



Statens vegvesen

Norwegian Public Roads
Administration

Standard

Road Tunnels





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Norwegian Public Roads Administration Handbooks

This is one of a series of handbooks prepared and issued by The Norwegian Public Roads Administration - a collection of consecutively numbered books which primarily are written for use within the Administration.

This English version is a translation of the Norwegian one. In case of linguistic differences between the two versions, the Norwegian version is the valid one.

The books are for sale and may be ordered from the Directorate of Public Roads at prices given in their book-list - Handbook no. 022. Preparing and updating the books is a responsibility for the Directorate of Public Roads.

Graphic Division at the Administration is generally responsible for designing and printing the books.

The handbooks are issued on two levels:

Level 1: Red marks on the cover indicates Regulations, Standards and Guidelines approved by the authority responsible or The Directorate of Public Roads with authorisation.

Level 2: Blue marks on the cover indicates Instructions, Teaching Manuals and Road Data approved by individual departments authorised by the Directorate of Public Roads.

Road Tunnels

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Preface

The manuals pertaining to the Public Roads Administration are given pursuant to the regulations relating to the Roads Act concerning highway construction.

This Design manual applies to all types of road tunnels. The manual apply for new tunnels but do not apply retrospectively. Initially, the manual shall apply in respect of upgrading of safety aspects of existing tunnels. Any deviation from the specifications in the norm must be approved by the Directorate of Public Roads.

The manual replace those stated in the edition of August 1992.

The manual cover all aspects of the planning of a tunnel project, from the early planning stages to completion of the project, together with operation and maintenance. Tunnels comprise a considerable part of the highway network in Norway. Particular attention is given to the environment relating to the requirements of nature conservation and the urban environment.

Tunnel construction implies long-term maintenance. It is important therefore that

the choice of solutions and technical equipment is made on the basis of life-expectancy where operation and maintenance costs are evaluated.

Compared to the 1992 edition, most chapters have been largely rewritten. A number of subjects which may be considered to fall outside the manual material have been included with regard to accessibility. Reference is also made to other norms and guidelines rather than these texts being copied here.

Work with revising the design manual was undertaken in the period 1997 - 2001. Regional offices, consultants, constructors and others have made important contributions.

The Design Manual will be available on the Norwegian Public Roads Administration's internet pages www.vegvesen.no.

*The Directorate of Public Roads,
June 2003.*

*Responsible Department:
Road Development Department*

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1. The Formal Basis for Planning Tunnels

101 A brief summary of relevant laws and regulations

The basic specifications relating to road construction, including tunnels, are contained in the “Plan- og bygningsloven” Planning and Building Act (PBA). A number of formal components are also governed by regulations including:

- Regulations to impact assessments, and
- Regulations concerning procedures and control of the construction process.(SAK)

In addition to the requirements of the PBA a number of other aspects of tunnel construction are required to be considered in accordance with other Acts. Those of particular importance are discussed below.

The Pollution Act

The Pollution Act applies to pollution arising from the construction site activity as well as pollution resulting from the actual highway construction.

Regarding pollution which may arise during the construction phase, dispensation may be necessary from the relevant pollution authority (normally the County Governor) according to §11 of the Act. It follows that consent is necessary, among other things, for activity which breaches that described as “normal pollution from temporary activity”.

Permission may also be required for permanent discharge into the atmosphere, water or soil resulting from highway construction. Further, the Pollution Act § 9 also requires that ground levelling must be reported to the authorities as determined by the Ministry of the Environment, 3. April 1989.

The necessity of obtaining permission according to the Pollution Act should be clarified with the pollution authorities at an early phase in planning, for example in connection with the approval of the principal design of the highway construction.

Reference is also made to Chapter 3, “Consideration of the local environment”.

Act relating to water courses and ground-water

For highway construction which is included in the definition of water course measures in the Water Resources Act § 3, certain concessions may be necessary as determined in § 8. For example, concession has to be given by the water resources authority in order to “commence water course projects which may be detrimental to the public interest”. Initially, it is the client who has to determine whether there is a responsibility to apply for concession. Further, the Norwegian Water Resources and Energy Directorate(NVE) – may also determine that concessions have to be applied for in respect of a specific construction. The rights to, or control of ground water, have to be granted by concession where determined by the water course authority. As no regulations specify which type of construction is subject to concession, it will largely be the responsibility of the water course authority to determine whether a concession has to be applied for in each individual project. Whether application has to be made for a concession should be determined at an early stage in the planning process, preferably in connection with the general plan of the highway project.

The Act relating to Historic Monuments

Highway construction which comes into conflict with ancient monuments protected under §§ 15, 19 or 20 of the Historic Monuments Act will not be permitted until the Directorate for Cultural Heritage has granted dispensation or exception for conservation. The status of specified monuments (and the obligation to investigate this pursuant to § 9 in the Act) should be determined during the planning stage.

The Nature Conservancy Act

Highway construction conflicting with protected areas as defined by the Nature Conservancy Act including areas of landscape preservation, national parks, nature reserves or significant geological features, will not be permitted without prior dispensation being granted for the protected area as required by the Nature Conservancy Act (§ 23). Initially it is the government which is the dispensation authority, but in certain instances these powers are delegated to the County Governor.

The Fire Protection Act

The Fire Protection Act applies to tunnels in use and provides for the local fire protection authority, among others, to determine the necessary fire-protection measures to be implemented (§ 25). Guidelines for considering fire protection measures in road tunnels, approved jointly by the Ministry of Local Government and the Ministry of Transport ensure that fire safety in new tunnels is determined in accordance with the Planning and Building Act.

Act relating to supervision of electrical plant and equipment

All electrical plant to be installed shall be in accordance with norms determined by the Norwegian electro-technical committee (NEK 400), and the regulations relating to low tension electrical installations.

Other relevant Acts of significance for tunnel construction include:

- Harbour and Coastal Waters Act
- Municipal Health Services Act
- Game Management Act
- Salmon and Inland Fisheries Act
- Reindeer Herding Act
- Cultivated Land Act
- Forestry Act

More information concerning these Acts is given in the Directorate of Public Road's information brochure *Special Acts of relevance to road planning as determined by*

the Planning and Building Act and Manual 054 "General planning".

(The titles of the relevant documents are translated, but are issued only in Norwegian). In general, when planning projects which are subject to the Planning and Building Act contact should be made at an early stage with the respective authorities in order to obtain their opinion on the extent to which it may be necessary to apply for dispensation for the projects in addition to clarifying the provisions of the Planning and Building Act.

102 Procedures according to the Planning and Building Act***102.1 General Planning***

In the guidelines for planning state and county roads according to the Planning and Building Act (PBA), it is required that the projected road shall comprise part of the *general plan*, either a *municipal plan* or a *county plan*. Detailed regulations for the administration of the municipal and county plans are given in the PBA, Chapters V and VI, particularly §§ 19-4 and 20-5.

In the initial phase of the general planning, a number of special reports may be required which may either be published as separate reports or be incorporated in the formal planning process.

That part of the *municipal plan* which is concerned with land-use for a specified area will be legally binding as soon as it is ratified (PBA § 20-6, No. 2). This implies that there will not be opportunity to carry out measures which conflict with land-use already ratified and included in the plan, except under certain specified circumstances. A *county plan* is not legally binding concerning land-use, but provides guidelines for land-use both for municipal and state planning as well specific activities.

Plan content and reports

Where the general plan provides the basis

for decisions on the choice of a road route and highway standards, specifications are included in the guidelines for national and county roads in the PBA (T-1057, Chap. 4.3).

Preparation of the general plan will normally require a number of fairly comprehensive reports. In the guidelines, there are, for example, requirements that the costs of the various alternatives for the parts of the municipal plan are prepared within a margin of $\pm 25\%$. This necessitates geological investigations and reports which are designed to meet these requirements. (See Chapter 2)

At an early stage in the preparation of the general plan, a programme should to be prepared in association with the planning authorities to include the main elements of the planning process. If an impact study is to be prepared as part of the process, this will be included as a part of the design.

Certain aspects of tunnel construction require to be specially evaluated or clarified during this planning stage of the tunnel, including:

- Circumstances which may require approval according to the Pollution Act § 11.
- Possible consequences for water courses (including ground water). Clarification with the NVE is required where dispensation has to be sought in accordance with the Water Resources Act
- Conflict with cultural monuments which are automatically protected and/or monuments included under the Historic Monuments Act §§ 15, 19 and 20. Concerning roads which may conflict with listed monuments and which will require dispensation or exception by the Director General for Cultural Heritage the question of dispensation/-exception must be taken up during the general planning.

- The influence areas or resources which are preserved according to the Nature Conservancy Act. Contact should be made with the County Governor in order to clarify whether the construction conflicts with the conservation order. The question of dispensation from the conservation requirements must be clarified before the plan is approved according to the Planning and Building Act.
- In the guidelines for fire protection in tunnels it is stated that the Norwegian Public Roads Administration in association with the local fire authorities undertake a general evaluation of fire protection measures in the proposed tunnel. In general resolutions on safety measures for tunnels is not included in the principal design. Questions which can have considerable significance for the project's total costs should, however, be clarified at his stage.

Structure of the Design

Regarding the county plan, no further details are given in the Planning and Building Act as to how this plan shall be prepared. The guidelines are given in the "Guidelines for national and county roads according to the Planning and Building Act" (T-1057) published jointly by the Ministry of the Environment and the Ministry of Transport, and also in the Ministry of the Environment's guide "Municipal Land-use Planning" (T-1382). In Manual 054, specific examples are given of the presentation of route choices in accordance with the guidelines in the above documents.

If the tunnel is to impose restrictions on existing land-use, this should be stated in the plan. This is important both for those who will be affected by the project and to ensure better control by the Norwegian Public Roads Administration such that measures are not commenced which may

be an obstacle to the plan, and that other measures are not permitted which may have unfortunate effects for the completed project. In addition to the tunnel route on the map being indicated as "... an important link in the communications system", or as "...restricted areas..", a description of the restrictions expected to be incurred by the tunnel project for activity on the surface should also be given. If these areas are "built-up areas" (for example housing development) or "agriculture, natural and recreation areas" where dispersed settlement is permitted, then to a certain extent these restrictions may be included in the provisions of the plan. Regarding other land-use categories where the possibility for determining provisions is more limited, the restrictions for the area above the tunnel are commented upon in the plan details.

Impact studies in accordance with Planning and Building Act.

The Planning and Building Act (Chapter VII-a) and accompanying regulations on impact studies contain more specific regulations regarding the planning of the individual measures. It is assumed that the impact study will be carried out according to the regulations in coordination with the evaluation of the first formal plan where the route or corridor is approved.

Which measures shall be the subject of an impact analysis are given in the regulations. The client shall then prepare a note proposing a programme of the impact studies to be included in the report. On the basis of the proposal the Directorate of Public Roads (in regard of trunk roads and new roads) or the planning authority (for other roads) shall determine that a programme be drawn up stating which reports are to be prepared, and of the content of the impact study which the client shall prepare.

The Ministry of the Environment give

more detailed information regarding the administrative process concerning impact analyses. The Ministry of the Environment has also prepared a separate guide to interpreting the criteria in the regulations.

102.2 Zone Plan

With the exception of minor projects, a zone plan has to be prepared for all national and county road construction as laid down in the Planning and Building Act. A zone plan shall always be made for tunnels. Similarly to the land-use plan in the municipal plan, a zone plan is legally binding as determined by the PBA § 31.

A zone plan which has been approved, provides the basis for expropriation as determined by the Highways Act § 50.

The tunnel route shall be specified in the zone plan.

Content

The requirements for zone plan is described in the guidelines for national and county road plans according to the Planning and Building Act.

The requirements in the guidelines are, among other things, that supplementary investigations shall be carried out.(See Chapter 2) The costs shall be calculated with a precision of $\pm 10\%$. If a broader range is required, the reason for this has to be given.

The legally binding design includes a map showing one or more objects of development. The fact that the zone plan is legally binding implies that there will not be opportunity to carry out subsequent measures which conflict with land-use approved by the plan, with the exception that smaller adjustments may be made through a formal dispensation of the existing plan, changes to the plan, or in connection with a new general or zone plan.

In the Ministry of the Environment's guide "Development plan. Building plans" (T-1381), detailed norms are given for

maps of development and building areas. A number of examples are included in the guidelines which provide directions preparations of the map and the accompanying design measures.

There are no special requirements in the law or regulations relating to the formulation of zone plans for tunnels. In each individual case it must be determined which aspects are required to be clarified in the design.

Based on the following, the design of the tunnel including the approach zones, should be established:

- It is assumed that a detailed account of fire-safety measures is included in the preparation of the zone plan according to “Guidelines for fire protection in road tunnels”, Chap. 3.2.
- Exceptions to procedural handling of tunnel construction are conditional upon the location of the tunnel, the design of the entrances and possible restrictions in use of the area above the tunnel having been incorporated in the design as outlined in the thematic guide “Public road construction and building projects” (Report HO-2/2000).

In particular, the location of the tunnel and restrictions for use of the area above the tunnel are most conveniently handled in the zone plan.

Other circumstances which will be significant in determining the detail of the design in connection with development of the tunnel area include:

- existing, planned and expected activity on the surface or in the ground
- the type of tunnel, rock cover and ground conditions
- control of sealing measures carried out.

The plan must indicate the necessary protective measures against activity which can cause damage of the tunnel construction. Consideration should therefore be made as to whether a safety zone should be defined around the tunnel. This implies

that restrictions on the surface must be shown on the map and/or in the provisions. Examples of such restrictions are the prohibition of specified construction work, blasting or boring in the ground. Alternatively, it may be stated that any work which may cause damage to the tunnel is prohibited, and that specific measures must be approved by the Public Roads Administration.

The assumption that the zone plan shall be the basis for acquiring land and rights to proceed with the construction and provide those affected with the best possible understanding of the consequences of the project require that any restrictions imposed are clearly described.

Some basic points concerning zone plans for tunnels:

- Regarding the tunnel construction itself together with the associated safety zone (assuming this is regulated) and the approach zones, the objectives “Public traffic areas” as stated in the PBA § 25, No. 3 is commonly used.
- Even though the tunnel might not have any physical impact on the surface, it would be appropriate to combine the objectives of “public traffic areas” with the regulations which is relevant to the area above the tunnel. Particularly where it is necessary to impose restrictions on land-use above the tunnel, it will be proper to indicate the area covered by such restrictions by combining purposes, or by adopting other development objectives.
- Concerning the portal construction and concrete tunnels, the construction phase will result in temporary upheaval on the surface which will frequently have broader consequences for the landowners and those licensed to use the area than the permanent restrictions. These circumstances should be clearly indicated in the zone plan.

This may be done, for example, by combining “public traffic area” with the development objectives covering the future land-use of the surface area, and the relationship between these two objectives is more precisely defined in the design regulations. These regulations can, among other things, contain a description of the effects during the construction period and rules relating to the preparation of – and restrictions on – the area above the tunnel following the completion of construction.

- The plan should contain reference to temporary construction measures such as construction roads, temporary road diversions, construction plant areas, deposition sites for waste (temporary and permanent), such that the plan provides the basis for any necessary expropriation associated with these measures.
- All questions likely to arise associated with the environment should be described in detail. If it has not been determined in any previous stage whether the tunnel construction requires permission or approval to be granted by special acts (for example, permission for run-off in respect of the Pollution Act § 11, concession based on the Water Resources Act etc.), an account must be given in the zone plan. It is a requirement in the plan that an investigation is made into the effects that the construction may have on monuments automatically covered by the Historic Monuments Act.
- A detailed explanation of fire safety measures shall be given as part of the plan.
- The plan shall clearly determine whether expropriation of property is necessary for the area above the tunnel where there is a thin rock cover and in the case of concrete tunnels.

102.3 The Construction Process

102.31 Application and notification requirements in general for road projects

According to the Planning and Building Act § 93, notification is required for all road projects. However, there are comprehensive exceptions for public roads as defined in “Regulations concerning procedures and control of the construction process” §§ 5 and 6. The exception to the general rule of notification applies to all road projects which are described in detail in the zone plan or construction plan as laid down in the Planning and Building Act. Further, public highway construction where the Norwegian Public Roads Administration is the client is always exempted from the regulations on liability and control.

The background for the exceptions which apply to road construction where the Norwegian Public Roads Administration is the client are as follows:

- It is not necessary to conduct a new evaluation of circumstances in construction projects which are accounted for in the previous plan.
- The rights of consultation in respect of planning affecting authorities, landowners, those with rights of access and neighbours, shall be ensured during the process.
- The regulations pertaining to the Roads Act and the experience and resources of the Norwegian Public Roads Administration imply that this body has the best assumptions for ensuring road construction of a high technical standard.

Work involving temporary or portable buildings, constructions or plant is initially subject to notification according to the Planning and Building Act. The regulations for notification do not, however, apply to buildings, constructions, or installations on building or construction sites in the immediate vicinity of such sites. Nevertheless, these shall not be placed

such that they are a hindrance to normal public access or recreation area or in other way are detrimental to the surroundings.

Even though public road projects will be largely exempt from building regulations, a number of regulations will always apply. See “Public road construction and building projects”:

- § 74, no. 2 on aesthetics
- § 77 on construction procedures and requirements for products used in construction
- § 92 on changes to or removing constructions
- Chapter XVIII on liabilities
- Chapter IX on illegal construction activity.

Reference is also made to Section 102.33 for processing of applications and notifications.

102.32 Further information on exceptions to construction applications

Where the road construction is not described in detail in the zone plan or construction plan, an application must be made for the remaining details associated with the project. As mentioned, the regulations on liability and control are not applicable.

Where it is desired that the zone plan is to be described in such detail as to exempt the road project from administrative procedures, it is important to understand that this will result in less room for adjustment in later stages of the project and that this can result in the need for a new evaluation of the plan to include circumstances which would have been sufficiently considered in an initial administrative evaluation.

Through the application or notification, residents and others in the vicinity will often be informed of the period of the project and practical circumstances during the construction period. For measures which are exempt from construction administrative procedures, it is assumed

that the client supplies corresponding information on the progress.

In the thematic guide “Public road construction and building projects” (Report HO-2/2000), the requirements for administrative procedures are described for a large number of elements incorporated in road construction. A summary of those most relevant to tunnel construction are included below. Those included under (A) should be considered as elements for which it is absolutely necessary that a detailed description is given, such that demands are not made for application or notification. Those listed under (B) are not absolute requirements, but documentation should nevertheless be presented.

“Tunnels

(A) Exception from administrative construction processes is dependent upon the location of the tunnel, the design of the tunnel portals and any restrictions in the use of the area above the tunnel being determined in the planning process. Any restrictions in use of the area above the tunnel must be clearly stated in the provisions of the plan. Further, reference must be made to the necessary technical drawings which show the design of the portals and any other related building measures.

(B) Subsidiary information should be supplied in the form of illustrations which provide the involved parties with an impression of the appearance of the tunnel portals.

Reference is also made to “Guidelines for considering fire protection in road tunnels” of July 2000, issued jointly by the Ministry of Transport and the Ministry of Local Government. The guidelines have been prepared within the existing regulations and are based upon a draft from the Directorate for Fire and Electrical Safety (DBE) and the Directorate of Public Roads in association with the National Office of Building Technology

Administration. The guidelines have been placed on the Internet by the Ministry of Transport:

<http://www.odin.dep.no/sd/>

Concrete tunnels

(A) Corresponding regulations apply to concrete tunnels. In addition, the exception to administrative procedures are on condition that the covering and use of the area above the tunnel having been specified in the planning process.

“Ventilation and electrical installations

Ordinary ventilation and electrical installations which are part of the road construction, i.e. that they can be regarded as road-technical installations, require neither application or notification.

This does not apply, however, to larger constructions such as ventilation shafts which are visible to neighbours.

(A) Where the location, design, choice of material has been specified in the planning process, there is no obligation to submit an application.

Ventilation and electrical installations which are incorporated into buildings are not included in the exceptions to administrative evaluation.”

A comparable review of other elements which may be relevant to road construction is given in Report HO-2/2000.

102.33 Administrative processes for applications and notification

The regulations relating to applications and notifications are given in the regulations concerning procedures and control of the construction process (SAK).

According to SAK § 5, the regulations on liability and control do not apply where the Norwegian Public Roads Administration is the client. This also means that the requirements of documentation stipulated in §§ 14 and 15 do not apply in respect of liability and control.

The requirements which nevertheless do apply are indicated in SAK § 14.

Administrative procedures undertaken in separate stages will apply only occasionally for public road measures in so far as Stage 2 of the administrative procedure is essentially concerned with a clarification of terms relating to liability and control. It should thus be considered that applications for public road construction are considered in a single stage.

Resulting from the fact that highway construction shall initially be considered according to the regulations relating to applications, the regulations relating to the administrative process for notification in SAK Chapter IV are scarcely relevant for road construction. An exception to this would be that certain constructions could be considered according to the regulations for notification. The administrative regulations in §23 no. 2 will apply to these projects. Among other things this implies that notification to neighbours is not required.

Summary of the process for handling applications and notifications

It is emphasised that on account of the exemption from the regulations on liability and control for public road construction where the Norwegian Public Roads Administration is the client, it will not be necessary to complete those parts of the forms in the summary which related to these themes.

Single stage administrative evaluation	Notification
Initial discussions	(Applies to temporary construction measures which are subject to notification according to the Planning and Building Act § 85)
(The need for discussion is determined in each individual case)	Initial discussions
Form NBR no. 5170 and no. 5169	Form NBR no. 5170 and no. 5169
Summary of initial discussions	
Form NBR no. 5171	Summary of initial discussions
Advice to neighbours	Form NBR no. 5171
Form NBR no. 5154	Advice to neighbours
Copy of Advice to neighbours	Form NBR no. 5154
Form NBR no. 5155	Copy of Advice to neighbours
Application to commence project	Form NBR no. 5155
(Alt. application for individual measures)	Notification of project
Form NBR no. 5151	Form no. NBR no. 5153
Permission for the project	
Form NBR no. 5151	

2 Geological Investigations

201 Introduction

Modern road construction places special demands on geological investigations in connection with tunnel construction. The investigations for tunnel projects shall provide an account of alternatives and total costs together with a survey of conditions relating to safety, the community, and the environment. Further details are included in the Manuals 054 – “Development planning”, 140 – “Impact analyses” and 151 – “Management of construction projects”.

An important requirement, among others, is geological investigations which comprise detailed geological mapping and engineering geology. This is often supplemented by geotechnical, hydro-geological and geophysical investigations.

A rational and qualitative procedure requires that the investigation is carried out systematically in stages and that the results are carefully evaluated before proceeding to the next stage. The extent of the investigations will depend upon the level of the specific plan.

The procedure and reports associated with the investigations shall be carried out such that the data from one planning phase may be satisfactorily transferred to the next. The nature and extent of the investigations must be considered in relation to the actual projects in hand. (See also Section 702 “Working face assignments”).

202 The preliminary plan

The investigations at this stage shall provide the basis for an evaluation whether the geological conditions are such that the project may be carried out. It is particularly important to obtain an impression of the regional geology. The following studies should be included:

- Locate suitable tunnel routes
- Mapping of those areas which may be critical for costs and safety, and the feasibility of alternative tunnel stretches

Tunnel projects extending under the sea must be planned according to the requirement of a minimum rock cover of 50 m. Special conditions apply to any deviation from this (See Section 204).

As a minimum the investigation must include:

- Assembly and evaluation of existing information, geological and topographic maps, and any reports from previous investigations.
- Stereographical studies of air photographs (Scale 1:15 000 – 1:30 000).
- Field investigations. Geological mapping scale 1:5000.
- Evaluation of areas which may particularly be affected by the tunnel including drainage, subsidence, vibrations, runoff etc.
- Maps which give a broad estimate of the thickness of the soil cover
- Evaluation of uncertainty concerning the rock cover.

The findings shall be summarised in a report which includes:

- A summary of the local geology, a description of structural geological and hydrogeological conditions of significance for the feasibility of the project together with alternatives
- Summary of areas which require special measures in connection with the project
- Feasibility study
- Suggestions for further investigations.

203 General plan (county plan/municipal plan)

An investigation at this level shall provide the geological basis for the selection of the road route.

This investigation will be based on the investigations from the previous planning phase and as a minimum will include:

- Air photo studies based on stereoscopic photos /Scale 1:6000 - 1:15 000) collated with topographic maps

(scale 1:1000 – 1:5000). These maps will be used to determine the distribution of soils and rock, weakness zones and the orientation of faults and joints.

- Field and site investigations. The investigations and evaluations shall include the following:
 - Soil cover. Type and thickness. Water depth for sub sea tunnels.
 - Rock type and boundaries For sub-sea tunnels rock types on both sides of the fjord or sound should be stated.
 - Bedding and foliation
 - Joint orientation and frequency
 - Weakness zones
 - Rock cover
 - Hydrological and hydrogeological registration:
 - Measuring programme for groundwater level and pore pressure where necessary, including registration of water reservoirs and marsh areas together with seasonal variation for these
 - Sensitivity with regard to flora and fauna
 - Registration of areas liable to subsidence
 - Requirements for control of leakage into the various sections of the tunnel
 - Quality of rock material with a view to possible use in road construction
 - Investigation for dumping sites
 - Tunnel entrance site alternatives, cuttings, danger of rockslides
 - Need for core drilling
 - Need for seismological investigations

If measurements are to be taken of the status of the water table and pore pressure, frequent measuring should be taken to document natural variations over time (for example, at monthly intervals).

The investigations undertaken shall

ensure that the technical solutions proposed may be implemented and that these provide the basis for quantitative estimates.

Following the completion of the investigations a report is prepared in sufficient detail as is required for the plan.

A distinction has to be made between measurements, actual observations and interpretations.

204 The Zone Plan

The need for supplementary investigations made in connection with the general plan must be considered.

The purpose of the evaluations at this stage are :

- To establish the geological basis for cost estimates
- Report the degree of uncertainty in the investigation results and the consequences of this for cost estimates

The impact of the tunnel in the neighbouring district must be examined and evaluated in detail.

The following must be carried out:

- A scrutiny of the results of previous investigations
- Planning and execution of supplementary investigations together with a verification of previous conclusions
- Vibrations

The limits for permitted vibrations within the area of influence are determined and a measurement programme prepared for follow-up. Plan for building inspection, registration of settlements and damage and the time when this shall be carried out is to be determined.
- Groundwater, pore pressure and settlement. Using investigations undertaken as part of the general plan an evaluation must be made of possible damage arising and necessary protective measures. Consideration must be made

as to whether concession must be applied for in respect of water, drainage, etc. as an alternative to comprehensive water tightning measures.

Reports are required for the following:

- areas of influence
- investigation of the thickness and potential for settlement of sediments
- registration of conditions for the fundament for constructions
- determination of permitted leakage along the tunnel route
- evaluation of necessary measures to meet demands for leakage control.

Special conditions relating to sub-sea tunnels include:

A rock cover of less than 50 m can only be accepted where it is well documented that the rock mass conditions are favourable. A cover of less than 50 m must be approved by the Directorate of Public Roads.

Reports

Special reports are required in connection with preparation of the zone plan.

205 The Construction Plan/Tendering

Complete construction plans shall be prepared such that these can be used as a basis for tenders.

205.1 Supplementary geological investigations

It may be appropriate to prepare supplementary investigations in order to confirm quantity estimated, or following other circumstances which emerge during the course of the project, for example details around the tunnel portals/cuttings which are essential for openings.

Further, it may be necessary to adjust the extent of registration and control planned in the vicinity as a result of measurements obtained.

205.2 Geological and geo-technical reports as a part of tendering

A separate report shall be prepared for submission of tenders on the basis of the investigations conducted. The report is specially formulated for tendering in so far as job descriptions associated with sealing, building, safety measures, completion etc. are considered elsewhere in the tender basis.

The report shall provide the constructor with a basis for his own evaluations and interpretations of the geological conditions.

The report shall therefore include:

- A description of geological, hydro-geological and geotechnical conditions along the tunnel route
- Maps and longitudinal profiles which show the occurrences of rock type, weakness zones and the rock cover. It shall be stated whether these are based on investigations, observations or interpretations
- Analysis of joints, frequency and direction
- Summary of calibrations from the detailed analyses. Reference to other reports where further data is given
- Particular local circumstances to which special attention is drawn (e.g. water wells)
- Reference list. Reports in the reference list shall be available for consultation if required.

3 Consideration of the local environment

301 Introduction

It is the client's responsibility to carry out an evaluation of risks to the environment and to ensure that the project proceeds with full regard to relevant laws and regulations.

With regard to the landscape, aesthetical values and so forth, reference is made to Chapter 5 "Aesthetic design of tunnels"

302 Requirements and constraints

The construction shall be carried out such that those regulations governing preparation of plans and their approval shall be complied with.

These requirements include, among others, the following:

- settlements, vibrations, air shock, noise, dust
- the natural environment, hydrologic balance
- assumptions included in the approved plans (particularly the zone plan)
- applications and reporting requirements in accordance with the Planning and Building Act and other laws and regulations
- Constraints of working hours
- Neighbour contact and information.

303 Registration and investigation programmes

On the basis of the investigations which have been carried out, an evaluation of the material to be registered and the accompanying investigations has to be made to ensure completion of the project. This will include, among other things:

- The need for, and extent of, building inspection
- programme for measurement of vibrations.
- the need for registration and control of ground settlements.
- the need to register the ground-water level (see section 203)

- measurement for documentation of water leakage in the tunnel in the light of specified requirements.
- the quality of runoff water from the tunnel following cleaning
- follow-up of water quality in the recipient area
- noise measurements with a view to documenting compliance with regulations

These measurements are to provide the basis for a detailed investigation and measurement programme. It must be determined who is to undertake the various investigations.

Responsibility will be divided between the client and the contractor:

Client's responsibility:

- determine the necessary restrictions and demands
- property inspection
- monitoring and follow-up programmes
- damage adjustment

Contractor's responsibility:

- implementation according to the regulations
- measurements which are specified as the responsibility of the contractor
- damage liability where the regulations have not been complied with.

304 Vibrationrestrictions and building inspection

Limitations have to be determined for vibrations resulting from blasting. One method for determining this is given in the Norwegian Standards publication NS 8141

The limits are determined such that possible damage may be avoided. Normally these values are determined such that they apply to the fundament or the load-bearing construction in proximity of the fundament.

The possible danger for disturbances/-settlements resulting from activities lead-

ing to vibrations shall be particularly evaluated. This also applies to possible damage to sensitive inventory, computer installations etc, and also the possible inconvenience to neighbours. The limits apply to the maximum permissible peak particle velocity given as mm/sec., and which are determined on the basis of the following:

- ground conditions where the construction is located
- the type of construction and the quality of building materials used
- method by which the fundamnet is prepared
- distance from the blast
- type of vibration (blasting, demolition, piling, etc.)

Special ground conditions, at distances of less than 5 m and other special circumstances may require separate risk-analyses.

Inspection and registration of buildings are to be undertaken in the presence of the owner and conducted by an independent specialist. The description should be supplemented by photographs or video film. In areas where specified limits have been determined, vibration measurements should always be undertaken. The guidelines in NS 8141 state the required specifications of the investigation equipment and how the vibration should be measured and reported. The measurements should ensure the necessary documentation and provide the basis for continual adjustment of the salvo.

305 Requirements for water control

305.1 Water tightness criteria

The investigations and evaluation of the consequences for the environment resulting from leakage in the tunnels should be made as part of the geological investigations.

(See Chap. 2, Geological Investigations”).

On the basis of these it should be determined whether specifications should be made regarding maximum allowable leakage into the tunnel. These may vary along the tunnel route dependent upon the conditions of the influence zone, settlement conditions and the risk of damage to the surrounding area.

305.2 Methods for meeting the sealing requirements. Organisation of the task

If demands for sealing are determined for the whole or part of the tunnel, there are number of circumstances which must be continually followed up in order to ascertain that these demands are complied with.

Pre-grouting ahead of face is a normal method of water control during tunnel construction.

Post-grouting can easily result in poor results as there are limitations on the pressure that may be applied and the grout material may easily return into the tunnel.

If there is a danger that the water tightness requirements cannot be met by systematic pre-grouting methods, the relevant parts of the tunnel must then be sealed with a membrane-isolated concrete construction designed to withstand the actual water pressure. Preparation must be made for this, for example in the design of the tunnel cross-section during construction.

Water injection from the surface or from the tunnel can contribute to maintaining the groundwater and the pore pressure during the construction periods. The effect of water injection is, however, difficult to predict. Water injection also requires continual supervision and maintenance. The method is consequently only exceptionally employed as a permanent measure.

In order to be able to carry out pre-grouting based on systematic probe drilling criteria as to critical amount of leakage from the probes must be determined.

In order that the need for grouting shall be precisely determined, the number of probes should be carefully calculated. In the initial phase the number should be increased to above that which is normally determined as necessary.

In addition careful consideration should be made of those circumstances which could influence the content and performance of the grouting work such that unexpected consequences are avoided. These include circumstances such as:

- measurement of leakage in the tunnel. This is carried out by measuring the total leakage from the tunnel and over sections
- measurement of ground water level, pore water pressure and ground settlements
- registration of the water level in streams and marshes
- water seepage in injection wells.

All the information assembled shall be considered in total.

306 Temporary water effluent

306.1 General

Permission must be applied for temporary effluent resulting for the construction work.

The various forms of effluent may be classified as follows:

Category A:

Discharge from sanitation in connection with workman's sheds, offices etc.

Category B:

Discharge from workshops and washing places

Category C:

Discharge from operations during tunnel construction.

The application for temporary discharge is considered by the County Governor's

Environmental Department.

Smaller installations in categories A and B may be handled by the municipality. These are defined as installations serving a maximum of 25 persons or equivalent.

Effluent resulting from chemical injections must be considered separately.

306.2 Contents of the application

Information about the applicant

The applicant must be registered. Normally this will be the client. If another is to be the registered applicant (e.g. the constructor) this must be agreed with the County Governor's Environmental Department in advance.

Information about the project

A description of the project with estimates of the extent and duration. In addition the rigging areas, waste tips etc., should be indicated. Any necessary maps should be attached.

The application coverage

The various forms of effluent and estimated extent, water volume and quality should be described. Regarding runoff and drainage from operations estimates should be given of the suspended material, nitrogen from explosives and pH following the use of cement products.

Description of the recipient

Description of the water quality and water volume throughout the year for the recipient.

Cleansing

- The planned cleansing plants shall be described.
- Measures for effluent from workshops and washing places are designed according to "Regulations

relating to discharge of oil-containing water”.

- Measures for sanitation drainage are designed according to “Regulations on discharge from separate drainage systems”.
- Run-off from operations and drainage from tunnelling. The normal cleansing methods will be use of oil separators and sediment basin. With particularly sensitive recipients, further cleansing may be made by sand filters.

Evaluation of the effluent (consequences for the environment)

A summary is to be given of the user interests for the recipient together with an evaluation of possible effects of the discharge.

Other information:

The following shall be referred to in the application:

- seepage from mass rock waste sites
- routines for depositing sludge and oil from the oil separators
- safety measures for oil and fuel deposits.

306.3 Control and supervision

A programme for supervision of the water quality of drainage water following cleansing is normally required together with a follow-up of the water quality in the recipient.

A proposal should accompany the application for a control and supervision programme aimed at ensuring that the cleansing units function as anticipated.

307 Use of chemicals in tunnel construction

Use of chemical injection products or other chemicals obliges the producer, importer and/or supplier of such material to prepare and provide documentation.

The product information shall include, among other things, the chemical composition, risks to health and the environment, and preventive measures.

Procedures for acquiring of chemicals which are a health and environmental hazard are given in Manual 214, “Health, environment and safety”.

The conditions in the recipient shall be registered with regard to water mass, and on the basis of this the appropriate dilution shall be calculated. Further, user-interests, biological circumstances etc. of the recipient shall be registered.

An evaluation of the environmental hazard resulting from the use of these materials shall be undertaken by qualified personnel.

If the environmental hazard is considered to be such that there is a danger of pollution, the client shall ensure that the necessary dispensation is obtained for the pollution control authorities.

308 Permanent drainage

An application for permanent drainage of water is not required.

When planning the tunnel consideration has to be made to those assumptions which apply to cleaning as a part of operations and maintenance.

As a general rule the washing frequency should be planned such that special measures are not required to accumulate washing water outside the tunnel.

For tunnels where long intervals between washing occur, or where the volume of traffic is particularly heavy, consideration should be made as to whether the washing water can be so polluted that a special drainage system outside the tunnel is required such that water which may be an environmental hazard can be managed.

309 Emission of gas and particles

309.1 Impact analysis

The ventilation method in road tunnels can be decisive for the level of emission and location of the emission points. In connection with the zone plan, an impact analysis is required of the tunnel ventilation including the possible need for and location of a ventilation tower, cleaning plant, etc.

In the impact analysis the level of air pollution in the vicinity of housing is calculated based on the recommended criteria determined by the Norwegian Pollution Control Authority (SFT). Simultaneously, it should be ensured that the levels of pollution defined in the Pollution Act covering local air pollution and noise are not exceeded.

On the basis of the estimated concentration of pollution in the emission, the level of pollution in the immediate vicinity must be evaluated. The term ‘concentration of pollution’ implies a comparison of the actual level with that of the recommended air quality criteria as given by the Norwegian Pollution Control Authority.

See Appendix A for an evaluation and calculation of air pollution for road tunnels.

309.2 Recommended air quality criteria

The recommended values for air quality determined by the Norwegian Pollution Control Authority are given in Table 3.1

309.3 Emissions through ventilation shafts

Where it is difficult to achieve the recommended levels of air quality criteria through emission at the tunnel entrances, emission via a ventilation shaft is an alternative.

The dispersion of the emission from ventilation shafts is calculated with the aid of dispersion models used for chimneys. The ventilated air jet stream is directed vertically upwards. This implies that the pollution is lessened before reaching ground level.

The height and the dimensions of the shaft are determined by the air volume and demands for air quality at ground level. In addition, consideration shall be made for noise emanating from the ventilation shaft (especially with high air speeds).

310 Cleansing tunnel air

Today, equipment is available which enables tunnel air to be cleansed both of particles and NO₂.

The necessity of cleansing measures is determined by the permitted concentration in the tunnel or the recommended air quality criteria outside the tunnel.

Table 3.1 Recommended air quality criteria for air outside the tunnel

Marginal values C	Unit of measurement	Period of measurement*				
		15 min.	1 hour	8 hours	24 hours	6 months
CO	mg/m ³	80	25	10		
NO ₂	µg/m ³	500	100		75	50
Airborne articles PM ₁₀	µg/m ³				35	
Airborne articles PM _{2,5}	µg/m ³				20	

* The period of measurement is that for which the mean level of pollution shall be calculated.

