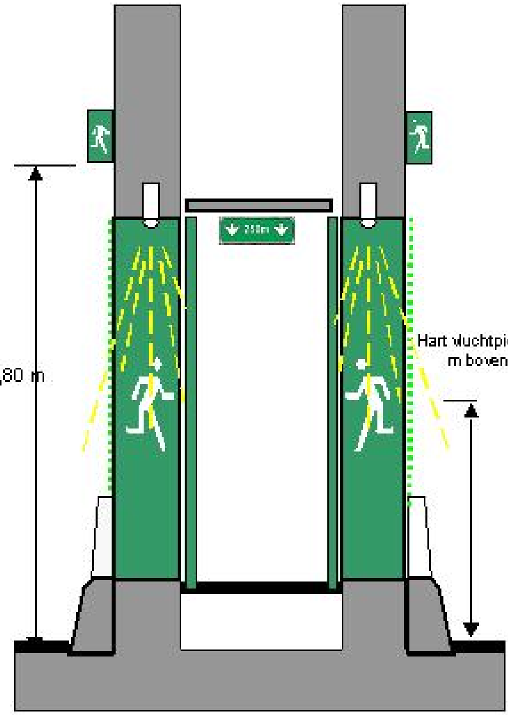
35. In any event, escape routes (in emergency situations anyway) must, as such, be unambiguously recognisable in their shape, colouring and indications.

36. At every spot where there's a change of direction, well lit indicators of a sufficiently large size must be fitted.

37. In order to prevent stumbling at possible essential height differences (thresholds, step-ups and suchlike) these should be illuminated or visibly well marked.

Indicators in the tunnel tubes

38. Emergency doors must be well recognisable. Here the following is of importance:
    - The clarity of the emergency doors in respect of their surroundings must be as such, that the emergency doors are obvious.
    - When traffic is present, the symbols in the tunnel must be properly visible and recognisable.



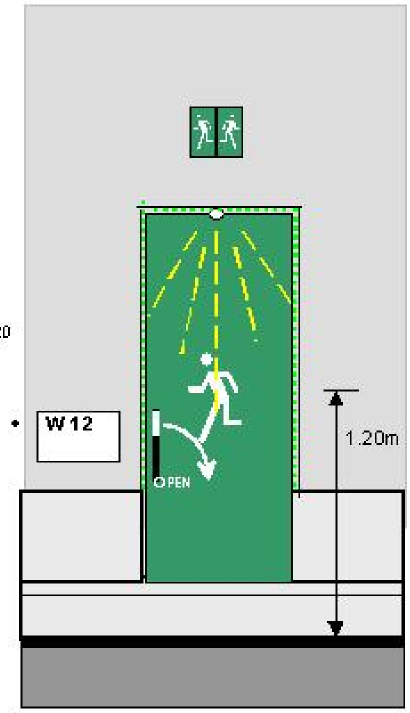


Figure 1 Cross-section of escape corridor

Figure 2 View of emergency door

Nederlands	English
Hart vluchtpictogram op 1.20m	Center of escape pictogram at 1,20m
boven het wegdek	above the road surface

39. Fit a permanently lit pictogram symbol above the emergency door which is legible from both sides. The pictogram symbol must be a white image on a green background (RAL 6024) of a person fleeing in the direction of a door in conformity with ISO 7010 (see figures 1, 2 and 3).

40. Fit a loud speaker above the emergency door which, if escape is deemed necessary, announces the following message repeatedly: "EXIT HERE", alternated with a three-pip signal. The loud speaker to comply with the requirements of TNO report no. TNO-DV3 2005-M034.

41. The emergency doors on the tunnel tube side to be installed as follows:
    - in the colour green reference RAL 6024;
    - an image of a fleeing person to be placed on the door in conformity with ISO 7010 (see figures 2 and 3); the size of the fleeing person image to be 500mm.
    - the door must be permanently lit; the luminance, as measured on the spot of each of the fleeing person images, must be a minimum of 200 lux and a maximum of 400 lux.

Figure 3

- on the door, show the turning direction of the door handle by means of a curved arrow as indicated in figure 2;
- colour the top 100mm of the door handle in a light shade;
- the word "OPEN" to be written on the door as indicated in figure 2.

41. Recesses to be carried out as follows:
    - colour the walls of the recesses green reference RAL 6024;
    - at a height of 1,200mm above the road surface, on either side in the reveal of the recess, apply an image of a person fleeing in the direction of the door in conformity with figures 1 and 3; fit the size of the image to the space available;
    - the lighting as mentioned under requirement 43 to be carried out as accent lighting in the 'door head' of the recess.

42. Install green LED lighting around the door on the tunnel wall (see figure 2). This lighting:
    may only light up when an escape instruction is given in the relevant tunnel tube;
    must contain at least 9 LEDs per running meter;
    must be recognisable from a distance of 100m.

43. Mount a flat door number beside the door at a height of 1,200mm above the road surface. Use black letters on a white background; typeface size 100mm.

44. On the walls of every tunnel tube, between the emergency doors, mount images opposite each other, spaced 25m apart in conformity with figure 4. The images must be made of a material that glows afterwards for at least 30 minutes.
The pictogram symbol must show:
 - a person fleeing in conformity with ISO 7010;
 - the distance to the nearest door in the indicated direction to be in multiples of 25m;
 - 1 horizontal arrow and 1 rectangle.

Use light shaded indicators on a green background (RAL 6024); typeface size 100mm.

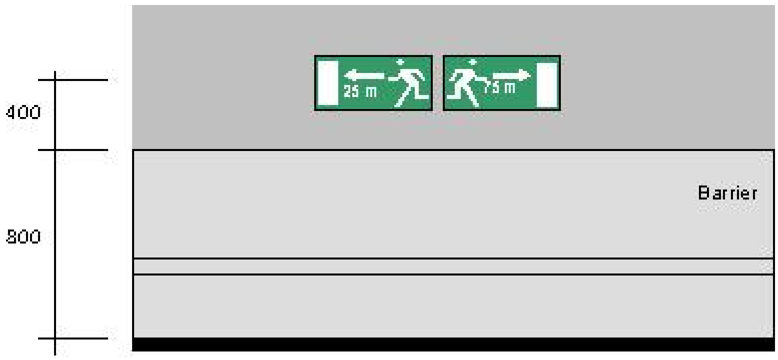


Figure 4

45. On the wall directly opposite the emergency door, apply an image in conformity with figure 5. The images must be made of a material that glows afterwards for at least 30 minutes.
The pictogram symbol must show:
 - 2 arrows pointing downwards and 2 rectangles;
 - the words “EXIT OPPOSITE SIDE”.

Use light shaded indicators on a green background (RAL 6024); typeface size 100mm.

