Tunnels: Design and Construction. Loads

1 Purpose and scope

This chapter stipulates requirements for the design of loads on structures.

1.1 Structures for water and frost protection

1.2 General

Loads, limit states, symbols, etc. are generally defined in NS-EN 1991 Laster på konstruksjoner

For load factors and combination factors, refer to NS-EN 1990 Grunnlag for prosjektering av konstruksjoner.

Load coefficients are provided in dimensjonerende lastvirkning.

Loads are divided into four types:

- Permanent loads (dead load)
- Variable loads (utility load)
- Deformation loads
- Accident loads

a) The structures must satisfy the static and dynamic design criteria.

b) Structures and connections selected must be suitable for changing load effects/vibrations. This means performing calculations to show that there has been compliance with all the requirements described in the relevant structure standards and any special requirements described in these design rules.

c) Specified functional requirements must be documented. Documented long-term experience may replace theoretical documentation.

d) For conditions not automatically covered by Norwegian Standards or where the functional use has been significantly changed in relation to Norwegian Standards, a special assessment is required.

e) Calculations regarding the impact of temperature, shrinkage, creep, etc. must be performed in accordance with the construction standards specified.

f) The accident situation must be assessed as specified in ulykke.

g) Every case must be individually assessed to determine whether there are other loads occurring, or whether higher values for stated loads should be used.

For the design of loads, see Bruer/Prosjektering og bygging/Laster

1.3 Design load effect

The following limit states must be checked:

Ultimate limit state

a) For designing at the ultimate limit state, the loads must be multiplied by coefficients as stated in NS-EN 1990:2002/A1:2005+NA:2010, table NA.A2.4(A), NA.A2.4(B) og NA.A2.4(C). Combination factors ? are described in NS-EN 1990:2002/A1:2005+NA:2010, table NA.A2.3.

Serviceability limit state

a) For load coefficients at the serviceability limit state, use NS-EN 1990:2002/A1:2005+NA:2010, table NA.A2.6. Combination factors are described in NS-EN 1990:2002/A1:2005+NA:2010, table NA.A2.3.

Fatigue limit state

a) All loads that have an effect at this state are given the load factor 1.0.

b) Characteristic compression and suction loads are given in Tabell 2.

c) For single-track tunnels, the structure must be designed for the number of load cycles stated in Tabell 1.

d) For double-track tunnels, the structure must be designed independently of the train density for $1 \cdot 10^7$ load cycles. The cycle figure is an equivalent train density, where it has been taken into consideration that train crossings are highly significant.

Accidental limit state All loads here that have an effect at this state are given the load factor 1.0.

Tabell 1: Load cycles for single-track tunnel

Train density (number of trains per 24 hrs)	Number of load cycles
up to 50	$2 \cdot 10^6$
50-150	$5 \cdot 10^6$
over 150	$1 \cdot 10^7$

1.4 Payload

Compression and suction loads from train traffic

Compression and suction from traffic is a variable load.

a) The structure must be designed for compression/suction loads that affect the entire cross section.

Characteristic compression/suction loads are given in Tabell 2.

Tabell 2: Characteristic compression and suction loads

Load from train traffic	Single-track tunnel (kN/m^2)	Double-track tunnel (kN/m^2)
V = 200 km/h	±3	±4
200 < V = 250 km/h	±4	±5

Prerequisites:

- Single-track tunnel with 50-60 m^2 cross section
- Double-track tunnel with 90-100 m^2 cross section
- Ballasted track
- Fully insulated bed
- No pressure relief

b) The size of compression and suction loads must be given a close assessment if there is:

- Slab track
- Deviation from stipulated tunnel cross section
- Deviation from stipulated speed
- Funnel-shaped portal zones and/or shafts

Comfort criteria

When a train runs through a tunnel mouth, it creates a rapid change in pressure. In addition to the effect of this change, the pressure from the train will decrease from nose to tail as the train passes through the tunnel. These types of pressure changes may affect the comfort of train passengers. Major pressure changes inside a carriage may result in discomfort and, in extreme cases, cause injury to passengers and staff.