From SFT-report no. 92:16 “Effects of air pollution on health and the environment. Recommended air quality criteria”.

If a ventilation solution is planned which includes cleansing measures, this has to be approved by the Norwegian Public Roads Administration.

Cleansing particles

On order to clean the tunnel air of particles, an electrostatic filter may be employed. This technology enables 80–95% of particles to be removed from tunnel air which goes through the filter and which is bound to special particle fractions.

In order to attain the greatest efficiency the design and planning shall be adapted to the actual tunnel.

Electrostatic filters for cleansing particles can be installed in side tunnels as an overlying installation, or included in the ventilation shaft.

The risk of an explosion is present in the event of a major leakage of heavy, inflammable gases/fluids. When mounted in a side tunnel a raised skirt at the entrance to the bypass is recommended in order to divert the gases.

Cleansing NO₂

In order to clear the tunnel of NO₂, a special type of active carbon is used resulting in up to 70% of the NO₂ content in the tunnel air being removed. On account of the restricted space, the cleaning equipment is placed in a side-tunnel.

311 Noise in the proximity of the tunnel entrances

Two levels of noise exist in proximity to the tunnel entrances:

- noise from the open road in the tunnel approach
- noise emanating from the tunnel itself.

Inside the tunnel, a higher noise level is generated than that of the open road on

account of the reflecting surfaces. In addition to the distance, the length of the tunnel and the gradient of the roadway in the tunnel entrance will also be factors in determining the noise level. A higher gradient will result in a higher noise level on account of acceleration.

The Ministry of the Environment defines the noise limits for new constructions. The pollution limits prescribed in the provisions of the Pollution Act concerning local air pollution are required to be complied with for existing roads.

A simplified method for calculation of noise levels from road tunnels has been prepared and which is designed to evaluate the need for counter-measures. This is illustrated in Appendix B. The method shows the calculated noise level from the tunnel entrance. When aggregated with the noise level outside the tunnel, this shows the total noise level at any point. When this is compared to other guidelines, it is then possible to determine whether measures are required for noise reduction.

4 Geometric design

401 General

Tunnels are distinguished from open roads in respect of conditions such as:

- little or no lateral movement
- other winter conditions
- regular lighting throughout the day and year, except from the entry zone
- difficulties in estimating gradients
- difficulties in estimating distance to vehicle in front
- other safety measures, breakdown services, etc.

These require that a number of design elements will differ to those of the open road.

Maintenance and operations shall ensure a constant level of safety in the tunnel.

Important elements in this connection are:

- selection of the appropriate construction method and equipment in the planning and construction phases
- uniform standard for tunnels along the

same road with corresponding traffic type and volume.

The demands placed on standards increase correspondingly with traffic volume and tunnel length. Tunnels are therefore placed in categories which determine the required geometric specifications and features.

402 Selection of tunnel category

The traffic volume is normally given in AADT (Annual Average Daily Traffic volume). AADT is the total annual traffic divided by 365 and is given as the total traffic volume in both directions.

The tunnel category is determined according to the estimated traffic volume twenty years after opening, AADT(20).

Where the traffic volume varies throughout the day or over the year, or where there is considerable uncertainty in calculating AADT(20), the tunnel category may be based on selected criteria. The chosen category must be approved by the

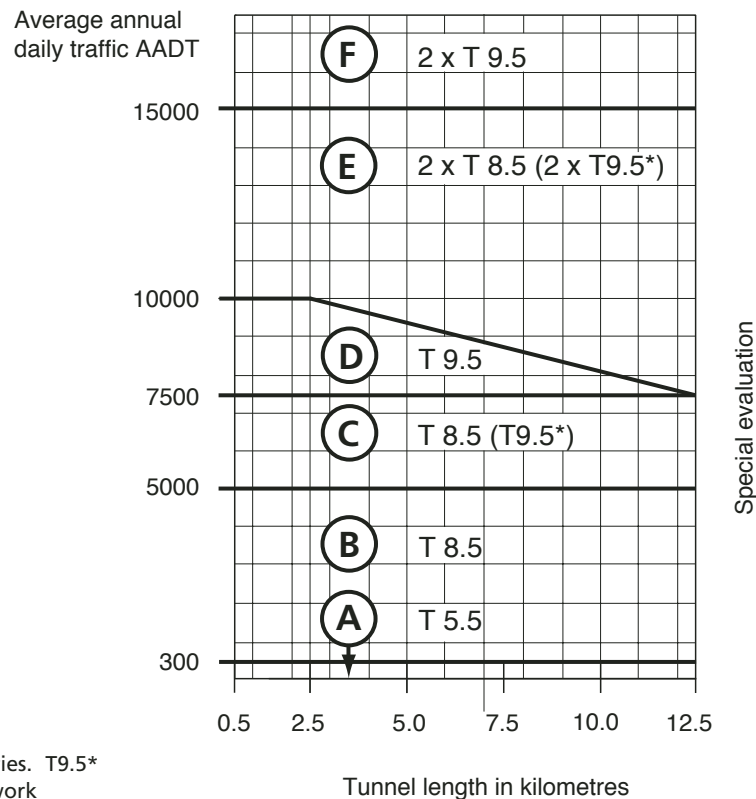


Figure 4.1 Tunnel categories. T9.5* applies to trunk road network

Directorate of Public Roads.

The tunnel categories are based upon traffic volume and tunnel length. (See Figure 4.1) The tunnel categories are the basis for a specific cross-section, number of traffic lanes, need for emergency lay-bys and turning points together with safety equipment. The latter is described in more detail in Chapter 6, "Traffic and Fire Safety".

Figure 4.1 applies to tunnels longer than 500 m. Initially, the cross-section is also selected according to this figure for shorter tunnels except that the width of the shoulder at the open road may be extended throughout the tunnel.

Tunnels with a single lane (AADT < 300 on county roads) are defined as Tunnel Category A. The cross-section of these tunnels is shown in Figure 4.4.

Tunnels on trunk roads in Categories C and E shall be constructed with tunnel cross-section 9.5

If traffic volume AADT(20) prescribes tunnel Category E, a decision of when to construct the second tube shall be made. Where this is deferred, circumstances

must be allowed facilitating construction of this second tube at a later point in time.

If construction of tunnel tube number two is deferred, this may necessitate construction of an overtaking lane in accordance with section 412.5 "Overtaking lanes".

403 Tunnel cross-sections

The tunnel cross-sections are designated according to the total width of the road surface. (See Figure 4.2).

The cross-section of Tunnel T4 has vertical walls.

Tunnel cross-sections T5.5 – T12.5 have a circular contour above the road surface.

The vertical clearance requirements in tunnels is 4.6 m except for pedestrian and cycle tunnels. The vertical clearance specifications apply to the vertical distance measured on the carriageway boundary.

Normal cross-sections will be in excess of this to allow for:

- extra clearance for subsequent road resurfacing

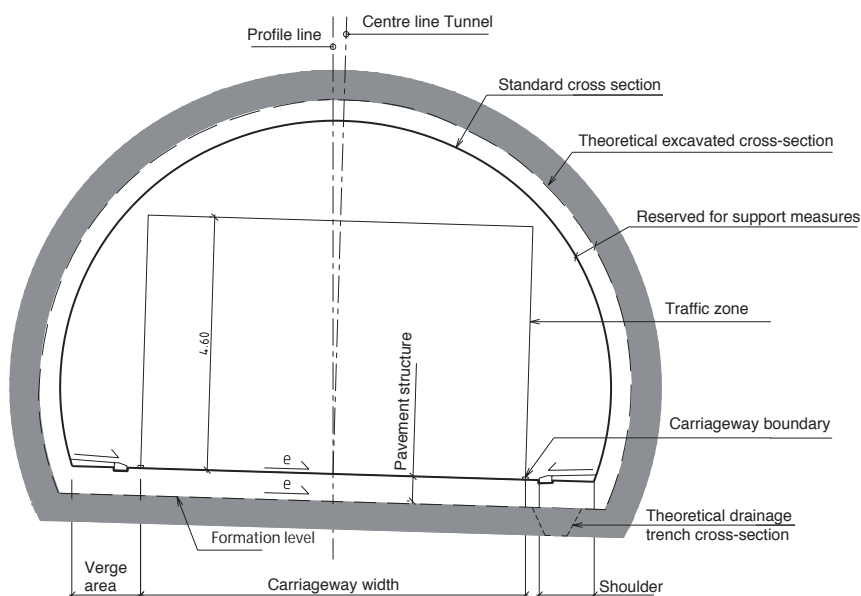


Figure 4.2 Tunnel cross-section

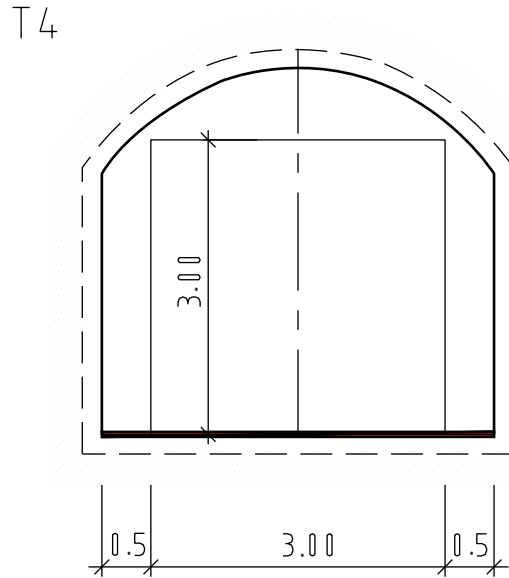


Figure 4.3 Tunnel cross-section T4 (measured in metres) T4 is used for pedestrian and cycle paths. Stipulated clearance height is 3 m. This cross-section is also used for footway interconnections in tunnels with two tubes (Tunnel categories E and F)

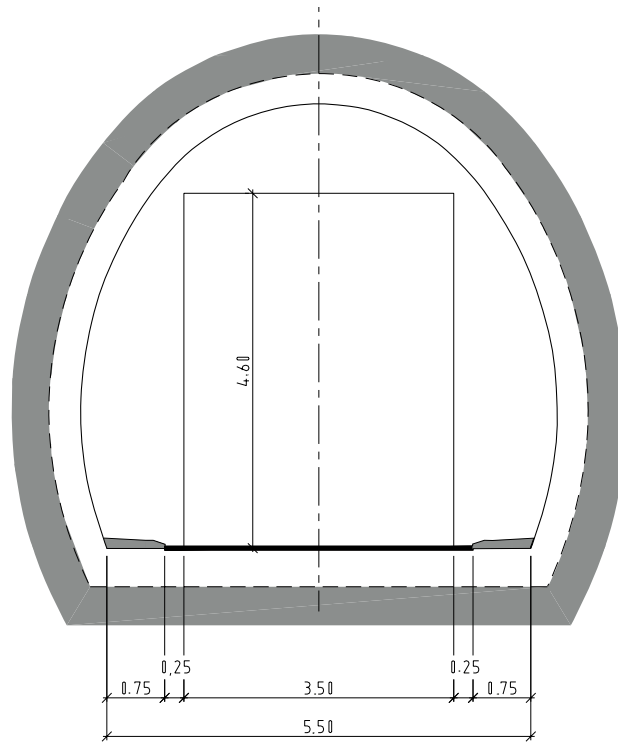


Figure 4.4 Tunnel cross-section T5.5 (measured in metres) T5.5 is used for sliproads with a single lane without requirements that a broken-down vehicle may be passed. T5.5 is also used for single lane roads with meeting points in Tunnel category A. Vertical walls may be an alternative in single-lane tunnels.

T7

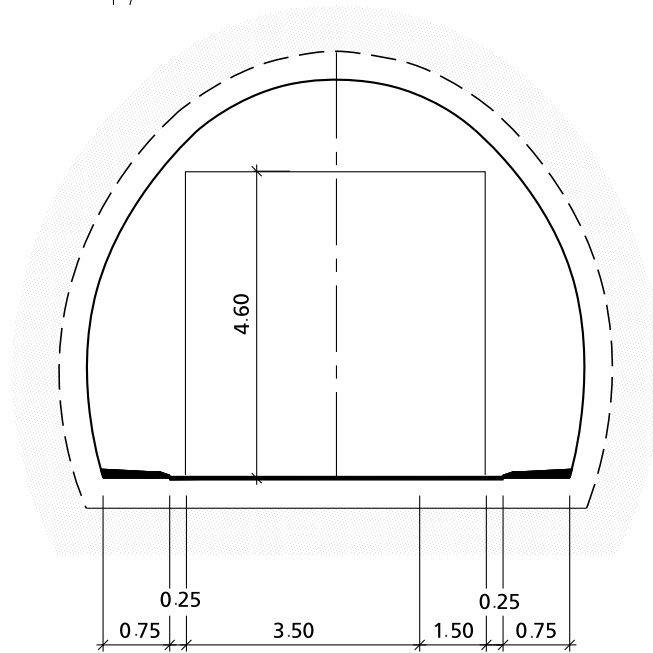


Figure 4.5 Tunnel cross-section T7 (measured in metres). T7 shall be used for slip roads on a single lane with possibilities for a broken-down vehicle to be passed. The carriageway is marked as a driving line width 3.5 m, and an emergency lane width 1.5 m. The emergency lane is included in the extended breadth in order to ensure vision requirements.

T8.5

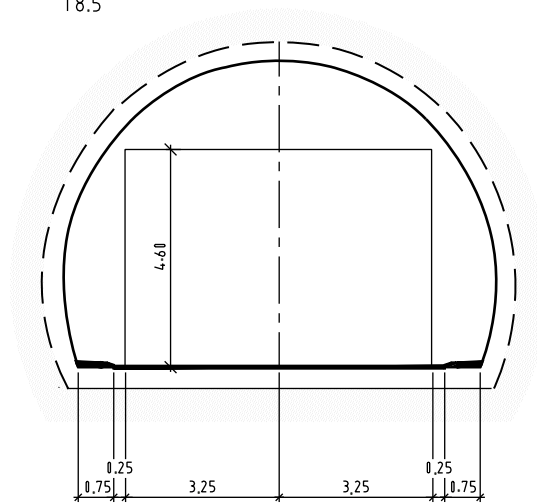


Figure 4.6 Tunnel cross-section T8.5 (measured in metres) T8.5 is used for tunnels with two-way traffic in tunnel categories B and C, and for each tube in Tunnel category E.

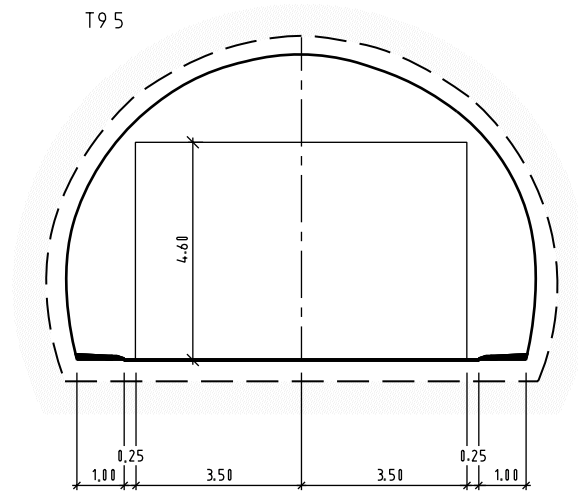


Figure 4.7 Tunnel cross-section T9.5 (measured in metres). T9.5 is used for tunnels with two-way traffic in tunnel category D, and for each tube in tunnel category F together with tunnel categories C and E on the trunk road network.

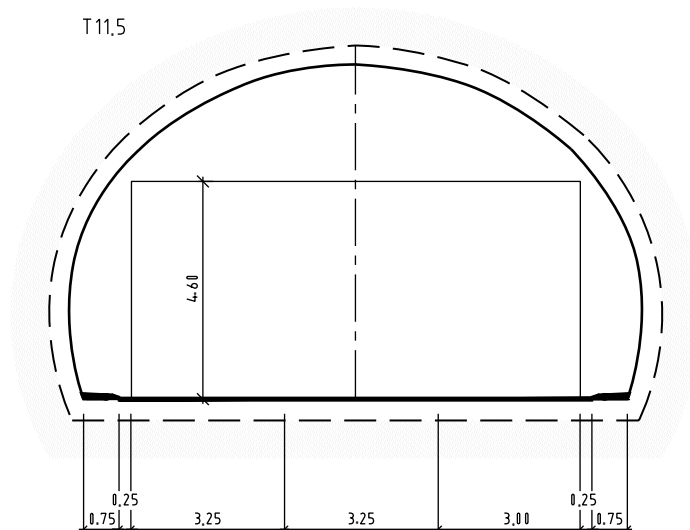


Figure 4.8 Tunnel cross-section T11.5 (measured in metres) T11.5 is used where there is a requirement for three lanes or an emergency lay-by in tunnel categories B,C and E. The cross-sections also provides room for two lanes and a separate pedestrian and cycle path separated with concrete guardrail. (see Figure 4.16). The figure shows normal lane partitioning with an emergency lay-by. In other situations the lane partitioning must be considered in the light of the local traffic situation.

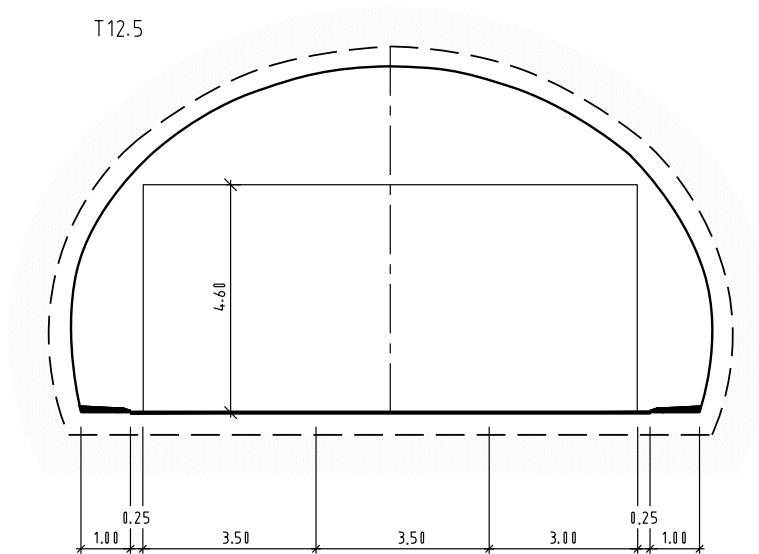


Figure 4.9 Tunnel cross-section T12.5 (measured in metres) T12.5 is used where there is a requirement for 3 lanes or emergency lay-by in tunnel categories D and F. The figure shows the normal partitioning with an emergency lay-by. In other situations the lane partitioning must be considered in the light of the local traffic situation.

- normal tolerance for tunnel linings, water and frost protection / concrete linings (total deviation = 0.1 m)
- requirements for vertical clearance including kerbstone.

Normally the tunnel cross-section will also include space for traffic signs and technical installations. The need for extra width locally must be considered in each individual case. The minimum height for technical equipment must be 4.8 m above

the carriageway. For laterally-mounted equipment such as traffic signs etc., the clearance must be individually determined. With consideration to emergency exits laterally mounted signs should be placed such that the minimum height below the sign is at least 2.0 m. Requirements of signs are discussed in Section 414.

Table 4.1 Geometric specification for the various tunnel cross-sections

Cross-section	Total width B_T	Carriage-way width B_K	Centre point wall radius X	Centre height wall radius Y_V	Wall radius R_V	Centre height lining radius Y_H	Lining radius R_H
T4	4.0	3.0	-	-	-	1.33	2.40
T5.5	5.5	3.5	3.40	1.77	4.79	3.17	2.59
T7	7.0	5.0	2.06	1.57	4.79	2.78	3.20
T8.5	8.5	6.5	0.40	1.77	4.79	1.98	4.50
T9.5	9.5	7.0	0.44	1.57	4.79	1.22	5.20
T11.5	11.5	9.5	2.60	1.77	4.79	- 0.26	7.20
T12.5	12.5	10.0	3.44	1.57	4.79	- 0.46	7.45

All measurements in metres

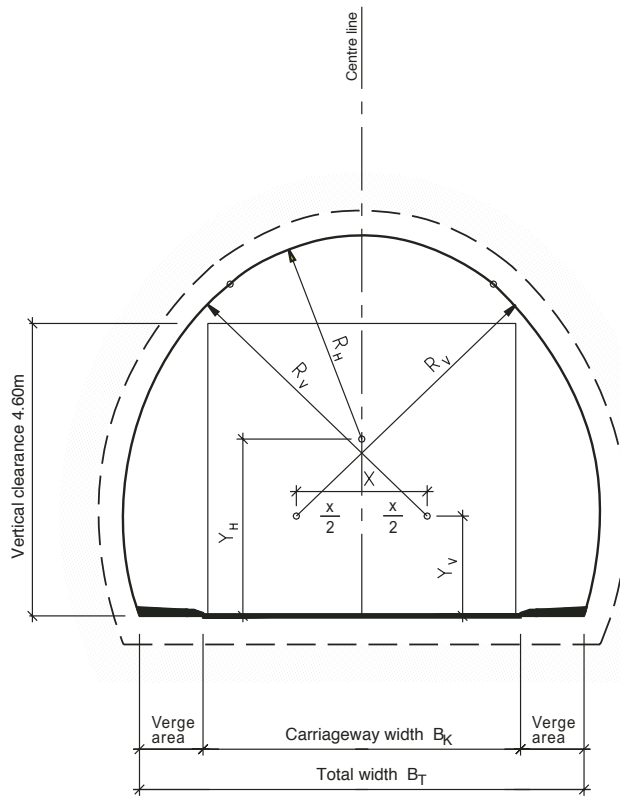


Figure 4.10 Geometric measurements for tunnel cross-sections categories T4 - T8.5 (measurements are given in Table 4.1).

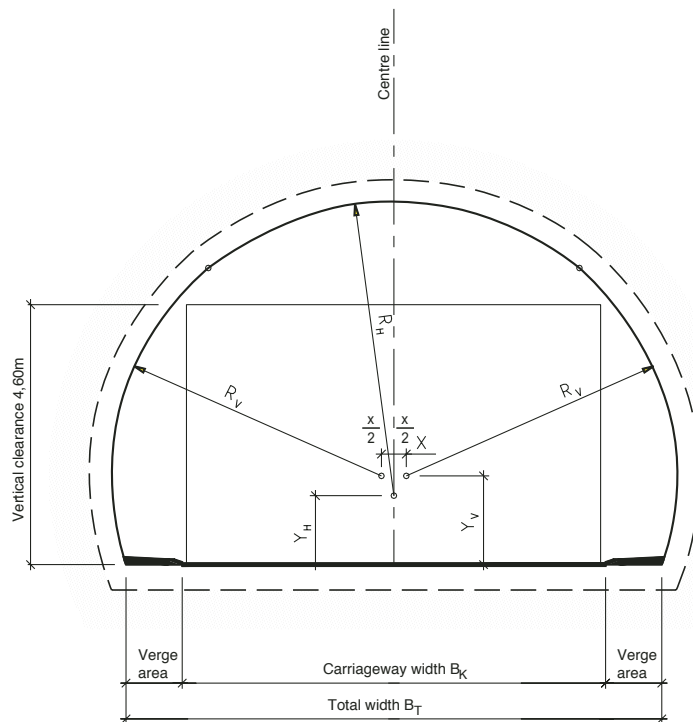


Figure 4.11 Geometric measurements for tunnel cross-sections categories T9.5 - T12.5 (measurements are given in Table 4.1).

Table 4.2 Cross-section data for the various tunnel cross-sections

Tunnel cross-section	Theoretical excavated cross-section		Normal cross-section	
	Area A_S m ²	Arc length, B_S m	Area A_N m ²	Arc length, B_N m
T4	20.31	12.31	13.65	10.04
T5.5	39.11	17.12	28.77	14.90
T7	47.85	18.32	37.23	16.01
T8.5	61.92	20.56	49.66	18.24
T9.5	66.53	21.02	53.53	18.71
T11.5	85.95	23.76	70.89	21.43
T12.5	91.23	24.30	75.41	21.99

Specifications will be dependent upon the pavement construction and area reserved for lining. The following specifications apply to the table:

A_S = Area calculated on a theoretical excavation cross-section. The pavement has been determined at 0.5 m and lining at 0.4 m in the table.

A_N = Calculated area of a normal cross-section above the carriageway and verge area assuming a 5% decline on the shoulder

B_S = Calculated arc length based on a theoretical excavation cross-section down to the formation level assuming 0.5 m for the pavement and 0.4 m for lining.

B_N = Calculated area of a normal cross-section down to the level for the carriageway

Geometric measurements

The geometric specifications are given in Table 4.1 and illustrated in Figures 4.10 and 4.11

The cross-section data of the tunnel cross-section are given under the assumptions made in Table 4.2 and Figure 4.2.

The tables also apply to tunnel cross-sections with a unilateral cross-fall. In this event the cross-section pivots on the centre carriageway. The tables are thus independent of the degree of the cross-fall.

Standard cambers are not normally used in tunnels.

404 Verge area

The verge area refers to the area outside the marked driving lane.

The shoulder should be bordered with kerbstones and constructed of asphalt or concrete with a minimum decline of 5% towards the carriageway. The kerbstones should be low with an obtuse face (lip kerbs) placed 0.25 m from the edge of the carriageway. (See Figure 4.2).

In the entry zones where the environmental impact is particularly large, shoulders shall always have a concrete surface in tunnel categories C, D, E and F.

Shoulders in these zones with a concrete surface should extend a minimum of 200 m into the tunnel at each end.

405 Safety measures with dangerous side obstacles

Cushions should be used along slip roads and other structures which may comprise dangerous side obstacles.

The ends of the linings shall be designed to take safety into consideration. This is done using a slope (1:10) for a minimum of 0.9 m above the carriageway.

406 Construction below the carriageway level.

The formation level (the theoretical excavation cross-section) is determined by the thickness of the pavement. The formation below the carriageway level is otherwise

determined by drainage trenches, cable ducts, and so forth.

The excavated base shall have an inclination corresponding to that of the pavement.

See also Chapter 8 and Chapter 9

407 The tunnel cross-section for concrete tunnels

The choice of tunnel cross-section is determined following a comprehensive technical/economic evaluation. The main rule is that the ordinary tunnel cross-sections will apply unless special circumstances determine otherwise.

Examples of circumstances which

might suggest a deviation from the normal tunnel cross-section include:

- The need for a shallow tunnel course. The tunnel roof is formed parallel to the carriageway while the circular cross-section is retained for the walls
- When it is desirable that the breadth of the building site is reduced
- For tunnels where the design is determined by water pressure, a square profile has a lower volume and consequently less buoyancy.

If it is necessary to reduce the height of a concrete tunnel, the technical equipment and signs can be placed in the side areas. This may then require the shoulder area to be increased.

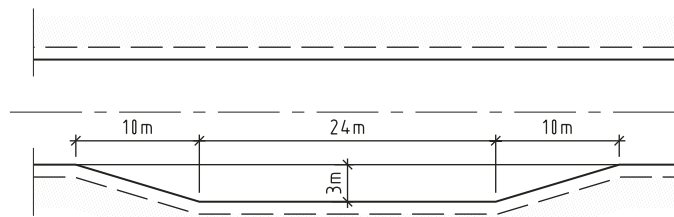


Figure 4.12 Emergency lay-by

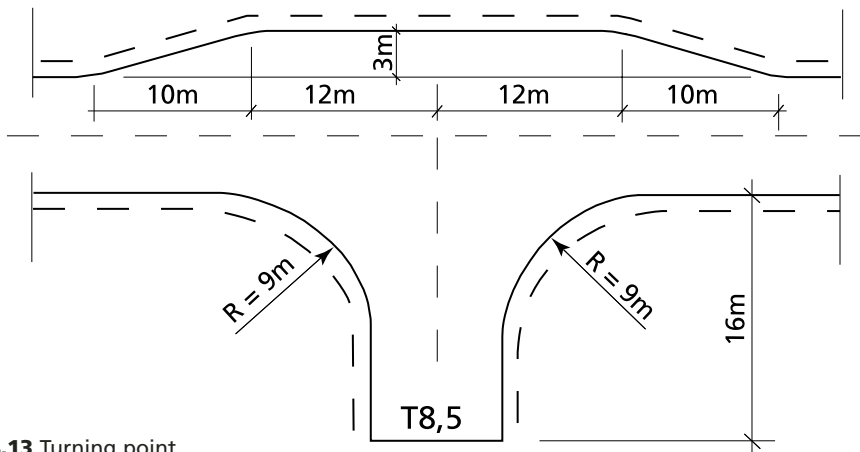


Figure 4.13 Turning point

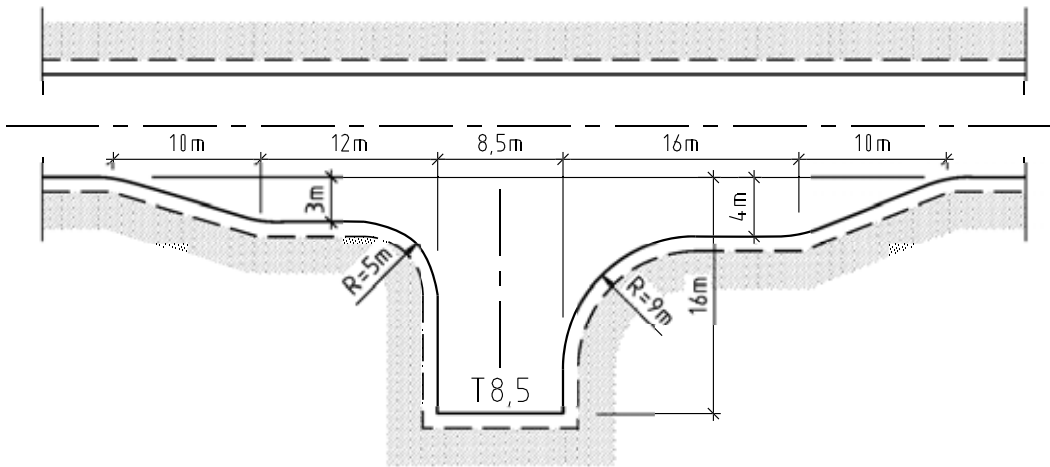


Figure 4.14 Example of a turning point for a snowplough.

408 Extension for lay-bys and niches

408.1 Design and location of emergency lay-bys and turning points

Emergency lay-bys enable parking outside of the carriageway in the case of emergency. Emergency lay-bys are designed as in Figure 4.12. The tunnel cross-sections in emergency lay-bys are shown in Figures 4.8 and 4.9.

Turning points are built into two-way tunnels. Emergency lay-bys can also function as turning points for light vehicles. Turning points for heavy vehicles are designed as in Figure 4.13.

Technical equipment is located in separate niches with an enclosing wall along side the traffic lane. These niches should

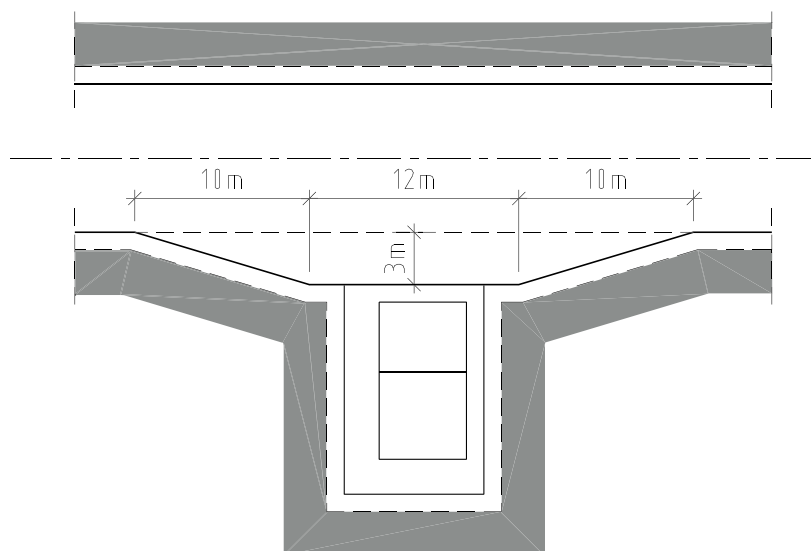
be located together with the emergency lay-bys. See Section 408.2.

In long tunnels, special turning points for snow ploughs are required. An example of the design is given in Figure 4.14

The distance between the lay-bys is determined by the tunnel category. The distances given are approximate. The location will depend upon the local circumstances including rock mechanics and geometric considerations. Further, consideration must be made to designing niches for several purposes (for example, technical room, pump station etc.). Deviations in location should be within ± 50 m for emergency lay-bys and ± 100 m for turning points.

Table 4.3 Normal distances between lay-bys

Tunnel category	Normal distance emergency lay-bays	Normal distance turning points	Comments
A	-	-	See Section 410 for meeting points
B	500 m	2 000 m	The given distances for tunnel categories E and F apply to each of the tunnels tubes
C	375 m	1 500 m	
D	250 m	1 000 m	
E, F	500 m	-	



Figur 4.15 Niche for technical equipment

The normal distance between lay-bys is shown in Table 4.3. Examples of location are given in Chapter 6 “Traffic and fire safety”.

For Tunnels in Category A, single lane tunnels, see section 410.

The first emergency lay-by shall be located not less than 250 m from the tunnel entrance.

When preparing a lay-by plan the following additional considerations must be made regarding the number of lay-bys and their location:

- Normally, lay-bys should not be situated on an inside curve with regard to visibility for approaching vehicles
- At a junction in the tunnel, the start and the end of the slip roads is considered as an emergency lay-by area
- In tunnels where the AADT(20) ≤ 2500 and the gradient $\geq 6\%$ over a length of 1 km, consideration should be given to an extra emergency lay-by for every kilometre of the incline.

If the AADT(20) is >2500 in tunnels with two-way traffic, the need for an extra lay-by is catered for in so far as

an extra overtaking lane is constructed (see Section 412.5).

408.2 Niches for technical equipment

Technical equipment must be located in a separate niche, preferably linked to an emergency lay-by and separated by a sealed off wall from the traffic lanes (Figure 4.15). Regulations for cooling require that the technical equipment niche shall be constructed in concrete.

Where the niche is located away from an emergency lay-by, a separate parking lay-by must be constructed. The design for this is illustrated in Figure 4.15.

408.3 Extension in mountain tunnels with convoy traffic

In tunnels with periodic closures on account of convoy traffic for example, consideration should be given to increasing the width in order to increase the safety factor with convoy formation.

409 Interconnections

Where two parallel tunnel tubes have been constructed, interconnections linking the

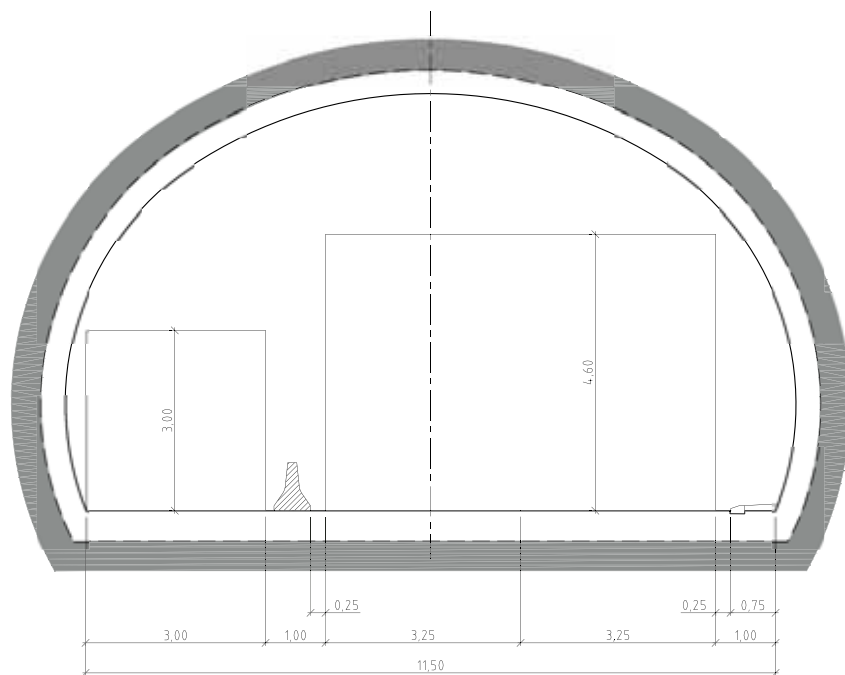


Figure 4.16 Pedestrian and cycle paths in a two-lane tunnel, tunnel cross-section T11.5

two tunnels shall be constructed at intervals of 250 m.

The footway interconnections shall be constructed using tunnel cross-section T4.

Further information is given in Chapter 6 “Traffic and fire safety”.

410 Single lane tunnels

In single lane tunnels used by traffic in both directions meeting points have to be constructed. Distance between meeting-points should be 250 m, but never longer than that a driver can see ahead to the next meeting point. Meeting points shall be designed as emergency lay-bys. See Figure 4.12.

411 Pedestrians and cyclists

Under certain circumstances it may be necessary to permit pedestrian and cycle traffic in tunnels where no alternative route exists. Only in exceptional circumstances should pedestrian and cycle traf-

fic be permitted in tunnels longer than 4 km. There are special requirements for lighting and ventilation for these tunnels, as described in Chapter 10 “Technical equipment”

The pedestrian and cycling area is located on one side of the tunnel, having a minimum breadth of 2.0 m and a minimum height of 3.0 m. A concrete safety barrier separates pedestrian/cycle traffic from automobile traffic.

Tunnel cross-section T11.5 is designed to permit the construction of a pedestrian/cycle way separated from the two-lane carriageway by a concrete safety barrier (Figure 4.16). In special circumstances the Directorate of Public Roads can permit pedestrian and cycle traffic in tunnels with other cross-sections, and without a concrete barrier. One solution can be a footway with a high kerbstone combined with a low speed limit.

Where pedestrian and cycle traffic pro-

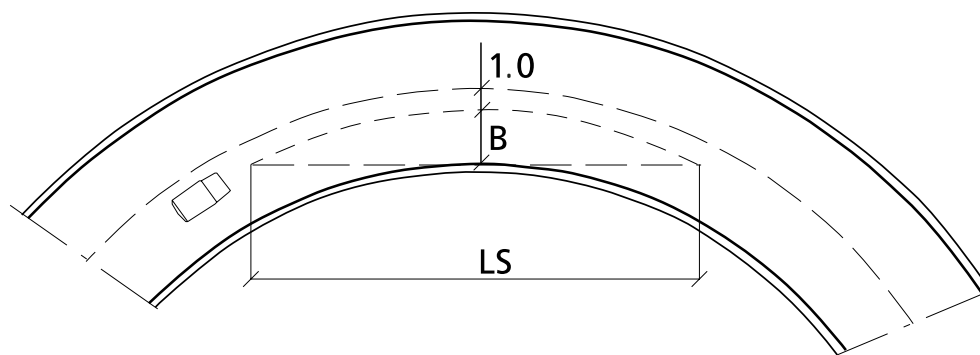


Figure 4.17 Line of sight in a tunnel

ceed in a separate tunnels cross-section T4 is used.