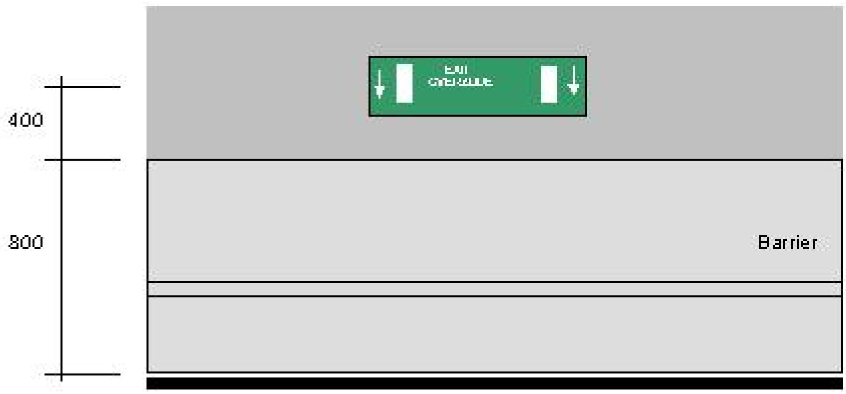
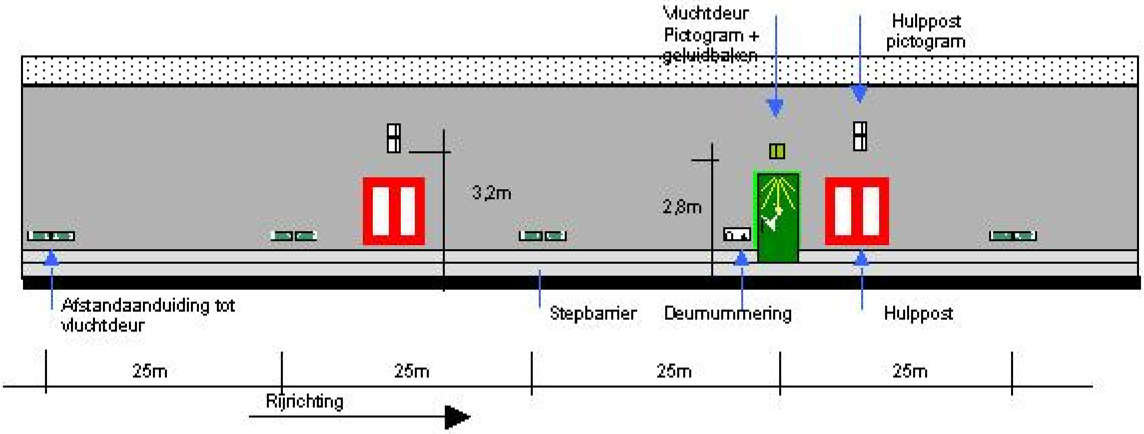
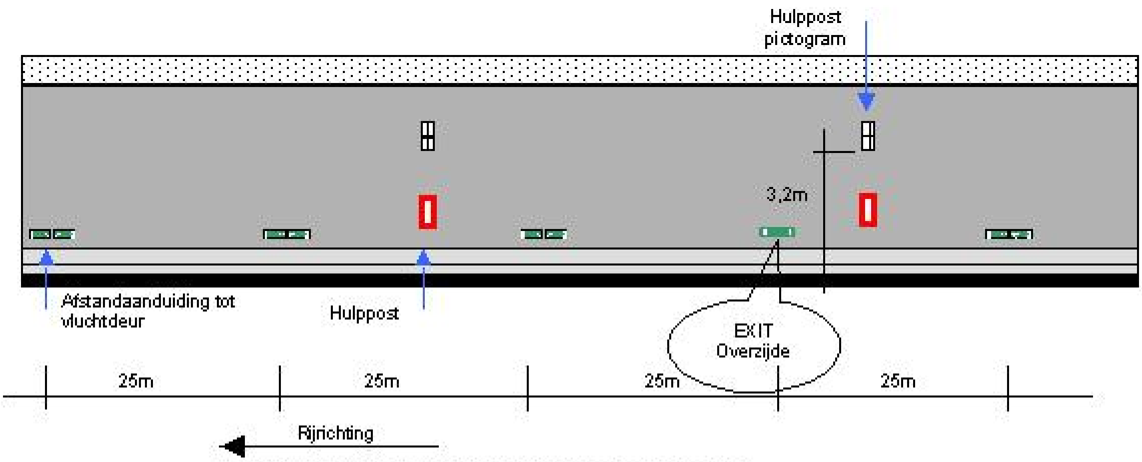


Figure 5

An overview of all the indicators that appear on the walls is shown in the diagramme below.



AANZICHT WAND VLUCHTKANAAL



AANZICHT WAND TEGENOVER VLUCHTKANAAL

Nederlands	English
Vluchtdeur pictogram + geluidbaken	Emergency door pictogram + loud speaker
Hulppost pictogram	Emergency post pictogram symbol
Afstandaanduiding tot vluchtdeur	Distance indicator to emergency door
Stepbarrier	Step barrier
Deurnummering	Door numbering
Hulppost	Emergency post
Rijrichting	Driving direction
Aanzicht wand vluchtkanaal	View of wall to escape corridor
EXIT Overzijde	EXIT opposite side
Aanzicht wand tegenover vluchtkanaal	View of wall opposite the escape corridor

45. At the emergency doors, on the road surface on either side of the roadway, from the edge lane marking up to 150mm in front of the barrier, apply a white arrow according to NEN 3322:2000 which points in the direction of the emergency door (see figure 6).

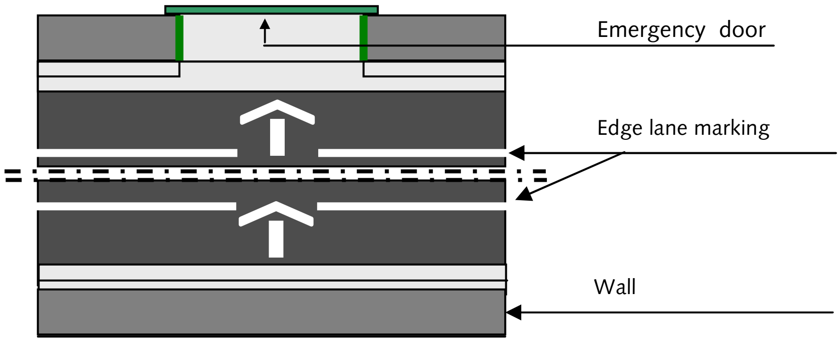


Figure 6 Indicators to an escape corridor

46. The emergency doors on the escape corridor side to be implemented as follows:
    - In a grey colour reference RAL 1013;
    - with an image on it in conformity with figure 7 and having a diameter of 400mm.

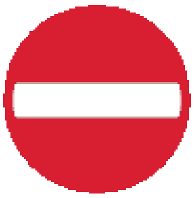


Figure 7

47. If a single previously determined direction of escape is applicable in the escape corridor, place the route signage as follows: hang signboards from the ceiling of the escape corridor, on either side of the door opening, at a distance of 5 meters, in conformity with figure 8.
    - The following must be indicated in the desired direction of escape, in white on a green background: two arrows pointing downwards and the distance up to the end of the escape corridor.
    - In the direction which is not to be taken, show an image on a grey background, in conformity with figure 7.
    - The size of the boards must be 200 x 700mm.
    - Position similar boards between the abovementioned boards in such a manner that the distance between two sequential boards is no more than 50m.

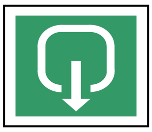
Figure 8

In situations, dependent on the spot of an incident, where there could be different directions of escape, this route signage to be carried out in such a manner that reversibility of the direction of escape is possible and can be followed. Here, the essence of the foregoing must be maintained.

48. If necessary, clearly indicate which doors in the escape corridor are not part of the escape route. Clearly show which way to go.

49. At the end of the escape corridor above the emergency doors apply a pictogram symbol in conformity with NEN 6088. (see figure 9)

Figure 9



53. Install a loudspeaker at every emergency door in the escape corridor so that announced instructions can be given to the fleeing people.

Indicators for cross connections

54. The emergency doors on the cross connection side to be carried out as follows:
    - in the colour green reference RAL 6024;
    - an image of a fleeing person to be placed on the door in conformity with ISO 7010 (see figures 2 and 3); the size of the fleeing person image to be 500mm.
    - on the door, show the turning direction of the door handle by means of a curved arrow as indicated in figure 2;
    - colour the top 100mm of the door handle in a light shade;
    - the word "OPEN" to be written on the door as indicated in figure 2.

55. Install loudspeakers in the cross sections so that announced instructions can be given to the escaping people.

12 Ventilation

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12.1 General

The objective of ventilation is to remove gases, smoke and heat from the tunnel.
In principle, ventilation can occur naturally as well as mechanically.

Ventilation has an influence on:
- the emission concentration (inside and outside the tunnel);
- the possibilities of escape for road users during a fire;
- the possibilities for the emergency services during a fire.

Due to the fact that a fire generally is the normative for ventilation, the guidelines below, with the exception of guideline number 1, are particularly relevant to the situation during a fire.