TSI medical criterion:

The European specification for the interoperability of high speed trains specifies the requirement that pressure changes must not exceed 10 kPa. This value applies even to a complete failure of the train's seals (e.g. broken window) and to two high-speed trains passing each other. For lower pressure changes, the comfort criteria are related to individual perception.

Requirement for pressure-resistant trains: 1.6 kPa/4s

Requirement for non-pressure-resistant trains:

- 3 kPa/4s (single-track tunnel)
- 4.5 kPa/4s (double-track tunnel)

General payload

a) The general payload must ensure an increased capacity of the structure in order to cope with conditions such as ice loads, fall loads and special conditions associated with compression/suction loads generated by traffic.

b) General payload is defined as variable load. Its size has been set to $q_g = 3{,}0\ kN/m^2$

c) The load must be calculated as an evenly distributed load, acting on the horizontal and/or vertical projection of the structure.

d) The load must be applied symmetrically and only on one half of the cross section.

For the design and calculation of payloads, refer to Bruer

Suspended load

Suspended loads are loads from the overhead contact line, signs and other equipment suspended in the structures. A suspended load is defined as a variable load.

Loads from ventilators are normally transferred to rock.

d) In addition to dead loads, wind loads resulting from wind pressure on equipment must also be taken into account.

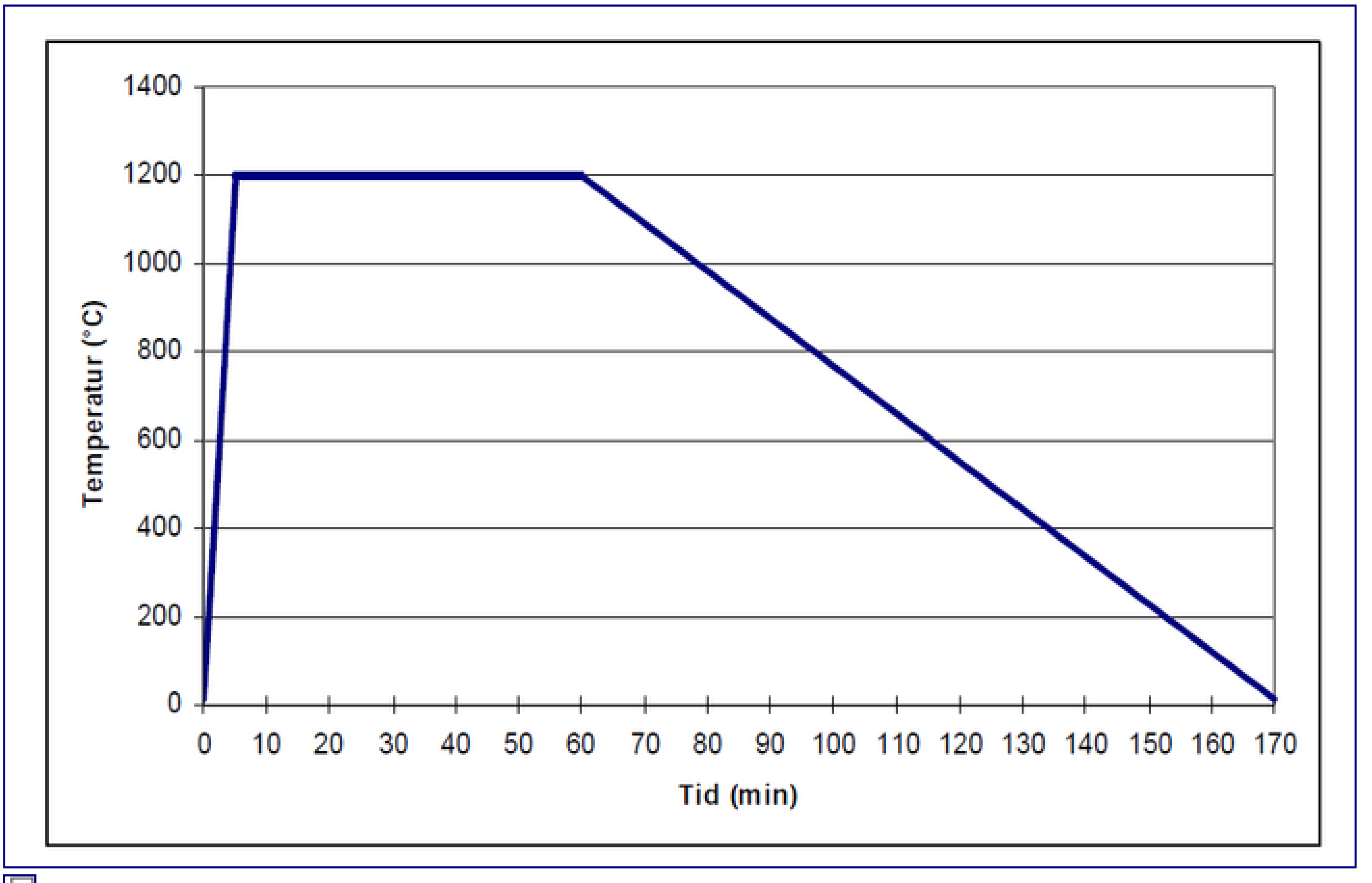
e) Wind loads must be calculated in accordance with tekniske installasjoner, vindlast på frittstående utstyr.