412 Alignment

412.1 General

Alignment specifications in a tunnel differ from those of a normal highway on account of different driving conditions.

Trunk roads employ a different alignment theory which may permit some deviation to that described below.

Both the under-mentioned and trunk road norms can be used in the design.

412.2 Design speeds

In tunnels the radius of the sharpest horizontal curve is determined by the viewing distance. Thus, based on dynamic considerations it is possible to drive faster than the speed for which the tunnel is designed. If the tunnel exceeds 2.5 km the design speed should be at least 80 km/h.

If the gradient is 6% or steeper for at least 1 km, the design speed should be at least 80 km/h.

For shorter tunnels and tunnels in urban areas the design speed may be determined by the neighbouring road system of which the tunnel forms a part.

412.3 Horizontal curves/view

A curve should be considered as part of the approach at each end of the tunnel to

prevent overtaking and to avoid daylight in the openings complicating the lighting conditions for motorists. In tunnels longer than 6 km gentle curves may be designed to counteract monotony.

The horizontal curve diameter is constant within 2/3 of the stopping sight distance within the tunnel entrance and the approach section. It is particularly important to avoid a transition from a curve to a straight section within the immediate tunnel entrance.

The requirements of the stopping sight distances will determine the sharpest horizontal curve. (See Table 4.4).

Where it is desirable or necessary that the horizontal radius is less than that required by the stopping sight distance, the width of the inner curve must be increased.

The association between the horizontal curve radius (R), the length of sight (stopping distance) (LS) and distance as viewed from the driver's eye to the tunnel wall (B) is given by the formula:

$$R = LS^2 / 8B [m]$$

See Figure 4.17, Table 4.4 and Figure 16.25 in Manual 017 for further specifications.

In two-way tunnels the eye is considered to lie 1.1 m above the carriageway and 1 m from the centre line.

Table 4.4 Stopping sight distances (LS) in metres for different incline gradients, AADT and design speeds

Design. speed km/h	AADT(20) 0 - 1 500			AADT (20) 1 500 - 5 000			AADT(20) > 5 000		
	gradient s			gradient s			gradient s		
	≥ -8 %	-7 - +7 %	≥ 8 %	≥ -8 %	-7 - +7 %	≥ 8 %	≥ -8 %	-7 - +7 %	≥ 8 %
50	55	49	41	59	57	47	64	54	49
60	72	64	58	79	68	61	88	73	64
70	94	82	74	109	87	77	116	94	82
80	119	102	91	131	109	96	149	119	102
90	146	124	110	164	134	116	189	147	124
100	178	149	131	201	162	139	234	178	149
110	215	177	154	244	193	165	288	215	177
120	255	208	180	293	229	193	350	255	208

In left-handed curves in one-way tunnels, the eye distance is considered to lie 1 m from the carriageway boundary.

The specifications for lane widening are the same as for open roads.

Widening is carried out on the inside lane and does not change the radius of the tunnel wall.

412.4 Vertical curves

The maximum incline for tunnels is shown in Table 4.5.

Where an overtaking lane is constructed, the values in the table may be increased by 1%.

Tunnels with local characteristics and low traffic volume, together with urban tunnels outside the main road network, may be constructed with a gradient of up to 10%. It is necessary to have this ratified by the Directorate of Public Roads.

The AADT values for one-way traffic in Table 4.5 apply to both tunnel tubes in aggregate.

The AADT values in Table 4.5 apply to road stretches with a normal traffic distribution throughout the year and where the proportion of heavy vehicles throughout the year is 10-15%.

In suburban areas with typical rush-hour traffic where the proportion of heavy vehicles is < 7%, the AADT values in the table may be increased by 25%.

412.5 Overtaking lanes

With regard to the general norms for overtaking possibilities along each 5 km road stretch, measures will often be required in tunnels to facilitate overtaking.

Opportunities for overtaking require that the line of sight is sufficient, or that an extra lane is constructed.

The need for an overtaking lane is based upon estimated capacity.

In tunnels with two-way traffic and a gradient of $\geq 6\%$ over a stretch exceeding 1 km, a separate overtaking lane shall be constructed when the AADT(20) is > 2500.

Table 4.5 Permitted gradients for tunnel

AADT (20)	Two-way traffic		One-way traffic	
	0 - 1 500	> 1 500	< 15 000	> 15 000
Max.gradient	8 %	7 %	7 %	6 %

Table 4.6 Minimum permitted vertical radius (m) in dips

Design speed (km/h)	30	40	50	60	70	80	90	100
Standard class								
H1, S1	240	420	650	930	1270	1650	2090	2580
H2, S2	140	250	390	560	760	990	1250	1550
H3, S3, A1	100	180	280	400	550	710	900	1110

The lane commences latest at that point where the difference in speed of heavy vehicles and light vehicles is 15 km/h or greater, and should be at least 1 km in length.

In tunnels where overtaking possibilities have to be ensured with an adequate line of sight, it is preferable to construct long straight stretches rather than long curves with large radii. This also applies to tunnels with an overtaking lane in long gradients to give the possibility for overtaking traffic in a single lane (decline). Very strict regulations apply where such overtaking may be allowed.

412.6 Vertical curve radius

The recommended vertical curve radius is shown in Table 4.6.

In dips with a gentle curve the driver will have difficulty in recognising the change from a decline to an incline. This can result in an involuntary reduction in speed resulting in reduced traffic flow and danger of collision in the rear.

The radius of the summit is designed as for open roads in accordance with Manual 017.

The transition from decline to incline can be indicated with the warning sign “Steep Incline”, or with horizontal marking on the tunnel wall.

413 Intersections

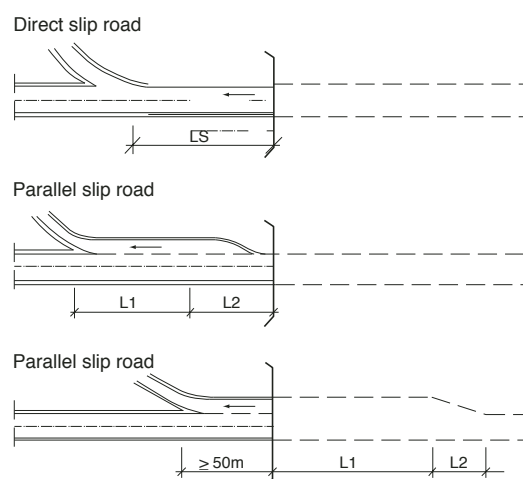
413.1 Intersections outside the tunnel entrance

When the road through the tunnel has pri-

ority, normal intersections (X-junction and T-junction) should not be located closer to the tunnel entrance than 2 x the stopping sight distance (LS). With good visibility and satisfactory advance warning of the junction, the distance may be reduced somewhat, but not less than 1.5 x the stopping sight distance.

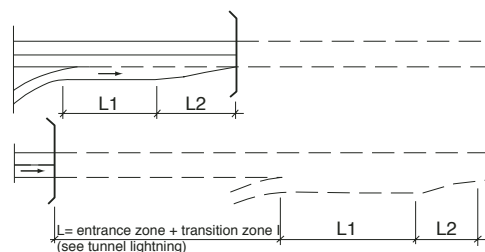
When traffic exiting the tunnel has the obligation to give way or is controlled by traffic lights, the distance from the tunnel opening to the give-way line, stop line or pedestrian crossing shall not be less than

Figure 4.18 Required lengths of the deceleration lane at the tunnel exit. Values for LS are given in Table 4.4



Design speed km/h	70 - 80	90 - 100
L1	70 m	90 m
L2	30 m	50 m

Figure 4.19 Required length of acceleration lane at the tunnel entrance and in the tunnel



Design speed km/h	60	70	80	90 - 100
L1	80 m	110 m	140 m	175 m
L2	30 m	50 m	50 m	50 m

the stopping sight distance, based on the speed limit at the tunnel exit. In tunnels in urban areas with a speed limit 50 km/h or lower, this distance may be reduced where there is satisfactory stopping sight distance to traffic islands, signs, traffic lights and other road users. Roundabouts may be situated near to the tunnel opening if the traffic speed is low and the central island can be observed in good time before exiting from the tunnel. If the roundabout is located closer to the tunnel than $2 \times LS$, the give-way warning should be shown on a dual-faced sign in the tunnel.

When the junction is located outside the tunnel opening, special importance must be attached to the reduction of glare problems for traffic driving out of the tunnel. In two-level junctions outside the tunnel entrance, neither the entry nor exit lanes shall be shorter than that stated in Manual 017. The entry lanes shall have merged before the tunnel opening.

A direct slip road shall not commence closer to the tunnel entrance than the stopping sight distance (Figure 4.18). A parallel deceleration lane may commence at the tunnel entrance although can be located entirely within the tunnel. In this event the lane shall be extended for an extra 50 m beyond the tunnel entrance. Where a

deceleration lane commences within the tunnel, road signs shall be placed above the driving line.

413.2 Intersections inside the tunnel

413.21 General

Intersections within the tunnel shall always be approved by the Directorate of Public Roads.

Intersections in tunnels often require large excavated space. Rock-mass properties shall always be evaluated to ensure that the required excavations are possible.

With regard to lighting, no part of an intersection shall be located closer to the tunnel entrance than a distance corresponding to the entry zone where special lighting requirements apply *plus* transition zone I (see Figure 4.19). A slip road may, however, commence in the transition zone if the deceleration lane commences at least 100 m before the tunnel entrance. In the intersection zone and on stretches where much lane-changing occurs in connection with the intersection, the minimum luminance shall be 3 cd/m^2 .

Ventilation in the tunnel is complicated by intersections. It is important that electro-technical considerations are made at an early stage in the planning process.

With regard to safety, the intersection in the tunnel shall be designed for a higher traffic volume than for corresponding intersections on open roads. The ratio of designed traffic/calculated capacity (v/k) shall not exceed 0.75 for the period of maximum traffic volume.

Crossroads or signal-controlled intersections shall not be used in tunnels.

Forks in tunnels shall be protected with buffers (see Section 405).

413.22 Roundabouts

Roundabouts in tunnels may be used in urban and built-up areas where the speed level (defined as 85 % fractile) in the tunnel does not exceed 60 km/h. A 3-arm mini-roundabout or a larger roundabout

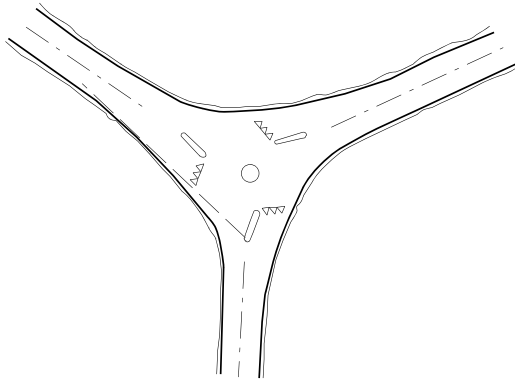


Figure 4.20 Three-armed mini-roundabout

with 3 or 4 arms and a raised central island may be used (Figures 4.20 and 4.21).

Mini-roundabouts are primarily used on local roads where AADT(20) is less than ca. 5000.

3-arm mini-roundabouts entail 120-degree angles between the arms, and a marked-out central island about 1.5 m in diameter. Under these conditions the sight zone (10 x 50 m) will correspond to the broadened approach to the junction.

Medium sized and large roundabouts may be constructed with concrete or natural rock pillars on the central island.

The size of the pillars depends upon rock mechanics. A free-sight zone with a width of ca. 4 m is required around the pillar. The width of the carriageway around the roundabout should be 8–10 m. For a 3-arm roundabout with an 120 degree angle between the arms, the diameter may be reduced slightly.

The criterion for free sight is that from a point 10 m behind the give-way line in each approach, there shall be 50 m free sight to the left along the circulation area and into the previous approach road (Figures 4.20 and 4.21).

413.23 Exit and Entry slip roads – two-level junctions

Exit slip roads with a small amount of traffic can be designed as a direct lane leading to a curve with $R > 50$ m. Where a small-

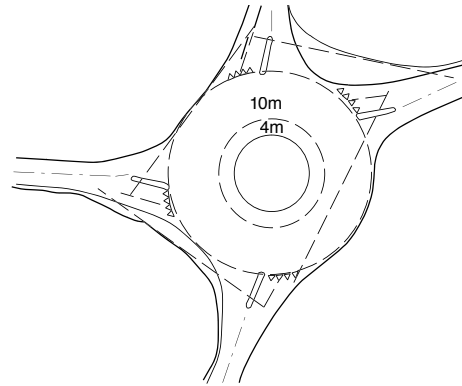


Figure 4.21 Large roundabout, three or four-armed

er curve radius is required or where the traffic volume is greater, a parallel deceleration lane should be used.

The entry slip roads shall end with a parallel lane for acceleration and shall be at least 50 m longer than the corresponding lane on open roads as the sight conditions from the slip road are more restricted in junctions inside the tunnel.

Slip roads in the tunnel should be broader on the inner curves to satisfy the requirements for free sight in the curve. If possible, the slip roads should not have sharper curves than $R = 50$ m.

When planning two-level junctions in tunnels, importance should be attached to solutions which reduce the need for changing lanes inside the tunnel.

Where traffic on the entry slip road exceeds 1200 vehicles/h in designed time, consideration should be given to the entry slip road continuing as a separate lane. A separate lane for exiting traffic should also be considered where there is a high risk of queue formation in the exit lane.

Where traffic on the through-lane and the entry/exit lanes is of such volume that there is a danger for queues, speed restrictions should be considered on the tunnel approach rather than in the tunnel itself.

413.24 T-junctions

T-junctions should not be used in tunnels, although may be exceptionally permitted

where the traffic volume is small with $AADT(20) < 500$ on the main highway, and $AADT(20) < 100$ on the side road. The design will be considered with regard to the specific circumstances.

414 Equipment, traffic signs and road marking

414.1 General

A detailed sign/signal plan shall be prepared for the tunnel. This is done at an early stage in the project as this is essential for the design of the tunnel and can be a decisive factor for important construction aspects.

Detailed regulations for traffic signs and road marking are given in Manual 50 "Traffic signs" and Manual 49 "Road marking" (in Norwegian). Signs and marking outside the tunnel shall be in accordance with these manuals. Some signs and selected road markings require to be approved. These are specified in the manuals together with the approval authorities.

Signs in connection with road works and surveillance equipment are supplementary to ordinary traffic signs and are described in Chapter 6 "Traffic and fire safety".

414.2 Equipment and traffic signs outside the tunnel

With regard to traffic safety, signs near the tunnel entrance should be reduced to a minimum. Signs shall be considered with respect to the individual tunnel. Some of the safety measures inside the tunnel will require to be linked to signs

The sign 712 "Tunnel name" with a tunnel symbol and length shall be used for tunnels exceeding 500 m in length. The sign is located on the right-hand side, at least 50 m from the tunnel entrance.

As an alternative to sign 712, warning sign 122 "Tunnel" may be used where the tunnel entrance is not clearly visible and

appears suddenly for road users. Sign 122 may be combined with sign 802 "Distance" positioned below sign 122, but shall not be used in conjunction with sub-signs which show the tunnel length.

The prohibition sign 314 "Height limit" is only used for tunnels where the measured clearance is 4.59 m or less. Prohibition sign 334 "No overtaking" and 306.8 "Prohibited for pedestrians and cyclists" is only used where curves in the road or other special circumstances advise this. Special regulations apply to the cross-section, illuminations and ventilation in tunnels used by pedestrians and cyclists.

The information sign 601 "Radio station" shall be used in all tunnels with radio communication

The flashing red stop signal (see Section 602.207 and Manual 048 "Traffic signals") is indicated with sub-sign 808. No other signs shall be placed on the same pole as the flashing red warning sign.

Barriers must bear sign 908 "Barrier", or be similarly designed but in red and white. See also Section 602.208 "Remote-controlled barriers for tunnel closure". The barriers should be located at least 50 m before the tunnel entrance to ensure sufficient space in the event of evacuation, smoke hazard, etc.

Emergency telephones and fire extinguishers, where found (See Chapter 6), are installed outside the tunnel entrances. The precise location will depend upon the actual tunnel, but it will be convenient to assemble emergency equipment, emergency telephone, fire extinguishers etc at the same place, i.e. about 50 m from the tunnel entrance.

The minimum distance between signs given in Manual 050 "Traffic signs" also applies to the tunnel approach. The Manual also gives precise information on which signs may be attached to the same pole/mast and the maximum number of signs per post.

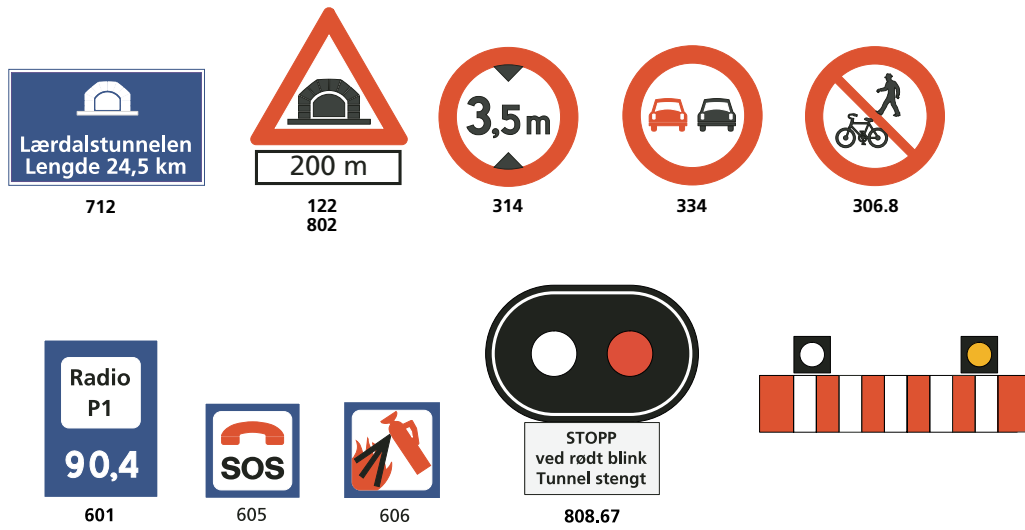


Figure 4.22 Road signs approaching the tunnel

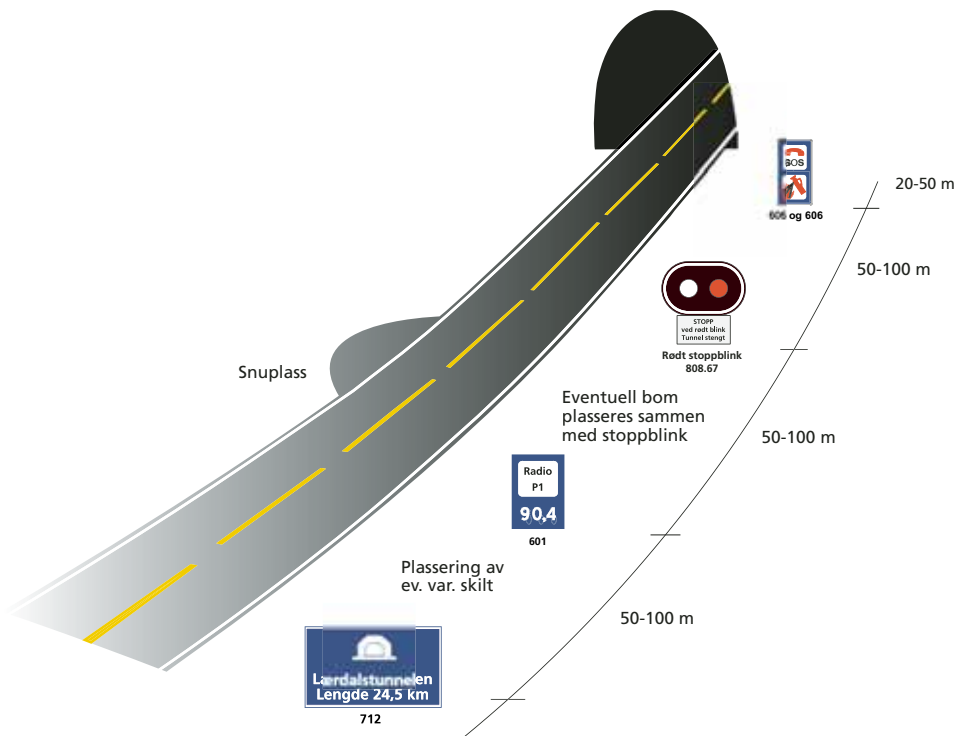


Figure 4. 23 Example showing location of signs in the tunnel approach



Figure 4.24 Signs used in the tunnel

Consideration shall be given whether signs relating to the tunnel and which are normally located near the tunnel entrance are better located at the last opportunity for turning or the last intersection before the tunnel. Examples of such signs are 314 “Restricted height” combined with sub-sign 802 “Distance”, together with a flashing red stop signal with associated sub-signs and barriers.

Example of the location of signs is shown in Figure 4.23.

414.3 Traffic signs in the tunnel

The number of signs inside the tunnel should be kept to a minimum. This applies particularly to large signs as the tunnel cross-section provides only restricted place for signs. Intersections in the tunnel or immediately after the tunnel require a number of signs, and this should be taken into consideration.

All signs in the tunnel shall be clearly visible using either built-in or external lighting.

Signs in the tunnel do not differ from those employed outside the tunnel. Traffic regulation signs, warning, information and direction signs shall be considered in a similar manner to signs on the open road. The following describes some signs which are especially appropriate to tunnels.

See Figure 4.24.

The service sign 601 “Radio station” is located outside the tunnel as described in Section 414.2. Where it is possible for the Norwegian Public Roads Administration or emergency services to be able to interrupt broadcasts with warnings to road users the sign must be repeated every 500 m in the tunnel. The sign is then combined with a flashing amber warning light which is activated when the warning is broadcast (See Table 6.1 and Chapter 6 “Traffic and Fire Safety”). The text on the sign shall also refer to radio NRK channel P1 even though the warning is broadcast on other channels.

All emergency telephones are indicated with service sign 605 “Emergency telephone”. All fire extinguishers are indicated with service sign 606 “Fire extinguisher”. The signs shall be indicated on the front and reverse; alternatively signs are placed facing oncoming traffic in both directions.

Sign 916 “Distance marking for tunnels” shows the distance to the tunnel entrance in both directions. These are relevant for tunnels longer than 3 km.

Turning points are indicated with a separate sign with a flashing stop signal. These have to be approved by the Directorate of Public Roads. In the event

of a fire extinguisher being removed all signs up to the point of closure will be automatically switched on. In the direction of the exit all signs are switched off.

For emergency signs which are not traffic signs, see Section 602.203 “Emergency exit signs”.

Certain interior-illuminated signs may be reduced in size compared to those on the open road. This applies to triangular and circular signs where those of medium size (900 and 800 mm respectively), and large size (1200 and 1000 mm respectively), can be reduced by one class size. This applies also to information signs 530–538, which may be reduced by up to 30 percent, and service signs 605 and 606 which can have a width of 440 mm. For overhead traffic lane sign 724, a minimum height for the text of 210 mm can be used. Manual (050) “Traffic signs” provides details.

As far as possible effort should be made to locate signs in the tunnel corresponding to that on the open road. Road direction signs require considerable space and should be placed above the driving lanes. The effect of signs on ventilation and illumination have to be especially considered. Normally, there is insufficient space for more than one or two text lines on road direction signs above the lane. The number of direction signs should therefore be reduced to a minimum. Laterally placed signs which are too large with regard to the tunnel cross-section may be placed in the emergency lay-bys. The clearance under lateral signs should to be at least 2.0 m. See Section 403 “Tunnel cross-sections”.

See also Chapter 6 “Traffic and fire safety”.

414.4 Road marking and visibility

Warning lines, prohibitory lines and combinations of these together with the carriageway boundary line in the tunnels

shall be indicated according to the given cross-sections. See guidelines for use of profiled road marking. Reflectors on the road should be considered, particularly where lighting is poor. Normally the profiled marking and road reflectors should continue for at least 100 m outside the tunnel. Otherwise the marking is as for the open road.

In tunnels with poor lighting and difficult curves, sign 914 “Tunnel marking” may be used to improve visibility.

5 Aesthetic design of tunnels

501 The main objectives

As a rule tunnels are a part of a more comprehensive road system which again is part of a route way. Tunnel projects require to be planned as a sequence of the route way of which it is part.

The highway/tunnel driving experience in a car consists of movement where space is experienced as a continual sequence. Tunnel projects shall be located and designed such that:

- the journey comprises a continual and positive experience
- the immediate vicinity outside the tunnels has a well-designed landscape architecture with consideration to the environment

Longer tunnels shall additionally:

- maintain a continuity of the journey experience
- be informative providing the possibility for orientation, for example provide information on the distance driven in the tunnel and distance to the exit
- provide the traveller with the possibility to locate himself in respect of the main features of the landscape traversed by the tunnel
- give an understanding of, or supply information about the district traversed
- provide contrasts with good transition together with a rhythm and balance along the route
- comprise several subsidiary goals.

Tunnels can be designed as an experience of a theme. Different tunnels should have different themes. A journey can be compared to reading a fascinating book where the tunnel, for example, relates the history of the region one is crossing.

502 The tunnel approach zone

502.1 General

The tunnel approach comprises the entire zone which is affected by the excavation.

This includes cuttings in soil and rock, vegetation, tunnel entrance, the portals, walls etc. The approach zone shall be located and designed as part of the setting such that contributes to a positive driving experience .

In general, the same principles apply for defining and designing the tunnel as for the open road. That which distinguishes the tunnel approach zone from the open road is that the cuttings, breaks in the landscape and the portals often make a greater encroachment upon the landscape. This places particular requirements on the location and design of the tunnel approaches.

The tunnel cutting shall be located such that the approach zone makes minimal encroachment upon the terrain. Scars in the landscape resulting from poor location must be rectified using the appropriate measures.

The tunnel approach zones can be located and designed according to two principles. The construction can:

- be integrated into the existing landscape
- comprise a positive visual contrast to the landscape.

In most cases a 'positive contrast' will imply that the tunnel approach zone is regarded and designed on the basis of an architectural theme which contrasts positively with the general landscape without that the natural landscape of the tunnel entrance becomes secondary or camouflaged. The construction or terrain design should have:

- good architecture
- good craftsmanship
- materials which maintain their quality over time.

The curves forming part of the highway known as *Vinhellavegen* (Figure 5.1) and the tunnel on national highway 15 (Figure 5.2) are examples of independent structures which are positively incorporated visually into the overall landscape. Here



Figure 5.1 Vinhellavegen. A historic mountain road. (Photo: Ingerlise Amundsen)

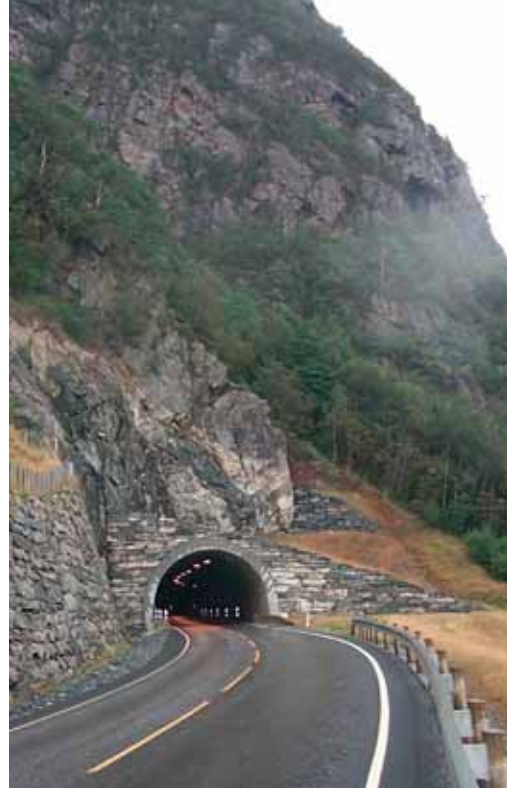


Figure 5.2 National highway 15 (Photo: Astrid Taklo)

the construction has been well designed with material and craftsmanship which stand the test of time.

502.2 Location

As far as possible the tunnel approach zones should be located with respect to the natural features of the landscape, and the tunnel entrance placed in a steep rock face. The most suitable locations are where the terrain changes relatively abruptly from undulating to steep. Gently sloping terrain should be avoided as long cuttings make deep scars in the landscape (Figure 5.3). It is very expensive to construct long portals, slope the lateral terrain (Figure 5.4), or employ other measures to mould the terrain.

As far as possible the tunnel approach zone should be located such that:

- the direction of the tunnel approach follows the form of the natural landscape
- the entrance to the tunnel is orthogonal to the natural rock face of the entrance
- cuttings in soil and rock are kept to a minimum.

Long cuttings in valley sides should be avoided as these will normally be quite exposed. Where it is unavoidable that the cutting shall be along a valley side the effects from a distance must be particularly evaluated.

In towns and built-up areas efforts should be made to locate the tunnel approach zones in areas which are not in the view of the built-up areas, Where this is not possible the location must take into consideration existing buildings and street



Figure 5.3 Approach zone in an area with slight gradient. The cutting is long and deep and does not give a clear impression of approaching a tunnel. Illus. Ingeborg Langeland Degnes.



Figure 5.4 Approach zone in an area with slight gradient. In order to avoid the impression of entering a shaft at the tunnel entrance, the landscape has been comprehensively planned. Illus. Ingeborg Langeland Degnes.

layout such that the portals are incorporated into this structure as much as possible. In built-up areas the approach zones should be as restricted as possible.

502.3 Design

502.31 Terrain and building constructions

The approach zone, including the tunnel portal, shall be designed with consideration to the character of the local surroundings. That is to say it should be based on the existing landscape. Where a principal visual contrast is selected, this contrast should result in a positive visual experience. The terrain and/or constructions such as the portals and similar shall be deliberately designed according to an architectural motive which makes a positive contribution to the landscape.

In landscapes where the tunnel approach zone has to be located on a valley side, special demands are made concerning the design of this zone. In many instances the design will result in a positive contrast in these situations.

When the design of the tunnel approach zone is to be based on the existing landscape, it shall appear as a part of the natural landscape to the greatest possible degree. The design shall include:

- placement of the tunnel entrance
- the length of the portal
- lateral areas towards the portal opening
- the portal construction

The tunnel ought not to commence in a vertical curve.

Normally the entrance should commence at the earliest possible point. In many instances this will necessitate special safety measures. The lateral areas towards the tunnel entrance shall be designed to harmonize with the landscape. Where traffic is particularly heavy, landscaping and afforestation may be used to provide variety in the landscape.

As far as possible landscaping shall:

- give the tunnel approach zone an open characteristic
- restrict visible rock face cuttings.

A good location in a terrain which changes relatively abruptly from an undulating to a steep terrain provides the best possibilities for designing the terrain, resulting in a pleasing landscape architecture.

The tunnel approach zone in a relatively gentle terrain often requires considerably more preparation in order to achieve a pleasant driving experience.

502.32 Existing and new vegetation

When building the tunnel entrance particular importance should be attached to preserving the existing vegetation. The vegetation area should be protected such that individual landowners cannot fell trees which are of visual significance for the portal area. This may be done either by acquiring the land or through a written agreement with the landowner.

The need for new vegetation shall also be considered. New vegetation shall be planted such that it is incorporated as a natural feature of the landscape. Normally, new vegetation shall reflect the predominant existing vegetation. In addition trees may be used as separate elements. The vegetation shall give the road-user a satisfying impression. The general principles for vegetation are given in Manual 017.

Vegetation is particularly important in the portal area as it can contribute to moderating and integrating the encroachment into the landscape (Figure 5.5). Conscious use of vegetation can reduce some of the effect of technical equipment situated in the tunnel approach zone. Where these zones are characterised by many signs and equipment, vegetation can modify the effect of visual chaos. For example, vegetation may be used as the background for signs and other equipment.

Vegetation in the area shall be planned with both short and long term objectives in

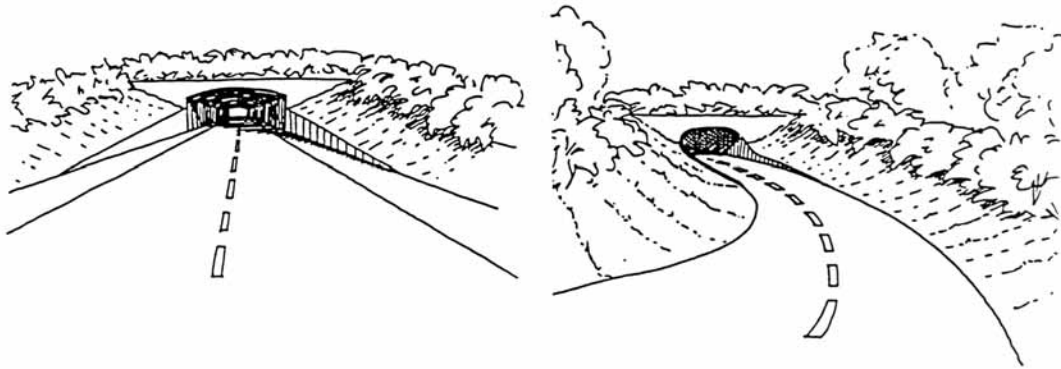


Figure 5.5 Tunnel entrance with afforestation. Examples.

mind. For example, before existing vegetation is removed, new vegetation areas may be established which will gradually take over from existing areas.

Draughts and air currents will frequently occur around the tunnel opening. Plants must be selected which can adapt to the local environment.

502.33 Tunnel portals and other constructions

The practical function of a tunnel portal is to protect the road from rock falls and slides as well as against ice formation, snow and water. In principle, tunnels can be constructed without concrete portals where the rock face is dry and stable and surface water is not a problem.

The aesthetical function of a tunnel portal is to provide a transition from the open landscape to a tunnel. The design of the portal must harmonize both with the general features of the landscape and the tunnel cross-section. In a natural landscape a gradual transition will normally be preferred. A portal which slopes backwards and which is designed as a funnel provides the impression of a spacious tunnel. The portal must be designed to combine aesthetics with traffic safety. As a general rule the portal should be designed such that guard-rails are unnecessary within and outside the tunnel entrance.

The portal may be designed with a straight form or sloping, dependent upon the terrain. A sloping face is normally best where the portal is to be covered. The slope of the filling is determined by the local terrain and the best results achieved where the slope of the filling coincides with that of the new terrain.

Colour may be used to emphasise the architecture of the portal. In a natural landscape the selection of colours should harmonise with that of nature. In towns and built-up areas buildings in the vicinity will have decisive influence.

In an urban situation the portal shall have a conscious architectural structure which accords with that of the district in general. Existing and planned structures shall provide the premises for the design.

Sidewalls to slip roads should not be more than 1 m high such that pedestrians can also experience the urban space. Rather than using solid concrete walls, railings designed to fit in with the local architecture, also in respect of colour, are to be preferred.

Bridges and other constructions should be avoided in the tunnel approach (Figure 5.6). If this is unavoidable then these should correspond to the design and construction of the tunnel portal. In addition the direction of the construction shall correspond to that of the tunnel portal.

Sloping lines created by roads crossing in front of or behind the portal should also be avoided (Figure 5.7). If it is necessary for a road to cross near the tunnel portal it will often be better for this to cross above the portal rather than immediately before

it. The portal should be constructed long enough to provide a visual screen between the portal and the road above. This may be done with the assistance of terrain formation or vegetation, or a combination of both.

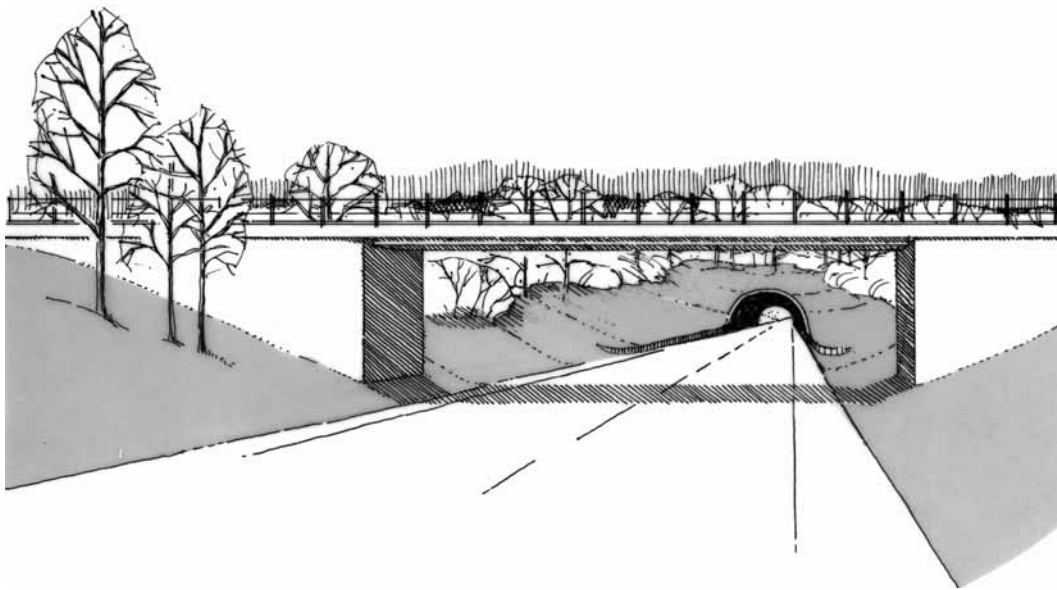


Figure 5.6 A bridge located near a tunnel entrance can result in visual chaos. Ill. Ingeborg Langeland Degnes.