Reference is made to the appendix for a detailed explanation.

1. For tunnels which are longer than 2,000m, consider the criterion relating to pollution when making a choice about the type and capacity of the ventilation system.

   For lengthy tunnels the criterion relating to pollution could be normative. Obviously the composition and flow intensity of the traffic, play an important part here (see also chapter 14).

2. For closed structures that are shorter than 250m no (mechanical) ventilation is necessary. However, a good set of escape facilities must be provided here in conformity with chapter 11.

   Natural ventilation to the outer ends of closed structures shorter than 250m is considered adequate. The smoke and gases will exhaust to outside along the ceiling. Dependent on the size of the fire, escape below the layer of smoke is possible for longer or shorter periods. As a result of this, the group risk remains limited. Taking the short distances to the outside air into consideration, a stagnating air supply to the fire is almost negligible. With or without any influence by the wind, the smoke merely needs to travel a short distance to the open air where it can rise further and blend with the outside air.

3. Always apply ventilation facilities for closed structures longer than 500m.

   At a certain distance from the fire in lengthy closed structures without any ventilation, account must be taken of the loss of the stratification of the smoke as a result of the smoke production as such, its cooling down and its becoming heavier. This cooling down is influenced if heat-resistant cladding is present or not (insulating effect). Where there's a stagnating air supply, unburned gaseous residual products from the fire could become ignited elsewhere within or outside the tunnel, which could result in an uncontrollable spread of the fire (and possible explosions).

4. For closed structures that have a length of more than 250m but less than 500m, make a decision which is based on an analysis of the design with and without ventilation facilities. Make this decision clear to the policy decision maker and decide on the choice together.

   This can occur by carrying out:
   - *a quantitative risk analysis and thus determining the risk;*
   - *a scenario analysis and thus the assessment of the incident situation with fire, for the degree of self-rescuing and for the emergency services; a greater number of escape facilities than is commonly used, could for example, lead to the fact that ventilation is omitted.*

   In view of this, determine the safety benefit and compare this to the extra costs. Keep in mind that for mechanical ventilation, the facilities don't remain restricted to the ventilation system as such, but that electrical feeding systems, detection and operating systems are necessary as well as a certain form of monitoring.

12.2 Design of a ventilation system

5. Natural ventilation via partially open structures above the roadway (being slats, grids or openings) are considered as adequate when the amount of smoke from the largest fire expected, can effortlessly be discharged from the structure without the smoke spreading to possible adjacent closed tunnel sections.

6. When applying mechanical ventilation in tunnel tubes that have one-way traffic in a normal situation, then assume longitudinal ventilation. However, take the possibility of tailbacks into account.

   Longitudinal ventilation ensures that the space upstream of the fire is free of smoke, toxic substances and temperatures that are too high for enabling stranded motorists to escape, and to make/keep the fire zone reachable for the fire department and other emergency services. Likewise, longitudinal ventilation ensures a good air supply to the seat of the fire.
   In cases of increasing traffic flow and tunnel lengths, there's an increasing chance that there's already a tailback downstream of an (accident with) fire; whether as a result of a primary accident or as a result of tailbacks, particularly in very busy areas. In such a case, the situation will especially have to be analysed regarding self-rescue and/or measures that will have to be taken to prevent a tailback downstream outside the tunnel continuing to grow into the tunnel.
   As an alternative to longitudinal ventilation, one could in such a case, consider the application of transverse ventilation, yet care must be taken here in view of the maximum capacity of smoke discharge and the reliability of such a system. A more reliable possibility is then perhaps the creation of inbetween openings ('cutting' the relatively long tunnel into shorter pieces).

7. In the ventilation design and the calculation of the ventilation capacity, account must be taken of:
   - the size of the fire;
   - the spot of the fire (determinative for the number of effectively operating ventilators and the effectiveness of the ventilators);
   - the influence of the wind (wind direction and wind speed);
   - the flow resistance as a consequence of the vehicles present;
   - the influence of the longitudinal gradient on the behaviour of the smoke.

8. For a longitudinal ventilation system it must be proven that:
   - the chance of a technical failure is smaller than 20.10^{-3} per event;
   - the chance of a system failure, for each of the rates of heat release indicated, is smaller than the values given in the table below.

Rate of heat release	Minimum longitudinal speed	Chance of system failure
20 MW	1.8 m/s	1×10^{-3}
50 MW	2.25 m/s	5×10^{-3}
100 MW	2.5 m/s	15×10^{-3}
200 MW	2.5 m/s	50×10^{-3}

Technical failure in this respect is meant the failure of the ventilation due to e.g. a fault in the electrical feed, power failure, defective ventilators or the operating system. The chance of technical failure in modern tunnels is approximately 15×10^{-3} per event[9].

By chance of system failure, in this respect, is understood: the chance that the minimum longitudinal speed is not achieved. The minimum longitudinal speed indicated, is the speed at which backlayering (the flow-back of smoke in the opposite direction than that of the ventilation direction) is counteracted.

[9] Risk Analysis report 400V/PLC mains Wijker Tunnel, DHV, March 1999

When making the calculation of the chance of failure for a system failure, then the chance of a technical failure need not be included in the calculation.
If no freight traffic is permitted into the tunnel, then the calculation for heat releases greater than 20MW may be omitted.
Failure of the ventilators or a reduction of their function as a result of the fire, only needs to be taken into account during the first 60 minutes of the fire.

9. When applying mechanical ventilation, it must be prevented that smoke escapes from the incident tube to the other tube. The ventilation direction must therefore be partially reversible when longitudinal ventilation is applied.

   Reference is made to the ventilation handbook for detailed design specifications[10].

10. For an activated mechanical ventilation the noise pressure may not be higher than 92 dB(A).

12.3 Civil engineering aspects

11. For tunnels that are longer than 250m the exit portal of a tunnel tube must be at least 2 hydraulic diameters further to the outside, than the entrance portal of an adjacent tunnel tube with an opposite driving direction.
    A less favourable alternative, is the application of a dividing wall connected to tunnel portals situated next to each other, at a height which is at least equal to the height of possible side walls over a length of at least 2 hydraulic diameters.

12. An investigation must be carried out regarding the temperature development as a result of the traffic, if the application of heat-resistant cladding is considered for lengthy tunnels (closed section > 2,000m) with an intense traffic flow.

    Orientation calculations have shown that for lengthy tunnels that have major traffic flows, the temperature (even during continuous ventilation) can rise substantially when heat-resistant cladding is applied. This is particularly so for bored tunnels, in which heat-resistant cladding is applied to the entire top section of the structure (from road surface to road surface). This is far less the case for immersed tunnels, where the walls do not have a heat-resistant cladding.

[10] The ventilation handbook will be developed in 2004.

13 Communication

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13.1 General

Reference is made to the appendix for a detailed explanation.

The table below provides an overview of the application possibilities for communication systems for various object lengths and control conditions. For matters regarding control conditions, a differentiation is made between operated, monitored and unattended closed structures.

Length of closed section	road in cutting	< 250m	< 250m		from 250 to 500m		> 500m	
Control conditions / Commun. system	not operated not monitored	not operated not monitored	Moni-tored	Oper-ated	Moni-tored	Oper-ated	Operated	Remarks
CCTV system	no	no	no	yes	no	yes	yes	
Intercom system	no	no	no	yes	no	yes	yes	
AA reporting devices	optional	optional	optional	no	optional	no	no	optional dependent on the length
HF system	no	yes	yes	yes	yes	yes	yes	prove for lengths < 180m
Loudspeaker system	no	no	no	yes	no	yes	yes	
Dedicated telephone system	yes	yes	yes	yes	yes	yes	yes	if plant room is present
Mobile telephone system for road users	no	no	no	no	no	no	no	only support for providers in tunnel tubes

13.2 Communication Systems

1. Apply a CCTV system in operated tunnels.

   A CCTV system is important for a visual observation by the operator and provides important information during calamities. In cases of a risky combination of length, traffic density and category, dependent on the degree, the pictures are transmitted to a traffic management office (high level of surveillance) or to a (police) incident room (reduced level of surveillance).

