

Tunnels: Design and Construction. Support

1 Purpose and scope

The chapter sets requirements for supports in tunnels, and requirements regarding materials for bolted and steel structures.

2 Support

a) The following factors must be regarded as particularly important when selecting the method and extent of supports:

- Properties of the rock mass
- Water leaks, frost level
 - Method of water and frost protection
- Volume of traffic and train speed
- Maintenance requirements

Where two tunnel bores are excavated in parallel, sufficient distance should be left between the working faces to allow the experience gained from one tunnel bore to be utilised in the other. The minimum distance between two tunnel bores is to be determined with respect to:

- Properties of the rock mass
- Excavation method
- Tunnel cross section
- Evacuation routes
- Other nearby structures

b) Geological surveys in accordance with the Q system must be carried out before any sprayed concrete is applied along the full tunnel length, and used as a basis for decisions on supports, as well as later documentation of the geology and implemented support. Registration and rock support must be carried out in accordance with [Statens vegvesens håndbok 021, Vegtunneler, tabell 7.1](#)

c) Sufficient time must be allocated to geological surveys during the construction phase.

d) All supports must be implemented in such a way that they can form part of the permanent support.

2.1 Scaling

a) Scaling must be carried out before any other supports are installed.

b) Scaling must be carried out after each blasting salvo.

c) As a general rule, mechanical scaling must always be followed by scaling using hand tools.

d) Where scaling has occurred as a result of rock pressure, limited scaling must be carried out, and the rock stabilised as quickly as possible with end anchored bolts, rock straps, nets and/or sprayed concrete.

2.2 Bolting

Main areas of application for bolts are:

Fractured rock: Support against rock slides/rock falls (spot bolting).

- Heavily fissured rock: Systematic bolting, usually in combination with other methods.
- Rock burst/high stress: Systematic bolting, usually in combination with fibre-reinforced sprayed concrete.
- Weakness zones: As one element in a larger concept, for example the use of sprayed concrete arches (spiling bolts and radial bolts).
- Tunnel entrance: Support with spiling bolts.

2.2.1 Implementation and testing

a) Bolt type, length, number, direction and location must ensure that the bolting stabilises the rock which is to be secured.

Main categories of bolt types:

- Anchored bolts
- Fully grouted bolts
- Combination bolts

For a description of bolt types, refer to [Statens vegvesens Håndbok 215 Fjellbolting](#).

b) End anchored bolts must not be used as permanent support, with the exception of areas of high rock stress.

c) Procedures must be drawn up for bolt testing. The scope of these tests may be determined in accordance with [Norsk Standard for stikkprøvekontroll, NS-ISO-2859 "Prosedyre for prøvetaking for attributtkontroll"](#).

Tests on grouted bolts may be performed using boltometer tests or by drilling the bolts out. If a bolt is drilled out, the entire bolt must be drilled out using core drilling equipment.

2.3 Rock straps

a) Rock straps must be used locally in combination with bolts in fractured rock, and as a supplement to sprayed concrete in particularly weak areas.

2.4 Sprayed concrete

a) When rock is reinforced with sprayed concrete, tests must be performed to ensure that the rock has been adequately cleaned before the sprayed concrete is applied.

b) Sprayed concrete must be applied when the surfaces are drip-dry, i.e. damp. Degreaser must be used if necessary. If degreaser is used, it must be given sufficient time to act before the cleaning procedure begins. Degreasing is particularly important if there has been a long interval between blasting and the start of support work.

c) If it is necessary to use sprayed concrete to temporarily support the rock, the rock must also be bolted afterwards. If the required survey of the rock surface was not performed before the sprayed concrete is applied, the bolting must be applied as systematic bolting.

d) In areas with clay-filled joints, in rock burst and where sprayed concrete has been used as an alternative to full lining, the sprayed concrete must have normal mesh or fibre reinforcement.

e) During the design phase, the following must be determined:

- Material quality
- Need for fibre or reinforcement, type and quantity
- Extent and thickness
- Method of ensuring that curing conditions are achieved
- Minimum thickness requirements

f) For reasons of durability/service life, the sprayed concrete must be applied at an average thickness of no less than 80 mm, and the addition of accelerators must be properly controlled.