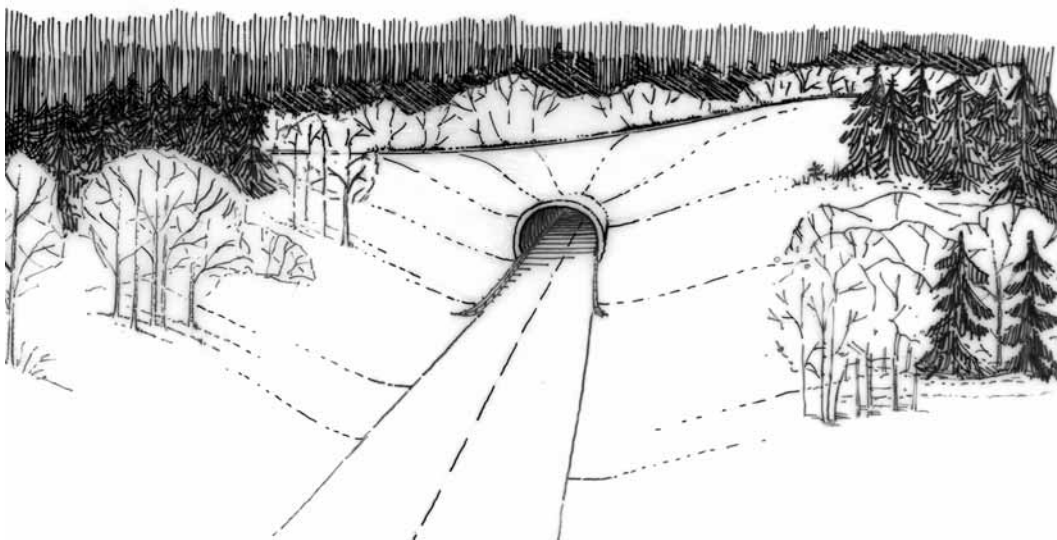


Figure 5.7 Example of an unsatisfactory profile with a transverse slope above the entrance. Illus. Ingeborg Langeland Degnes.

502.4 Vegetation and signs

In the tunnel approach area there is normally a considerable amount of equipment. In order to avoid visual chaos the number of signs and their size should be reduced as much as possible. Necessary signs and equipment should be placed some way from the portal. The last lamp standard before the tunnel entrance should not be nearer than a half of the normal distance between the lamp posts.

The types of sign and equipment and their location should be considered as an entity and planned together when designing the portal and tunnel approach. The placement of each individual element must be seen in relation to other equipment. Gantries for signs should be avoided in front of the portal.

Amber lighting (low-pressure Sodium) which results in a distorted reproduction of colour should be avoided.

Masts for mobile telephones

Construction of new mobile telephone masts should be avoided. Fibre-optics are used to transmit the signal to the nearest mast if this is located not too far away. If a mast is nevertheless necessary fibre-optics should be used. (In principle this enables the mast to be placed anywhere within a reasonable distance of the tunnel).

New masts (up to 20 m height) must be located according to landscaping principles, and not visible from the road. This must be considered with respect to other local circumstances. The location should also take into consideration the need for a cable duct between the mast and the portal. The mast may be hidden or the effect diminished by vegetation, for example.

Design and colour have to be evaluated. Where the mast is exposed, special design must be considered. The colour will depend upon the surroundings, but in most cases a neutral colour which reduces the impact of the mast should be chosen. For

example, where the mast is positioned against dark background, the impact is effectively reduced by a dark green colour rather than the light grey of the unpainted mast.

Traffic lights, barriers and technical equipment boxes

Similarly to other equipment, these should be placed some distance from the portal. Traffic lights and barriers should be placed as far away as possible. For practical purposes, control boxes have to be located close to the portal. These should be included when designing the portal and where technical boxes may be concealed.

Essential barriers should be opened horizontally and not vertically as the former will be less domineering than those opening vertically.

Sound barriers

Noise conditions outside the tunnel opening are discussed in Chapter 3 "Consideration of the local environment". Sound barriers shall be adapted to the portal and the local surroundings concerning materials, design and colour.

503 The tunnel

503.1 General design

The tunnel space shall be specifically designed employing:

- possibilities for interior variation
- lighting which breaks the monotony
- variations afforded by the line and geometry of the tunnel.

503.2 Line of the tunnel

As far as possible the line of the route shall provide the basis for dividing the tunnel into sequences and spaces which yield a satisfactory driving experience. A combination of horizontal and vertical curves which provide a clear division of space should be aimed at. The length of spaces shall:

- be regarded in association with the length and radius of the curve
- be adjusted to the length of the entrance zones, transition zones and the inner zone
- suited to designed speed.

The line of the tunnel shall have a good rhythm and a gentle continual flow. The line of the route shall have:

- a horizontal curvature which changes directions
- a line with continual curves and small, constant, gentle changes in direction.

Drivers are aware of objects which are situated in direct line of the vehicle. Curves in the tunnel will ensure that more attention is focussed on the walls rather than straight ahead.

503.3 Designing the tunnel space

The tunnel space is planned on the basis of an idea which will provide a different experience to that of the open road. The design shall be an interplay between the line of the road, lighting, design and colour and/or surface treatment of walls and roof together with the placement and design of inventory such as signs and other equipment. The design and rhythm of signs is particularly important. In long tunnels sound (the radio for example) can serve to emphasise the sequence. When planning the tunnel, signs, illumination and all other technical equipment must be taken into consideration with regard to design and their placement in the tunnel. Signs and equipment must be clearly visible and easily accessible and incorporated into the general architecture. This also applies to emergency telephone kiosks, boxes housing technical equipment, fire extinguishers, doors and hatches etc. Equipment shall be supplied ready painted in the selected colour.

Illumination which faithfully reflects colours should be chosen. In long tunnels in particular, attention should be given to breaking the monotony by creating varia-

tion with the aid of illumination. One solution can be to choose special illumination, for example in niches or emergency lay-bys.

In tunnels with a lining, all equipment not considered for public use such as technical and communication equipment, pumping stations etc., should be concealed behind the lining. If this equipment is placed in tunnels without lining, the walls and surfaces shall be constructed using suitable materials. Entrances and doors, however, shall be specifically designed and delivered ready painted in the chosen colour.

In particularly long tunnels it is possible for the cross-section to vary throughout the tunnel. Small “mountain halls” along the tunnel can give the effect of a “breathing space” and contribute to breaking the monotony to which drivers are subjected. This can be solved through redesigning elements already planned such as emergency lay-bys, turning points, pumping stations and others.

602 Safety equipment

602.1 Safety equipment in the various tunnel categories

Table 6.1 Safety equipment in tunnels

EQUIPMENT	TUNNEL CATEGORY						NOTES
	A	B	C	D	E	F	
<ul style="list-style-type: none"> ● Obligatory ⌚ Evaluated 							
Emergency lay-bys		●	●	●	●	●	See Ch. 4 "Geometric design"
Turning points		●	●	●			
Escape possibility by foot					●	●	Interconnections every 250 m
Power supply, lighting and ventilation	See Chapter 10 "Technical equipment"						
Emergency power supply		●	●	●	●	●	Lighting in the event of power failure See Sections 602.201 and 1003.6
Emergency exit lighting			⌚	●	●	●	Approx. every 62.5 m. See Sec. 602.202
Emergency Exit sign					●	●	Also obligatory in other categories if the tunnel is constructed with alternative emergency exits, e.g. interconnections. See Sections 602.203
Emergency telephone		●	●	●	●	●	Category B: Approx. every 500 m ¹⁾ C: Approx. every 375 m ¹⁾ D: Approx. every 250 m (both sides) ¹⁾ E: Approx. every 500 m ¹⁾ F: Approx. every 250 m ¹⁾
Fire extinguishers	⌚	●	●	●	●	●	Category B: Approx. every 250 m ^{1) 2)} C, D: Approx. every 125 m ^{1) 2)} E: Approx. every 125 m ¹⁾ F: Approx. every 62,5 m ¹⁾
Water for fire extinguishing		●	●	●	●	●	Alternative solutions in Section 602.206
Flashing red stop signal		●	●	●	●	●	See Section 602.207
Remote controlled barriers		⌚	⌚	⌚	⌚	●	Evaluated on basis of expected frequency of use. See Section 602.208
Changeable signs		⌚	⌚	⌚	⌚	⌚	See Section 602.209 and 603
Lane signals					⌚	⌚	See Section 602.209
CCTV surveillance					⌚	⌚	See Section 602.210 and 603
Communication and broadcasting equipment		●	●	●	●	●	See Section 602.3
Mobile telephone		⌚	⌚	⌚	⌚	⌚	Determined in conjunction with mobile teleph. company
Height control barrier	●	●	●	●	●	●	See Section 602.211

1) Emergency telephone and fire extinguisher additionally installed outside each tunnel entrance (See Section 414.2)

2) Fire extinguishers mounted on one side at given intervals. In addition, fire extinguishers are located together with all emergency telephones on the opposite side

A solid circle indicates that the stated equipment is obligatory.

An open circle indicates that the need to install this equipment has to be considered. The equipment shall only be installed if it can be documented that there are special circumstances which deem this necessary.

In Figures 6.2 – 6.6, the location of emergency lay-bys, emergency telephones and fire extinguishers are indicated schematically for the various tunnel categories. In addition, an emergency telephone and fire extinguishers shall be

placed outside each tunnel opening (see Section 414.2).

Design of lay-bays, niches, interconnections etc. are given in Chapter 4 “Geometric design”.

In Section 602.2, a more detailed description is given of the requirements relating to the various installations included under safety equipment.

Concerning power supplies, lighting and ventilation, reference is made to Chapter 10 “Technical equipment”.

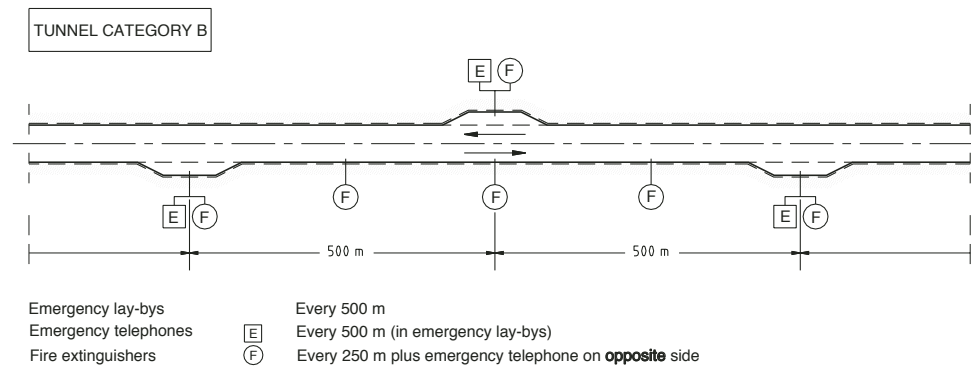


Figure 6.2 Lay-bys and equipment. Tunnel category B.

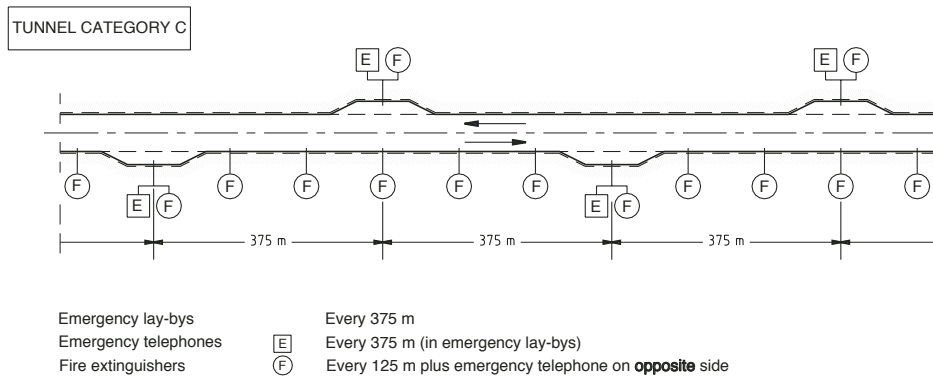


Figure 6.3 Lay-bys and equipment. Tunnel category C.

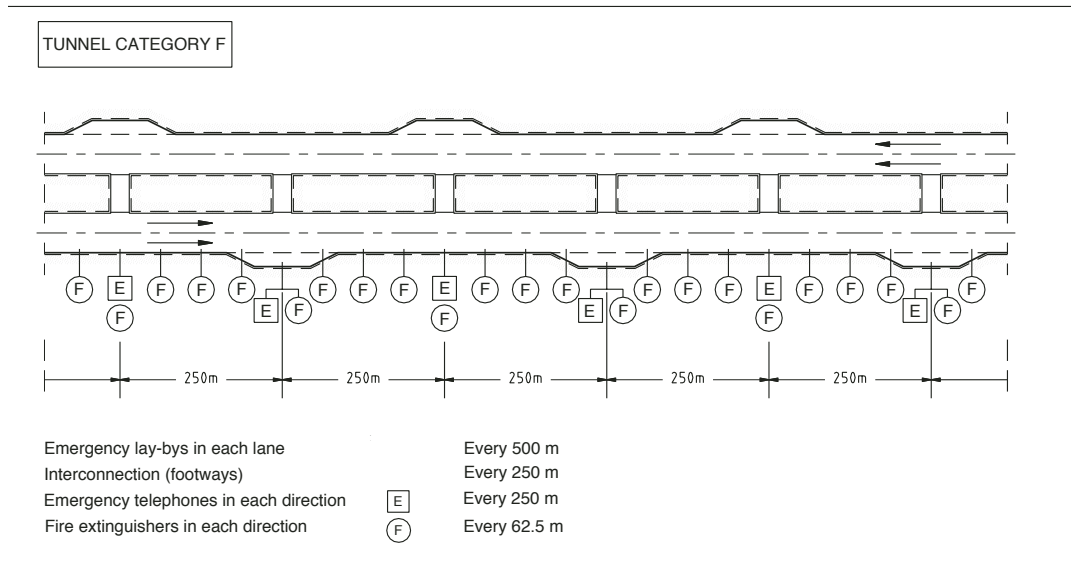


Figure 6.6 Lay-bys and equipment. Tunnel category F.

602.2 Equipment specifications for tunnel safety equipment

602.201 Emergency power supply

In order to ensure that road users are not handicapped by power failure the following equipment shall be connected to continuous power supply equipment (batteries or aggregate):

- Surveillance, control
- Flashing red stop signal
- Priority lighting See Section 1003.6
- Escape route lighting
- Emergency telephone
- Service signs
- Emergency Exit signs
- Communication and broadcasting equipment.

In addition, an evaluation should be made as to whether other equipment is to be connected to the emergency power supply for tunnel categories E and F.

The emergency power supply shall function for a minimum of one hour's duration with the designed load. In the event of an incident occurring in the tunnel the safety

equipment shall function in accordance with Section 1002.

If the emergency power supply is based on a central battery plant, these shall be placed within a special room.

In tunnel categories E and F the interconnections shall have emergency power supply from the sources for both tubes.

602.202 Emergency escape route lighting

Emergency escape route lighting is used to direct road users towards the exits in smoke-filled tunnels. The lights are automatically turned on when a fire extinguisher is removed or when the alarm is given from the fire control base. The lights are mounted 1.0 m above the carriageway, on one side at intervals of approx. 62.5 m. In curves the lights shall be placed such that the next one can be observed. The output shall be approx. 1800 lumen (Lm) and a colour temperature of approx 4000 degrees Kelvin (K). In twin-tube tunnels the escape route lights shall be located on the right hand side with the emergency



Figure 6.7 Emergency Exit sign.

exit sign indicating the interconnection placed above and vertical to the driving direction. The light fittings shall be of hardened glass.

602.203 Emergency Exit signs

Internally lit signs in green and white are used in interconnections and other emergency routes within the tunnel (Figure 6.7). These shall have a format of 400 x 400 mm and placed vertical to the driving directions.

602.204 Emergency telephone

The emergency telephone shall give a

dialling tone when lifted. The telephone shall be connected directly to a manned emergency operations room, preferably a traffic control centre. The telephones shall be mounted such that it is possible to see where the call is being made from. The telephones should be mounted in a dust-free kiosk with internal lighting. An example of the design of a niche for a kiosk with emergency telephone is shown in Figure 6.8. The door should be equipped with a panic release.

Directions for use of the telephone should be given in several languages. The following is an example:

Løft av røret og vent på svar

Hvis ingen svarer innen ett minutt,
legg på røret og prøv igjen.

*Lift the receiver, and wait for an
answer. If no one answers within the
first minute, hang up and try again.*

Hörer abnehmen, und Antwort abwar-
ten. Falls innerhalb einer Minute keine
Antwort kommt, Hörer auflegen und
erneut versuchen.

Décrochez et attendez. Si vous n'avez

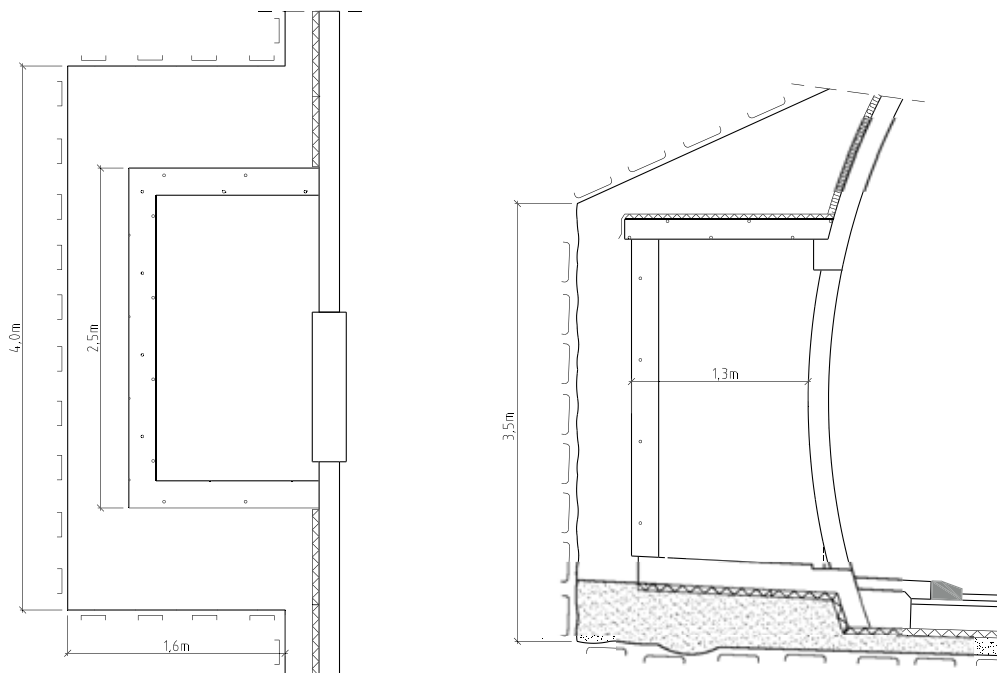


Figure 6.8 Example of plan for emergency telephone niche.

pas, de réponse au bout d'une minute, reposez le combiné, et répétez l'opération.

602.205 Fire extinguishers

Fire extinguishers should be a minimum of 6 kg ABC (NS EN3). The extinguishers should be mounted in separate boxes. These are marked with approved symbols. For tunnels in categories D and F, two extinguishers are mounted in each box.

The boxes shall be coloured orange code 80 and marked "Norwegian Public Roads Administration".

A signal shall be sent to the traffic control centre if a fire extinguisher is removed. A sign shall inform road users that removal of an extinguisher will automatically raise the alarm and closure of the tunnel. For tunnels in Category A the need for a signal to a traffic control centre shall be specially considered. In addition, the alarm is transmitted to the control centre when a box is opened.

Fire extinguishers are indicated with sign 606, see Section 414.3.

602.206 Water for fire extinguishing

Alternative solutions include:

- separate wells (approx. 6 m³) linked to the drainage system (See Section 805)
- tank vehicle with sufficient capacity (approx. 6 m³)
- reservoir in the dip

In special circumstances where high-pressure water is easily available, for example in urban tunnels, the transient water pipe may provide an alternative.

602.207 Flashing red stop signal

A flashing red stop signal is operated when the tunnel has to be closed to traffic, for example on account of high pollution levels, traffic accident, maintenance or for other particular reasons.

The flashing red stop signal shall have two horizontally placed red lamp holders,

if necessary placed against a black background. If the cause of the closure is not immediately clear the signal may be supplemented with a sub-sign (808).

Where closure in connection with maintenance occurs relatively frequently a variable sign may be used where both a flashing red stop signal and a blinking amber warning signal are mounted on the sign plate.

The flashing red stop signal may be located at three alternative places:

- in front of the tunnel portal (see Section 414.2)
- in turning points in the tunnel
- immediately after the place defined as a diversion route prior to the tunnel.

In certain circumstances it can be appropriate to erect signals at several of these alternatives.

The position of the flashing red stop signal is shown in Figure 4.23. When determining the location of the equipment consideration should also be made of the aesthetic design of the portal and the immediate surroundings.

The flashing red stop signal may be activated as follows:

- automatically with removal of a fire extinguisher
- automatically when poor air quality is detected
- remote control from traffic control centre
- locally through control panels on the equipment.

602.208 Remote-controlled barriers for tunnel closure

Experience shows that open manual barriers can conflict with the interpretation of closure with the flashing red stop signal. Remote-controlled barriers should thus be used only in combination with this signal.

The barrier should be long enough to ensure that the entry lane is blocked but such that it is possible to drive out of the tunnel. The need for remote-controlled barriers shall be considered on the basis of expected frequency of use. Remote-controlled barriers should also be able to be operated manually at the site. In tunnel category F, remote-controlled barriers are obligatory.

Remote-controlled barriers are used either to give a clear indication and rapid closure of the tunnel, or to provide safety directions to road users, as for example, along a two-lane single flow section temporarily regulated to contra-flow.

The need for remote-controlled barriers are evaluated as part of the automatic traffic control system (for example CCTV surveillance) for traffic redirection, or to undertake certain critical measures with regard to safety.

When the barriers are used for redirection purposes these are equipped with flashing amber warning signals or as alternating flashes between two single lamps, dependent upon the purpose of the signals.

Remote-controlled barriers may be of the raise/lower type or as horizontal swinging barriers. The latter are preferred on aesthetic grounds.

When remote-controlled barriers are used these shall be equipped with a control function to ensure that vehicles are not situated under the barrier when it is lowered, and that the operator is always aware of

the position of the barrier. The remote-controlled barrier should not be able to be operated unless sufficient advance warning has been given by the red light linked to the barrier.

602.209 Changeable signs and lane signals

Changeable signs can be operated using various technologies. The most common are mechanical-variable signs or diode-based signs.

With regard to uniformity in the design of road signs, mechanical-variable signs are used almost without exception for installations which indicate road directions.

The signs can be designed with permanent features or as freely programmable signs. The latter are mainly used on information sign boards. Messages can be programmed by an operator in the traffic control centre and immediately directed to the sign for local storage and/or display.

Lane signals are light signal displayed with symbols as in Figure 6.9: red diagonal cross; yellow diagonal arrow (left/right); and green vertical (downward) arrow.

Lane signals in tunnels are used to indicate exceptional use of lanes in one-way tunnels.

The signals may be used to close a lane in the event of an accident, to operate two-way traffic in the tunnel, or in connection with highway maintenance. Under normal

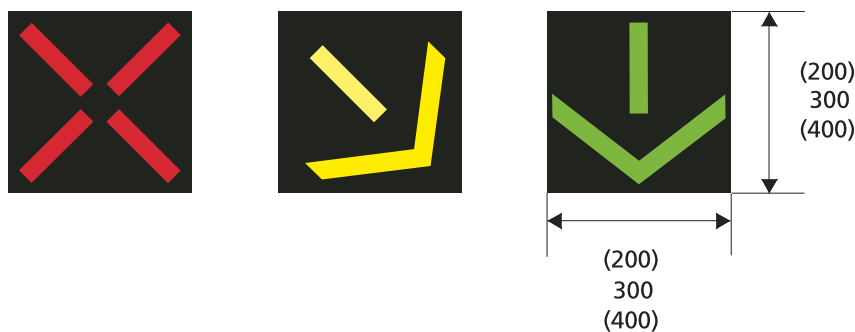


Figure 6.9 Lane signals (measurements in mm)

traffic conditions the signals will be off.

The signals are placed above each lane and inform the road user whether he/she may use that lane (green arrow) or not (red cross). The blinking yellow arrow indicates that the lane is closed ahead and that road users should move into the indicated lane at the first opportunity. (Details are given in Manual 048)

In tunnel tubes where the lane signals are used for contra flows, these are mounted “back to back” above each lane. The paired signals are coupled such that they cannot both show green simultaneously.

Traffic control equipment which involves lane signals must be approved by the Directorate of Public Roads.

602.210 CCTV surveillance

CCTV (Closed circuit television) surveillance is only applicable to tunnels with a high capacity usage throughout much of the day such that those incidents requiring traffic regulation measures may be immediately and efficiently recognised and where queues and possible incidents arise.

CCTV surveillance necessitates links to a traffic control centre.

Local CCTV surveillance can be relevant for areas of remote controlled barriers (see Section 602.208).

602.211 Height barriers

Height barriers are obligatory in all tunnel categories. These barriers are not required, however, where bridges or other constructions on the road network leading to the tunnel have the necessary constraining effect. Height barriers shall be solidly constructed such that any vehicle coming into contact with it will be aware of this.

602.3 Radio equipment

The Norwegian Public Roads Administration has the responsibility for installing radio equipment in new tunnels longer than 500 m. For tunnels shorter

than 500 m radio equipment shall be installed only after a special evaluation. An evaluation shall take into consideration the extent to which transmitters outside the tunnel will be effective inside the tunnel.

The radio equipment shall encompass communication and broadcasting facilities (see Sections 602.21 and 602.32). Radio equipment utilised shall satisfy the authorities' specifications and be approved for use in Norway. The equipment shall be installed in a purpose-designed room meeting temperature requirements, and if necessary, cooling equipment shall be installed.

The radio equipment must be capable of expansion to include several channels and for future transmission systems. The inclusion of additional channels/systems implies that the channel or system proprietor must cover the costs of establishment and lease space for the equipment from the Norwegian Public Roads Administration.

A cable antenna is used as sender. All radio signal cables utilized in the tunnel shall satisfy the requirements of cable class 3, see Chapter 10 “Technical equipment” (1001.4). The electro-technical requirements of cables have to be specified for the individual tunnel when designing the radio equipment.

Radio signal cable shall be installed at least 80 mm from associated metal constructions, such as cable bridges and other cables. The method of suspension must be determined when the decision has been made for other electrical installations and approved by the cable manufacturer.

In long tunnels several “amplifiers” must be linked together to form a “radio base” via fibre cables. When several tunnels are located close to each other a joint radio system may be constructed comprising a number of linked technical installations.

In order to establish a link to the exter-

nal radio station it is necessary to construct antenna in one or more masts outside the tunnel. The dimensions and number of masts will be dependent upon local circumstances and determined following measurements undertaken at the site. The costs of masts required by the Norwegian Public Roads Administration will be borne by this authority, but where, for example, mobile telephone operators wish to lease capacity for their antenna, this will be paid according to the main agreement.

602.31 Communication equipment

The Norwegian Public Roads Administration has the responsibility for installing and operating communication equipment necessary to ensure that each emergency service may operate their own system within the tunnel, including the joint dual frequency emergency channel.

Equipment must be installed such that the emergency services have the same coverage inside the tunnel as outside. The configuration for each tunnel shall be prepared and approved in conjunction with the local emergency service.

A corresponding responsibility also applies to the Norwegian Public Roads Administration's own communication system in those tunnels where it has been determined that this shall be installed.

The individual authorities are themselves responsible for use of their own radio channels in the tunnels in accordance with their concession. The Ministry of Justice is the licensing authority for dual frequency channels.

In the event of any of the emergency services undertaking a reconstruction or essential changes in their communications system outside tunnels which result in the equipment in the tunnels also requiring to be upgraded, any necessary reconstruction will be at expense of the relevant authority.

602.32 Broadcasting equipment with "interruption facilities"

The Norwegian Public Roads Administration has the responsibility for establishing and operating broadcasting equipment which is necessary to give coverage of the Norwegian Broadcasting Corporation channel NRK P1. The equipment shall provide satisfactory coverage through the entire tunnel and be installed with an "interruption facility" for transmission of traffic information.

For all other radio channels except NRK P1 the costs of installation and operation must be covered by the broadcasting company itself. An annual leasing charge shall be paid to the Norwegian Public Roads Administration for the space utilised by the equipment.

When planning radio services contact should be made with the individual radio station/local broadcasting services to clarify their interest in inclusion in the project.

All broadcasting channels which are incorporated into the system shall have the same "interruption facility" as for NRK P1.

602.33 Mobile telephones

The network operators for mobile telephones have the responsibility for planning, installing and operating mobile telephone equipment in road tunnels. The operator shall pay a proportion of the installation costs and leasing charges in accordance with the main agreement.

When planning new tunnels, cooperation must be entered into at the earliest possible opportunity with the network operators in order to clarify their requirements for space for equipment in telephone kiosks, masts, antenna in tunnels, cable ducts, cables and power.

The operators shall be given access to diagrams and technical drawings which are essential for their planning, and invited to necessary meetings both in the plan-

ning stage and following commencement of the project.

Specified work and any supplies made on behalf of the net operator by the Norwegian Public Roads Administration shall be invoiced when the supplies have been delivered.

Installation of mobile telephone equipment in older tunnels by the operator must be approved by the Norwegian Public Roads Administration before work is commenced. Costs of installation and leasing costs are paid according to the main contract.

603 Traffic control and incident detection

603.1 Means analysis

An analysis of the need for traffic control equipment other than the flashing red stop signal should be made at an early stage and as an integrated part of the geometric design of the tunnel and associated approach zones.

The principles of traffic control are an integral part of the preparation of emergency plans for the tunnel.

As a basis for determining the essential equipment for traffic control and incident detection, a means analysis is required to be carried out to clarify the following:

- traffic regulation procedures in the event of tunnel closure
- need for surveillance, regulation and warning systems with respect to traffic safety and optimum traffic flow in the tunnel

The means analysis is normally carried out on the basis of the following elements:

- expected frequency of traffic incidents (fire in automobiles, accidents involving persons, accidents with material damage and vehicle stops in emergency lay-bys, or in the traffic lane)
- extent of strategies for operations and maintenance in the tunnel

- environmental and safety aspects related to diversion routes for the tunnel
- capacity analyses.

On the basis of the above the frequency of use for the traffic regulating equipment may be estimated.

The need for automatic detection of traffic incidents is essentially based on the following:

- queue warning systems (for example) as a basis for the operation of locally directed traffic control systems
- ensuring the quickest recognition of incidents in the tunnel as a basis for implementing traffic control.

The means analysis shall include a cost-benefit analysis of the relevant traffic surveillance systems and traffic control concepts achieved through the use of various degrees of automation for technical installations (various levels of use of remote controlled barriers, lane signals and variable signs). The Directorate of Public Roads has developed a model for cost-benefit studies of different traffic control concepts for closure of tunnels with associated installation of redirection signs.

Planning of traffic control equipment shall be carried out as an umbrella process for the entire road system independently of an eventual division of the construction into sub-parcels.

A traffic control system for a tunnel will frequently require installations to be located outside the construction area. These installations along with associated supply and communication cables should be considered as part of the entire tunnel construction project.

The consequences for established traffic control units and/or operational units shall also be clarified during the planning process.

Table 6.2 *Programmed control implemented manually*

Traffic control measures	Relevant technical equipment	Aspects to be considered before installation
Decisive and rapid closure of tunnels	Remote controlled barriers	- Increased safety in tunnels with considerable traffic volume and/or particularly long tunnels - Reduced manning costs in the event of tunnel closure
Installation of redirection signs (relief roads)	Changeable signs (+ lane signals on multiple lane roads)	Requirements for road user services on the relevant roads regarding information, traffic flow and delays. Requirements for directions signs, e.g. lane instructions/diversions on multiple lane highways Reduced manning costs related to installation of redirection signs during tunnel closure
Closure of lanes (tunnel categories E and F)	Lane signals	Traffic safety, avoidance of chain collisions in tunnels Reduce need for tunnel closure Necessary part of maintenance warning system during works with traffic in the tunnel
Two-way traffic control system (tunnel categories E and F)	Lane signals Changeable signs Remote controlled barriers	Minimise use of redirection with consideration to the environment, driving and accident costs Requirements of services to road users regarding information and redirection Road works warning system which ensures complete tunnel closure
Warning of incidents within the tunnel	Changeable warning-/information signs before and inside the tunnel	Traffic safety, avoidance of chain collisions in tunnels Reduced need for tunnel closure
Information on cause and duration of tunnel closure	Variable information signs before the tunnel	Requirements for services to road users where redirection routes not found or where redirection signs are not desired

603.2 Main types of traffic control systems

Traffic control systems associated with tunnels may be operated in two ways:

- Pre-programmed measures which are operated manually by the operator in the control centre, or from control panels located at the site of the tunnel.

- Systems which automatically regulate traffic or warn road users directly as a result of detection measures of the traffic situation.

603.21 Pre-programmed measures

In tables 6.2 and 6.3 a list is given of those measures which are relevant to the use of

Table 6.3 Examples of automatic traffic control measures

Traffic control measures	Relevant traffic-technical equipment	Considerations to be made
Queue warning	Variable speed limits/warning signs/information signs	Increased traffic safety, primarily accidents from rear
Optimisation of traffic flow	Variable speed limits	Increased capacity Reduced driving costs Increased traffic safety
Tunnel approach control	Traffic lights at control points + advance warning of controls	- Prevention of queues in tunnels with regard to road users' subjective experience of tunnel queues Control of queue length in tunnel with regard to installed ventilation capacity
Warning of slow-moving vehicles	Variable information/warning signs before and inside tunnel	Traffic safety in tunnels with long and steep slopes

dirigible traffic-technical installations.

The traffic control programmes are remote-controlled from the control centre which is contacted prior to tenders. In addition, it shall always be possible to open and close the tunnel from manually operated control panels located at the tunnel entrance. The same control panels shall also be capable of controlling lighting and ventilation in the tunnel.

It is advisable that automatic traffic control systems are installed following a period of evaluation of the specific requirements, i.e. after the tunnel has been opened. In order that installation may then be carried out with minimum inconvenience to road users, allowances should be made in the construction phase for later installations as may be found to be required. This may involve extra cable ducts, reservation of space for future equipment, design of local equipment to take account of future increase in demand etc.

603.3 Detection of incidents – technical solutions

Detection systems can be placed into two categories: direct and indirect.

603.31 Indirect detection

A vehicle break-down is recognised when reduced traffic flow is detected in a section or a length of the tunnel. The detection systems based on indirect detection generally place few demands on equipment.

603.32 Direct detection

These systems are directed towards detecting an individual vehicle having stopped in the carriageway thus constituting a considerable danger. The systems are frequently based on video-technology and therefore require comprehensive coverage with cameras.

Incident detection systems can be based on different technologies, for example:

- inductive loops
- image interpretation systems
- infrared detectors

With consideration to traffic safety, it may be appropriate to install incident detectors in those instances where rapid detection of incidents is desirable such as a break down in the carriageway or irregular queues.

604 Warning of Road works

Similarly to the open road, advance warning of road works in a tunnel shall ensure the safety of workers while simultaneously preparing the road user for an unusual traffic situation which might affect normal traffic flow. It can often be difficult for a driver to judge the actual distance to other vehicles in the tunnel. Special demands are therefore made to warnings concerning re-direction of traffic. Warnings of road works shall thus be given in advance of the stretch where the works are in progress.

Routines must be prepared for the actual tunnel, adapted to the type of works in progress, the warning signs in the tunnel, traffic volume, redirection possibilities, etc. Procedures for warning, signposting and work procedures are described in Manual 051 and 213.

605 Fire protection

605.1 General

Regulations pertaining to fire protection in tunnels are stipulated in the Fire Protection Act of 1987 and the accompanying regulations. Recommendations are made in the regulations that tunnels longer than 500 m are classified as particular fire objects. The municipality/fire service may also determine that other tunnels are classified accordingly. Tunnels longer than 500 m on trunk roads must be considered as particular fire objects irrespective of formal municipal resolutions.

An emergency plan has to be prepared for all tunnels longer than 500 m. This must be prepared during the planning phase and in close cooperation with the local emergency services. Other tunnels in the vicinity should also be included when the emergency plan is prepared.

Consideration of a simplified emergency plan for shorter tunnels should be made in cooperation with the fire service.

The Ministry of Transport and Communications and the Ministry of Local Government and Regional Development have prepared guidelines for the administrative procedures concerning fire protection in road tunnels (July 2000). The guidelines outline cooperation between the Norwegian Public Roads Administration and the fire authorities, procedures for risk analyses, responsibility and cooperation in exercises, emergency plans and participation, and also state regulations for upgrading of existing tunnels. Similarly, the Directorate for Fire and Electrical Safety (DBE) has prepared a brochure on fire safety in road tunnels (May 1999).

605.2 Fire load: specifications for constructions and equipment

Tunnels shall be designed for a fire load of 5 MW when $AADT(10) < 10,000$, and 20 MW when $AADT(10) > 10,000$.

In tunnels where there is a risk of infrastructure damage resulting from a fire, the designed fire load must be particularly considered.

The specifications of cables which shall function during the event of fire are given in Chapter 10 "Technical equipment", Section 1001.4. Cable class 3, fire-proof cables, shall be used in all open ducts up to the location of the equipment which must be operational during a fire.

For equipment which shall function during a fire (lighting, ventilation, signal cables, etc.), these shall be installed/linked such that the tunnel is divided into sections.

For twin-tube tunnels, a firewall shall be established in all interconnections. All firewalls shall have a fire resistance of at least REI-M 120 as specified in the Planning and Building Act regulations. Doors in the fire wall shall have a fire resistance of EI-C 60. Doors into technical

rooms shall have a fire resistance of EI 60.

All doors in firewalls shall be designed as locks and shall be gas- and smoke-proof. Walls in the lock shall have the same specifications as the firewall.

606 Transport of hazardous goods

Regulations and conditions for transport of hazardous goods are regulated according to §18 in the Road Traffic Act. In the regulations the following special conditions and restrictions are specified:

§4-1. Concerning demands for transport on specified roads and in specified road tunnels, "Upon the recommendation of the responsible authority the Directorate of Public Roads can resolve that transport of hazardous substances has to be reported, and may also determine that transport of certain hazardous substances along specified roads and road tunnels shall be permitted subject to certain conditions or completely prohibited. The Directorate of Public Roads may delegate this responsibility to the appropriate road authority".

All normal tunnels with low traffic volume are normally open to transport of hazardous goods. For tunnels in urban areas,

sub-sea tunnels and in long concrete tunnels (immersed tunnels, tunnels directly under buildings etc.) special considerations should be made. The analysis shall include calculations and comparison of personal injuries and material damage in the tunnel and for alternative routes.

