Tunnels: Design and Construction. Water and frost protection

1 Purpose and scope

This chapter sets requirements for the design of water and frost protection structures.

2 Water and frost protection structures

2.1 Functional requirements for water and frost protection

a) Water leaking into tunnels must be prevented from freezing and directed into the drainage system.

b) In the frost zone, the tunnel must have an insulated cladding that prevents water from dripping and ice from forming.

c) The frost-free section must be equipped with water protection that ensures that there is no dripping water.

d) The water protection must cover the full length of the tunnel, and the tunnel's cross-section above the bed.

2.2 Technical service life

> Technical service life is the time it takes until components or equipment no longer fulfil their intended function. Technical service life (TSL) requirements are expressed in the number of years that are expected to be achieved with a probability of at least 90%. The average value of the technical service life is expected to be at least 25% greater than the required service life.

The technical service life requirement applies to the entire system. It is assumed that certain components can be maintained or replaced during the specified technical service life.

a) For the purposes of designing the water and frost protection solutions, the structure has a technical service life equivalent to 80 years.

b) The life-cycle cost must be calculated over a period equivalent to the technical service life.

A reduced technical service life may be used as a basis if this is justified with a life-cycle cost. The life-cycle cost must be calculated over a period equivalent to the required technical service life of the water and frost protection structure. Traffic costs associated with tunnel closure for maintenance and replacement work must also be included.

2.3 Types of structure

The following types of structure may be used:

- Arch of concrete slabs
- Arch of PE foam, with fire protection of reinforced sprayed concrete
- Spray-on membrane (only as waterproofing)

Different types of structures may be chosen for different parts of the tunnel.

2.3.1 Cavity behind the water and frost protection structure

a) Stability measures must fitted at such a level as to render routine inspection and cleaning unnecessary.

b) Where the structure prevents visual inspection from the tunnel, one of the following requirements must be satisfied:

- Provision must be made to allow remote inspection
- The structure must be designed for ekstrem blokklast

2.4 Design of frost insulation

2.4.1 General

a) The frost insulation must be designed in accordance with the frost level at a site.

b) For the purpose of determining design criteria, the frost level used as a basis must be F_{100} (h°C). F_{100} is defined as the frost level that is statistically exceeded once during a period of 100 years.

A map of frost levels may be found in Underbygning/Prosjektering og bygging/Frost.

c) The frost level inwards along a tunnel must be evaluated on an individual basis.

In cases where a lower frost level can be documented inwards along a tunnel, the frost level inside the tunnel may be used as a basis for reducing the thickness of insulation, F_{100T} (h°C).

Local conditions may create frost levels greater than F_{100} stated in Underbygning/Prosjektering og bygging/Frost. The frost levels used for design purposes should therefore ideally be based on local measurements.

2.5 Additional requirements

2.5.1 Protective earthing

a) Each case must be evaluated on an individual basis to determine whether special measures are necessary in order to meet earthing requirements, e.g. where segmentation has been carried out. Cf. Felles elektro/Prosjektering og bygging/Jording.

2.5.2 Sealing

a) The structures must be designed to withstand the high suction and compression forces that are caused by passing trains, cf. laster.

2.5.3 Methods of waterproofing

a) For arches of concrete slabs, a full-cover membrane with welded seams must generally be used. The membrane may be in the form of an unreinforced or reinforced PVC membrane, PE membrane or PP membrane. These must satisfy the requirements in Statens vegvesens Håndbok -163 “Vann- og frostsikring i tunneler”.

If the structure is built with its own outer cladding (against the rock) that provides a level of waterproofing equivalent to that of a membrane, the requirement for a full-cover membrane does not apply.

2.5.4 Choice of membrane

The choice of membrane is determined by the type of use and practical functional requirements. Factors to be considered would be method of assembly, weight, strength requirements, details, and whether modifications or inspections are necessary. Unreinforced and reinforced membranes may require different technical solutions for details such as penetrations or modifications.

a) Seams in membranes must be hot welded. All of the installation's seams must be double welded. Single welds may be used for waterproofing around details.

b) Double welds may be tested for leaks using compressed air.

Overlap welding may be accepted for welds carried out by the supplier in the factory, provided that their strength and watertightness can be documented. The minimum effective width of an overlap weld must be 30 mm.

c) During tensile testing, the welded membrane must not break at the weld, but to one side of it. No delamination of the weld or membrane may occur during testing.

d) The membrane must be stored and handled in accordance with the supplier's instructions (e.g. UV protection, protection against damp ingress, etc.).