2. Cameras must be of such a type and placed in such a way that an adequate picture resolution comes about and a good overview of the situation to the operator is provided.

   Vehicles, people and objects must be able to be observed[11] *and the chance of being cut-off by trucks must be limited. The overlapping area between consecutive camera images must be sufficiently large enough*[12]*. Cameras for traffic observation must be pivotable and have a zoom function. Cameras are also used for the detection of vehicle behaviour, for vehicles that are*

[11] Research is being carried out in this respect.

[12] 3D programming is being developed for this.

too high and for vehicle counts by means of image processing. Such applications must be well co-ordinated with the individual requirements.

3. Apply an intercom system to operated tunnels.

   An intercom system is of importance for the reporting of an accident and provides the operator with a means of giving directions. Intercom devices will, as much as possible, be incorporated into emergency posts; these are equipped with a handset. If intercom devices are required along the tunnel route where no emergency posts have been installed, it is important that they are easily recognised by the road user. It is important to be able to differentiate these (hands-free) intercom devices from the AA reporting devices, which is why they are fitted in an adapted uniform casing.

4. It is required that the intercom devices have a major degree of speech audibility, after all the noise levels in a tunnel and along the open roadway could be extremely high. The first requirement in this respect, is the application of 'noise-cancelling'.

   The system must be able to bring about a full-duplex speaking connection while the traffic drives past, but also while the ventilation system is active.
   In the interim, the performance requirements have been defined in an IEC standard and formulated in STI: Speech Transmission Index. The STI value amounts to 0.6 in which the speaking distance is defined as: 100mm in front of the handset and 250mm in front of the hands-free device.

5. The intercom system must be capable of bringing about a connection with the operator within a few seconds, whereby it is possible to process a multiple of calls.

6. Consider applying AA reporting devices inside or near (un)attended closed structures and roads in cutting.

   An AA reporting device is of importance in the reporting of an accident and provides the central operator with a means of giving directions. Fit the positions into the AA intercom-post network.
   For applications in roads in cutting, the reporting device must, in any event, be situated at the deepest point. For applications in closed structures preferably place a reporting device just before to the entrance portal.
   For applications in closed structures the devices are to be located in the vicinity of emergency doors.
   By making use of the previously mentioned intercom devices, the construction of large deepened recesses is prevented.
   The AA reporting devices must comply with the same speech audibility demands as stipulated for the intercom devices.

7. For closed structures install an HF system if the dimensions and (geographical) positioning causes an obstruction of the 'ether'.

   An HF system is necessary for wireless communication and also makes it possible to give instructions to the road users.
   An HF system is meant for communications by the Public Works Dept. and Water Management services, emergency services and the broadcasting of some FM radio stations, notwithstanding the nature of the object, operated, monitored or unattended.
   Where a tunnel length measures less than 180m, then the necessity to apply an HF system must be proven by means of a field intensity survey.

8. The possibility for communication through the HF system must be applied in operated tunnels.

   It must be possible for the operator to make announcements via the FM channels, or to use pre-recorded messages, based on RDS coding. At present (2003) only 3 FM channels are being broadcast. The number of reachable road users with 'old' radio receivers is therefore limited.

9. An HF system must be able to reach a large group of users.

Every user has access to a part of the frequency band and uses one or more channels. Currently, use is being made of the FM band for radio reception in vehicles, the VHF band is used by the fire department and ambulance services and the UHF band by the police and Public Works Depart. and Water Management services. In future the VHF band will disappear and C2000 will be on the UHF band. A high degree of selectivity is required due to the flexible usage of channels and a disruption-free operation for a multiple of users.

10. An HF system must be suitable for the walkie-talkie connection between two tunnel tubes, the so-called 'tube-to-tube communication'.

11. In cases of partial obliteration of the HF tunnel antenna, e.g. due to fire, the remaining section must continue to operate and there may not be any loss of function in the system behind it.

12. Install a loudspeaker system in operated tunnels.

    A loudspeaker system can be used by the operator for giving instructions to the road users. A loudspeaker system is only useful if the operator has sight of the situation in the tunnel and can speak directionally, and is therefore always accompanied by a CCTV system.

13. Loudspeaker systems must comply with the high degree of audibility under various circumstances.

    The acoustics in a tunnel is important in connection with the number of disruptive sources of noise such as traffic and ventilators.
    The system must be able to allow making announcements to people while the traffic drives past, but also while the ventilation system is active.
    The performance requirements are expressed in the STI value: 0.45 (80% value) and 0.35 (20% value). The audio level of the loudspeakers may not be higher than 105 dB(A) at an average listening height.
    Aided by the so-called Ray-tracing method[13] it is possible to define the system design at an early stage.
    In stressful circumstances, verbal messages must be pre-recorded, whereby it is possible to achieve the precise and correct wording and a proper speech audibility. It is recommended to use a multiple of languages.

14. Install a dedicated telephone system in the plants rooms.

    A dedicated telephone system is necessary for the control and maintenance in buildings and other technical areas.
    Such a telephone system must be installed, notwithstanding the nature of the object, operated, monitored or unattended.
    This system consists of a switchboard connected to the public telephone network and permanent telephones in all technical areas. The assurance of reciprocal accessibility by maintenance personnel and supervisors requires additional facilities for mobile telephones.

15. Lend your co-operation to providers for the installation of facilities for mobile telephones.

    For commercial reasons, use of mobile telephones for road users is desired for use in tunnel tubes.
    Given the major increase in mobile telephones, providers also want to include traffic tunnels in their coverage. From a commercial point of view it is consequentially justified that the provider supplies the necessary equipment himself.
    In light of the safety, this medium cannot be considered of primary importance, given the fact that the operator cannot be contacted quickly and directly.
    Although a great deal of accident reports occur by means of mobile telephones, its value as an initial means of reporting in a tunnel is relative. The problem is the caller's orientation: which tunnel tube and at which spot[14].
    Despite that, there is support for the installation of facilities for mobile telephones.

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[13] A calculation model has been developed in the meantime.

[14] Technological developments could lead to improvements in the long term.

14 Detection of dangerous situations

14.1 General

Reference is made to the appendix for a detailed explanation.

14.2 Application possibilities

Table 14.1 shows the relationship between various types of structures, divided into length, operated or monitored, with or without ventilation and the associated detection systems.

1. For tunnels longer than 10km, consideration must be taken into account whether or not to apply visibility measuring equipment for determining the visibility conditions. If applying visibility measuring equipment, then it should automatically activate the ventilation when measured visibility values are (too) low.

   Detection of visibility conditions makes sense in tunnels where there's a probability of high concentrations of exhaust fumes, dust and fog being formed. This is only usable in combination with a ventilation system. Such visibility measuring equipment can be combined with that which is meant in clauses 2 and/or 4.

2. Install visibility measuring equipment in tunnels with mechanical ventilation for determining the NO_2 concentration. In cases where the NO_2 concentrations are (too) high, then the system must automatically activate the ventilation.

   Visibility measuring equipment can be used for determining the NO_2 concentration. Application makes sense in tunnels where there's a probability of high concentrations of NO_2 being formed (the length and the traffic flow intensity play a role in this). This is only usable in combination with a ventilation system. Such visibility measuring equipment can be combined with that which is meant in clauses 1 and/or 4.

3. In view of chapter 10, determine whether a system for speed limit differences / speed drop detection must be applied.

   The detection of differences and drops in vehicle speeds (SLD/SDD) makes sense for operated tunnels, and is very effective for an early detection of deviating traffic behaviour when there's a breakdown or accident, whereby it is possible for the tunnel operator to anticipate the situation.
   This is only effective in combination with cameras, possibly supplemented with loudspeakers, dependent on the necessity to pass on escape instructions.
   This does not make sense for tunnels which are only monitored, because of the absence of the possibility to anticipate.