Hazardous goods are defined in the ADR Agreement (The European Agreement on International Road Transport of Hazardous Goods) and UN Agreement ECE/TRANS/60. Products which are included in the ADR Agreement are grouped into the following 9 main groups with sub-groups:

Class 1 – Explosive substances and objects

Class 2- Gases: condensed, liquid, or under pressure

Class 3 – Flammable liquids

Class 4.1 – Flammable solids

Class 4.3 – Self-combustible substances

Class 4.3 – Substances which react with water emitting flammable gases

Class 5.1 – Oxidizing (fire-intensifying) substances

Table 6.4 Primary effects following an accident involving hazardous goods

ADR class	Fire	Poisoning	Explosion	Other
1	X		X	
2	X	X	X	
3	X			
4	X			
5			X	
6		X		
7				X
8				X
9				X

Class 5.2 – Flammable organic peroxides

Class 6.1 – Toxic or harmful substances

Class 6.2 – Infectious substances

Class 7 – Radioactive material

Class 8 – Corrosive substances

Class 9 – Miscellaneous dangerous substances

As the risk for pedestrians, cyclists and third parties is generally less in the event of an accident inside the tunnel than outside, transport of hazardous goods shall be through tunnels in urban areas unless the risk analysis suggests otherwise.

Hazardous substances, which in the event of an accident, do not have greater consequences inside a tunnel than on an alternative route, shall be transported through tunnel in accordance with the regulations relating to transport on the alternative route.

Measures which can reduce the consequences, and to a certain extent the risk of an accident with hazardous goods, include restrictions on transport, escorting, surveillance/registration, water pipes, fire alarms and fire ventilation.

607 Emergency plans

In principle an emergency plan is an agreement between the tunnel's owner and the emergency services on shared responsibility and tasks in the event of an accident in the tunnel.

The emergency plan essentially comprises three parts:

- A description of the tunnel, equipment in the tunnel, redirection possibilities and available equipment
- A risk analysis
- A description of a number of important scenarios and the input plans for each of these with a clarification of the responsibilities of each of the emergency services.

The emergency plan shall be prepared dur-

ing the planning stage of the tunnel, and shall be revised according to need. It is important that the plan is simple to execute and that regular practice exercises are undertaken. A separate guide has been prepared to show the contents of the plan in detail.

It is a requirement that a risk analysis is undertaken for tunnels classified as special fire objects. A guide has been prepared to indicate how these analyses should be carried out. Risk analyses are also described in a number of other brochures (in Norwegian) prepared by the Directorate of Public Roads.

As part of the emergency plan restriction on transport of hazardous goods through the tunnel should be evaluated. Determination of restrictions is determined by the Directorate of Public Roads.

7 The Workface, support, water and frost protection

701 Cuttings and the tunnel entrance

The rock mass is generally of poorer quality at the tunnel entrance than in the tunnel itself. Zones of weakness in the vicinity of, or within the tunnel entrance area, must be given special attention.

Detailed design of the open cut and tunnel entrance with regard to the incline and direction will require that special attention is given to weaknesses in the rock face.

Rock blasting must be carried out so as to avoid destabilization of possible sliding planes which will result in unstable excavation.

A special blasting and support plan must be prepared for the tunnel entrance.

Normally, a complete cross-section with a full blast round is not used with the initial blasting of the tunnel entrance. As a rule, the depth of the first blast round are reduced until a stable entrance has been established. Alternatively, an initial pilot boring may be made, or a partial section of the cross-section prior to subsequent enlargement to the full cross-section.

Securing the entrance may include advanced pre-cautionary measures as well as traditional measures. These will often include fore-bolting, sprayed concrete and/or cast concrete.

In order to eliminate traffic danger resulting from rock falls, snow slides, ice blocks or similar, and to prevent water dripping from the tunnel entrance and onto the road surface, portals are constructed in the entrance. The portals extend to a sufficient distance so as to collect all rock and ice spoil.

In addition precautions must be made to ensure that the open cut leading to the portal has sufficient breadth with respect to possible spoil. See Manual 018.

It is important to ensure that the tunnel entrance and the portals have an aesthetic design. See Chapter 5.

If twin-tube tunnels are to be excavated, the minimum distance between these must be 10 m. An exception to this is the area in the vicinity of the entrance where the distance should be reduced and evaluated with consideration to stability, the extent of the open cuts and aesthetics.

702 Work face assignments

702.1 Exploratory drilling (probing ahead of tunnel face)

Exploratory drilling is carried out to obtain information on the rock quality, the rock cover and water-bearing zones ahead of tunnel face. On the basis of exploratory drilling a decision can be made regarding any special measures to be carried out such as further drilling, pre-grouting, bolting, reduced blast round depths, etc. Sufficient exploratory drilling must be undertaken to determine the extent of potential leakages. This is particularly important in the start phase when leakages are least known.

Exploratory drilling can be carried out as:

- percussive drilling at the workface
- core drilling.

Normally percussive drilling is used with the tunnel jumbo.

Core drilling is used in special circumstances where further information is required on the rock condition, for example in large weakness zones. Core drilling is then used as a supplement to percussive drilling and is carried out from the tunnel face.

In sub-sea tunnels systematic exploratory drilling shall be carried out below sea-level.

702.2 Pre-grouting

Pre-grouting are used in areas where water leakages can result in damage or problems with tunnel equipment, and/or where maximum leakage is specified in order to prevent environmental damage.

Based on data from the geological investigations, exploratory drilling, and leakage measurements, a hydrological evaluation is made of the rock mass ahead of the tunnel face. This provides the basis of a plan for pre-grouting. Other circumstances related to the need for pre-grouting are described in Section 305.2.

Planning and execution of pre-grouting require consideration of the following:

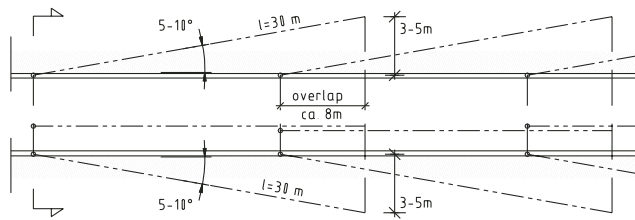
- It is important that the grouting fan is appropriate for local geological conditions
- Drilling of control holes shall not puncture the pre-grouted zone.
- Bolting is also carried out such that the pre-grouting zone is not penetrated or punctured.

- Blasting shall be carried out in a manner to ensure that the pre-grouted zone is not damaged
- The injection pressure and stop criteria must be determined
- Pre-grouting shall also be carried out at the tunnel face itself.
- For permanent water control, demands are placed upon the long-term durability of the pre-grouting material.

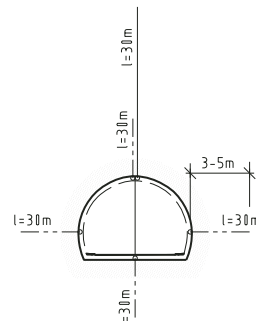
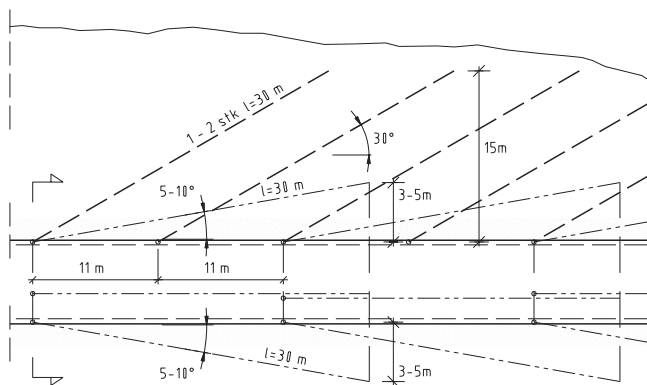
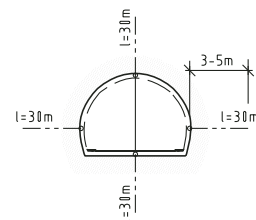
703 Support

703.1 General

The geological conditions encountered at each blast round shall be registered for the purposes of support and documentation of the geological conditions. The extent to which this is carried out will



Exploratory drilling



EXPLORATORY DRILLING (drillholes 30 m long, every 22 m)
CONTROL OF ROCK SURFACE (30° drillholes, 30 m long, every 11 m)

Figure 7.1 Example of exploratory drilling from the working face.

depend on the encountered geology.

If twin-tube tunnels are constructed, the distance between the workfaces shall be sufficient (for example 50 m) so that experiences from the one tunnel may be utilized in the other.

A distinction is made between temporary support measures and permanent support.

Temporary support that fulfils the technical specifications for permanent support measures are being incorporated into the permanent support design.

The method chosen for support will be dependent upon the nature of the rock. In addition importance is attached to water leakage, frost, methods used for water and frost protection and the tunnel standard in general.

For those parts of the tunnel where water and frost protection measures have been constructed the extent of the support must be seen in association with the strength of the construction.

Support measures carried out must be recorded to provide a documentation of the types of measures used, the extent, location and special circumstances registered.

703.2 Methods

The following methods are used for support, alone or in combination:

- scaling
- bolting
- strips and wire mesh
- sprayed concrete
- concreting
- pre-grouting
- spiling

Where bolts are applied in particularly corrosive conditions, and always in a salt-water zone in sub-sea tunnels, a combination of hot-dip galvanizing and coating powder with epoxy or corresponding anti-corrosion shall be used.

With consideration to longevity sprayed concrete less than 60 mm shall not be applied and with good control of accelerator additives.

Concreting shall be used on and behind the tunnel face to provide a permanent support in unstable areas and in zones of swelling clay. In areas with risk of uneven pressure load it may be necessary to cast the tunnel invert.

The need for reinforcement must be evaluated in each individual circumstance. Reinforcement can be necessary where lateral pressure may cause a problem, or to support the roof.

704 Requirements for equipment and emergency plans for sub-sea tunnelling.

Procedures and equipment are necessary to investigate the rock mass ahead of the tunnel face. Further, preparations have to be made to control water leakage and enable pre-grouting to be undertaken rapidly.

The pumps must have sufficient capacity to cope with major leaks.

It may also be necessary to have extra pumps and drain pipes in readiness. Further, an emergency power supply is normally required.

All equipment and material required to carry out pre-grouting work shall be available when the tunnel excavation commences.

When operating in the sub-sea part of the tunnel a shield should always be in preparedness for immediate action. This should be designed so as to facilitate closure of the tunnel face. The shield shall always be mounted and ready near the workface.

705 Frost penetration in tunnels

705.1 General

Frost protection is designed according to the amount of frost at the locality. In deter-

mining the design criteria, the frost level is usually based on F_{10} (h°C).

F_{10} is defined as the amount of frost which, statistically seen, is exceeded *once* every ten years.

Where it can be documented that the frost level is lower further into the tunnel the frost level F_{10T} (h°C) may be applied.

Local conditions may result in more frost than F_{10} as given for the municipality. The designed frost amount should therefore be based on local measurements.

The table showing frost levels in all municipalities in Norway is given in Appendix E.

705.2 Frost penetration

There are several reasons that frost may be able to penetrate tunnels. These may be summarized as follows:

- The main reason for the natural change of air in tunnels is the temperature difference where warm air is lighter than cold air, and when rising air is replaced by colder heavy air (chimney effect).
- In horizontal tunnels warm air will flow out through the openings and be compensated by cold air below at the road level. In short tunnels and during long cold periods, cold air will gradually penetrate the whole tunnel. The prevailing wind direction, mechanical ventilation and the piston effect of traffic will affect frost penetration.
- In twin-tube tunnels with a high volume of traffic and ventilation in the direction of traffic, ventilation and the piston effect will be predominant. Frost will penetrate a long way in the direction of the traffic but virtually no frost will penetrate the exit end. Frost penetration in these tunnels is scarcely affected by the chimney effect. A corresponding frost profile also exists in twin-tube sub-sea tunnels.
- Sub-sea tunnels are very largely affect

ed by local climatic conditions. Most are located in areas with little frost, but frost may penetrate locally. A certain control over this may be provided with the aid of ventilation equipment.

- Some long tunnels can be located on a climate divide. Frost penetration in these tunnels may vary from the normal picture, for example, through the effect of high/low pressure.
- In tunnels with an asymmetric frost profile (in long tunnels with a gradient and in one-way tunnels with a high traffic volume) it is seldom that frost penetrates more than 200–300 m from the upper entrance or exit.

Uncertainty around frost penetration is so considerable that all tunnels up to 500 m shall be designed according to the external frost conditions defined as F_{10} .

In longer tunnels frost penetration must be evaluated individually. Local conditions combined with experience from similar tunnels form the basis of this evaluation. Where possible, measurements should be made of draughts in the tunnel.

706 Water and frost protection methods

706.1 General

Road tunnels must be especially protected against water and ice. This is normally done by erecting a lining which directs water down into a trench. If the frost exceeds given limits the lining is carried out as an insulated construction. The actual constructions require a life-expectancy of 50 years assuming normal maintenance. The types of construction, functional requirements and design are given in Manual 163 “Water and Frost-Protection in tunnels”.(in Norwegian).

Constructions of new design require prior approval by the Directorate of Public Roads. This also applies to modifications of previously approved solutions.

706.2 Choice of construction

The choice of frost protection system is based on traffic volume (tunnel category), driving speed, tunnel length, standard of the tunnel, aesthetics, frost level, maintenance requirements and economics. In addition consideration must be made of local circumstances.

For tunnels in categories E and F, the lining shall include continuous concrete wall elements. These elements normally extend to 3.5 m above the road surface.

For tunnels in categories C and D the entrance zones shall comprise concrete wall elements.

The length of the entrance zone must be seen in connection with the lighting zones. Concrete wall elements shall be used at least as far as transition zone I (see Table 10.3). If sprayed concrete is used for the remaining stretches this should be surface treated so as to give increased durability, simpler maintenance and improved safety and driving comfort.

Other alternative solutions to concrete elements can also be considered in connection with approval of construction types.

For tunnels in categories A and B with sprayed concrete down to the road level, the extent of surface treatment must be evaluated in the light of local conditions, but shall at least comprise the entrance zone.

Surface treatment by sprayed concrete shall extend at least 1.5 m above the road surface.

For light steel and aluminium constructions these may only exceptionally be used in those zones which are most exposed to an corrosive environment. This applies to the entrance zones and the lower part of wall surfaces. Detailed regulations are determined according to the approved construction.

707 Frost protection with the aid of thermal doors

Thermal doors shall be placed at least 150 m inside the tunnel measured from the portal opening. In addition, their location must take into consideration rock conditions and leakages. As a rule a single door will be sufficient. Particular pressure loads and/or the need to limit particular frost penetration can give rise to the need for two doors.

For new tunnels the door frames shall be constructed from concrete. In the vicinity of the door the excavation cross-section will require to be extended.

The following specifications apply to clearance:

- Breadth dependent upon tunnel category. The minimum permitted breadth is the road width plus 0.25 m on either side
- The minimum free height is 4.7 m
- When open, the door shall be protected by the frame.

Normally, access will also be available through a ordinary door. On account of the pressure load which may build up this must be designed as a lock with a double door.

The lock can be utilized as a technical room for a switch box and other technical equipment in connection with the thermal door function.

The thermal door area shall be protected against collision by a guard rail. The guard rail shall be extended parallel to the roadway for a minimum of 8 m before the door, thereafter turning outwards to the side at an angle of 1:10.

The thermal door with fixtures and machinery shall be designed for the constant wind load that can be expected.

The extent of the wind load must be evaluated in each individual case. This will depend upon the wind speed in the tunnel and the draughts in the doorway

when closing. Wind load is defined as a variable load.

Thermal doors must be designed for the following static wind load including the structural factor:

$$p_v = 1.0 \text{ kN/m}^2$$

The load works in both directions on the door.

Thermal doors are controlled by magnetic circuits in the road and shall normally have the following equipment in addition to the motors and switch box:

- Detection system which ensures that the door is open when the vehicle approaches
- Photocells which prevent closure if the vehicle stops in the opening
- Possibility for control based on pollution levels
- Possibility for control based on temperature detectors
- Battery-operated DC motor for automatic opening in the event of power failure
- Capstan for manual operation
- Lighting.

708 Portals

The portals are constructed with cast concrete, alternatively in pre-fabricated concrete elements thereby comprising an in-situ concrete part and a concrete element.

The length of the portal is dependent upon local circumstances. This shall extend sufficiently to protect the roadway from rock falls and earth slides, and to protect the entrance from snow and ice accumulation. The portal should extend 1 – 2 m beyond the filling. The portal should terminate with a vertical collar of not less than 300 mm.

With consideration to traffic safety particular attention should be given to water protection.

The aesthetic design is discussed in

Chapter 5.

The waterproofing construction of the portal itself is essentially taken care of as follows:

- The in-situ cast concrete shall be laid onto a membrane which extends down to the trench
- An external membrane is used on the concrete elements
- In the event of risk for rock fall etc. onto the portal, the need for a protective cushion shall be evaluated in each case
- Injection tubes are to be placed within in-situ concrete joints.

Further details are given in Manual 163 “Water and frost protection in tunnels”.

The portal is designed such that it will avert accidents. Normally the portal should terminate such that guard rails are not necessary

A portal is not necessary where local conditions are particularly favourable.

See also Section 502 “The tunnel approach zone”.

8 Drainage

801 General

Water leakages in the tunnel shall be drained without exposure to frost out of the tunnel via the drainage system. Leakages in the walls and crown are collected by mounting a lining which directs the water to the drainage trench.

Water leakages in the tunnel invert are just as normal as leakages on the walls and crown and are collected via a filter above the formation level.

In addition to the drainage system for leakages, a separate system is constructed for collecting flushing water from tunnel cleaning. This system for collection of flushing water may be lead to a magasin outside the tunnel.

802 The Drainage system

When the tunnel is completed, the locations of wet and dry stretches and the accumulated water volume will be mapped. It is now possible to make the final design of the drainage system.

When designing the drainage system the following circumstances, among others, shall be taken into consideration:

- expected leakage
- possible changes in leakage over time
- catchment area and precipitation in the approach zones
- particular evaluations of problems with low gradients, silting and/or fouling in the drain pipes
- need for reserve storage in connection with the low point in the tunnel
- need for auxiliary trenches in wet areas (see Figure 8.2).

The internal diameter of drain pipes in the main trenches shall not be less than 150 mm, and 100 mm in auxiliary trenches. In addition to the drain pipes it may be necessary to use a separate pipe for transporting drainage water. This is used when the pipe from that place in the tunnel where the combined leakage results in 50% or more of the drainage capacity is utilized. A

separate transport pipe should also be considered for long stretches with a shallow gradient where there is a danger of sedimentation in the drain pipe. As an alternative increasing the dimension of the drain pipe can be considered so as to limit the extent of a separate drainage system.

The drainage system in sub-sea tunnels is exposed to risk of becoming clogged. The system should therefore have a redundant capacity of 50% or more in relation to the designed capacity in tunnels which are not sub-sea tunnels. If the gradient is under 1:100, the capacity should be doubled.

The distance between the man-holes along the same pipe ought not to exceed 80 m.

In tunnels with limited traffic and open shoulders, the need for man-holes and distances between them should be specially evaluated.

The main rule is that the drainage system is completed after the tunnel has come into operation to avoid blockage by sediment. If the drainage system has to be constructed during tunnelling, consideration must be made for unexpected increase in leakage amounts and dangers for silting. In this case a temporary drain pipe should be used for drainage from operations and leakages.

803 Drainage trench

The theoretical excavation cross-section for the base of the drainage trench is defined as the drainpipe fundament. The thickness of the fundament shall be minimum 150 mm below the base of the pipe such that it is at least 100 mm under the sleeve. The breadth of the fundament shall be at least 1.5 times that of the nominal diameter of the pipe, or at least the equivalent of the outside diameter of the pipe plus 200 mm, whichever is the greater.

The trench is placed at a sufficient

Table 8.1 Requirements for minimum distance from the completed road surface to the drain pipe fundament without frost insulation

Frost level F_{10T} in tunnel (h°C)	Minimum distance from completed road surface to drainage pipe fundament (m)	Comments
< 6 000	-	No requirements for frost protection
6 000 - 10 000	1.0	
10 000 - 15 000	1.5	
> 15 000	-	Trench always frost protected

distance from the tunnel wall such that water and frost protection measures can be undertaken outside the trench at the level of the tunnel fundament.

In the event of frost level (F_{10T}) in the tunnel exceeding 6000 h°C, the drainage system shall be protected against frost with insulation or with a sufficiently deep trench. The requirements for the minimum trench depth are given in Table 8.1.

Where the sub-base is insulated (see Chapter 9), protection against frost is ensured by extending the road insulation over the trench and in contact with any construction for water and frost protection of the walls or vaults. Special consideration must be given to the risk of frost in the transition zone between the trench and the construction for water/frost protection.

Where there is a risk of considerable leakage, it may be expedient to construct trenches on both sides of the tunnel.

Frost protection of trenches with insulation boards shall be done using extruded polystyrene (XPS) with a short-duration compressive strength minimum 500 kPa (as documented in Manual 014). The thickness of the boards shall be at least 50 mm. These shall be placed as deep as possible in the trench.

Specifications for compression must be determined such that the boards are not overloaded.

Requirements of screen coating material in contact with the insulation boards are given in Section 904.2.

Figure 8.2 illustrates the principles of an insulated fundament and drainage system in a tunnel. At the base of a leakage zone a crosstrench shall be constructed to prevent water in the fundament spreading to the dry zones.

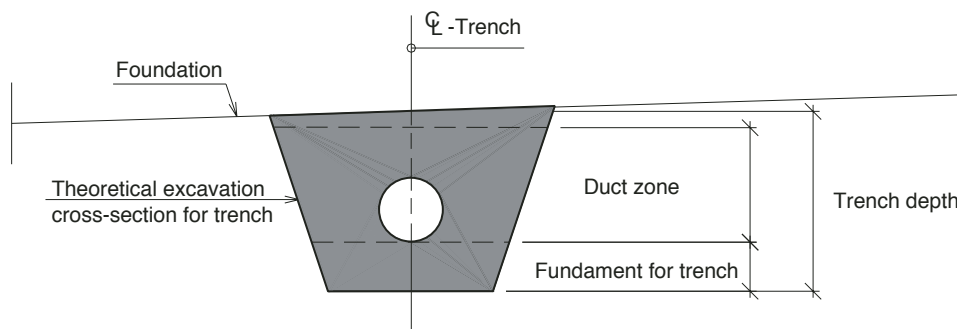


Figure 8.1 Specifications for drainage trench depth. Schematic diagram

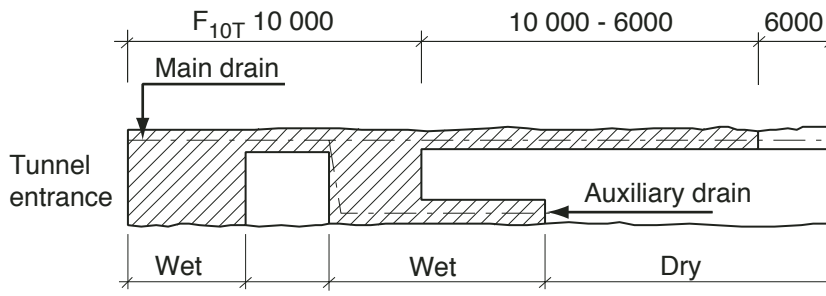


Figure 8.2 Principles for frost protection using insulation. The hatched area shows the area with frost protection measures at the base level.

804 System for accumulation of wash-water

Sand traps shall be installed at intervals, maximum 80 m, along the drain pipes for amassing washwater from tunnel cleaning. The sand traps should preferably be placed halfway between the inspection man-holes along the drain pipe.

The sand traps shall have a solid base and should be able to tolerate a sediment volume of at least 0.6 m^3 . The distance from the base to the lower edge of the discharge pipe should be at least 0.75 m.

In tunnels with kerbstones, a drain should be installed to direct the water into the sand traps. The drain shall be of a type that can be integrated with the shoulder/kerb stone and which take into account the space required for ducts which shall convey pipes past the drain.

The dimension of pipes used for draining washwater shall be at least $D = 150\text{ mm}$.

In general the tunnel shall be flushed/washed so often that special measures are not required to amass the water outside the tunnel. (See Chapter 3 "Consideration of the local environment").

805 Water reserves for fire emergencies

The drainage system may be supplemented with separate storage tanks for fire extinguishing (see Section 602.206). This

necessitates a closed system for collecting washwater. The washwater pipes will then accumulate inflammable liquids and direct these elsewhere than to fire-extinguishing storage tanks. The tanks should be located in an emergency lay-by. The system must be discussed with the local fire authorities. The tanks may also be filled for use as supplementary water source for washing the tunnel.

806 Pumping stations, pumping system

Strong demands are made for operational reliability and material quality. The pumping equipment will normally comprise a pump system and pump reservoir. In addition a separator for sediment and oil separator will be included. Normally, drainage water will be directed via a sediment filter while washwater will be directed to the oil separator. The size of the pump reservoir will be determined by the local circumstances and the general level of safety and preparedness chosen.

In sub-sea tunnels the pump reservoir shall not be less than that corresponding to 24 hour steady leakage. The electrical installations should be placed as high as possible such that the pumps will not fail in the event of the reservoir capacity being exceeded. A reserve pump line is recommended with a view to safety.

Regarding the actual pump installation, consideration shall be given to changes in the leakage levels over time. It

may be necessary to make reservations for an increase in pump capacity. As a rule the pumps are designed with a 50% reserve capacity.

In order to reduce the maximum power requirements of the tunnel, this should take into consideration when the pumps are planned to be in operation. It must also be seen with regard to fluctuations in the price of energy throughout the day.

Strong demands are made on the durability of the pumps and pump piping. The

quality of the material shall be related to water quality, salinity, demands of endurance etc.

Pump piping should be constructed in plastic as long as this meets the requirements of the pressure load class. Present experience suggests that brass alloy should be used for pumping salt or brackish water. In the pump station, where there is access to piping and pipe parts, the pump piping shall be mounted with flanges thereby facilitating replacement.

9 Sub-base and pavement

901 General

The choice of construction of the sub-base determines the thickness of the combined road surface materials and thereby the theoretical level for the excavation cross-section (the formation level). The choice of material and construction will thus incorporate a technical/economic appraisal where all circumstances affecting the formation level are included. In addition to the sub-base, this also applies to the following:

- Costs of excavation and removal
- Need for frost protection
- Consequences for trench depth and installation of drainage system
- Consequences for conduits, size of manholes etc.
- Foundation for the selected construction method for water and frost protection.

The need for frost protection must be evaluated in each case. The tunnel invert shall be protected against frost where the frost level (F_{10T}) in the tunnel exceeds $1000 \text{ h}^\circ\text{C}$. Where it can be shown that there are dry stretches in the tunnel, frost protection is not required along these stretches. Frost penetration in tunnels in general is discussed in Chapter 7, Section 705. Based on the requirements determining vertical clearance, the tolerance levels for thickness and evenness of the various layers in the sub-base and pavement shall be checked to ensure that these conform individually and in total.

The general requirements are given in Manual 018 "Road construction".

902 The formation level

Theoretical excavated cross-section shall be set at a level which allows sufficient space for the selected pavement (see Section 903). The formation level shall thus correspond with this theoretical cross-section. In practice the construction of the formation level will require both

excavation of material and filling, then levelling. The formation level shall have a uniform slope of at least 3% .

It is assumed that the remaining material has sufficient load bearing capacity. If the load bearing capacity under this level is not sufficient, then the material must be removed down to that depth which ensures sufficient load bearing capacity.

903 Pavement without frost protection

An example of non-insulated pavement is illustrated in Figure 9.1. Using Cg as a upper base course, only one filter layer of 100 mm is laid. (See Manual 018 for thickness of the Cg-layer).

903.1 Lower base course

The lower base course in the tunnels shall comprise open and well-graded materials such that the course also acts as a filter in the invert. The lower base course comprises crushed stone or chippings with a minimum thickness of 250 mm.

The mixture shall contain a maximum of 15% material $< 2 \text{ mm}$. Otherwise the material requirements are as specified in Manual 018. Examples of grading which can be appropriate are 0-64, 10-100, 1-120, 20-120 and 0-150 mm.

The lower base course is levelled with crushed rock (Fk) or bituminous mass (for example Gja, Eg, Sg, etc. as specified in

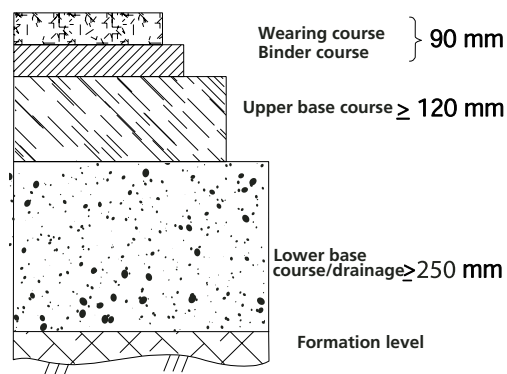


Figure 9.1 Example of pavement in a tunnel without requirements for frost protection

Manual 018). Gravel grading and quantity is adjusted such that the lower base course is “saturated” and keyed on the top surface.

903.2 Upper base course, binder and wearing course

In general the upper base course and surface layer are constructed as described in Manual 018. Where the upper base course comprises cement-stabilised gravel (Cg), special demands are made (see Section 904.2).

904 Frost protected pavement

Frost protection of the pavement is achieved either by constructing a frost protection layer or by using insulation material according to the principle shown in Figure 9.2.

In areas experiencing heavy frost, special attention should be given to frost protection at the entrance of the tunnel.

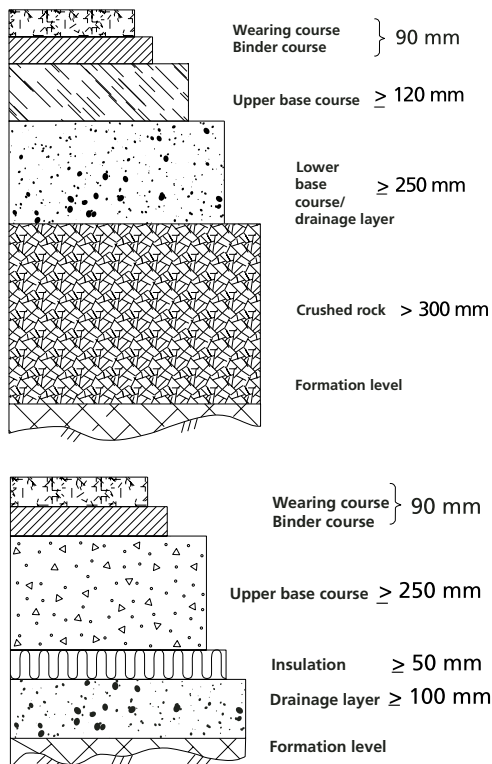


Figure 9.2 Example of frost-protected pavement, with a frost protection layer(a), or insulating material (b).

Where a frost-protected pavement is constructed the transition to the open road should also be protected to avoid icing.

904.1 The frost protection layer

The frost protection layer is constructed by lowering the formation level which is then filled with crushed stone as specified in Manual 018 up to the base of the lower base course. The pavement is otherwise designed as for frost-free construction (see Section 903).

904.2 Insulation materials and cement-stabilised gravel (Cg)

The construction of the pavement using insulation sheets and cement-stabilised gravel (Cg) follows the principles shown in Figure 9.2b.

A drainage layer is placed on top of the formation level and has a minimum thickness of 100 mm. Material is used which simultaneously assists drainage and is graded, for example 0–20 mm or 0–32 mm. Sorted material should contain a maximum of 15% < 2 mm.

The same demands for evenness apply as to the surface of the upper base course.

Insulating boards for frost protection shall be made of extruded polystyrene (XPS) with flanges, minimum thickness 50 mm, with a short-duration compressive strength of minimum 700 kPa documented by tests as given in Manual 015 and NS-EN 826. Other insulation materials must be specially approved by the Directorate of Public Roads.

The thickness of the Cg-layer above the insulation boards shall have a thickness of at least 250 mm and be placed in a single layer. Until the Cg layer has set no traffic is allowed on the mass other than that required for the layer construction. The composition of the materials in the Cg must be especially considered in order to achieve a satisfactory compressive strength and compression. Use of machine

sand is a possible alternative to natural sand. The compression of the Cg must not damage the insulation boards.

The compressive strength for Cg shall be a minimum of 15 MPa under testing using standard NS 3420 I6-1999.

Newly-laid Cg is very sensitive to damage by water droplets from the roof. Free-flowing water on the surface can also result in adhesion problems between the Cg-layer and the overlying asphalt layer. If the Cg is laid prior to the lining for water and frost protection, the Cg-layer must be protected against water leakage/drips using another method.

During the initial period after the Cg has been laid (1–2 weeks) it is particularly important to maintain the dampness in the Cg-layer with regard to solidification. The need for solidification measures must be considered in the light of dampness conditions and the air speed (draught) in the tunnel.

Combining solidification measures with tacking (sealing) may be considered. In this case the sealing compound is applied as soon as possible after the Cg has been laid in order to conserve dampness during solidification. With this solution the initial asphalt layer must be laid immediately.

Emulsified polymer-modified bitumen PmBE shall be used in association with the bonding of the Cg and the above bitumen layer.

The bonding shall be carried out at the as near as possible to the time when the surface layer construction takes place. With regard to the degradation of the emulsion, the bonding should remain for a minimum of 2 days prior to the bitumen being applied. The Cg-layer must not be subjected to traffic after the bonding has been applied as may severely damage the bonding layer.

The Cg surface must not contain any loss sand or similar when the bonding process is carried out. Otherwise this must

be removed by sweeping or hosing down.

When the bonding is applied the surface should preferably be dry although a slightly damp surface is acceptable. The bonding is very easily damaged by water drops from the roof. Measures must be taken to cover these areas.

The bonding process is carried out twice using 0.3–0.4 l/m² (emulsion) on each occasion and 2–3 kg/m² dry sand (0–4 mm) is applied after each bonding. Any surplus is brushed away. This is applied during both the first and second times that the bonding is applied.

The composition and structure of the Cg surface can vary somewhat. A trial section should thus be laid in order to determine the appropriate quantity of emulsion and sand. The adhesion between the bonding and the Cg-layer should also be tested on this section.

904.3 Binder course and wearing course

These are determined following the guidelines in Manual 018.

10 Technical Equipment

1001 Specifications for technical equipment

1001.1 General requirements for electrical equipment

All equipment shall be CE approved. In addition, the manufacturer or their agent shall confirm that the equipment conforms with the specified requirements

The lifespan must be evaluated for each individual component based on estimates of approximate lifespan costs. The following table shows the recommended lifespan for a number of electrical components based on previous experience.

Upon completion of the tunnel a reserve cable duct shall be available for future use.

1001.2 Protection against corrosion of technical equipment

The atmosphere in the tunnel is corrosive. This is due to condensation arising from warm, damp air. The water may be weakly acid due to nitrous acid and nitric acid from the nitrous gases in the exhaust. The

Table 10.1 Recommended lifespan for selected electrical components

Installation	Recommended min. lifespan [years]
Transformers	30
Emergency power aggregates	20
Battery bank-lead	8
Battery bank-Ni-Cd	10
Power cables	40
Cable ducts	40
Light fittings	20
Ventilation-motor/fan	20
CCT cameras	15
Radio cables	15
Light signals	15

equipment must therefore be protected from corrosion or be constructed from corrosion-resistant materials such that the minimum recommended lifespan is achieved.

In tunnel categories C, D, E and F, together with tunnels characterised by a particularly corrosive environment, (for example sub-sea tunnels), cable duct bridges and light fittings must be supplied in stainless steel.

1001.3 Degree of armouring

All equipment in the trafficked area shall have an armouring for protection against dust according to standard IP6x. The exception to this is for motors on the ventilators where the standard requirements are IP5x.

Protection against water leakages shall have an armour protection, minimum IPx5.

The level of armouring for selected equipment is:

- Fan motors IP 55
- Electric cabinets, emergency lighting, and internally illuminated signs IP 66
- Light fittings IP 65, nipples on light fittings IP 66
- Junction boxes and nipples in the tunnel room IP 66
- Junction boxes and nipples in the shoulder and pavement IP 68.

1001.4 Cables

Cables which are to be used in tunnels are classified according to their requirements. EX cables shall not be used.

For open ducts a distinction is made between cables which supply power to equipment which shall function in a fire situation (Cable class 3), and cables for non-critical equipment (Cable class 2). The individual cables shall be clearly marked so as to distinguish between the classes. For Cable class 3, colour coding should also be specified.

Cable class 1

This applies to cables which contain halogen. The cables are laid in a trench or in pipelines laid into a trench, alternatively together with cables required to be contained in fire-proof casings.

Cable class 2

This applies to non-critical equipment in open ducts. The cables shall be halogen-free and satisfy the requirements of the following standards:

- Flame-resistant
IEC 69332-1
- Fire escalation along ducts
IEC 60332-3
- Smoke development
IEC 60134-2
- Corrosive exhaust gases
IEC 60332-3

Cable class 3, Fire-proof cables

This applies to cables which shall function in a fire situation. In addition to the requirements of Cable class 2, these shall satisfy the demands of reliability according to standard IEC 60331-21. This implies that cables in Class 3 shall function for a period of 90 minutes in a flame temperature of 750°C.

1001.5 Technical rooms

The room where the control panel is situated and other rooms with technical equipment shall have an operating temperature related to the requirements of the installed equipment. If cooling plant is installed to maintain the required temperature, an automatic warning system shall be installed to warn of any failure of the plant.

1002 Power supply

Where possible, the power supply shall be fed independently from both tunnel entrances, but linked as a ring main.

1003 Lighting**1003.1 General**

Road tunnels longer than 100 m shall have lighting.

The need for lighting in tunnels shorter than 100 m must be evaluated with consideration to low sunlight, risk of dazzle, reflections from walls, etc.

Light walls and linings in the tunnel can reduce the need for lighting, assuming regular cleaning. A white light gives good colour reproduction and better contrast, and should therefore be generally chosen. High pressure sodium lighting is used in the entry and transitional zones.

1003.2 Lighting in the tunnel approach – adaptation luminance

Adaptation luminance, L [cd/m²] outside the tunnel is determinant for the luminance level inside the tunnel. The adaptation luminance which will be used in determining the tunnel lighting is defined as the mean luminance in a field of vision with an angle of 20 degrees from the driver's eyes directed towards a point 1.5 m above the road surface and at a distance as given in Table 10.2.

For economic reasons adaptation luminance shall not exceed 8000 cd/m², but neither shall it be less than 1000 cd/m². When an illuminated tunnel forms part of a non-illuminated road, the transition zone shall satisfy the requirements which apply to road lighting outside the tunnel. (See Manual 017).

The level of luminance to which the driver is adapted when entering the tunnel determines the level of luminance for the entry zone such that this takes into consideration the safety of the driver.

Various types of construction such as fencing, vegetation, choice of material and colour, may reduce the need for lighting and generally improve safety within the entry zone.