2.5.5 Bolts and fixing details

a) Supporting anchor bolts must be securely anchored to rock.

b) Following installation, anchors must be tested in accordance with test procedures specified in NS-ISO-2859 ”Prosedyre for prøvetaking for attributtkontroll”.

c) Only bolts with rolled threads may be used.

d) Bolts with nuts and washers subject to pulsating loads must be secured in such a way that the nuts cannot come loose.

e) The minimum corrosion protection for anchor bolts and steel fixing details must be hot dip galvanising materialkrav betong- og stålkonstruksjoner.

f) The minimum bolt diameter must be 16 mm. The minimum corrosion protection for these bolts must be hot dip galvanising as follows:

- Average thickness 55 µm
- Minimum local thickness 50 µm

e) The minimum corrosion protection for 20 mm diameter bolts must be:

- Average thickness 71 µm
- Minimum local thickness 65 µm

g) In special high-corrosion environments, all bolts must also be powder coated with epoxy.

2.5.6 Arch of concrete slabs

a) Concrete with a quality of B45 SV-40 must be used, in accordance with Håndbok 026 fra Statens vegvesen, prosesskode 2, prosess 84.4.

b) The slabs must be positioned in relation to reference lines in the tunnel that are set out in accordance with NS 3463.

Prefabricated arches must have a tolerance no greater than that specified in **???**. Unless otherwise specified, a joint width of 20 mm must be used as a basis.

Horizontal location in relation to a secondary line ||

	+25
Vertical location in relation to a secondary line	
	+25

Tabell 1: Tolerances

Type of tolerance	Permitted tolerance (mm)
Width of joint	+12
Gap between joints both sides	+20

d) Watertightness against runoff must principally be ensured by the use of a full-cover membrane, cf. metode for vanntetting.

e) All joints must be watertight, as extra protection against leaks resulting from damage to the membrane, and to make them air-tight, thus preventing air changes.

f) Joints must be sealed in a two-stage process.

g) Joints must be sealed on the traffic side using a suitable grout.

h) Joints sealed in this way must also satisfy the following requirements:

- Absorb the specified tolerances
- Absorb movements in the joint as a result of temperature variations
- Tolerate temperature variations
- Tolerate suction and compression loads, in accordance with nyttelast.

2.5.7 Fireproofing with reinforced sprayed concrete

a) Tolerance requirements for thickness after spraying must be determined on an individual basis.

b) The thickness of the sprayed concrete must be 80 mm when mesh reinforcement is used.

c) The sprayed concrete must contain fine polypropylene fibres (PP fibres).

d) The tolerances must be taken into account when calculating design dimensions and dead load. This means using the maximum thickness to calculate dead weight and the minimum thickness to check design dimensions.

e) For structures with reinforcement mesh, the distance between the mesh and the insulating material must be a minimum of 25 mm. The top cover must be at least equivalent to durability class M45 and exposure class XC4 (NS-EN 206-1).

At reinforcement mesh joints, grouted steel components, etc., it may be necessary to increase thickness locally, in order to satisfy the top cover requirement.

f) The following factors must be regarded as particularly important when selecting material composition and application:

- Concrete with a reduced shrinkage potential must be used if possible
- The material composition selected for mesh reinforced sprayed concrete must ensure that reinforcement and fixing details are properly encased.
- Good curing conditions must be ensured.
- If membrane curing is used, at least l/m^2 must be used (2 layers).

f) In order to be able to absorb movements due to shrinkage and temperature variations, there must be transverse expansion joints. The distance between centres must take into account expected shrinkage and temperature conditions. The joints must be constructed so as to ensure that they maintain watertightness in the event of movement in the joints.

2.6 Frost-reduction solutions

Automatic frost gates are a potential solution that can reduce the need to protect tunnels from frost.

Controlling a tunnel's natural draught using longitudinal fan-driven ventilation should be avoided because of the high operating cost and limited opportunities to access these fans for maintenance.

2.7 Implementation

a) Production and installation must be organised in such a way that a defined portion of the tunnel is completed first, in order to be able to verify that procedures, methods and other conditions have worked in accordance with prerequisites, and that the specified requirements have been satisfied.

b) Full production and installation may only begin when any necessary corrective measures have been implemented.