4. For operated tunnels, visibility measuring equipment must be applied for the detection of smoke.

   The detection of smoke, as an indicator of a fire at an early stage, makes sense given the fact that it's possible for the tunnel operator to anticipate the situation.
   Such visibility measuring equipment can be combined with that which is meant in clauses 1 and/or 2. Visibility measuring equipment can potentially be used as a fire detection with automatic warning to the fire department[15].

5. When installing visibility measuring equipment, the following switching limitations must be maintained:

   k < 0.004/m ventilation switch OFF (visibility is good);

[15] This will be investigated in more detail.

k > 0.007/m ventilation switch ON (NO_2 content too high);
k > 0.012/m attention warning to the operator and switch ON (in fact it's an extra start up command for the ventilation);
k > 0.020/m warning to operator and ventilation switch ON (in fact it's an extra start up command for the ventilation).

These values apply per visibility measuring device, therefore if a single visibility measuring device exceeds the limitations given, then the relevant actions must be carried out.

The activation value of k = 0.007 for NO_2 covers the activation value for poor visibility (k = 0.009) adequately. At k = 0.012 the visibility is so bad that additional measures are desired, such as the closing of the relevant tunnel tube or permitting traffic in doses. At k = 0.020 there is a big chance of there being a fire. That is why the operator must be warned and should immediately investigate whether there is indeed a fire.

6. Consider the application of temperature measuring equipment for the detection of fire.

   The detection of fire is optional for tunnels which are only monitored and in cases where the object is of major economic importance, as a primary detection with the possibility of warning the fire department.
   It is optional for operated tunnels as an additional measure, to localize and to observe a fire where the use of cameras is inadequate. It is also used to guide ventilation systems in relation to the emergency services and for limiting damage.

7. Consider the application of a detection system for explosive hazardous gases.

   The detection of explosive hazardous gases does not make any sense as a safety device for the road user. In certain circumstances, consider this as an additional safety device for the emergency services.

Table 14.1 Application of detection means

Length of closed section	< 250m	< 250m		from 250 to 500m			>500m	
Control conditions / Detection from	without ventilation	without ventilation		without ventilation		with ventilation	with ventilation	Remarks
	not operated not monitored	moni-tored	oper-ated	monitored	oper-ated	Operated	Operated	
Visibility conditions through visibility measuring equipment	no	no	no	no	no	no	no	perhaps necessary for tunnel lengths >10km
NO_2 determined through visibility measuring equipment	no	no	no	no	no	yes	yes	
Vehicle behaviour by means of SLD/SDD	no	no	optional	no	yes	yes	yes	optional for major economic value and high operational risk
Smoke by means of visibility measuring equipment	no	no	yes	no	yes	yes	yes	
Fire by means of temperature measurement	no	optional	optional	optional	optional	optional	optional	optional as a compensating measure
Fire by means of heat radiation	no	no	no	no	no	no	no	hardly possible due to tunnel height
Explosive hazardous gases for the road user	no	no	no	no	no	no	no	no assurance
Explosive hazardous gases for the emergency services	no	optional	optional	optional	optional	optional	optional	dependent on the actions by emergency services
Toxic gases for the road user	no	no	no	no	no	no	no	no assurance
Toxic gases for the emergency services	no	no	no	no	no	no	no	fire brigade use their own equipment

15 Fire fighting

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15.1 General

For the permanently fitted fire-fighting equipment described in this chapter, the following differentiation has been made:

- facilities for the road users;
- facilities for the fire department;

Reference is made to the appendix for a detailed explanation. For the emergency posts, please refer to chapter 17.

1. Laterally closed structures basically have no facilities applied.

   Do keep the accessibility to open water in mind (see chapter 11).

2. Applicable to partially closed structures:
   - In principle no facilities for road users are necessary. For objects which are of major economic importance and where application is obvious (such as for partially closed structures connected to a tunnel) the application of portable fire extinguishers is recommended, on condition that there is monitoring.
   - Basically, no facilities for the fire brigade are necessary. If accessibility to open water is very difficult, then local vertical dry risers or ducts could provide a solution.

3. Applicable to closed structures for tunnels:

Facilities for road users					
Closed length	< 250m	100 - 250m	250 - 500m		> 500m
Condition	not operated	operated	no mechanical ventilation	mechanical ventilation	mechanical ventilation
Portable fire extinguishers	Only for monitored objects of major economic importance (exception)	Yes, c.t.c. maximum: 100m	Yes, c.t.c. maximum 100m	Yes, c.t.c. maximum 60m if in combination with fire hose reels, otherwise c.t.c. maximum 100m	
Fire hose reels	No	No	No	For structure of major economic importance, c.t.c. maximum 60m	

Facilities for fire brigade				
Closed length	< 100m	100 - 250m	250 – 500m	> 500m
Distribution piping with fire hydrants	Basically, no. Where necessary local vertical dry risers or ducts could provide a solution.		Yes, Fire hydrants c.t.c. maximum 100m	Yes, Fire hydrants c.t.c. maximum 100m
Pressure increase suitable for fire brigade capability	No	No	Option	Option
Internal Reservoir	No	No	Option	Option
External water supply	No	Option	Yes	Yes

15.2 Facilities for the road users

4. Portable fire extinguishers to be of such a type that operation is logical and is in line with the thinking pattern of the inexperienced users. The portable fire extinguishers, notwithstanding the legally stipulated inscriptions, must be provided with a brief and clear indication regarding its purpose of use (see chapter 17). Portable fire extinguishers must be easily removable from the emergency posts and, if necessary, must be equipped with extra handles. The extinguishing capacity must be at least 27A/183B. The maximum total weight of the extinguisher must not be more than 16 kg. Preferably apply foam-spraying extinguishers.

5. Consider applying fire hose reels for structures of major economic importance which are provided with mechanical ventilation. In structures without mechanical ventilation, do not apply fire hose reels.
When applying fire hose reels, the distance between the fire hose reels may not be greater than the length of the hose (maximum 60m).

6. For emergency posts with fire hose reels, always install portable fire extinguishers as well.

7. Always add foaming agents to the fire hose reels, preferably just before the reel, in order to effectively combat liquid fires.

   The time in which a foaming agent may be added to a fire hose reel is limited. The idea here is, that the fire brigade will be present after an average of approximately 15 minutes and then they require a certain amount of time for getting their own extinguishing equipment operational. Having some extra time, it is recommended that the foaming agent be added for at least 25 minutes.

8. The extraction of the spray nozzle must automatically activate the fire extinguishing pumps.

9. In order to give road users the opportunity to extinguish the fire from a certain distance, then spraying with a solid blast and a head wind of 3 Beaufort, the range distance as defined in NEN 3211 must be at least 14 meters.

10. When the spray nozzle opens, the maximum reaction force may not lead to a shock reaction by the road user or it being knocked out of his hands. In the event of a spray nozzle already being opened, the force must be limited to the extent that inexperienced users can operate it.

    Recommended reaction forces are: on opening, no more than 120N, for a continuously opened spray nozzle, no more than 90N.

11. The distribution piping for fire hose reels must always be filled with clean water in order to guarantee an immediate availability.

    If a distribution system for fire hose reels would be dry under normal circumstances, then it would take some time before a fire hose reel produces water. An unskilled user who is unfamiliar with the situation (and that would basically count for all road users) would quickly put the hose down and wouldn't make any further extinguishing attempts. This is most undesirable.

15.3 Facilities for the fire department

12. For a fire extinguishing system comprising a distribution system, possibly supplemented with a facility for pressure increases and water feeds, keep the following in mind:

    Distribution:
    - If fire hose reels are applied, then the piping for the fire hose reels and for the distribution by the fire department must be combined into a single wet pipe with adequate capacity for

the fire brigade. The positioning of the fire hydrants to be combined with the positioning of the fire hose reels;
- a distribution pipe which is intended exclusively for the fire brigade may be carried out dry, as long as the filling time is less than 10 minutes;
- the distribution pipe must be provided with a replenishment connection for the fire brigade.