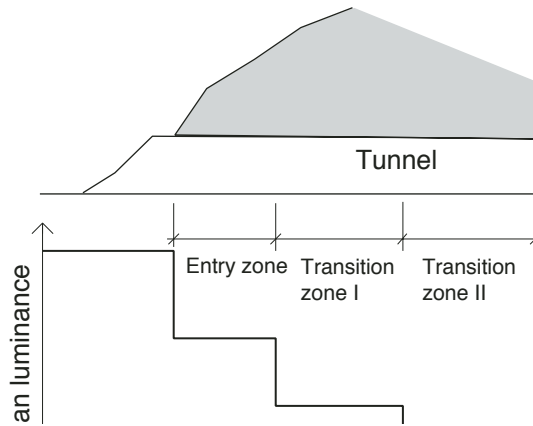


Figure 10.1 Schematic diagram showing progressive illumination zones in tunnels.

1003.3 Lighting in the tunnel
1003.31 Lighting level (luminance) in the tunnel. Zone demarcation

Technically, a tunnel is divided into an entry zone, a transition zone and an inner zone (Figure 10.1).

The adaptation of the eye is subject to a time delay. The gradual reduction in luminance has as its aim that of assisting the adaptation of the eyes and as such is dependent upon the driving speed.

Table 10.3 shows the length of the entry zone and transition zone as a function of speed.

Table 10.4 gives the requirements of the lowest mean luminance level of the various lighting zones as a function of traffic volume defined as AADT(10) and the speed limit in the tunnel.

For twin-tube tunnels, the value of AADT(10) shall be used for each tunnel.

Table 10.3 Length of entry and transition zones

Speed limit (km/h)	Entry zone length (m)	Transition zone length (m)	
		I	II
50	40	70	70
60	50	80	80
70	60	100	100
80	70	110	110
90	75	120	120

Table 10.2 Distance from tunnel entrance to monitoring point for adaptation luminance

Speed limit (km/h)	Distance (m)
50	45
60	60
70	80
80	100
90	130

The requirements are stated as the lowest mean luminance during the day expressed as a percentage of the adaptation luminance in each zone, or as cd/m^2 .

Comments to Table 10.4:

- The luminance requirements for other speeds are determined by extrapolation/interpolation
- The luminance level shall apply to the full length of each zone
- The calculated mean luminance values shall be the operation values (equivalent to 75% of the new value)
- Between the entry zone and the transition zone I, the transition shall be supplemented with extra light fittings when the mean luminance in the entry zone is $>250 cd/m^2$ (2–6 400 W Na-H fittings will normally be sufficient)

Tabell 10.4 Requirements for luminance in the various lighting zones expressed as the lowest mean during the day as a percentage of the adaptation luminance or as cd/m^2

Zone	AADT (10)	2 500 - 5 000		5 000 - 7 500		> 7 500
	Speed limit	-	50 km/h	80 km/h	50 km/h	80 km/h
Entry zone	50 cd/m^2	1.50 %	3.00 %	2.5 %	5.0 %	5.0 %
Transition zone I	10 cd/m^2	0.30 %	0.60 %	0.5 %	1.0 %	1.0 %
Transition zone II	2 cd/m^2	0.06 %	0.12 %	0.1 %	0.2 %	0.2 %
Inner zone day	0.5 cd/m^2	2 cd/m^2	2 cd/m^2	2 cd/m^2	2 cd/m^2	4 cd/m^2
Inner zone night	0.5 cd/m^2	1 cd/m^2	1 cd/m^2	1 cd/m^2	1 cd/m^2	2 cd/m^2

- Where the ratio of the lighting level in transition zone II to the inner zone is greater than 5:1, an extra transition zone III of same length as transition zone II shall be defined
- The inner zone shall have two levels: day and night
- In tunnel categories D, E and F, it may be practical to increase the luminance level to 6 cd/m^2 (day) / 3 cd/m^2 (night) where the traffic situation is particularly demanding, for example with several entry slip roads and stretches where lane changing is frequent.

Requirements for a stable luminance level

In the transition and inner zones the total luminance stability is given by:

$$U_o = \frac{L_{\min}}{L_{\text{mid}}} \approx 0.4$$

For transition zones and inner zones the luminance level throughout shall be:

$$U_l = \frac{L_{\min}}{L_{\max}} \approx 0.6$$

The demands do not apply to tunnels where $\text{AADT}(10) < 2500$.

In tunnels where cyclists and pedestrians are permitted, the minimum luminance level is 2 cd/m^2

Calculations are made in accordance with the most recent publications on tunnel lighting issued by CIE (the International Commission on Illumination).

Light distribution shall be such that tunnel walls are illuminated for approx. 1.5 m above the carriageway.

1003.32 Lighting in lay-bys

Emergency lay-bys and turning points require special illumination to distinguish these from the rest of the tunnel.

1003.4 Distance between light fittings

An unfavourable combination of driving speed and distance between light fittings may result in a flickering effect for the driver. For short zones this will not result in any problem, but in very long tunnels this may be very uncomfortable. In order to avoid the flickering effect, a distance between light fittings where driving speed is equivalent to a frequency in the interval range 2.5 to 15 Hz should be avoided.

For lighting zones where the driving time is less than 2 minutes, the flickering effect can be ignored.

1003.5 Light fittings

The light fittings shall be easily maintained and where the light tubes/bulbs may be easily replaced. Optical parts (reflector, glass) should be replaceable.

In tunnel categories A and B (AADT(10) <2500) the fittings should have a deep shade to assist visibility.

1003.6 Priority lighting / emergency lighting

Priority lighting is determined by every fourth or fifth light continuing to operate for about 1 hour following a power breakdown.

1004 Ventilation

1004.1 Air quality requirements in tunnels

1004.11 General

The ventilation equipment shall be designed to cope with expected pollution levels 10 years following the opening of the tunnel (AADT(10)).

With a normal mixture of exhaust gases it is only necessary to determine the level of permissible concentration of carbon monoxide (CO-gas) and nitrogen dioxide (NO₂ gas). The concentration of the other toxic gases does not present a health hazard if a sufficient dilution of CO and NO₂ gases is achieved. In order to attain sufficient control of gas concentration in the tunnel, measuring instruments should be installed in the middle of the tunnel and at both ends. In one-way tunnels, measuring equipment is not required in the entrance zone.

The measurement range for CO shall be a minimum of 0–300 ppm and 0–25 ppm for NO₂.

1004.12 Permitted concentration levels for carbon monoxide, nitrogen dioxide and visibility pollution

For tunnels with longitudinal ventilation, the degree of pollution increases from the entry point of the fresh air to that where it is expelled. In determining the permitted level of concentration in order to calculate the requirement for fresh air, the background concentration of intake air has to be considered.

1004.2 Mechanical longitudinal ventilation

1004.21 General

Mechanical longitudinal ventilation is based on the use of impulse ventilator fans. In long tunnels and those with a high traffic volume, or where specific pollution regulations apply in the areas around the tunnel entrances, ventilation with the aid of a ventilation shaft will be appropriate. Even though a ventilation shaft is con-

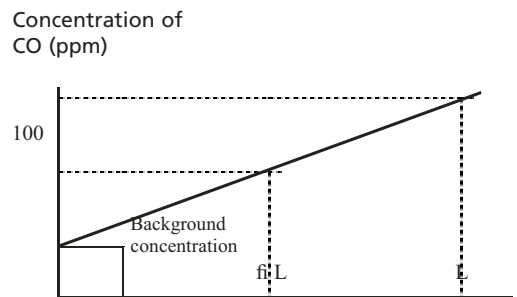


Figure 10.2 Permitted CO concentration in tunnels (The background concentration will vary locally).

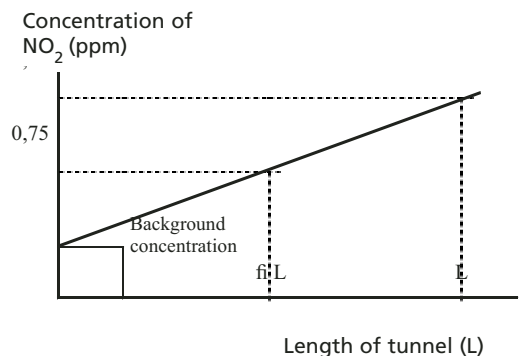


Figure 10.3 Permitted NO₂ concentration in tunnels (The background concentration will vary locally).

Table 10.5 Permitted concentrations of CO, NO₂, NO_x, NO and visibility pollution

	Permitted concentrations *	Assumptions
CO	C _{co} = 200 ppm	In operation a concentration of 100 ppm is only occasionally reached in the tunnel and must not be exceeded. If the CO measuring instrument in the mid-tunnel registers 100 ppm for more than 15 minutes, the tunnel must be closed to traffic. During normal traffic the CO content in the air will be essentially lower. This is achieved by controlling the ventilation equipment such that the ventilators are coupled in groups and in stages. For example, the first stage will operate at 25 ppm, the second stage at 50 ppm and all three at 75 ppm. This applies to control by the CO measuring instrument in the mid-tunnel. Corresponding values at each end of the tunnel are twice that of the concentration in the middle.
NO₂	C _{NO₂} = 1,5 ppm	In the event of the NO ₂ concentration exceeding 0.75 ppm for more than 15 minutes measured in the mid-tunnel, the tunnel should be closed to traffic. NO _x is the common term for nitrogen oxides and essentially comprise NO and NO ₂ . It is assumed that the proportion of NO ₂ is 10 % of NO _x .
NO_x	C _{NO_x} = 15 ppm	
NO	C _{NO} = 13,5 ppm	
Visibility	C _{sight} = 1,5 mg/m ³	

* Permitted concentration is used for the calculation necessary fresh air to be injected into the tunnel (Appendix C).
Conversion factor mg/m³ CO = 1.20 ppm CO.

structured it will frequently be necessary to install impulse ventilator fans in order to control the air quality in the tunnel.

The air speed should not exceed 10 m/s in one-way tunnels, and 7 m/s in two-way tunnels based on considerations of installation and operational costs, dust circulation, control of air flow in the event of fire, etc.

Calculation of ventilation requirements is given in Appendix C.

1004.22 Impulse ventilators

The distance between impulse ventilator fans along the tunnel length shall be a minimum of 70 meters in order to attain an even and stable air stream between each fan or group of fans.

In order to control smoke in the desired direction in the event of fire it is required that the impulse ventilators are reversible.

In one-way tunnels the ventilation direction will normally be in the direction of the traffic flow.

1004.23 Ventilators in ventilation shafts or side adits

Dividing the tunnel into several ventilation sections with the aid of shafts or side adits assists in the renewal of air in a longitudinal system. The construction of shafts or side adits will, however, result in the airflow through the tunnel being more complicated. This requires careful calculations and planning when designing the particular ventilation system.

1005 Fire ventilation

Where ventilation equipment is installed in a tunnel, this must be designed with regard to fire ventilation requirements.

In the event of fire and smoke, the air

Table 10.6 Acceptable air quality levels of CO and NO in tunnels open to cyclists and pedestrians

Length (km)	CO (ppm)	NO (ppm)
0 - 1	100	2
1 - 4	25	2

speed should be able to be reduced to the lowest possible speed, yet sufficient to direct the smoke in the desired direction. The ventilation direction will be determined in consultation with the fire authorities and incorporated into an emergency plan.

The ventilation equipment must be designed so as to be able to control a fire of 5 MW or 20 MW, dependent upon the traffic volume. See Chapter 6 “Traffic and fire safety”, Section 605.

For tunnels longer than 500 m and an average incline $\geq 2\%$, a calculation model for fire ventilation is given in Appendix D.

For other tunnels with a gradient $< 2\%$ the net designed air speed will be a minimum of 2 m/s for tunnels designed for

fires in light vehicles (5MW), and a minimum of 3.5 m/s designed for fires in heavy vehicles (20MW).

In order to achieve the necessary control of air flow in the tunnel, the ventilation shall be designed such that:

- it has the capacity to counteract the build-up of pressure in the tunnel. On account of the general upward buoyancy, external wind and the fire itself, together with natural draughts on account of temperature differences inside and outside the tunnel.
- sufficient capacity is ensured in the ventilation equipment for the necessary time for the tunnel to be evacuated.

11 Operation and maintenance

1101 General

Operation and maintenance should ensure that the level of safety in the tunnel is upheld by maintaining the assumed functional requirements and functional safety.

Important elements in this connection are:

- Resource use based on needs is constantly checked, changed and adapted to the actual needs
- The necessary level of qualifications and skill are found at all levels in the organisation.

As far as possible, operations and maintenance should be carried out systematically and at appropriate intervals. The life-cycle considerations of both construction and technical equipment shall be taken into account when determining maintenance routines. Optimised maintenance frequency will reduce the probability for costly replacements.

Systematic planning shall include one or more of the following maintenance procedures:

- Calendar-based maintenance
- Operational-based maintenance
- Situation-based maintenance

Maintenance may be classified according to construction, sub-base, pavement, and technical equipment.

A continual evaluation should be made of energy-saving processes.

Warning of road works in the tunnel, see Section 604.

Manual 111 “Standards for operation and maintenance” determines the standards applicable at any time. Any deviation from these has to be approved by the Directorate of Public Roads.

1102 Methods of maintenance

1102.1 General

All operational and maintenance tasks carried out, both planned and unforeseen, shall be documented with the aid of an appropriate registration programme for

management, operation and maintenance. This should be able to verify the standard noted and any deviation from required standards. The documentation may also be used to verify the need for internal control. If, exceptionally, a manual control system is used, a signature should be obtained to confirm that the task has been duly carried out.

The systematic use of an administrative computer-based programme will enable experience to be registered such that at any given time the tunnel operator/owner will be able to initiate measures for more efficient maintenance.

The use of this programme will enable all technical data relating to the individual tunnel to be registered along with technical diagrams and descriptions of all equipment used.

1102.2 Calendar-based maintenance

Calendar-based maintenance involves standardised working instructions to be carried out periodically. This may be weekly, monthly, every second month, etc. The periods are determined by what is normal for the individual routines.

The working instructions shall state what is to be carried out each time, who authorises this, and the necessary skills required. Completion of the task shall be registered and the job instruction signed by the person responsible for supervising the work.

Calendar-based maintenance is a simple method if other routines are unsuitable, and ensures systematic maintenance. An optimal maintenance will require regular change of the intervals between the various tasks.

1102.3 Operational-base maintenance

Generally, operational-based maintenance is based upon the same principles as calendar-based routines, although the time interval will vary according to the time that equipment is used.

The working instructions are based upon the components having automatic registration systems in the form of time counters. Based on estimations of the time when the specified control has to be carried out, working instructions are issued describing the tasks that are to be done.

1102.4 Situation-based maintenance based on visual inspection

Situation-based maintenance is based on the registration of specific conditions and that maintenance is planned based on the results. Some installations will have regular routines for maintenance ensuring that that unnecessary wear-and-tear is avoided. This requires a routine for regular inspection, service and maintenance to be carried out according to need rather than at fixed intervals.

Maintenance may be carried out as the result of an inspection. The results are registered and evaluated and the decision made whether maintenance shall be carried out immediately, or alternatively postponed until the next inspection.

1102.5 Situation-based maintenance based on registration

This is similar to the above situation but instead of inspection, measurements are made of the condition of the various components. For example, fans and pumps where a temperature gauge registers the heat of bearings, and vibration gauges indicate a deviation from the norm. The results of the measurements are used similarly to the results of inspections in order to determine when maintenance operations shall be carried out.

1102.6 Experience from systematic maintenance

Irrespective of the maintenance method, it is essential that an administrative programme is installed so as to provide a comprehensive registration of damage,

operational problems and other incidents which arise from time to time. When changes to routines are being considered the database will assist in pointing to those circumstances which must be changed or improved due to incidents that occur with greater frequency than might be desired on the basis of safety or economy.

Routines shall be prepared such that experience registered in the database will be of use in the planning and construction of future tunnels.

The programme shall be used to ensure a continuous active optimizing of tunnel maintenance.

1103 Maintenance of constructions

1103.1 General

In addition to the recommended maintenance procedures by the suppliers, the requirements of maintenance standards for construction elements are given in Manual 111 "Standards for operation and maintenance"

1103.2 Functional control

Functional control is designed to ensure that the constructional elements function according to the given specifications. Control routines must be designed to ensure this. The aim is to ensure that the component fulfils the functional safety required. At the same time it is essential that the required standard does not decrease below a defined acceptable level without measures being implemented. It will normally be required that function control is carried out for only some of the construction elements.

Examples of construction elements where function control should be carried out include:

- portals
- constructions for water and frost protection
- sealing

- support
- buildings for technical equipment
- pumping stations

1103.3 Evaluation of condition (status reports)

Regular registration of the condition of the individual elements must be incorporated into routines such that future maintenance and resource requirements can be planned. A status report can occur at several levels, for example a main investigation is required to be carried out at regular intervals. When the main investigation reveals that certain measures should be implemented, a supplementary investigation is immediately made with the intention of determining the full extent of damage. This should also make clear recommendations for repair or replacement.

The interval between these evaluations will vary from annual investigations to several years. The main investigation will cover specific structural elements where, for each of these, the following are incorporated:

- element description
- evaluation of status or condition
- recommendation of measures to be undertaken
- financial estimates
- dependency upon other measures requiring to be undertaken
- time plan for carrying out measures and financial review.

Example:

Status report of concrete wall elements carried out every third year. The following should be registered:

- discolouring of the surface
- surfaces indicating damp
- leakage points
- cracks with water penetration
- cracks and joints
- peeling cement
- salt accumulation
- condensation

- need for samples, particularly in the entrance zone (carbonation, chlorides)
- wear and tear, discolouring, etc., of surface treatments, painting below standard.

1104 Maintenance of the road surface

1104.1 General

Maintenance comprises:

- Pavement
 - renewal
 - cleaning
 - dust control
 - marking
 - winter-related tasks such as surface friction control, removal of ice
 - Drainage
 - Kerbstones and shoulders/verge areas
- The functional requirements will normally be the same as for the open road.

1104.2 Functional control

Normally, functional control will only be required for road marking and drainage. For other road elements, or in the pavement structure, it will be sufficient to determine that the function has to be controlled.

1104.3 Particular requirements

Pavement:

Consideration must be made to the special material specifications for the pavement in the tunnel and the requirements for lighting (see Chapters 9 and 10). With regard to health hazard, surface materials for the roadway with a high level of alpha quartz should be avoided in tunnels with a high traffic volume. This is particularly important in areas where studded tyres are widely used.

Marking:

To ensure that the road marking is always visible profiled marking should be used (see Section 414.4).

Drainage:

Waterpools in the roadway should not arise due to lack of maintenance of the drainage system.

The drainage function should be checked and the drain pipes flushed out at least every third year. The general condition of the drainage system must also be checked during tunnel cleaning and following any maintenance carried out.

Sediment which has accumulated in manholes and sediment tanks shall be deposited at special sites approved for the disposal of this sort of waste.

In sub-sea tunnels drainage and water pipes will frequently have a larger dimension than in other tunnels (see Chapter 8, "Drainage"). This applies particularly to flat stretches where there is a danger of bacteria accumulating in the pipes. In this case periodic controls should be carried out more frequently accompanied by necessary flushing of the pipes.

1105 Maintenance of technical installations

1105.1 General

Maintenance of technical installations is normally that part of tunnel maintenance which requires the greatest resource input. This largely involves frequent and repeated operations which may be characterised as service. As a rule this maintenance shall be systematically organised by working instructions following prescribed routines in accordance with the administrative programme.

1105.2 Maintenance manual

In order to ensure that maintenance is carried out systematically, a maintenance manual should be prepared such that the same routines are followed by everybody involved in operations and maintenance of the tunnel. Recommended procedures made by the suppliers shall be included in the basis for the manual. Information from

suppliers should be available electronically.

The manual should contain a precise description of service routines and the functions of the individual elements, procedures for control and testing.

For each element the manual shall contain the following information:

- description of the equipment
- function of the equipment
- functional specifications
- requirements for operating standard
- description of possible faults arising
- description of those parts to be maintained
- service and reparation procedures.

In addition, function control and status forms shall be used.

1105.3 Functional control

In order to ensure that the equipment and installations shall function as required at all times, manual or automatic control routines shall be specified. The frequency with which such controls are undertaken is dependent upon the operational reliability and importance of the equipment. The interval for manual inspection can be at monthly, half-yearly, annually, or even longer intervals.

1105.4 Status reports

Status reports of the equipment shall be carried out for the various constructions and installations in the tunnel. Consideration may also be given as to whether a status report should be carried out by external consultants. It is also important for more comprehensive status reports to be carried out at regular intervals by specialists.

1106 Cleaning

Cleaning shall ensure:

- road users and their opinion of using the tunnel
- the working environment in the tunnel

- installed equipment, reliability, life-span and economic factors
- the local environment.

Cleaning routines shall include the entire tunnel including equipment and installations.

The road users shall be ensured a level of cleaning where grime/grit on the road surface, walls and so forth does not reduce their general impression of the tunnel.

The road user's opinion of the tunnel environment is frequently based on the senses including the sense of smell, visual impression and noise. Many road users feel uncomfortable when driving in tunnels. A light and clean environment without the smell of exhaust and grit on the road surface are important factors for the road user's safety and satisfaction. The standard of cleaning will also be one of the most important contributions to the road user's comfort.

The standard of cleaning should be such that there is no problem with dust/grit. Grit on the tunnel walls, verge areas and the road surface which contain PAH elements, lead, zinc, nickel and other heavy metals shall be removed before the accumulation of such materials can present an environmental hazard in the tunnel and the local environment. (More information is included in Manual 213).

Functional failure of installations and equipment should not arise as a result of negligent cleaning influencing heating in mechanical components, overloading of electrical components as a result of pollution, leaking current etc.

1107 Winter maintenance

Frost and ice formation on the road surface can be overlooked in the tunnel itself, but it will always be necessary to consider special measures against ice (icicle) formation in the frost zone at the tunnel entrance.

Winter maintenance routines shall ensure a proper road surface at the entrance and approach zone to the tunnel. Measures must also be taken when icicles form inside the tunnel before these become a traffic hazard or a risk to construction and equipment.

12 Documentation upon handover

The complete documentation folder containing all documents of importance to the future operation, maintenance and extension of the tunnel are to be delivered to the Traffic Section, latest upon handover. (See Manual 151 “Management of development projects”). The documentation shall be systematically assembled, and where possible presented in electronic form. Those parts of the documentation which are relevant for operation and maintenance of the tunnel and its equipment should be registered using a programme of management, operation, and maintenance. This shall detail the type of equipment, maintenance and operation routines and intervals, suppliers, guarantee documentation etc.

The specific documents to be includ-

ed shall be determined by the Road and Traffic Department during the planning phase. Requirements for documentation from suppliers shall be specified in tenders.

Prior to handing over the tunnel, a test should be carried out to verify that equipment is working as specified. A report should be made of the test and which should accompany the handing over.

In addition, a technical and economic report is to be presented after the tunnel has come into operation, latest three months after the project has been handed over. The final report follows a specified layout made by the Norwegian Public Roads administration.

Appendix A Evaluation and calculation of air pollution from road tunnels

Exhaust gases from the tunnel entrance

A simplified method for calculating is given below.

The method is empirical, and is based on measurements of the dispersion of trace elements outside the tunnel entrances and atmospheric dispersion model adjusted to take into account dispersion at ground level. The calculation method is presented as nomogrammes, see Figures A.2 – A.4.

Air pollution originating from the tunnel is defined as two phases: a jet phase and a smoke phase. In the jet phase it is initially the air speed out of the tunnel opening (u) which is decisive, whereas in the smoke phase the atmospheric conditions (e.g. external wind speed, w) are the most important. This is presented schematically in Figure A.1. The selected parameters are dependent upon representative measurements. The transition from the jet phase to the smoke phase is very complicated and is estimated.

In order to calculate the level of pollution as accurately as possible at selected points outside the tunnel entrance, atmospheric measurements are made (wind, stability etc.) in the immediate vicinity over a long period. The measurements should include the

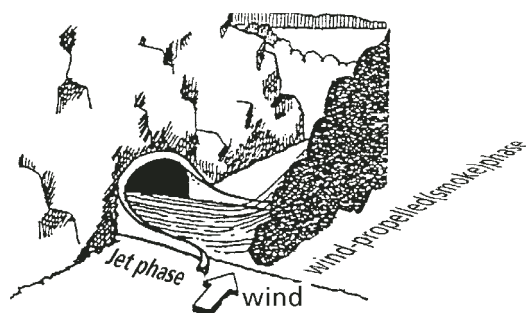


Figure A.1 Jet phase and smoke phase

winter period as it is then that pollution is normally the highest. In addition the background concentration in the local area must be measured.

The local topography and the shape of the portals can also be of major importance for the dispersion effects.

Nomogrammes used in calculation of dispersion

The nomogrammes are presented in Figures A.2 to A.4.

Nomogrammes are well suited to an initial evaluation to determine whether dispersion from the tunnel can result in pollution. In this event, more detailed calculations shall be made using specified models.

Nomogrammes can be used for carbon monoxide (CO) and nitrogen dioxide (NO₂). In the calculation of NO₂, inclusion of 60 µg/m³ is made to allow for the fact that NO from the tunnel reacts with ozone (O₃) to form NO₂. The nomogrammes cannot be used to calculate the daily mean concentration of PM₁₀. In this case a more basic study must be made, among other things, of the dispersion effects. As a rule NO₂ in the tunnel entrance is the determining feature.

1. Definitions

C = limit value outdoor air

C_t = exhaust concentration in tunnel
[-]

w = wind speed [m/s]

u = calculated air speed in tunnel
[m/s]

--- jet phase

— smoke phase

2. Limitations to the nomogrammes

- Tunnel cross-section $A_T = 48 \text{ m}^2$
 - The nomogrammes are not to be used where $w < 1 \text{ m/s}$ and $u > 8 \text{ m/s}$.
- See Report from The Norwegian Institute for Air Research no. 27/82 (ref. 23179)

3. Using the nomogrammes

Nomogrammes have been constructed for three different wind speeds ($w = 1 \text{ m/s}$, $w = 2 \text{ m/s}$ and $w = 5 \text{ m/s}$).

The nomogrammes to the left show C/C_t in the area 0 – 1.0.

The nomogrammes to the right show C/C_t in the area 0 – 0.1 (i.e. magnified 10x).

Where w and u do not have precise values, the nearest curve which overestimates the concentration shall be used:

- the curves for the highest w which is less than the actual value
- the curves for the smallest u which is larger than the actual value.

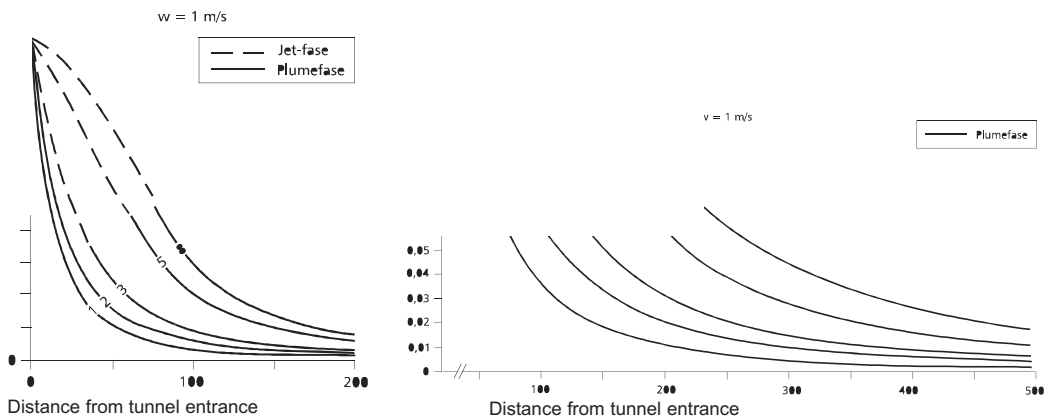


Figure A.2 Nomogrammes for dispersion calculations, wind speed $w=1 \text{ m/s}$

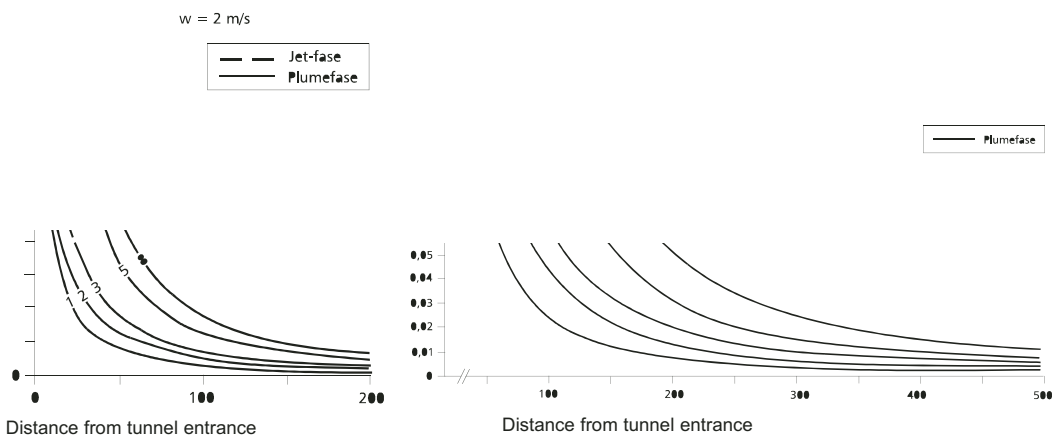


Figure A.3 Nomogrammes for dispersion calculation, wind speed $w = 2 \text{ m/s}$

ROAD TUNNELS APPENDIX A EVALUATION AND CALCULATION OF AIR POLLUTION FROM ROAD TUNNELS

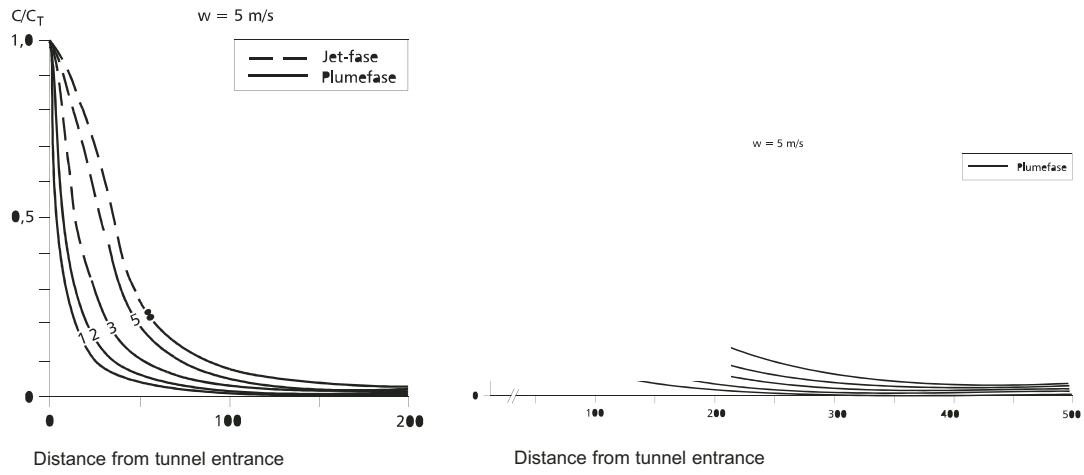


Figure A.4 Nomograms for dispersion calculation,,wind speed $w = 5 \text{ m/s}$

Appendix B Calculation of noise dispersion from road tunnels

Reference is made to SINTEF Report STF40-A96005 for complete conditions for calculations.

The calculations are carried out in four stages described below.

1. Exit level L_{utg} :

The exit level is calculated according to the Nordic method of calculating traffic noise.

2. Correction K2 for noise dispersion from the tunnel entrance

Noise from the tunnel entrance has particular distance and direction characteristics as illustrated in Figure B.1.

The tunnel entrance is situated where $X = Y = 0$. The actual correction is found directly from the figure for the coordinates of the calculation point through the interpolation between the contours.

3. Correction for short tunnels

Short tunnels yield lower noise levels. The correction is given in Table B.1.

4. Noise from the tunnel L_t , dBA

The noise emitted from the tunnel entrance yields the noise level:

$$L_t = L_{utg} + 14 + K2 + K3$$

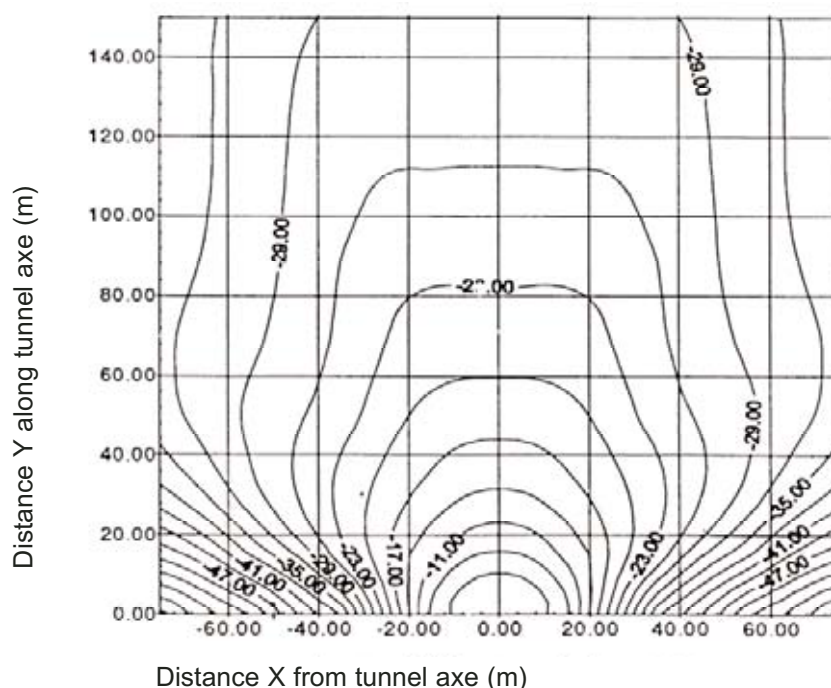


Figure B.1 Correction K2 for noise emission from the tunnel mouth

Table B.1 Correction K3 for tunnel length, dBA

Tunnel length (m)	50	75	100	150	200	300
Correction K3	-5	-4	-3	-2	-1	0

Appendix C Ventilation

1. Calculation of fresh air requirements

Where the traffic distribution between the two directions is not known, two-thirds are assumed to drive uphill.

The ventilation equipment shall be designed to the expected pollution level 10 years after opening.

Introduction of catalysers on petrol-driven vehicles has resulted in a reduction of CO and NO_x levels, and are included in the formulae.

CO-production

The calculation model for CO production from vehicles:

$$Q_{O\ CO} = q_{O\ CO} \cdot (k_{kat} \cdot M_l + M_t) \cdot k_{hh} \cdot k_s \cdot k_f \cdot L \text{ [m}^3/\text{h]}$$

$$Q_{O\ CO} = \text{total CO produced [m}^3/\text{h]}$$

$$q_{O\ CO} = \text{basic value, CO-production per vehicle, [m}^3/\text{km}\cdot\text{veh].}$$

The basic value for CO-production, $q_{O\ CO}$ is assumed to be 0.013 m³/km·veh when driving on a horizontal road, speed 60 km/h.

With the motor running idle, a mean CO-production of 0.5 m³/h·veh can be estimated. This value corresponds to petrol consumption of approx. 1 litre/hour and 6 % CO in the exhaust gases.

k_{kat} = catalyser effect, determined as 0.3

M_l = traffic volume, light vehicles [veh/h]

M_t = traffic volume, heavy vehicles [veh/h]

k_{hh} = correction factor for height above sea level, see Table C.1

k_s = correction factor for driving uphill, see Table C.2

k_f = correction factor for driving at

reduced speed, see Table C.3

L = tunnel length in km

The fresh air requirements, $Q_{O\ air}$, are

calculated on the basis of CO production ($Q_{O\ CO}$), and permitted CO-concentration in the tunnel C_∞ (ppm). C is found from Figure 10.2.

$$Q_{O\ air} = \frac{Q_{O\ CO} \cdot 10^6}{C_\infty} \text{ [m}^3/\text{h]}$$

The fresh air requirement which assumes normal pressure (1013 millibars) and temperature 0° C is converted to the fresh air requirement in unfavourable atmospheric circumstances with the designed traffic volume.

$$Q_{air} = Q_{O\ air} \left[\frac{P_o \cdot T_t}{P \cdot T_o} \right] \text{ [m}^3/\text{h]}$$

P_o = 101.3 [kPa] (1013 millibars)

P = actual pressure [kPa]

T_o = normal temperature 273 K (0 °C)

T_t = actual mean air temperature in tunnel in K (273 + t_{tunnel} [°C])

Traffic volume, M

The designed traffic volume is normally stated in vehicles/h. With short and intensive traffic peaks a shorter interval may be used. A shorter time than the time needed to ventilate the tunnel cannot be used. The minimum air-change time is based on an air speed of 2 m/s.

Table C.1 Correction factor for height above sea level, k_{hh} when calculating CO-content

Height above sea level (m)	400	800	1200
k_{hh}	1.25	1.60	2.00

Table C.2 Correction factor for driving uphill or downhill k_s , when calculating CO-content

	Decline in %		Incline in %			
	4	2	0	2	4	6
k_s	0.85	0.95	1.0	1.1	1.2	1.3

Table C.3 Correction factor for driving at reduced speed, k_f , when calculating CO-content

Traffic speed (km/h)	5	10	20	30	40	50	60	> 60
k_f	6.3	3.5	2.0	1.5	1.2	1.1	1.0	0.9

Visibility-reducing particle content, **P_{vis}**

$$P_{vis} = p_{vis} (M_t + 0.08 M_l) k_{hh} \cdot k_s \cdot L \text{ [mg/h]}$$

P_{vis} = quantity of soot produced in the tunnel [mg/h]

p_{vis} = basic value for soot production per heavy vehicle determined at 750 [mg/veh·km]

M_t = traffic volume, heavy vehicles [veh/h]

M_l = traffic volume, light vehicles,

veh/h. It is calculated that a light vehicle results in 8% visibility pollution of that of a heavy vehicle.

k_{hh} = correction factor for height above sea level for tunnels >400 m asl. See Table C.4.

k_s = correction factor for driving uphill according to Table C.5. $k_s=0.5$ is used for downhill gradients

L = tunnel length [km].

Table C.4 Correction factor for height above sea level, k_{hh} , in calculating visibility-reducing particle content

Height asl (m)	500	600	700	800	900	1000	1100	1200
k_{hh}	1.12	1.24	1.35	1.47	1.58	1.69	1.81	1.93

Table C.5 Correction factor for gradients, k_s , in calculating visibility-reducing particle content

uphill gradient in %	0	2	4	6	8	10	12
k_s	1.0	1.8	2.7	3.6	4.5	5.2	5.5

Fresh air requirement for lowering the visibility-reducing particle content:

$$Q_{\text{air}} = \frac{P_{\text{vis}}}{C_{\text{vis}}} \quad [\text{m}^3 / \text{h}]$$

In calculating the necessary fresh air requirement, the particle content is determined as $C_{\text{vis}} = 1.5 \text{ mg/m}^3$.