1.5 Accidents

a) An overall assessment must be carried out of the consequences and the effect of the structure in an accident situation. This also includes an assessment of consequences when parts of the structure are removed (collapse).

b) The structure must be designed so as to limit the scale of any damage to the scene of the accident.

c) In cases where tunnels may result in the collapse of important nearby structures, the tunnel's finished surface must resist the temperature of a fire for a given period that allows the threatened tunnel areas and nearby structures to be evacuated. This period of time must be clarified in the emergency response plan. The specified temperature/time curve (EUREKA curve) to assess the resistance of the tunnel is shown in the figure below. This must only be used for concrete structures.



Figur 1: Temperature-time curve (EUREKA-curve)

1.5.1 Extreme block load

If the water and frost protection structure makes it impossible to inspect the supporting main system, the structure must be designed for the load of an extreme block. The load is assumed to be vertical with a size of 60 kN.

2 Technical installations, wind load on free-standing equipment

2.1 General

a) All equipment installed in tunnels must be designed for dead loads and payloads from the wind loads generated by passing trains.

b) Each case must be individually assessed to determine whether other payloads occur.

c) The wind loads must be calculated on the basis of air speeds that occur. The air speed in the tunnel's longitudinal and transverse directions must be taken into account.

The following structures in tunnels are subject to wind loads:

- Overhead contact line and catenary suspension
- Signal lights
- Signs
- Light fittings

- Other structures

Wind load is a variable load.

d) Wind load on structures must be calculated in accordance with NS-EN 1991-1-4.

e) Force on the structural element must be calculated in accordance with NS-EN 1991-1-4, and the following equation must be used: F = c • q • A(N)

c is a form factor

overhead contact line:	c = 1.2
catenary suspension:	c = 0.9
sign/signal light:	c = 1.15
sign support:	c = 1.2

q is velocity pressure: $q = 0.5 \cdot ? \cdot U^2_{dim}$

- $? = 1,25\ kg/m^3$

A is the surface area of the structure

2.2 Air speed in the tunnel's longitudinal direction

Air speed in the longitudinal direction U_{dim} may be found in Figur 2. The blockage ratio, ß, is given as the relation of surface area between train and tunnel:

ß is the relation of surface area A_{tog}/A_{tun}

For double-track tunnels, the blockage ratio is given as:

$ß = (A_{tog1} + A_{tog2})/A_{tun}$

The wind velocity changes direction with each passing train.