Pressure increases:
- permanent pumps are always necessary for fire hose reels because a breaker tank is required, yet these pumps need not have the same capacity as the fire extinguishing pumps for the fire brigade;
- the bringing of the extinguishing system up to pressure for the fire brigade, basically occurs by means of the fire engine pumps outside the tunnel;
- apply permanently erected fire extinguishing pumps if one or more of the following points are applied:
    - o there is an insufficient number of personnel available and the ancillary materials from the local fire department are inadequate;
    - o the setting up of a mobile pump including facilities, takes longer than 10 minutes;
    - o a wet distribution pipe is required.

Water feeds:
- due to the addition of a foaming agent, fire hose reels require a breaker tank;
- for the fire brigade facilities, make the choice between water mains (if adequate capacity and pressure is available), streaming water (if the water quality is acceptable), a water well near the tunnel (on condition that adequate capacity can be supplied), and a specially constructed reservoir near or in the tunnel.

13. If the engineering structure is of major economic importance, then consideration must be taken into account for the possible construction of a permanent water-booster system and water reservoir.

14. All feeding points must be connected to a centrally situated pipe.

15. If, at a partially closed structure, it is not possible to spray through the roof openings respectively to feed hoses through the openings, because of the structure (restricted accessibility and suchlike), then draw off points with water for fire-fighting must be present at the road surface level. Here it must be considered that the fire brigade must be able to realize the required hoses and connections in a maximum of 10 minutes.

16. Every feeding point must have a fire hydrant.

17. At every feeding point there must be a connection for a choice of:
    - a hand-held blaster pipe or a fire hose;
    - a manifold in conformity with NEN 3374, to which two hand-held blaster pipes or fire hoses can be connected;
    - a water canon;
    - (a fire engine).

    A water canon always has 2 feeding points and must therefore be connected to 2 hoses. This is possible by either using the single connections at two emergency posts (preferable), or by providing the possibility in an emergency post for both hoses to be connected by means of a manifold with taps.

16 Cables and piping

16.1 General

Cables and piping are present in tunnels for the electrical power supply and/or the operating of equipment, respectively for the supply and discharge of water. The operation of the tunnel is dependent on these connections.

1. Lay cables and piping as much as possible in centrally situated cable routes (in cable ducts or cable trays). Where possible, lay cable routes outside the traffic areas.

   Taking the vulnerability of cable routes within the traffic areas into consideration, such location must be avoided as much as possible. Outside the traffic tunnel tubes the vulnerability of cables and piping and hence the vulnerability of the associated systems is much less. Due to the less aggressive environment outside the traffic areas, less demands can be set on the cable seals and cable carrier systems than within the traffic areas. Activities can be carried out safer and more efficiently if it is not necessary to enter a traffic tunnel tube to do so.

2. In principle, main routes must continue to function under all circumstances. Branches must be equal to the equipment which is being fed by the branches, in other words, if exposed to extreme circumstances, the power supply cable must not be the cause of premature failure of the equipment if it is subjected to the same circumstances.

3. Cable ducts and cable tubes which cross fire-resistant walls or floors must be installed in such a manner that the fire-resistance of the walls or floors is not reduced by it.

16.2 Accessibility

4. Cable routes must preferably be located as such that they are reachable:
   - without having to enter the traffic areas to do so;
   - without dismantling or excavation activities having to be carried out;
   - without lids or other means of protection requiring removal;
   - in such a manner that inspection can take place in a simple fashion.

5. Cable routes which are situated in an environment where access to the cable route causes a nuisance to it (urban environment, below foot paths, road underpassages), preferably to be housed in cable tubes that are accessible by people.

6. Cable routes must be laid-out in such a manner that in future cables and piping can be added, removed or repaired without major dismantling and assembling activities being necessary.

   The routes must be laid out in such a manner, that cables can be rolled out or incorporated without 'being threaded through', therefore, as far as possible, cable routes should not be fully encased by the structure.

16.3 Design aspects

7. Cables which could influence each other inductively must be laid segregated as much as possible, or otherwise be protected from each other.

   It is therefore recommended that cables for operational signals are laid segregated or protected from high-voltage power supply cables. Medium voltage and high voltage cables to be laid in delta as well as being segregated or protected from other cables. Here one must remember, *that not only can an inductive influence be present during normal operation, but that very strong fields could come about particularly during short circuits.*

8. Redundant cable connections must be applied segregated from each other. The segregation must be as complete as possible in order to increase the chance that the other remains intact during the total loss of a single cable(route).

   A number of cable connections inside tunnels are considered of such importance, that they must be carried out redundant, in other words, when a single connection fails, its functioning can be fully taken over by the other. Examples of such connections are the main supply cable and the operating cables between main distribution boards and/or main operating units situated in separated buildings.

9. If it is not possible to lay the cable routes outside the traffic areas, then the cable routes must be protected as much as possible from damage caused by external violence and against fire.

   By laying the cable route on the outside of the structure gauge in the tunnel tube, the cable route will be reasonably protected from collisions. This set up will be at the expense of the accessibility. It is very difficult to protect a cable route inside the tunnel tube from being affected by fire. A very good protection is by means of concrete walls (e.g. concrete cable gallery covered with concrete panels). This kind of implementation is almost the same as the cable route which is laid outside the traffic areas, which by far is the preferred method. Protection by means of a cladding of heat-resistant sheeting, is also possible.
   For all the protection methods, a proper accessibility of the route must be the starting point in the design.

10. Piping or parts thereof, which have to be laid inside the tunnel tube and which also have to continue functioning during a fire, must be made of steel. In this, all the materials necessary for the proper functioning of the piping must also be resistant against the high temperatures to be expected.

11. Vulnerable spots in the cable route must be laid in such a manner, that (partial) loss of a cable or pipe cannot lead to complete failure of all the functions of the relevant system.

    The most vulnerable section of the cable route, is the section inside the traffic areas. It is unavoidable to lay power supply cables and operating cables within the traffic areas for the power supply and operation of installation sections inside the traffic areas. This concerns for example, the power supply and operation of light fittings, ventilators, CCTV cameras, detection systems, signalling boards, loudspeakers, intercom and HF equipment. These systems must be installed and protected in such a manner that faults or loss in a single tunnel tube do not influence operations in the other tunnel tube. Likewise, the local protection and/or loss of a cable or pipe may not result in the entire installation, or all of the functions of the installation failing in a single tunnel tube. This can be achieved by dividing the system into sections, which can be isolated from the common mains supply section of the system by means of separators (cut-out switches, circuit breakers and/or safeguards). The common mains supply section of a system, such as the main supply pipe and distribution cabinets, must be protected against damage and/or loss as much as possible. The length of a section is related to at least the maintaining of a safe operation in the tunnel tube. For the lighting sections this is a maximum of 150m for example.

12. Material properties and implementation of the carrier systems for cables and piping must be geared to the environmental conditions.

    Without exception, environmental conditions in tunnel tubes are extremely corrosive. The tunnel atmosphere is highly contaminated with aggressive substances such as soot, salt, weak acids and moisture. The combination of these substances causes major adverse effects to all the apparatus in the tunnel tube and makes special protective measures (inert materials and very good sealants) essential. In any case, the life span of the apparatus is shortened due to it being placed in tunnel tubes. The following materials appear to suffice in tunnel tubes:
    - *aluminium of sea water-resistant quality(AlMgSi), coated;*
    - *steel, hot-dip galvanized in accordance with NEN-ISO 1461, with a course thickness of 80 micron and coated (duplex system);*

- *stainless steel fastening materials;*
- *other fastening materials of A4 stainless steel; possibly made of hot-dip galvanized steel, if the dimensioning permits it;*
- *unreinforced plastics.*

No galvanized materials (electro-zincing) may be applied inside the tunnel tubes, not even when they've been coated.