NO_x - production

Calculation model for production of nitrous gases (NO_x):

Concentration of nitrous gases is given by:

$$C_{\text{Nox}} = \frac{Q_{\text{Nox}}}{Q_{\text{air}}}$$

Q_{air} is the required quantity of fresh air for reduction of CO-gas or visibility pollution in the tunnel.

Designed air speed,

$$u = Q_{\text{max}} / 3600 \times A_{\text{N}} \quad (\text{m/s})$$

A_{N} = standard cross-section

Table C.6 Correction factor for gradients, k_s , in calculating NO_x-content

Uphill gradient in %	0	2	4	6	8	10	12
k_s	1.0	1.7	2.2	2.8	3.4	4.0	4.6

For downhill gradient $k_s = 0.5$.

Table C.7 Correction factor heavy vehicles k_t , in calculating NO_x-content

Driving speed (km/t)	20	30	40	50	60	> 60
k_t	8	7	5	3.5	2.5	2.5

$$Q_{\text{Nox}} = q_{\text{Nox}} (k_{\text{kat}} \cdot M_l + k_t \cdot M_t) \cdot k_s \cdot L$$

[m³/km]

$$Q_{\text{Nox}} = \text{produced quantity of NO}_x\text{-gas}$$

[m³/km]

$$q_{\text{Nox}} = \text{basic value for light vehicles, } 1.3 \cdot 10^{-3}$$

m³/km·veh

$$k_{\text{kat}} = \text{catalyser effect, determined as } 0.3$$

$$M_l = \text{traffic volume, light vehicles [veh/h]}$$

$$M_t = \text{traffic volume, heavy vehicles [veh/h]}$$

$$k_s = \text{correction factor for driving on gradients, see Table C.6}$$

$$k_t = \text{correction factor for heavy vehicles see Table C.7}$$

2. Calculation of required thrust for longitudinal ventilation

General

A system of longitudinal ventilation may be constructed with or without a ventilation shaft/side-adit. The air flow may be calculated as pipe flow and a simple equation for air movement in the tunnel may be formulated.

The forces which generate ventilation in a tunnel are of three types:

- * mechanical ventilation force
- * meteorological ventilation force
- * piston effect from vehicles.

Mechanical ventilation force

Mechanical ventilation force is generated by fans installed in the tunnel

The contribution of pressure loss from the mechanical ventilation force is calculated from equations (1) and (2) below.

Meteorological ventilation force

Meteorological ventilation forces are frequently unstable and it can be difficult to estimate the strength and distribution of the various elements. This applies particularly to wind force and the effect of climatic divides. Thermal effects can be more stable and easier to obtain an overview. Measuring natural draught is recommended where possible. In order to obtain a picture of natural draught in the tunnel, the pressure loss from the meteorological ventilation force is calculated according to equation (2). If the natural draught cannot be determined from measurements, the contributions are calculated from equation (3).

Piston effect of vehicles

When vehicles pass through tunnels with a speed which differs from that of the air

Table C.8 Cross-section and hydraulic diameter

Cross-section	Standard cross-section area A_N m ²	Hydraulic diameter, D_H m
T5,5	28.77	5.6
T7	37.23	6.5
T8.5	49.66	7.4
T9.5	53.53	7.6
T11.5	70.89	8.7
T12.5	75.41	8.8

A_N = standard cross-section area above carriage-way and verge area, assuming a 5% decline on the shoulder (See Table 4.1)

D_H = Hydraulic diameter, defined as

$D_H = \frac{4A_N}{O}$ where O is the circumference of the standard cross-section

speed in the tunnel, it will exercise pressure against the air masses in the tunnel. This effect is calculated from equation (4) for tunnels with two-way traffic, and by equation (5) for one-way tunnels.

Designed net thrust

Designed net thrust is that power necessary to overcome the pressure loss from the meteorological ventilation forces, the piston effect from vehicles and mechanical ventilation forces

The actual data for cross-sections and hydraulic diameters for the various tunnel cross-sections is given in Table C.8.

Calculation of diverse pressure loss

a) mechanical ventilation forces, pressure loss based on calculated necessary air speed.

Equation (1):

$$\Delta p = \frac{\rho}{2} \left(i + \lambda \frac{L}{D} + 1 \right) u^2 + \rho \frac{du}{dt} \left[N/m^2 \right]$$

Δp = pressure loss through the tunnel, N/m²

ρ = air density [kg/m³]

i = entry loss

λ = coefficient for flow loss. Varies from 0.025 in concrete lined tunnels to 0.05 in bare rock tunnels.

L = tunnel length [m]

D = hydraulic diameter ($D = 4A_N/O$) [m]

u = required air speed [m/s]

The loss factor (friction factor) will frequently be the dominant factor in the equations. The acceleration factor will serve mostly in levelling out the air speed. In practice it may be assumed that the air flow is stationary and the equation may then be reduced to:

Equation (2):

$$\Delta p = \frac{\rho}{2} \left(i + \lambda \frac{L}{D} + 1 \right) u^2 \left[N/m^2 \right]$$

b) Pressure loss resulting from meteorological ventilation forces

When the air speed in the tunnel is measured after hole-through, the pressure loss from meteorological effects (temperature and wind) can be calculated from equation (2).

When the air speed in the tunnel is not measured after hole-through, the pressure difference between the tunnel entrances may be calculated from equation (3).

Equation (3):

$$\Delta p_m = \rho \left(g \frac{\Delta T}{T_t} \Delta H + \frac{w^2}{2} \right) \left[\text{N/m}^2 \right]$$

Δp_m	= meteorological ventilation force, [N/m ²]
ρ	= specific weight of air at the lower tunnel entrance [kg/m ³]
g	= acceleration due to gravity, 9.81 [m/s ²]
ΔT	= difference between mean air temperature in the tunnel and the air temperature at the lower tunnel entrance [K]
T_t	= mean air temperature in the tunnel, K
ΔH	= height difference between the tunnel entrances, alternatively between the tunnel entrance and a shaft [m]
w	= wind speed near tunnel entrance [m/s]

The direction of the air stream will depend upon the temperature differences between the tunnel and external air. When these are similar, unstable conditions arise. This is often the situation in the spring and autumn.

Piston effect from vehicles

a) Tunnels with two-way traffic

The piston effect from vehicles – the force exerted on the air in the tunnel by a vehicle (air resistance) – is expressed as:

Equation (4):

$$P_F = \frac{\rho}{2} \cdot \frac{i_F \cdot A_F}{\left(1 - \frac{A_F}{A_N}\right)^2} \left(N^+ (v_t - u)^2 - N^- (v_t + u)^2 \right) [N]$$

P_F	= “piston effect” [N]
ρ	= air density [kg/m ³]
A_N	= normal cross-section [m] (See Ch. 4 “Geometric design”)
A_F	= vehicle cross-section light vehicles $A_F = 2 \text{ m}^2$ heavy vehicles $A_F = 6 \text{ m}^2$
i_F	= design factor to estimate effective resistance surface: light vehicles = 0.5 heavy vehicles = 1.0 – 1.7
N^+, N^-	= number of vehicles in the tunnel at a given point of time within designed time driving with a designed speed, N^+ with the air flow and N^- against the air flow
v_t	= traffic speed [m/s]
u	= required air speed [m/s]

b) Tunnels with one-way traffic

For tunnels with one-way traffic, the equation for the force exerted by vehicles on air in the tunnel is reduced to:

Equation (5):

$$P_F = \frac{\rho}{2} \cdot \frac{i_F \cdot A_F}{\left(1 - \frac{A_F}{A_N}\right)^2} \left(N^+ (v_t - u)^2 \right) [N]$$

Designed thrust

Designed thrust

$$= \frac{\text{Dim. net thrust power}}{k_s} = \frac{P_F + \sum \Delta \rho \cdot A_N}{k_s} [N]$$

where

k_s = system coefficient [-]

Normal values for k_s :

$k_s = 0.5 - 0.6$ (laterally mounted fans)

$k_s = 0.7 - 0.8$ (centrally mounted fans).

Appendix D Calculation model for fire ventilation

Model for calculation of fan capacity for tunnels with a gradient

In a tunnel with a given gradient, smoke and gases will rise on account of the chimney effect. This effect can be modelled analytically based on the following assumptions:

- The time function is ignored, i.e. the equation applied in stationary conditions
- Constant gradient in the tunnel and constant cross-section throughout the tunnel.
- Moderate fire such that:
 - Heat radiation is assumed to be absorbed by the walls
 - Heat transfer is controlled by convection from the smoke gases to the tunnel walls
 - The tunnel walls' heat capacity is assumed to be infinitely greater than the heat capacity of the smoke gases, i.e. the heat exchange between the gas and the wall material results in a temperature changes only in the gas.
 - Approximately one-way flow in the tunnel, i.e. the effect of local chimney effects and layering of smoke gases in the vicinity of the fire may be overlooked
 - The mass flow (product: area · density · speed) is constant over every section of the tunnel.
 - Pressure build-up in the tunnel is due to the chimney effect (the model will not be suitable for calculating the chimney effect in tunnels with a small gradient. Pressure build-up resulting from the fire will then be dominated by local effects. (Local pressure build-up from a 5 MW fire is in the order of 10–20 Pa).

Ventilation speeds below 2 m/s are not recommended and therefore not included in these calculations.

Correspondingly, a minimum of 50 Pa is recommended for thrust.

For the sake of simplicity the same temperature is assumed externally and inside the tunnel. Any possible temperature differences will result in a natural draught. The natural draught and external wind will affect the need for smoke ventilation, and compensation can be made. Fire-induced speed and pressure in the tunnel are hardly affected by the area of the cross-section. This is included when the thrust requirement is to be calculated.

Ventilation data for tunnels with fires of 5 MW and 20 MW

In order to simplify the calculations the necessary ventilation speed and associated thrust pressure to surmount fire-induced air flows in fires of around 5 MW and 20 MW are presented graphically as a function of tunnel length and average gradients (2 %, 4 %, 6 %, 8 % and 10 %), and tunnel lengths of up to 10 km. Two types of tunnel are illustrated: one with a gradient throughout the tunnel without any dips which would form a typical low point; the other type with a dip and subsequent rise, giving a typical low point (sub-sea tunnels). In the figures, Δp expresses the sum of natural pressure conditions such as natural draught and external wind. The contribution of Δp is calculated according to equation (6). The tunnel cross-section is not included in the calculation until the thrust from the fan has been calculated from equation (7).

The ventilation speed is given for 2 m/s and above. The required ventilation speed (greater than 2 m/s) or necessary thrust of the fans (greater than 50 Pa) is found directly from the graphs.

Figures D.1 – D.4 show the required ventilation speed and ventilation pressure for 5 MW and 20 MW respective

ly but no contribution from natural conditions. The tunnel has a regular ascent.

Figures D.5 – D.8 show the required ventilation speed and ventilation pressure for 5 MW and 20 MW respectively but no contribution from natural conditions. Only half of the tunnel length contributes to the chimney effect (typical sub-sea tunnel).

Figures D.9 – D.12 show the required ventilation speed and ventilation pressure for 5 MW and 20 MW respectively where the contribution from natural conditions is 16 Pa. The tunnel has a regular ascent.

Figures D.13 – D.16 show the required ventilation speed and ventilation pressure for 5 MW and 20 MW respectively where the contribution from natural conditions is 16 Pa. Only half of the tunnel length contributes to the chimney effect (typical sub-sea tunnel).

Figures D.17 – D.20 show the required ventilation speed and ventilation pressure for 5 MW and 20 MW respectively where the contribution from natural conditions is 64 Pa. The tunnel has a regular ascent.

Figures D.21 – D.24 show the required ventilation speed and ventilation pressure for 5 MW and 20 MW respectively where the contribution from natural conditions is 64 Pa. Only half of the tunnel length contributes to the chimney effect (typical sub-sea tunnel).

By applying pressure that exceeds marginally that generated by the fire, the natural ventilation will gradually be overcome. If one uses lower values than those included in the calculations, the direction of flow will not be able to be reversed. It is recommended that the ventilation speed is determined as 2 m/s or an applied pressure of minimum 50 Pa.

The basic data are given in Table D.1. The distance from the fire to the tunnel entrance is determined as the length of the tunnel for tunnels with a regular ascent. For tunnels with both inclines and declines along the tunnel as, for example, sub-sea tunnels, the mean gradient from the lowest point to the exit is used to calculate the gradient. The total length of the tunnel is included in the calculations of total resistance. Consideration of this is included in the calculations below.

Calculation of pressure contribution Δp from natural wind and chimney effect

External winds towards the tunnel entrance can result in a pressure difference between the two entrances such that a natural draught arises. A precise calculation of this is very much dependent upon local circumstances. In equation (6) it is assumed that the wind is blowing directly into the entrance and that the exit lies in the lee (wind is idle).

Natural chimney effects are determined by the temperature difference in the tunnel in relation to the surroundings. This may result in air currents both upwards and downwards, dependent upon whether the temperature is highest in the tunnel or outside (higher temperature in the tunnel results in a positive chimney effect in equation (6)).

Equation (6):

Where

$$\Delta p = \frac{1}{2} [\rho_{out} u_{\infty}^2 + (\rho_{out} - \rho_{in}) g \Delta H]$$

u_{∞} = external wind [m/s]
 ρ = air density [kg/m³]
 g = gravitation acceleration, 9.8 [m/sec²]
 ΔH = height difference between tunnel entrances [m]

If Δp is positive, it will work in the same direction as a possible fire, and thereby increase the demands for fan capacity.

Example:

External wind 5 m/s, 10 °C in the tunnel, 0 °C outside and a height difference of 100 m.

Density ρ is determined by the condition equation for air, atmospheric pressure divided by the gas constant and temperature in Kelvin.

$$\rho_0 = 1.01 \cdot 10^5 / 287 / (273 + 0) = 1.29 \text{ kg/m}^3 \text{ and } \rho_{10} = 1.01 \cdot 10^5 / 287 / (273 + 10) = 1.24 \text{ kg/m}^3$$

$$\Delta p = \frac{1}{2} [1.29] 5^2 + (1.29 - 1.24) [9.8] 100 = 65 \text{ Pa}$$

Table D.1 Basic data utilised in Figures D.1 - D.24. A minimum ventilation speed of 2 m/s or applied thrust of minimum 50 Pa is recommended.

Parameter	Unit	Value	Comments
Q	[MW]	5 and 20	Fire effect
T _o	[K]	273	Initial temperature inside the tunnel and outside
L	[m]	500 - 5500	Tunnel length
Cross-section	[-]	T8.5 T9.5 T11.5 and T12.5	Cross-sections as given in Ch.4 "Geometric design"
α	%	2, 4, 6, 8, 10	Gradients used
x	[m]	500 - 10 000	Distance from fire source to exit, determined as tunnel length, $x = L$ or $x = fi L$
	[%]	2, 4, 6, 8, 10	Gradients used in the figures
Δp	[Pa]	0, 16 and 64	Natural thrust from chimney effect and external wind
h_e	[W/m ² · K]	20	Convective heating transitional value; 20 W/m ² K is an approximate value yielding reasonable results in relation to the experimental data. This is recommended for all tunnels. The value depends upon the coarseness of the surfaces where a lower h_e -value will result in higher convection pressure from fires
l	[-]	0.5	Resistance at entrance, dependent upon the design of the tunnel entrance
λ	[-]	0.04	Resistance coefficient for flows. Dependent upon coarseness of the surfaces. Lower values for λ will result in higher convection thrust.

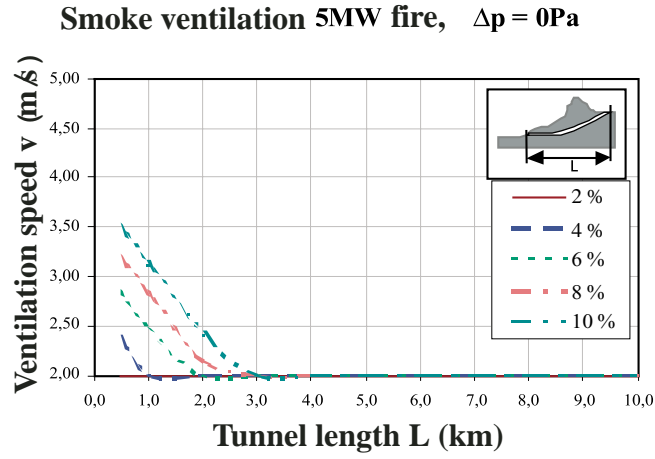


Figure D.1 Smoke ventilation 5 MW fire, regular ascent and $\Delta p = 0 Pa$

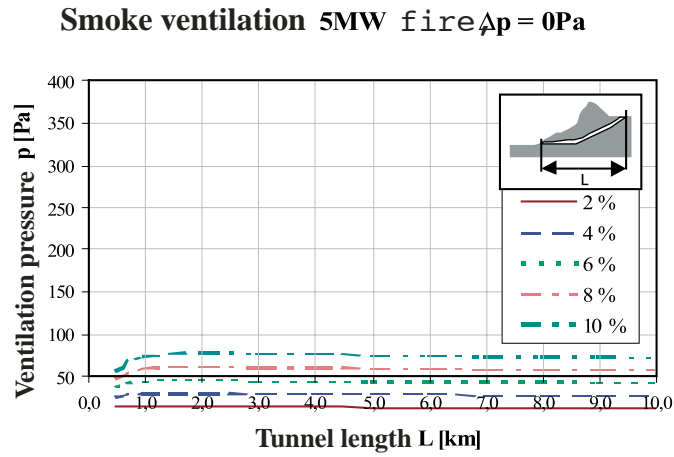


Figure D.2 Smoke ventilation 5 MW fire, regular ascent and $\Delta p = 0 Pa$

Smoke ventilation 20MW fire $\Delta p = 0\text{Pa}$

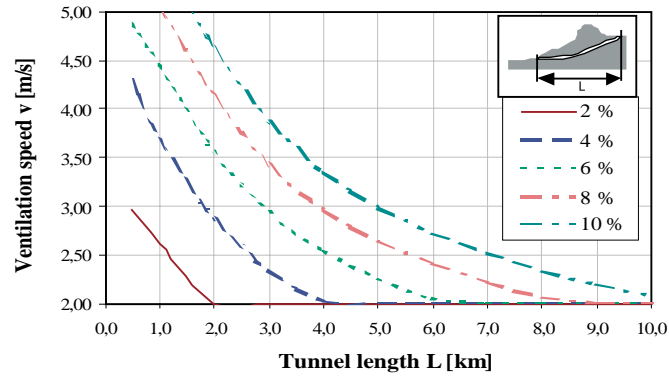


Figure D.3 Smoke ventilation 20 MW fire, regular ascent and $\Delta p = 0\text{ Pa}$

Smoke ventilation 20MW fire, $\Delta p = 0\text{Pa}$

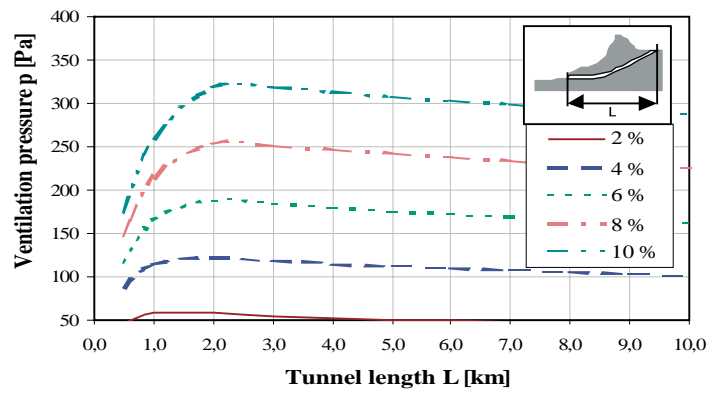


Figure D.4 Smoke ventilation 20 MW fire, regular ascent and $\Delta p = 0\text{ Pa}$

Smoke ventilation 5MW fire $\Delta p = 0Pa$

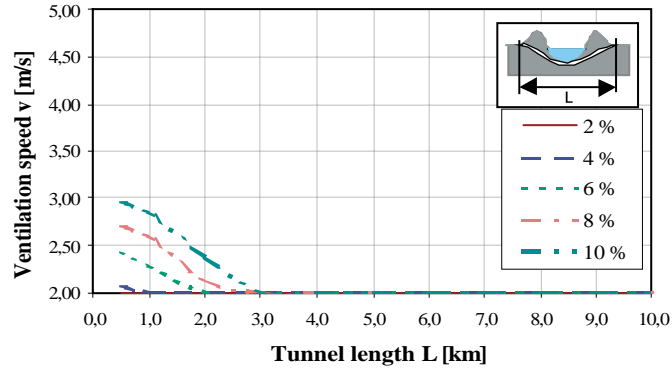


Figure D.5 Smoke ventilation 5 MW fire, increase over half distance and $\Delta p = 0 Pa$

Smoke ventilation 5MW fire, $\Delta p = 0Pa$

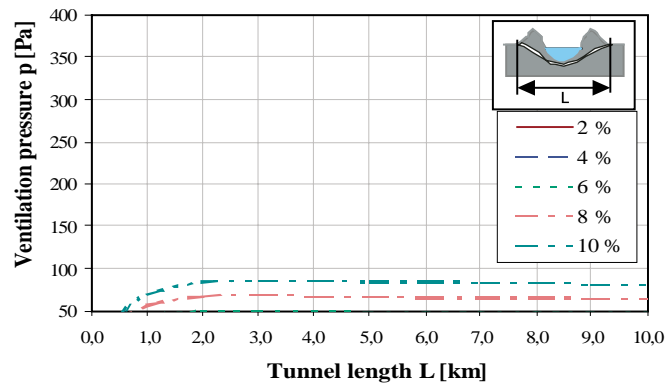


Figure D.6 Smoke ventilation 5 MW fire, increase over half distance and $\Delta p = 0 Pa$

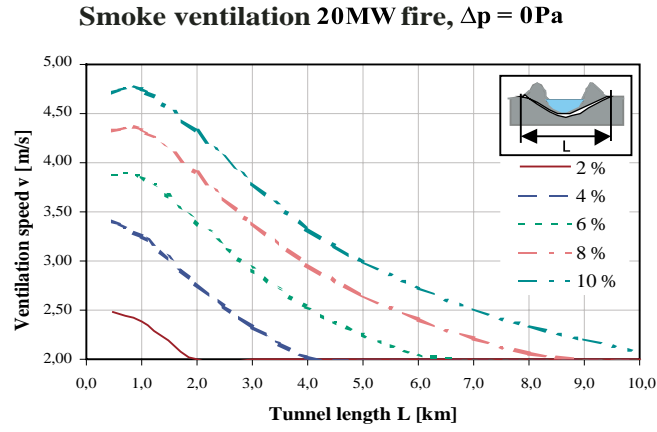


Figure D.7 Smoke ventilation 20 MW fire, increase over half distance and $\Delta p = 0 Pa$

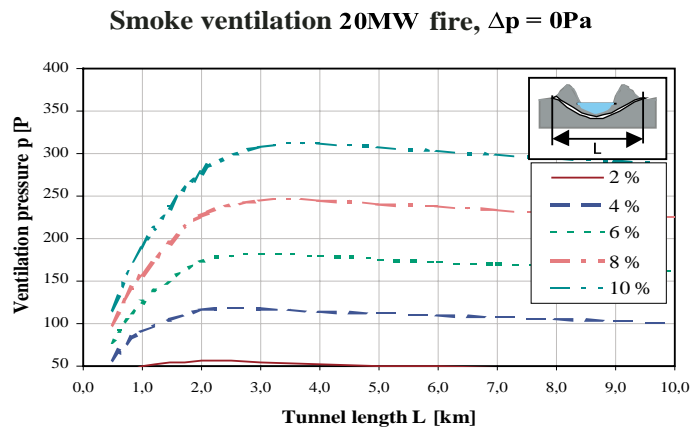


Figure D.8 Smoke ventilation 20 MW fire, increase over half distance and $\Delta p = 0 Pa$

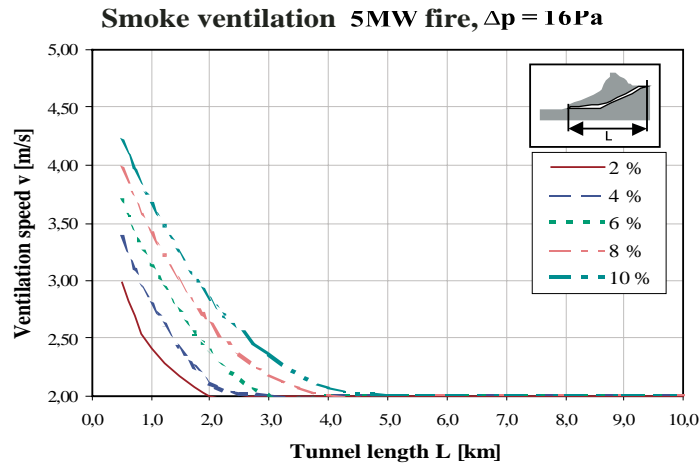


Figure D.9 Smoke ventilation 5 MW fire, regular ascent and $\Delta p = 16 Pa$

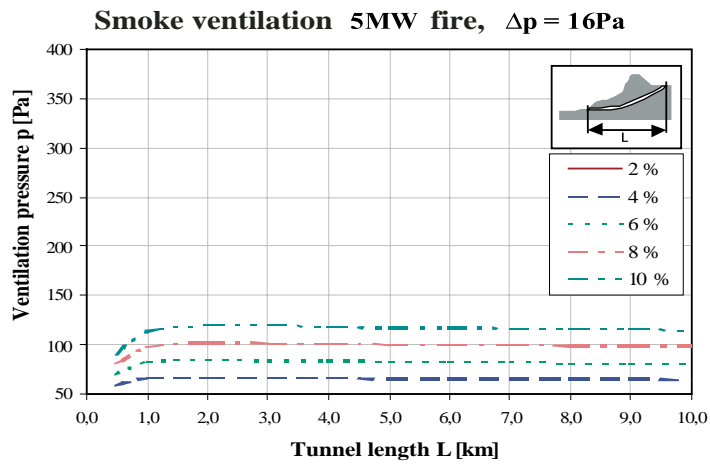


Figure D.10 Smoke ventilation 5 MW fire, regular ascent and $\Delta p = 16 Pa$

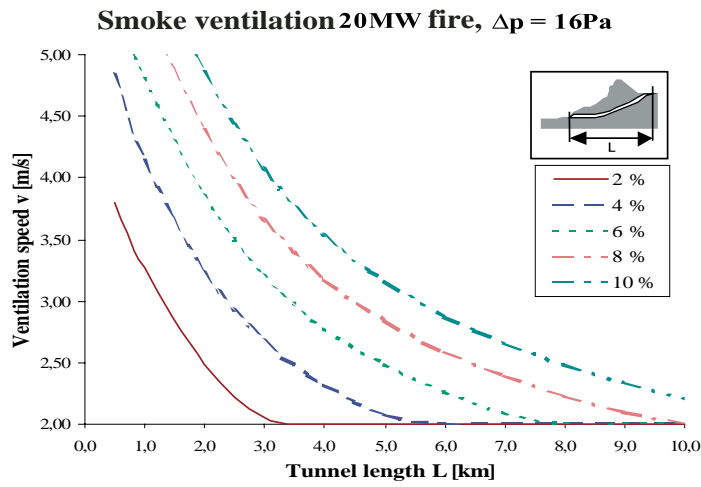


Figure D.11 Smoke ventilation 20 MW fire, regular ascent and $\Delta p = 16\text{ Pa}$

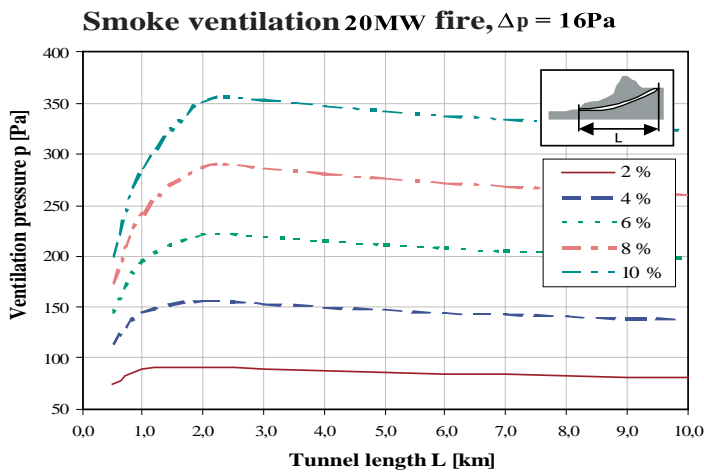


Figure D.12 Smoke ventilation 20 MW fire, regular ascent and $\Delta p = 16\text{ Pa}$

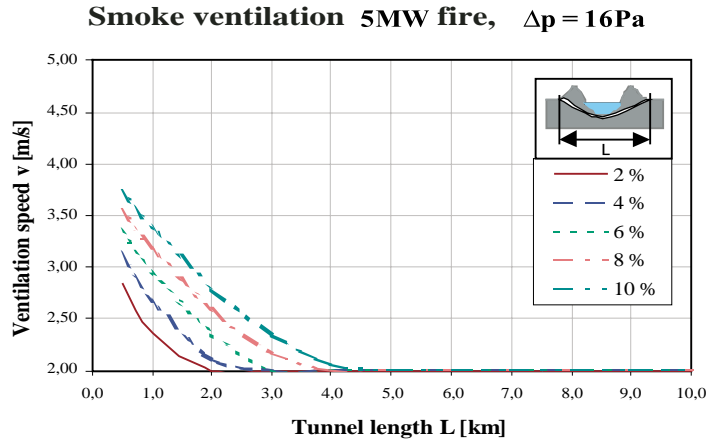


Figure D.13 Smoke ventilation 5 MW fire, increase over half distance and $\Delta p = 16\text{ Pa}$

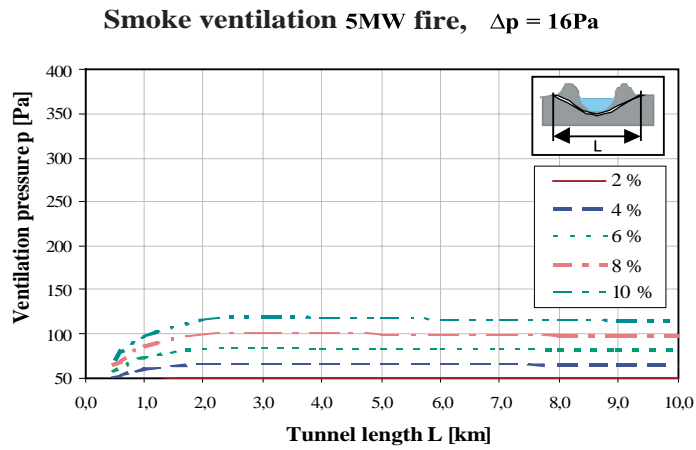


Figure D.14 Smoke ventilation 5 MW fire, increase over half distance and $\Delta p = 16\text{ Pa}$

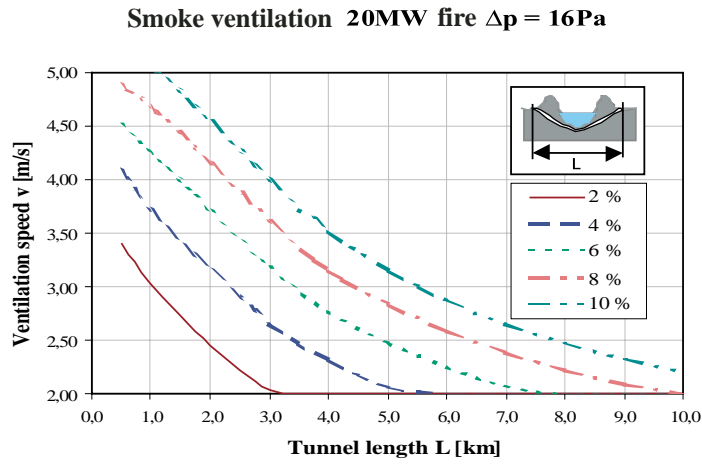


Figure D.15 Smoke ventilation 20 MW fire, increase over half distance and $\Delta p = 16\text{ Pa}$

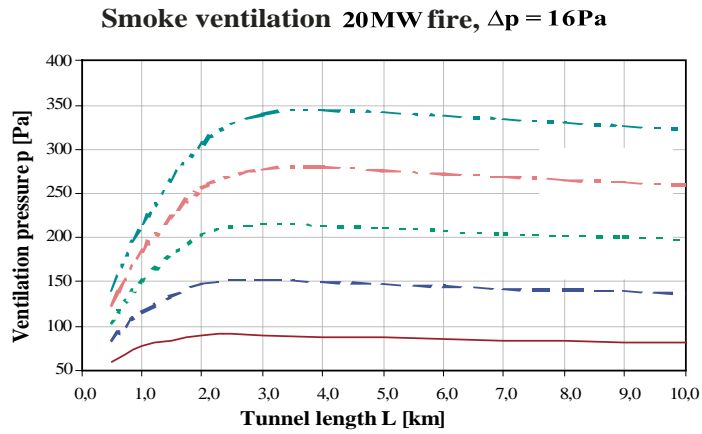


Figure D.16 Smoke ventilation 20 MW fire, increase over half distance and $\Delta p = 16\text{ Pa}$

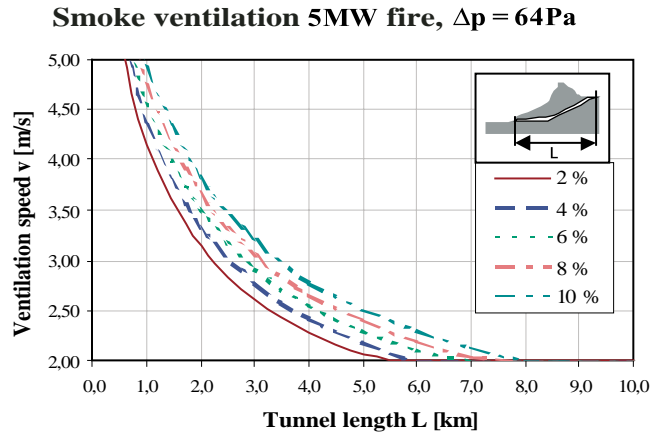


Figure D.17 Smoke ventilation 5 MW fire, regular ascent and $\Delta p = 64\text{ Pa}$

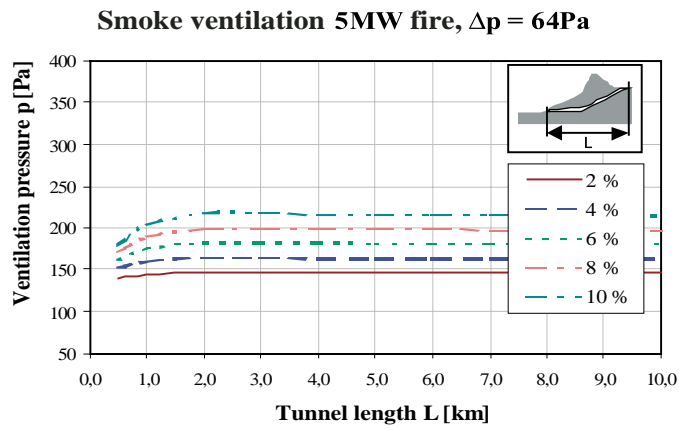


Figure D.18 Smoke ventilation 5 MW fire, regular ascent and $\Delta p = 64\text{ Pa}$

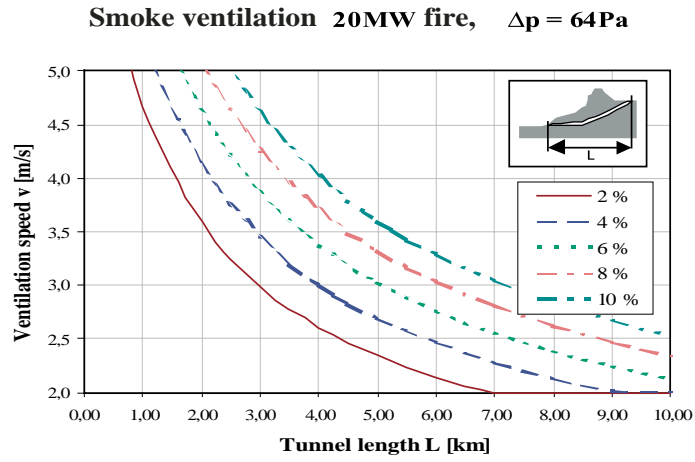


Figure D.19 Smoke ventilation 20 MW fire, regular ascent and $\Delta p = 64\text{ Pa}$

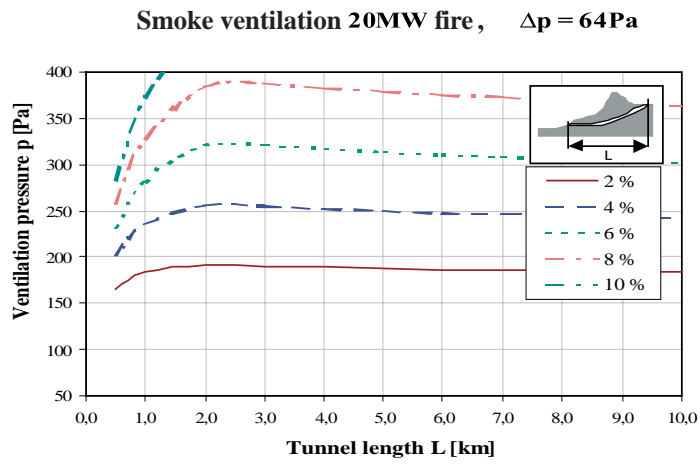


Figure D.20 Smoke ventilation 20 MW fire, regular ascent and $\Delta p = 64\text{ Pa}$

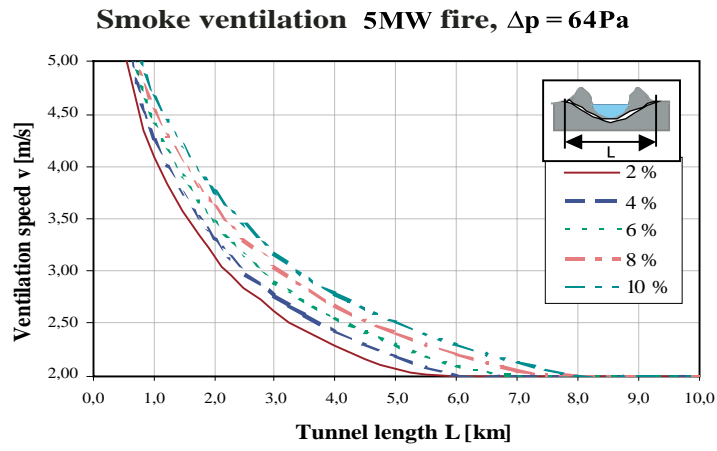


Figure D.21 Smoke ventilation 5 MW fire, increase over half distance and $\Delta p = 64\text{ Pa}$

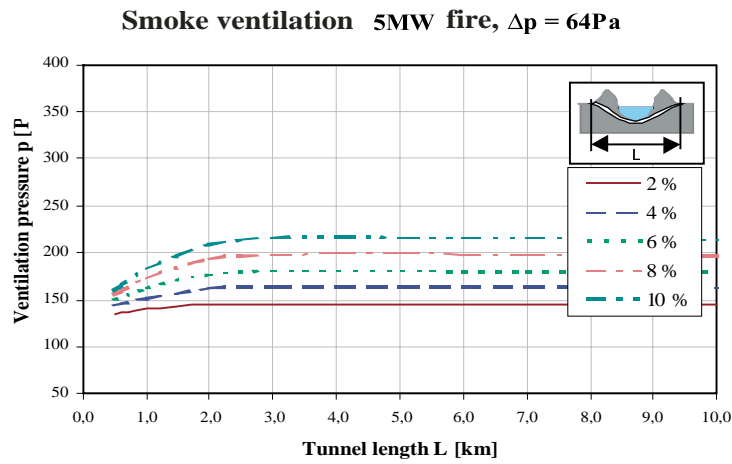


Figure D.22 Smoke ventilation 5 MW fire, increase over half distance and $\Delta p = 64\text{ Pa}$

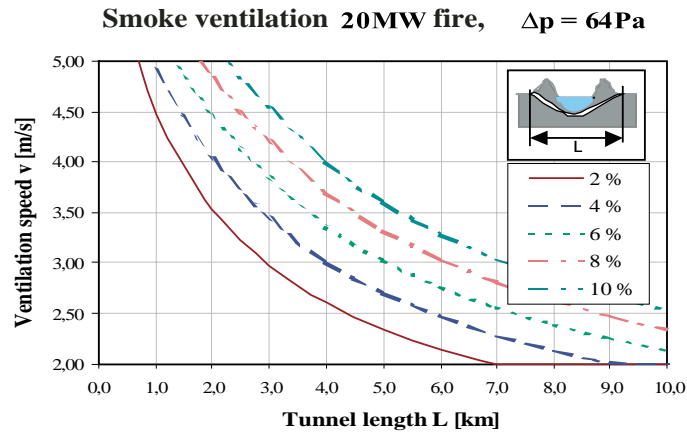


Figure D.23 Smoke ventilation 20 MW fire, increase over half distance and $\Delta p = 64 \text{ Pa}$

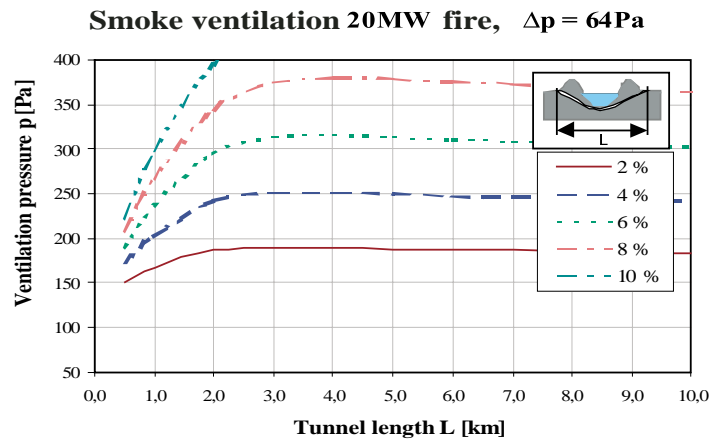


Figure D.24 Smoke ventilation 20 MW fire, increase over half distance and $\Delta p = 64 \text{ Pa}$

Applications and limitations

The calculation of convection pressure within the model assumes a reasonable gradient in order to provide a reasonable estimate. This is to say that the convection pressure must be considerably greater than the local pressure build-up (10–20 Pa for a fire of 5 MW in the tunnel). The thrust effects in the vicinity of the fire are ignored and the convection is calculated in accordance with the so-called chimney effect. In order to use the equation, the height difference throughout the length of the tunnel must not exceed that of the internal height. It may be assumed that the local build-up of pressure in the vicinity of the fire is in the order of 10–20 Pa, and comes in addition to the convection along the length of the tunnel. If the calculations yield a thrust pressure less than 50 Pa, then the thrust of 50 Pa, or 2 m/s as the ventilation speed is selected.