g) Sprayed concrete must not be applied to surfaces with temperatures lower than + 2 °C. Sprayed concrete must be protected against frost until a minimum rigidity of 5 MPa has been achieved.

h) When reinforcement is used in sprayed concrete, the following consequences must be assessed:

- Induced stress
- Electrical circuits for signalling systems
- Touch hazard

2.5 Sprayed concrete arches

Sprayed concrete arches can be used as a permanent method of support in most cases, with the exception of isolated areas where concrete lining must be used.

a) Sprayed concrete arches must be created with the correct theoretical profile, and constructed at a sufficient thickness and with adequate reinforcement.

b) Sprayed concrete arches must have foundations.

Sprayed concrete arches may be either single-reinforced or double-reinforced.

Latticed arches may be used instead of double-reinforced sprayed concrete arches.

For a description of the design and implementation, see Norwegian Public Roads Administration Teknologirapport no 2538.

2.6 Full lining

Concrete lining may be used as a permanent means of support in the following instances:

- When passing extensive swelling clay zones with swelling pressure > 0.5 MPa, found using oedometer testing.
- Large unstable portions.
- Portions with critical top rock cover above a long section.
- Extensive shatter zones.

a) Each case must be assessed on an individual basis to determine whether reinforcement and anchoring is required, and whether the bed must be lined. For example, reinforcement/anchoring may be necessary if there is side pressure or if there are flat portions in the overhang.

b) The bed must be cleaned before it is lined.

c) A foundation must be constructed, in order to ensure a good transition between wall and bed. In special cases, it will also be necessary to line the tunnel bed.

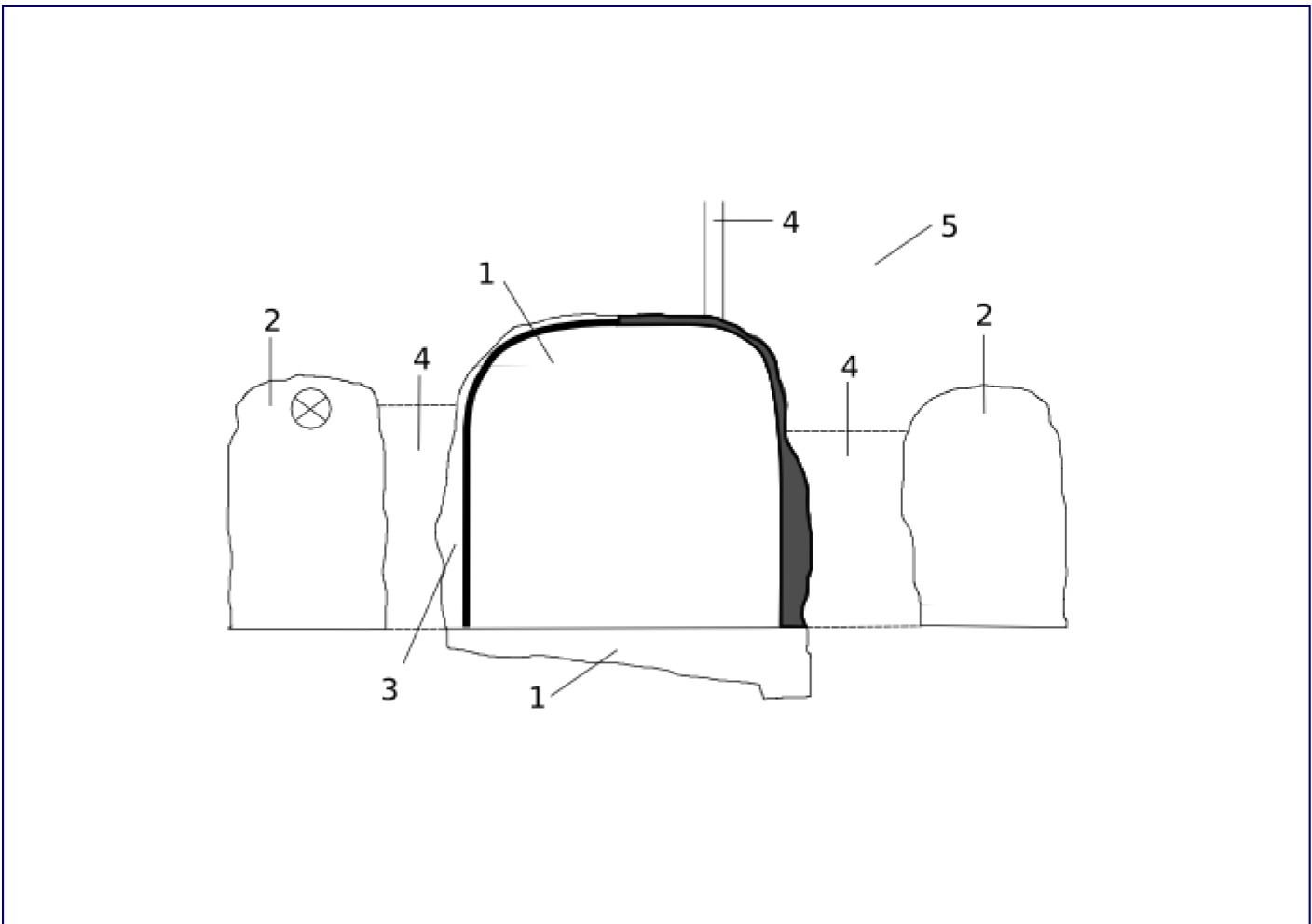
d) Tunnel face lining must leave room for any membrane insulation and new permanent casting, or for water and frost protection to be routed past the lining.