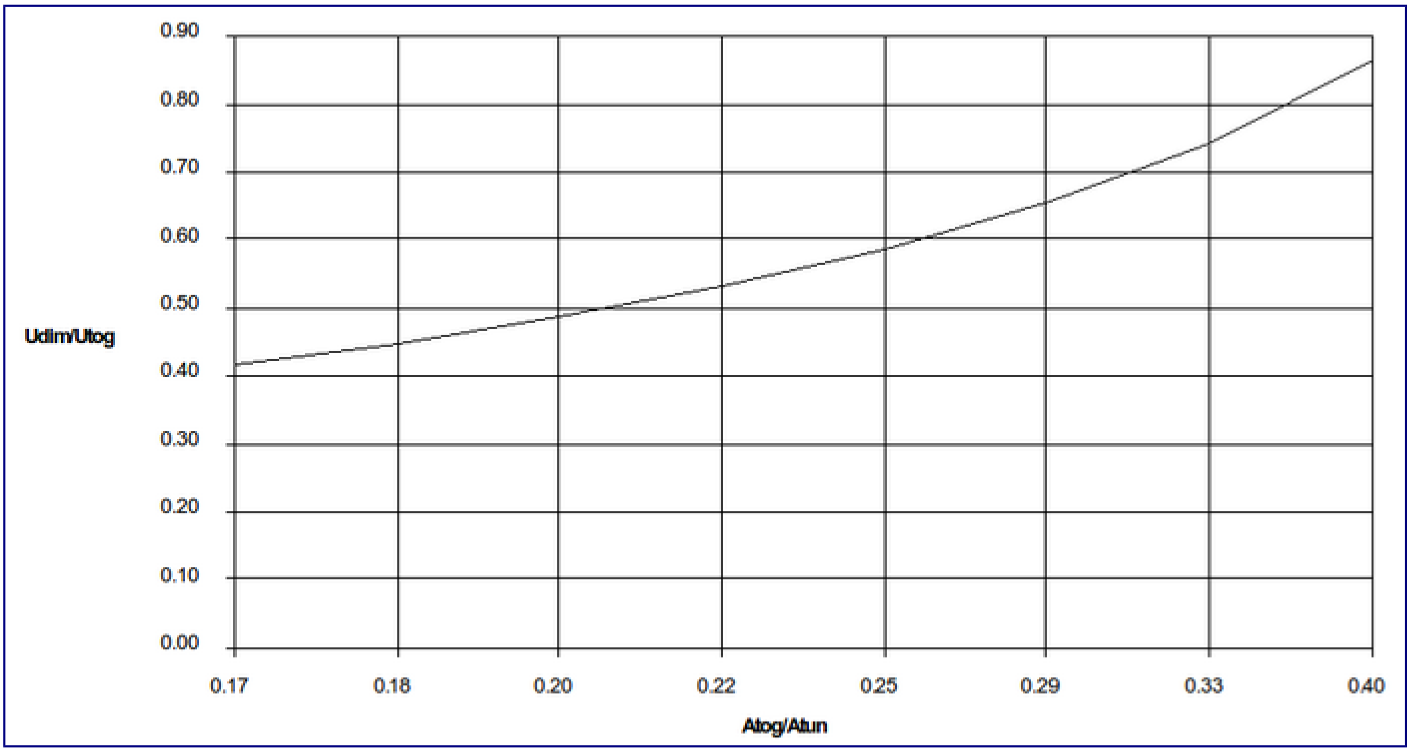
Figur 2 applies when the technical installations are no closer than 0.5 m from the smallest cross section, cf. chapter 5. For equipment installed closer than 0.5 m from the smallest cross section, the wind velocity increases in the direction of the train, linearly up to the speed of the train.

The wind velocity against the direction of the train must not increase.

The number of load cycles has been taken from Tabell 3. The table applies both to single and double-track tunnels.

Tabell 3: Load cycles for wind load on technical installations

Train density. Number of trains per 24 hour period.	**Number of load cycles**
Up to 50	$2 . 10^6$
50 – 150	$5 . 10^6$
More than 150	$1 . 10^7$



Figur 2: Maximum air speed in single and double-track tunnels

2.3 Air speed in the tunnel's transverse direction

a) The air speed in the transverse direction must be set equal to 30 % of train speed. This applies irrespective of the distance between train and technical installations.

b) The wind load must be calculated where it acts on a length of 10 m at each end of the train, as outward pressure from the train at the front and inward suction towards the train at the rear of the train.

The number of load cycles has been taken from Tabell 3.