13. Apparatus in tunnel tubes must be designed and placed in such a manner that the collection of dirt and dust on the apparatus is limited.

14. Cables and cable routes must always be provided with indelible cable numbering.

15. Cable and apparatus connections placed within the traffic areas by means of sockets are very susceptible to interference and must be avoided as much as possible.

17 Emergency posts

17.1 General

The objective of an emergency post is: the housing of communication and fire-fighting facilities in a single space for the road user and the emergency services.
For the considerations with regard to the application of communication facilities, reference is made to chapter 13 and for fire-fighting equipment, refer to chapter 15. Reference is made to the appendix for a general explanation.

17.2 Design aspects

1. The dimensions of the emergency posts must be adjusted to the size of the facilities to be installed. Dependent on the size of the emergency post, same will be fitted with a single or two hinged doors. The emergency post must be able to be unlocked by turning the door latch of the first opening door downwards. The doors with door latches must close in the driving direction. Emergency posts must be erected plumb.

2. Emergency posts must be recognizable as such.

   The recognisability of an emergency post is largely dependent on the degree of contrast with the surroundings. This is enhanced by[16]*:*
   - *the fitting of doors with transparent windows, of which the closed sections of the doors are to be finished in red (RAL 3000);*
   - *the installing of internal lighting; here the light must shine with an adequate luminosity through the doors of the emergency post;*
   - *apply a red frame (RAL 3000) around the emergency post (this may also be the framework);*
   - *fit an internally lit pictogram symbol above the upper edge of the emergency post, outside the structure gauge; the pictogram symbol must be legible from both sides in the longitudinal direction; in respect of the road surface, the bottom of the pictogram symbol must be mounted 200mm higher than the top of a pictogram symbol above an emergency door.*

3. An emergency post must be subdivided into a section for the road user and a technical section. The section with facilities for the road users to be installed behind the first opening door. In the technical section, install the facilities for the fire department and/or maintenance.

4. Only the facilities for the road user must be clearly recognizable and be inviting to be used. The facilities in the technical section (for the fire department and maintenance) must be screened off. This prevents the road user from being distracted as to what he can use (namely, the intercom, the portable fire extinguisher or the fire hose reel). Due to the fact that extinguishing with a fire hose reel lasts longer than with a portable fire extinguisher, it is desirable that, if both means of extinguishing are available, the road user uses the fire hose reel. It is therefore desirable that the fire hose reel stands out more than the portable fire extinguisher.

   In order to encourage that which is mentioned above, the following must be taken into consideration:
   Screening off of the technical section:
   - *to be carried out as inconspicuously as possible;*
   - *in a nondescript colour, for example grey;*
   - *not to be lockable.*

   Type of fire hose reel

[16] TNO Human Factors Report, TM-01-Co17

- *trace the round shape of the fire hose reel onto its mounting frame in the colour red;*
- *the background of the fire hose reel to be in a light shade (this will emphasize the round red shape);*
- *the spray nozzle to be carried out in red.*

Indicators:

apply the following text onto the fire hose reel:

WATER WITH FOAM
FOR ALL FIRES

Typeface height 15mm, black lettering on a white background.

apply the following text onto the foam extinguisher:

WATER WITH FOAM
SHORT EXTINGUISHING BLAST

Typeface height 15mm, black lettering on a white background.

apply the following text onto the intercom:

DIRECT CONTACT
LISTEN TO THE INSTRUCTIONS

Typeface height 10mm, black lettering on a white background.

5. For emergency posts that are installed in the wall between the tunnel tube and the escape corridor, the installation must be carried out in such a manner that, at a temperature of 1,350ºC in the tunnel tube, safe passage in the escape corridor is guaranteed for half an hour. Besides, the entire emergency post construction must be flame-tight during a fire for two hours, in conformity with the RWS fire curve.

6. In order to be able to ensure quick detection of the usage of the emergency post in an operated tunnel, the following actions must be detected:
   the opening of an emergency post door; here the surroundings of the emergency post must also be brought into the operator's view;
   the extraction of the spray nozzle; here the pressure increasing installation must also be activated;
   the extraction and/or absence of the portable fire extinguisher.

7. Emergency posts must be kept frost-free.

8. The distance between emergency doors and the nearest emergency post containing fire brigade connections, may not be more than 25m.

9. The fire hose reel must be installed as such, that on extraction of the spray nozzle or the opening of the emergency post door, the whole fire hose reel automatically tilts or turns outwards and in such a way, that the hose can be rolled out away from the tunnel structure.
   The outward tilting of the reel or the tilted reel may not obstruct the other facilities present in the emergency post.

17.3 Location and application

The following overviews show the relationship between the type of emergency post and its location in various object features.
See the appendix for the emergency post types.

Emergency posts in closed structures

Closed length	< 250m	100 - 250m	250 - 500m			> 500m
			without mechanical ventilation		with mechanical ventilation	
Object features	operated	operated	monitored	operated		
Carriageways with 1 traffic lane						
type of emergency post at the left-hand or the right-hand side	**D**[1] or **E**[2]	**C** or **B**[3]	**E**	**B**	**B or A**[1]	**B or A**[1]
maximum c.t.c. distance of emergency posts in meters	**100**	**100**	**100**	**100**	**100 or 60**[4]	**100 or 60** [4]
Carriageways with 1 traffic lane + hard shoulder						
type of emergency post on the right-hand side	**D**[1] or **E**[2]	**C** or **B**[3]	**E**	**B**	**B or A**[1]	**B or A**[1]
maximum c.t.c. distance of emergency posts in meters	**100**	**100**	**100**	**100**	**100 or 60 4)**	**100 or 60** [4]
Carriageways with more than 1 traffic lane						
type of emergency post on the one side	**D**[1] or **E**[2]	**C** or **B**[3]	**E**	**B**	**B or A**[1]	**B or A**[1]
type of emergency post on the other side	**D**[1] or **E**[2]	**C** or **B**[3]	**D**	**C**	**C**	**C**
maximum c.t.c. distance of emergency posts in meters[5]	**100**	**100**	**100**	**100**	**100 or 60 4)**	**100 or 60** [4]

1) only apply emergency posts at monitored objects of major economic importance
2) only apply emergency posts at monitored objects of major economic importance, whereby the accessibility to open water is very difficult and local dry risers or feed-throughs don't provide an adequate solution
3) only apply emergency posts if the accessibility to open water is difficult and local dry risers or feed-throughs don't provide an adequate solution
4) maintain this c.t.c. (center-to-center) distance on application of an emergency post type A
5) install emergency posts opposite each other, emergency post types A, B and E preferably on the same side as the distribution piping and/or vertical dry riser piping

Applicable to structures that have more than 1 traffic lane:

if emergency post types A or B have been applied on the left-hand side, then there must always be an emergency post on the right-hand side too;

if emergency post types A or B have been applied on the right-hand side, then there must also always be an emergency post on the left-hand side if there are 3 traffic lanes or more; where there are 2 traffic lanes an emergency post is not necessary on the left-hand side.

Emergency posts in partially closed structures

Carriageways with 1 driving lane	
type of emergency post at the left-hand or the right-hand side	**D**[1] or **E**[2]
maximum c.t.c. distance of emergency posts in meters	**100**
Carriageways with 1 traffic lane + hard shoulder	
type of emergency post on the right-hand side	**D**[1] or **E**[2]
maximum c.t.c. distance of emergency posts in meters	**100**
Carriageways with more than 1 traffic lane[3]	
type of emergency post on the left-hand side	**D**[1]
type of emergency post on the right-hand side	**D**[1] or **E**[2]
maximum c.t.c. distance of emergency posts in meters	**100**

1) only apply emergency post at monitored objects of major economic importance
2) only apply emergency posts at monitored objects of major economic importance, whereby the accessibility to open water is very difficult and local dry risers or feed-throughs don't provide an adequate solution. Apply preferably on the water supply side
3) apply emergency posts opposite each other, emergency post type E preferably on the water supply side

Emergency posts in laterally closed structures

Only an AA intercom post system. Do not apply emergency posts, unless for practical reasons it is more obvious than the AA (Automobile Association) network (connected to the traffic management office). In such special circumstances, emergency post type F is applied.