If the ventilation speed (v) is only slightly greater than the convection speed, then layering and bi-dimensional flow may occur in the tunnel with a tongue of smoke which goes against the direction of ventilation. This may be solved by introducing a safety factor, n_s , which is used to calculate the necessary thrust for the fans in equation 7.

Designing the fan capacity

Different tunnel configurations will result in different ventilation speeds (v). The required ventilation speed will increase with increasing gradient (I), increased fire effect (Q), increased external wind (u_{oo}), increased cross-section area (A), and increased tunnel length (L).

The thrust, P_v is calculated in equation 7 where the recommended safety factor, n_s , is 1.1.

Equation (7):

$$P_v = \frac{n_s}{n_v} [\Delta p_s] A \text{ [N]}$$

where

P_v [N] applied thrust from ventilation (designed thrust)

Δp_s [Pa] applied thrust from ventilation when the fire has been brought under control with speed u (after dynamic forces have been controlled)

n_s [-] safety factor for the calculations

n_v [-] level of effect of the fans

A [m²] cross-section area of the tunnel

Calculated examples:

Tunnel with regular ascent

Fire:	5 MW
Tunnel length:	1 km
Tunnel cross-section:	50 m ²
Tunnel gradient:	6 %
Equal temperature inside and outside the tunnel:	20 °C
External wind:	5 m/s
Effect level of fans:	0.72

Natural pressure in the tunnel from equation (6):

$$r_{20} = 1.01 \cdot 10^5 / 287 / (273 + 20) = 1.2 \text{ kg/m}^3$$

$$DH = 0.06 \cdot 1000 = 60 \text{ m}$$

$$\Delta p = \frac{1}{2} [1.2] 5^2 + (1.2 - 1.2) [9.8] 60 = 15 \text{ Pa}$$

The ventilation speed is given in Figure D.9 ($\Delta p = 16$ Pa or approx. 15 Pa) as 3.2 m/s and necessary pressure in Figure D.10 at 80 Pa (which exceeds the minimum 50 Pa).

The required thrust is given by equation (7)

$$P_V = \frac{n_s}{n_v} [\Delta p_s] A = \frac{1,1}{0,72} [80] 50 = 6111 N$$

Tunnel with downhill and uphill gradient (typical sub-sea tunnel)

Fire:	5 MW
Tunnel length:	6 km
Tunnel cross-section:	50 m ²
Tunnel gradient:	8 %
Height difference entrance to exit:	0 m
Temperature inside:	10 °C
Temperature outside:	0 °C
External wind:	5 m/s
Effect of fans:	0.72

Natural pressure in the tunnel from equation (6)

$$r_0 = 1,01 \cdot 10^5 / 287 / (273 + 0) = 1,29 \text{ kg/m}^3 \text{ og } r_{10} = 1,01 \cdot 10^5 / 287 / (273 + 10) = 1,24 \text{ kg/m}^3$$

$$\Delta p = \frac{1}{2} [1,29] 5^2 + (1,29 - 1,24) [9,8] 0 = 16 Pa$$

Ventilation speed is given in Figure D.13 as < 2 m/s and the necessary pressure in Figure D.14 as 100 Pa (which is greater than the minimum 50 Pa)

The necessary thrust is given by equation (7)

$$P_V = \frac{n_s}{n_v} [\Delta P_s] A = \frac{1,1}{0,72} [100] 50 = 7639 N$$

Appendix E Mean annual temperatures and frost levels

KOMMUNE = County and
adm.district

t_m = mean annual temperature

F_2 = The annual amount of frost
that is statistically exceeded
once in a period of two years

F_5 = The annual amount of frost
that is statistically exceeded
once in a period of five years

F_{10} = The annual amount of frost
that is statistically exceeded
once in a period of ten years

F_{100} = The annual amount of frost
that is statistically exceeded
once in a period of one hun
dred years

TUNNELS APPENDIX E MEAN ANNUAL TEMPERATURES AND FROST LEVELS

KOMMUNE	TEMP.		FROSTMENGDE			
	t _m		F ₂	F ₅	F ₁₀	F ₁₀₀
	°C		h°C			

KOMMUNE	TEMP.		FROSTMENGDE			
	t _m		F ₂	F ₅	F ₁₀	F ₁₀₀
	°C		h°C			

01 ØSTFOLD						
0101 Halden	6,0	7 000	13 000	18 000	22 000	
0102 Sarpsborg	6,0	7 000	13 000	18 000	22 000	
0103 Fredrikstad	6,5	5 000	11 000	16 000	24 000	
0104 Moss	6,0	6 000	12 000	17 000	21 000	
0111 Hvaler	7,0	3 000	7 000	11 000	15 000	
0113 Borge	6,5	5 000	11 000	16 000	20 000	
0114 Verteig	6,0	7 000	13 000	18 000	22 000	
0115 Skjeberg	6,0	7 000	13 000	18 000	22 000	
0118 Aremark	5,0	10 000	16 000	21 000	25 000	
0119 Marker	5,0	12 000	18 000	23 000	28 000	
0121 Rømskog	4,5	14 000	20 000	25 000	30 000	
0122 Trøgstad	5,0	10 000	16 000	21 000	26 000	
0123 Spydeberg	5,0	10 000	16 000	21 000	26 000	
0124 Askim	5,5	10 000	16 000	21 000	26 000	
0125 Eidsberg	5,5	10 000	16 000	21 000	26 000	
0127 Skiptvet	5,5	10 000	16 000	21 000	26 000	
0128 Rakkestad	5,5	10 000	16 000	21 000	26 000	
0130 Tune	6,0	7 000	13 000	18 000	22 000	
0131 Rolvsøy	6,0	8 000	14 000	19 000	23 000	
0133 Kråkery	7,0	4 000	9 000	13 000	18 000	
0134 Onøy	6,5	5 000	7 000	16 000	20 000	
0135 Råde	6,0	6 000	12 000	17 000	21 000	
0136 Rygge	6,0	5 000	11 000	16 000	20 000	
0137 Våler	6,0	7 000	14 000	20 000	24 000	
0138 Hobøl	5,5	8 000	15 000	21 000	25 000	
02 AKERSHUS						
0211 Vestby	5,5	7 000	14 000	20 000	24 000	
0213 Ski	5,5	8 000	15 000	21 000	25 000	
0214 Ås	5,5	8 000	15 000	21 000	25 000	
0215 Frogn	5,5	8 000	15 000	21 000	25 000	
0216 Nesodden	5,5	8 000	15 000	21 000	25 000	
0217 Oppegård	5,5	8 000	15 000	21 000	25 000	
0219 Bærum	6,0	11 000	15 000	18 000	26 000	
0220 Asker	5,5	11 000	15 000	18 000	26 000	
0221 Aurskog-Holand	4,5	12 000	18 000	24 000	29 000	
0226 Sørum	4,5	12 000	18 000	24 000	29 000	
0227 Fet	5,0	11 000	18 000	24 000	28 000	
0228 Rellingen	5,0	11 000	18 000	24 000	28 000	
0229 Enebakk	5,0	11 000	18 000	24 000	28 000	
0230 Lørenskog	5,0	11 000	18 000	24 000	28 000	
0231 Skedsmo	4,5	12 000	19 000	25 000	29 000	
0233 Nittedal	7,0	14 000	21 000	27 000	31 000	
0234 Gjerdrum	4,0	15 000	22 000	28 000	32 000	
0235 Ullensaker	4,5	15 000	22 000	28 000	32 000	
0236 Nes	4,0	15 000	22 000	31 000	36 000	
0237 Eidevoll	4,0	17 000	23 000	30 000	35 000	
0238 Nannestad	4,0	16 000	22 000	29 000	34 000	
0239 Hurdal	4,0	16 000	22 000	29 000	34 000	
OSLO						
0301 Byområdet	6,0	10 000	14 000	17 000	25 000	
Boligeråder	5,0	12 000	16 000	19 000	27 000	
Marka	4,0	14 000	18 000	23 000	29 000	
04 HEDMARK						
0401 Hamar	4,0	18 000	25 000	32 000	39 000	
0402 Kongsvinger	4,0	18 000	25 000	34 000	39 000	
0412 Ringsaker	4,0	20 000	27 000	33 000	41 000	
0414 Vang	3,0	20 000	27 000	33 000	41 000	
0415 Løten	3,5	20 000	27 000	34 000	41 000	
0417 Stange	4,0	18 000	25 000	32 000	39 000	
0418 Nord-Odal	4,0	18 000	25 000	34 000	39 000	
0419 Sør-Odal	4,0	18 000	25 000	34 000	39 000	
0420 Eidskog	4,0	15 000	22 000	31 000	36 000	
0423 Grue	3,5	20 000	27 000	36 000	41 000	
0425 Åsnes	3,5	21 000	28 000	37 000	42 000	
0426 Våler	3,5	21 000	28 000	37 000	42 000	
0427 Elverum	3,0	23 000	30 000	39 000	44 000	
0428 Trysil	2,0	27 000	34 000	43 000	48 000	
0429 Åmot	2,5	26 000	32 000	42 000	47 000	
0430 Stor-Elvdal	2,0	26 000	32 000	43 000	49 000	
0432 Rendalen	2,5	25 000	30 000	42 000	48 000	
0434 Engerdal	1,0	29 000	34 000	46 000	52 000	
0436 Tolga	0,5	31 000	36 000	48 000	54 000	
0437 Tynset	0,5	32 000	37 000	49 000	55 000	
0438 Alvdal	1,0	28 000	33 000	45 000	51 000	
0439 Follid	0,5	30 000	36 000	48 000	53 000	
0441 Os	0,5	31 000	36 000	48 000	54 000	
05 OPPLAND						
0501 Lillehammer	4,0	23 000	30 000	36 000	44 000	
0502 Gjøvik	4,0	18 000	25 000	30 000	36 000	
0511 Dovre	1,5	30 000	37 000	42 000	53 000	
0512 Lesja	1,5	25 000	32 000	37 000	48 000	
0513 Skjåk	1,0	24 000	31 000	36 000	42 000	
0514 Lom	1,5	24 000	31 000	36 000	42 000	
0515 Vågå	2,0	26 000	34 000	39 000	44 000	
0516 Nord-Fron	4,0	18 000	24 000	30 000	36 000	
0517 Sel	2,0	26 000	34 000	40 000	44 000	
0519 Sør-Fron	2,5	26 000	34 000	40 000	44 000	
0520 Ringebu	3,0	24 000	32 000	38 000	42 000	
0521 Øyer	3,5	23 000	30 000	36 000	41 000	
0522 Gausdal	2,0	26 000	34 000	40 000	44 000	
0528 Østre Toten	4,0	18 000	24 000	30 000	36 000	
0529 Vestre Toten	3,5	20 000	26 000	32 000	38 000	
0532 Jevnaker	4,0	15 000	22 000	28 000	33 000	
0533 Lunner	3,0	16 000	23 000	29 000	34 000	

0534 Gran	3,0	17 000	23 000	30 000	35 000	
0536 Søndre Land	3,0	19 000	25 000	31 000	37 000	
0538 Nordre Land	2,5	22 000	28 000	34 000	40 000	
0540 Sør-Aurdal	2,5	20 000	28 000	34 000	39 000	
0541 Etnedal	1,0	26 000	34 000	40 000	45 000	
0542 Nord-Aurdal	1,5	25 000	33 000	39 000	44 000	
0543 Vestre Slidre	2,0	25 000	33 000	39 000	44 000	
0544 Øystre Slidre	2,0	25 000	33 000	39 000	44 000	
0545 Vang	2,5	25 000	33 000	39 000	44 000	
06 BUSKERUD						
0602 Drammen	5,5	13 000	20 000	25 000	29 000	
0604 Kongsberg	4,5	15 000	23 000	28 000	31 000	
0605 Ringsaker	4,5	16 000	23 000	29 000	34 000	
0612 Hole	4,5	16 000	23 000	29 000	34 000	
0615 Flå	2,0	21 000	30 000	36 000	41 000	
0616 Nes	2,0	26 000	35 000	41 000	46 000	
0617 Gol	1,5	25 000	34 000	40 000	45 000	
0618 Hemsedal	2,0	20 000	29 000	34 000	42 000	
0619 Ål	2,0	20 000	27 000	33 000	42 000	
0620 Hol	1,0	25 000	32 000	38 000	47 000	
0621 Sigdal	3,0	18 000	27 000	33 000	38 000	
0622 Kredsherad	3,5	17 000	25 000	31 000	35 000	
0623 Modum	5,0	16 000	23 000	28 000	31 000	
0624 Øvre Eiker	4,5	15 000	22 000	28 000	31 000	
0625 Nedre Eiker	5,0	14 000	21 000	27 000	30 000	
0626 Lier	5,5	13 000	19 000	23 000	29 000	
0627 Røyken	5,5	10 000	16 000	20 000	26 000	
0628 Hurum	6,0	8 000	14 000	18 000	24 000	
0631 Flesberg	3,5	20 000	27 000	32 000	36 000	
0632 Røling	3,0	20 000	27 000	32 000	36 000	
0633 Nore og Uvdal	1,5	24 000	32 000	38 000	44 000	
07 VESTFOLD						
0701 Borre	6,5	5 000	10 000	15 000	20 000	
0702 Holmestrand	6,0	7 000	13 000	18 000	22 000	
0705 Tønsberg	6,5	4 000	9 000	14 000	19 000	
0706 Søndefjord	6,5	4 000	10 000	15 000	19 000	
0709 Larvik	6,5	4 000	9 000	14 000	17 000	
0711 Svelvik	6,0	10 000	17 000	22 000	26 000	
0713 Sande	6,0	9 000	16 000	21 000	25 000	
0714 Hof	6,0	10 000	17 000	22 000	26 000	
0716 Våle	6,0	6 000	12 000	18 000	22 000	
0718 Rannes	5,5	7 000	14 000	19 000	23 000	
0719 Andebu	5,5	7 000	13 000	19 000	23 000	
0720 Stokke	6,0	5 000	11 000	16 000	20 000	
0722 Nøtterøy	6,5	4 000	9 000	14 000	19 000	
0723 Tjøme	7,0	3 000	7 000	11 000	15 000	
0728 Lardal	5,5	7 000	14 000	19 000	23 000	
08 TELEMARK						
0805 Porsgrunn	6,0	10 000	15 000	18 000	22 000	
0806 Skien	5,0	11 000	16 000	21 000	25 000	
0807 Notodden	3,5	13 000	19 000	27 000	29 000	
0811 Siljan	5,5	10 000	16 000	21 000	25 000	
0814 Bamble	6,0	6 000	10 000	13 000	17 000	
0815 Kragere	6,0	4 000	8 000	11 000	15 000	
0817 Drangedal	5,5	10 000	16 000	20 000	25 000	
0819 Nome	11,0	16 000	22 000	28 000	34 000	
0821 Bø	4,0	12 000	17 000	23 000	26 000	
0822 Sauherad	4,5	13 000	18 000	25 000	27 000	
0826 Tinn	2,0	25 000	31 000	37 000	41 000	
0827 Hjertdal	2,5	15 000	21 000	27 000	31 000	
0828 Seljord	3,5	15 000	18 000	24 000	27 000	
0829 Kviteseid	5,0	12 000	17 000	21 000	25 000	
0830 Nissedal	5,5	10 000	15 000	20 000	25 000	
0831 Fyresdal	5,0	10 000	14 000	19 000	23 000	
0833 Tokke	5,0	11 000	16 000	20 000	24 000	
0834 Vinje	2,0	20 000	26 000	32 000	36 000	
09 AUST-AGDER						
0901 Risør	6,5	2 000	6 000	9 000	13 000	
0903 Arendal	7,0	1 000	5 000	8 000	12 000	
0904 Grimstad	7,0	1 000	5 000	8 000	12 000	
0911 Gjerstad	6,0	5 000	10 000	14 000	19 000	
0912 Vegårshei	6,0	5 000	9 000	12 000	16 000	
0914 Tvedestrand	6,5	2 000	6 000	9 000	13 000	
0918 Moland	7,0	1 000	5 000	8 000	12 000	
0919 Froland	6,0	5 000	9 000	13 000	16 000	
0920 Øystad	7,0	1 000	5 000			

ROAD TUNNELS APPENDIX E MEAN ANNUAL TEMPERATURES AND FROST LEVELS

KOMMUNE	TEMP.		FROSTMENGDE			
	t _m		F ₂	F ₅	F ₁₀	F ₁₀₀
	°C		h°C			

1017 Songdalen	6,0		5 000	9 000	13 000	16 000
1018 Søgne	7,0		1 000	6 000	9 000	12 000
1021 Marnardal	6,5		4 000	9 000	12 000	15 000
1026 Åseral	5,0		6 000	10 000	14 000	17 000
1027 Audnedal	5,0		5 000	10 000	13 000	16 000
1029 Lindsnes	7,0		1 000	6 000	9 000	12 000
1032 Lyngdal	6,5		1 000	6 000	9 000	12 000
1034 Hegebostad	5,5		4 000	9 000	12 000	15 000
1037 Kvinesdal	5,5		4 000	9 000	12 000	15 000
1046 Sirdal	4,5		4 000	9 000	12 000	15 000

11 ROGALAND

1101 Eigersund	7,5		0	3 000	6 000	11 000
1102 Sandnes	7,5		0	2 000	3 000	7 000
1103 Stavanger	7,5		0	2 000	3 000	7 000
1106 Haugealand	7,5		0	1 000	3 000	6 000
1111 Sokndal	7,0		0	3 000	6 000	11 000
1112 Lund	6,5		1 000	5 000	8 000	12 000
1114 Bjerkreim	6,5		1 000	5 000	8 000	12 000
1119 Hå	7,5		0	1 000	3 000	7 000
1120 Klepp	7,0		0	1 000	3 000	7 000
1121 Time	7,0		0	2 000	3 000	7 000
1122 Gjesdal	6,0		1 000	4 000	7 000	12 000
1124 Sole	7,5		0	1 000	3 000	7 000
1127 Randaberg	7,5		0	2 000	3 000	7 000
1129 Forsand	7,0		1 000	5 000	7 000	12 000
1130 Strand	7,5		0	2 000	3 000	7 000
1133 Hjeltnes	6,5		1 000	4 000	7 000	12 000
1134 Suldal	5,0		5 000	10 000	14 000	17 000
1135 Sauda	6,0		4 000	8 000	11 000	15 000
1141 Finøy	7,5		0	1 000	3 000	7 000
1142 Rennesøy	7,5		0	1 000	3 000	6 000
1144 Kvitsøy	7,5		0	1 000	2 000	6 000
1145 Bokn	7,5		0	1 000	3 000	6 000
1146 Tysvær	7,5		0	2 000	3 000	7 000
1149 Karmøy	7,5		0	1 000	3 000	6 000
1151 Utsira	7,5		0	0	1 000	2 000
1154 Vindafjord	7,5		0	2 000	3 000	7 000

12 HORDALAND

1201 Bergen	7,5		0	2 000	3 000	5 000
1211 Etne	6,0		2 000	5 000	8 000	13 000
1214 Øien	7,0		0	2 000	4 000	7 000
1216 Sveio	7,5		0	2 000	4 000	7 000
1219 Bømlo	7,5		0	1 000	2 000	5 000
1221 Stord	7,5		0	1 000	2 000	5 000
1222 Fitjar	7,5		0	1 000	2 000	5 000
1223 Tysnes	7,5		0	1 000	2 000	5 000
1224 Kvinnherad	6,5		1 000	3 000	6 000	11 000
1227 Jondal	6,0		1 000	3 000	5 000	11 000
1228 Odda	5,5		5 000	8 000	11 000	16 000
1231 Ullensvang	5,0		6 000	8 000	11 000	17 000
1232 Eidfjord	5,0		6 000	8 000	11 000	17 000
1233 Ulvik	5,0		9 000	11 000	14 000	20 000
1234 Granvin	5,0		8 000	10 000	13 000	19 000
1235 Voss	4,5		10 000	14 000	18 000	24 000
1238 Kvam	6,0		1 000	3 000	5 000	11 000
1241 Fusa	6,0		1 000	2 000	4 000	8 000
1242 Samnanger	5,5		5 000	7 000	10 000	15 000
1243 Os	6,5		1 000	2 000	5 000	8 000
1244 Austevoll	7,0		0	1 000	2 000	5 000
1245 Sund	7,0		0	1 000	2 000	5 000
1246 Fjell	7,0		0	1 000	2 000	5 000
1247 Askei	7,0		0	1 000	2 000	5 000
1251 Vaksdal	4,5		8 000	12 000	16 000	22 000
1252 Modalen	5,0		5 000	8 000	13 000	19 000
1253 Osterøy	7,0		2 000	4 000	6 000	9 000
1256 Meland	7,0		0	1 000	2 000	5 000
1259 Øygarden	7,5		0	1 000	2 000	5 000
1260 Rådei	7,0		0	1 000	2 000	5 000
1263 Lindås	6,5		1 000	3 000	5 000	7 000
1264 Austrheim	7,0		0	1 000	2 000	5 000
1265 Fedje	7,5		0	1 000	2 000	5 000
1266 Masfjorden	6,0		1 000	2 000	4 000	7 000

14 SOGN OG FJORDANE

1401 Flora	7,0		0	1 000	3 000	5 000
1411 Gulen	7,0		0	1 000	3 000	5 000
1412 Solund	7,0		0	1 000	3 000	5 000
1413 Hyllestad	7,0		0	1 000	3 000	5 000
1416 Høyanger	7,0		0	2 000	3 000	5 000
1417 Vik	6,5		1 000	3 000	4 000	6 000
1418 Balestrand	6,0		3 000	6 000	9 000	12 000
1419 Leikanger	6,5		1 000	4 000	7 000	10 000
1420 Sogndal	6,0		4 000	7 000	10 000	13 000
1421 Aurland	6,0		8 000	11 000	14 000	18 000
1422 Lerdal	6,0		5 000	9 000	11 000	15 000
1424 Årdal	4,5		8 000	12 000	14 000	18 000
1426 Luster	4,0		10 000	14 000	16 000	19 000
1428 Askvoll	7,0		0	1 000	3 000	5 000
1429 Fjaler	7,0		0	1 000	3 000	5 000
1430 Gauler	5,5		4 000	7 000	10 000	13 000
1431 Jølster	4,0		5 000	8 000	11 000	14 000
1432 Førde	5,5		4 000	7 000	10 000	13 000
1433 Naustdal	5,5		4 000	7 000	10 000	13 000
1438 Bremanger	7,0		0	1 000	3 000	5 000
1439 Vågsøy	7,0		0	1 000	3 000	5 000
1441 Selje	7,0		0	1 000	3 000	5 000
1443 Eid	6,0		3 000	4 000	6 000	8 000
1444 Hornindal	5,5		4 000	6 000	9 000	13 000
1445 Gloppen	6,0		2 000	3 000	5 000	7 000
1449 Strøm	5,5		4 000	6 000	9 000	13 000

KOMMUNE	TEMP.		FROSTMENGDE			
	t _m		F ₂	F ₅	F ₁₀	F ₁₀₀
	°C		h°C			

15 MØRE OG ROMSDAL

1502 Moide	6,0		0	2 000	3 000	5 000
1503 Kristiansund	7,0		0	1 000	2 000	5 000
1504 Ålesund	7,0		0	1 000	2 000	5 000
1511 Vanylven	6,0		0	1 000	3 000	5 000
1514 Sande	7,0		0	1 000	2 000	5 000
1515 Herøy	7,0		0	1 000	2 000	5 000
1516 Ulstein	7,0		0	1 000	2 000	5 000
1517 Hareid	7,0		0	1 000	2 000	5 000
1519 Volda	6,0		1 000	3 000	5 000	8 000
1520 Ørsta	6,0		1 000	3 000	5 000	8 000
1523 Ørskog	6,0		1 000	3 000	5 000	8 000
1524 Norddal	6,0		2 000	3 000	5 000	9 000
1525 Stranda	6,0		2 000	4 000	6 000	9 000
1526 Stordal	6,0		3 000	3 000	5 000	8 000
1528 Sykkylven	6,0		1 000	3 000	5 000	8 000
1529 Skodje	7,0		0	1 000	2 000	5 000
1531 Sula	7,0		0	1 000	2 000	5 000
1532 Giske	7,0		0	1 000	2 000	5 000
1534 Haram	7,0		0	1 000	2 000	5 000
1535 Vestnes	6,0		1 000	3 000	6 000	8 000
1539 Rauma	6,0		3 000	5 000	8 000	10 000
1543 Nesset	6,0		3 000	5 000	8 000	10 000
1545 Midsund	6,5		1 000	2 000	3 000	6 000
1546 Sandøy	7,0		0	1 000	2 000	5 000
1547 Aukra	7,0		0	1 000	2 000	5 000
1548 Frana	6,5		1 000	3 000	4 000	6 000
1551 Eide	6,5		1 000	2 000	3 000	6 000
1554 Averøy	6,5		1 000	2 000	3 000	6 000
1556 Frei	6,5		1 000	2 000	3 000	6 000
1557 Gjønnes	6,0		1 000	3 000	5 000	8 000
1560 Tingvoll	6,0		1 000	3 000	5 000	8 000
1563 Sunndal	5,5		4 000	7 000	11 000	14 000
1566 Sunndal	5,0		6 000	8 000	12 000	15 000
1567 Rindal	4,5		7 000	12 000	15 000	18 000
1569 Aure	5,5		1 000	3 000	6 000	8 000
1571 Halsa	5,5		1 000	3 000	6 000	8 000
1572 Tustna	5,5		1 000	3 000	4 000	6 000
1573 Smøla	5,5		0	1 000	2 000	5 000

16 SØR-TRØNDELAG

1601 Trondheim	5,0		7 000	12 000	14 000	16 000
1612 Hemne	5,5		5 000	7 000	10 000	12 000
1613 Snillfjord	5,5		4 000	6 000	9 000	11 000
1617 Hitra	6,0		1 000	2 000	3 000	6 000
1620 Freya	6,0		1 000	2 000	3 000	6 000
1621 Ørland	5,5		2 000	4 000	5 000	7 000
1622 Agdenes	5,5		2 000	4 000	5 000	7 000
1624 Rissa	5,5		4 000	6 000	8 000	11 000
1627 Bjugn	6,0		2 000	4 000	7 000	9 000
1630 Åfjord	5,5		2 000	4 000	7 000	9 000
1632 Roan	5,5		2 000	5 000	7 000	9 000
1633 Osøy	5,5		2 000	5 000	7 000	9 000
1634 Oppdal	2,0		14 000	20 000	23 000	26 000
1635 Rennebu	2,5		14 000	20 000	23 000	25 000
1636 Meldal	4,0		10 000	16 000	19 000	21 000
1638 Orkdal	5,0		6 000	11 000	13 000	15 000
1640 Røros	0,5		30 000	38 000	45 000	55 000
1644 Holtålen	1,5		14 000	21 000	23 000	27 000
1648 Midtre Gauldal	4,5		11 000	17 000	20 000	22 000
1653 Melhus	4,5		7 000	12 000	16 000	18 000
1657 Skaun	5,0		6 000	11 000	15 000	17 000
1662 Klæbu	4,5		7 000	12 000	16 000	18 000
1663 Malvik	5,0		6 000	11 000	13 000	15 000
1664 Selbu	4,0		10 000	15 000	19 000	21 000
1665 Tydal	2,0		14 000	19 000	23 000	27 000

17 NORD-TRØNDELAG

1702 Steinkjer	5,0		8 000	12 000	15 000	19 000
1703 Namsos	5,0		6 000	9 000	12 000	15 000
1711 Meråker	3,0		10 000	15 000	20 000	23 000
1714 Steiervold	5,0		6 000	10 000	13 000	17 000
1717 Frøsta	5,5		6 000	9 000	12 000	15 000
1718 Leksvik	5,5		6 000	9 000	12 000	15 000
1719 Levanger	5,0		6 000	10 000	13 000	17 000
1721 Verdal	5,0					

ROAD TUNNELS APPENDIX E MEAN ANNUAL TEMPERATURES AND FROST LEVELS

KOMMUNE	TEMP.		FROSTMENGDE			
	t _m		F ₂	F ₅	F ₁₀	F ₁₀₀
	°C		h°C			
1818 Herøy	5,5		2 000	4 000	7 000	11 000
1820 Alstahaug	5,5		1 000	4 000	7 000	13 000
1822 Leirfjord	5,0		3 000	6 000	9 000	15 000
1824 Vefsn	3,5		13 000	16 000	21 000	27 000
1825 Grane	2,5		18 000	23 000	28 000	32 000
1826 Hattfjelldal	1,5		26 000	32 000	37 000	42 000
1827 Dønna	5,5		2 000	4 000	7 000	11 000
1828 Nesna	5,5		2 000	4 000	7 000	11 000
1832 Hemnes	3,0		18 000	23 000	29 000	37 000
1833 Rana	3,0		16 000	18 000	25 000	35 000
1834 Lurøy	5,5		2 000	4 000	8 000	13 000
1835 Trana	6,0		0	1 000	2 000	6 000
1836 Rødøy	5,0		3 000	5 000	10 000	15 000
1837 Meløy	5,0		3 000	5 000	10 000	15 000
1838 Gildeskål	5,0		2 000	4 000	9 000	14 000
1839 Beiarn	3,5		10 000	13 000	18 000	24 000
1840 Saltdal	2,0		18 000	22 000	28 000	37 000
1841 Fauske	3,5		14 000	17 000	22 000	28 000
1842 Skjerstad	4,0		10 000	13 000	18 000	24 000
1845 Sørfold	4,0		10 000	13 000	18 000	24 000
1848 Steigen	4,5		4 000	6 000	10 000	15 000
1849 Hamarøy	4,0		7 000	9 000	13 000	18 000
1850 Tysfjord	3,5		10 000	13 000	18 000	24 000
1851 Lødingen	4,0		7 000	10 000	13 000	18 000
1852 Tjeldsund	4,0		8 000	11 000	14 000	19 000
1853 Evensen	5,0		9 000	11 000	15 000	21 000
1854 Ballangen	3,5		10 000	13 000	17 000	24 000
1856 Røst	5,5		0	1 000	2 000	6 000
1857 Verøy	5,5		0	1 000	2 000	6 000
1859 Flakstad	5,0		1 000	3 000	5 000	12 000
1860 Vestvågøy	5,0		3 000	5 000	8 000	14 000
1865 Vågan	5,0		3 000	5 000	8 000	14 000
1866 Hadsel	4,5		4 000	6 000	9 000	15 000
1867 Bø	4,5		3 000	4 000	7 000	14 000
1868 Øksnes	4,5		3 000	4 000	7 000	15 000
1870 Sortland	4,5		4 000	6 000	9 000	16 000
1871 Andøy	4,0		4 000	5 000	8 000	16 000
1874 Moskenes	5,0		1 000	3 000	5 000	12 000
19 TROMS						
1901 Herstad	4,5		5 000	7 000	10 000	16 000
1902 Tromsø	3,5		10 000	13 000	16 000	21 000
1911 Kvaefjord	4,5		7 000	9 000	12 000	18 000
1913 Skånland	4,0		8 000	10 000	13 000	19 000
1915 Bjerkeøy	4,5		6 000	8 000	10 000	16 000
1917 Ibestad	4,5		7 000	9 000	12 000	18 000
1919 Grøtangen	3,5		11 000	14 000	18 000	25 000
1920 Lavangen	3,5		12 000	15 000	19 000	26 000
1922 Bardu	2,0		27 000	29 000	36 000	47 000
1923 Salangen	3,5		12 000	15 000	19 000	26 000
1924 Målselv	2,0		27 000	29 000	36 000	47 000
1925 Sørrisa	3,0		12 000	16 000	19 000	26 000
1926 Dyrøy	3,5		11 000	15 000	18 000	25 000
1927 Tranøy	3,5		10 000	14 000	17 000	24 000
1928 Torsken	3,5		8 000	11 000	14 000	20 000
1929 Berg	3,5		10 000	13 000	16 000	21 000
1931 Lenvik	3,5		11 000	15 000	18 000	25 000
1933 Børsfjord	3,0		15 000	18 000	22 000	29 000
1936 Karlsøy	4,0		8 000	11 000	15 000	19 000
1938 Lyringen	3,0		17 000	21 000	25 000	31 000
1939 Storfjord	2,0		23 000	26 000	30 000	42 000
1940 Råfjord	2,0		23 000	26 000	30 000	42 000
1941 Skjervøy	3,5		10 000	14 000	19 000	24 000
1942 Nordreisa	2,0		23 000	26 000	30 000	42 000
1943 Kvanangen	2,0		25 000	28 000	32 000	44 000
20 FINNMARK						
2001 Hammerfest	2,0		15 000	18 000	21 000	32 000
2002 Vardø	1,0		17 000	23 000	26 000	33 000
2003 Vadsø	1,0		18 000	25 000	29 000	37 000
2011 Kautokeino	-2,0		51 000	56 000	65 000	76 000
2012 Alta	1,5		25 000	28 000	32 000	44 000
2014 Loppa	2,5		10 000	13 000	16 000	27 000
2015 Hasvik	3,0		8 000	11 000	14 000	25 000
2016 Sørøyund	3,0		9 000	12 000	15 000	26 000
2017 Kvalsund	2,0		18 000	21 000	26 000	37 000
2018 Måsøy	2,0		13 000	16 000	20 000	30 000
2019 Nordkapp	2,5		12 000	15 000	19 000	29 000
2020 Porsanger	1,5		30 000	33 000	37 000	49 000
2021 Karasjok	-1,5		52 000	57 000	69 000	78 000
2022 Lebesby	1,5		25 000	28 000	33 000	44 000
2023 Gamvik	1,5		17 000	20 000	24 000	34 000
2024 Berlevåg	1,5		18 000	24 000	28 000	35 000
2025 Tena	0,5		30 000	33 000	38 000	49 000
2027 Nesseby	1,0		30 000	35 000	40 000	49 000
2028 Sáttfjord	1,0		18 000	25 000	28 000	36 000
2030 Sør-Varanger	0,5		31 000	35 000	43 000	50 000