For a more detailed description of the design and implementation, see Norwegian Public Roads

3 Material requirements for concrete and steel structures

In general, refer to NS-EN 206-1, NS-EN 13670, NS 3576-3 and ISO 12944. The table below shows exposure and corrosion category requirements in accordance with the standards.

	Location on figure	Exposure category for carbonation/chloride corrosion	Exposure category for freezing/thawing	Corrosion category for construction steel
Location in tunnel installation				
Tunnel environment	1	XC4	XF3	C5-M
Heated and ventilated area (e.g. technical room)	2	XC2	-	C3
Area behind full-cover cladding	3	XC3	XF3	C4
Evacuation routes and other areas (e.g. ventilation shafts)	4	XC3	XF3	C4
Surrounding earth and rock				
Marine environment	5	XS3	XF4	Im3
Other environment	5	XC4	XF3	Im3
Surrounding water				
Fresh water	5	XC2	XF3	Im1
Salt- or brackish water	5	XS2	XF4	Im2



Figur 1: Sketch of tunnel

3.1 Bolts and rock straps

- a) Bolts used must be a minimum of 20 mm, steel quality B500NC, in accordance with the requirements in NS 3576-3.
- b) The bolts must be hot dip galvanised to a minimum of 65 μm in accordance with NS-EN ISO 1461, and powder coated with epoxy in accordance with prEN 13438.
- c) Base plates, hemispherical washers and nuts must have the same corrosion protection as the bolts.
- d) Rock straps must be powder coated with epoxy.

3.2 Sprayed concrete

3.2.1 General

- a) The selected material composition and design must be suitable for the area of application, and must ensure that the reinforcement and fixing details are properly grouted. It is also important that the material composition has reduced shrinkage properties.
- b) Materials and concrete production must satisfy the requirements of NS-EN 13670, with additional requirements in the Norwegian Concrete Association's Publication no 7 (NB7).
- c) Documentation of the rigidity class achieved must be provided in accordance with NS 3420.

d) Fibre type and dosage must satisfy energy absorption class E500, E700 or E1000.

3.2.2 Mesh-reinforced sprayed concrete

a) Tolerance requirements for thickness after spraying must be determined in each individual case, but as a minimum must satisfy durability category M45 and exposure category 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.

3.2.3 Finishing

a) Immediately after the sprayed concrete has been applied, membrane curing of a minimum of 0.5 l/m² must be applied.