18 Emergency services

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With regard to the emergency services during incidents, there must be clarity about the tasks and responsibilities of the parties involved.
Here it is important whether an object is operated from a (central) operations post or not.
For operated objects, the tasks and responsibilities between the emergency services and the operations must be consistent with each other. It will have to be established (dependent on the situation), how the input by the emergency services will take place so that the necessary measures are taken timeously by the operator.
Consultations with the institutions which provide emergency services for projects (particularly the fire department), will have to take place at the earliest stage possible.

The responsibilities of the parties involved, are divided up as follows:

- The tunnel operations will take care of a smooth and safe traffic flow and in the event of incidents, they must take the necessary measures timeously and warn the emergency services if need be.
- The fire department is responsible for rescuing, releasing and counteracting during accidents and fire.
- The police are responsible for maintaining or recovery of public order, the general security and for (criminal prosecution) investigations.
- The Area Health Authority is responsible for the medical organization and the ambulance services are responsible for the providing of medical aid services.
- The official authority (the mayor) is responsible for public order and security.

1. The object must be well accessible for the emergency services.

   For short, closed structures (such as aqueducts) it is not specifically necessary that the emergency services are able to switch driving lanes in a short space of time. For lengthy, closed structures there must be a possibility for the emergency services to enter the tunnel tube of their choice from both ends of the structure.

2. Consultations with the emergency services for projects (particularly the fire department), will have to take place at the earliest possible stage.

   Such consultation is necessary on the one hand, in order to establish a plan for combating emergencies (in the first instance, the main points) and on the other hand, to reach agreement about the measures to be taken (these could be geared towards the emergency services as well as towards self-rescue).

3. For operated objects, a plan for combating emergencies must be drawn up which organizes how to act during incidents. In this plan the following matters must be organized:
   - the organisation pertaining to emergencies;
   - the tasks and responsibilities of the parties involved;
   - the agreements between the tunnel operator and the public emergency services;
   - the co-ordination of the plans of attack (or contingency plans) by the emergency services.

   Refer to the 'Tunnel guide for the emergency services' and Part E (the safety organisation) of the integral safety philosophy of the Center for Tunnel Safety.

19 Perception

19.1 General

Guidelines specifically tailored for perception are difficult to formulate. Generally, they can implicitly be found in the (technically) formulated guidelines. Guidelines could differ anyway, dependent on whether it concerns the closed, partially closed or laterally closed structures. For the time being, the guidelines in this chapter are primarily meant for lengthy closed structures: therefore, tunnels. For these structures, some recommendations are given with regard to the aspect of perception[17].

19.2 Normal circumstances

1. It is wise to have the tunnel design including the tunnel access ramps, visually tested for spatial perception by means of road image simulation.

   This will have an added value if it concerns a design which clearly deviates from the generally accepted and previously built tunnels, in which the perception has been experienced as positive. In this type of analysis, the selected cross-section can be tested in relation to the visibility distances (vertical and horizontal gradients), lighting level and colour scheme.

2. Ensure that the tunnel complies with the road user's expectations, in other words, ensure there's uniformity.

3. In order to reduce feelings of distress and closeness, it is preferable that the cross-section of the tunnel be as spacious as possible.

   When establishing the most spacious cross-section possible, obviously the investment costs play a very important role, yet these may not lead to an inappropriate frugality. In that respect, the dimensions referred to in chapter 4 must be considered as minimum dimensions.

4. Use a (light) colour scheme which will have a positive influence on the spatial effect in the tunnel.

5. Ensure there is a clearly visible transition from the road surface to the wall.

   Also refer to chapter 6.

6. Apply curves as spaciously as possible (see chapter 4) and avoid a complicated geometry (traffic feeding-in and exiting and suchlike).

7. Use colours, patterns, textures and light to create variation and stimulation, and to demarcate tunnel zones, entrances and exits and emergency facilities.

8. Pay attention to the transition from the outside to the inside at the entrances.

9. Ensure that the road users are not distracted by special eye-catchers near the access ramps.

10. Provide clear road signage.

11. Provide a clear, well visible and unambiguous system of emergency posts, escape path direction signage and (emergency) warnings.

12. Pay attention to the acoustics in the tunnel (with regard to the speech audibility).

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[17] Refer to: General aspects of tunnel use and safety. Center for Environment and Traffic Psychology. State University of Groningen. COV 99-09 November 1999

19.3 Calamity situation

13. Ensure that the road users are quickly informed about a fire or other kind of calamity (see chapters 10 and 13).

14. Aim for a rapid initial attempt to extinguish a starting fire. In that respect, ensure there are unambiguous and simple indicators and information about extinguishing means (see chapters 15 and 17).

15. Ensure there are clearly visible communication facilities.

16. Ensure there are clear and persuasive evacuation instructions by means of verbal and visual messages.

20 Control and maintenance

20.1 General

Reference is made to the appendix for a general explanation.

1. Design a tunnel in such a manner that maintenance in the traffic areas is restricted to a minimum.

2. For every (sub) system, the designer must, in respect of the frequencies of inspection, maintenance and replacement, hand over the details to the operator.

3. The results of inspection, maintenance and replacement must clearly be registered in a maintenance manual, so that the situation for each (sub) system is clear at every moment. The following guidelines are applicable for the drawing up of a maintenance manual:
   1. where applicable, draw up the design specifications for each (sub) system;
   2. formulate the frequencies of inspection and maintenance for each (sub) system;
   3. where applicable, allow test runs to form part of the inspection and maintenance;
   4. draw up check-lists on which the inspections must be executed;
   5. formulate condition restrictions, as to when repairs and/or replacement are deemed necessary;
   6. always involve the designer when making changes;
   7. if these changes, in any manner, (could) influence the result of an incident, then always involve the emergency service(s) in this too.

4. The controller must be aware, for possible replacements, changes and/or renewals, that the underlying safety philosophy is not violated.

20.2 Maintenance situations

5. Set up a detour route wherever possible, to undertake maintenance[18]. Only if that is undesirable, consider blocking-off or contra-flow traffic and make an analysis of this.

   A specific analysis can possibly clarify the differences in safety between both systems.

6. For the maintenance situation, consider the application of one or more additional measures, such as:
   - stringent restriction of the maintenance being carried out within the quietest hours;
   - the prohibiting of hazardous substances or even all heavy duty vehicles when contra-flow traffic or blocking-off is implemented;
   - stringent speed limits;
   - extensive public awareness campaigns pointing out the extra dangers;
   - stringent checks on the maintaining of the measures.

[18] Taking into consideration that this is a primary responsibility for the road/tunnel operator, for the time being no detailed guideline is proposed.

21 Compensating measures on failure of the tunnel installations

21.1 General

A traffic tunnel is equipped with various electrical and mechanical installations. In respect of safety, it concerns:

- installations that make it possible for motorists to drive safely and comfortably through the tunnel;
- installations that make it possible to monitor and operate the tunnel;
- installations that make it possible to deal with incidents such as breakdowns, accidents or fire as safely and as efficiently as possible;

On failure of one or more of these installations, the tunnel in fact becomes less safe. On failure, the functions of an installation indeed are no longer (fully) available, but in a number of cases, they can be wholly or (mostly) partially compensated by temporary additional or replacement measures, whereby the tunnel need not fail as a whole. Refer to chapter 2 for the definitions of failure.
If the safety can no longer be adequately guaranteed, then the tunnel must be closed.

21.2 Measures

1. Determine and register per project, whether compensating measures must be taken or not, if (sections of) safety installations fail.

   The appendix explains which compensating measures can be applied to keep the tunnel operational during the partial or complete failure of the tunnel installations.