EN 1991 – Actions on Bridges

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Brief review of the structure of EN 1991
- Selfweight and imposed loads
- Wind (Example of application)
- Thermal actions
- Actions during execution
- Settlements
- Accidental actions (impact loads)

Traffic loads
- Brief review
- General Load Models
- Fatigue Load Model 3 (Example of application)

Combinations of actions
- ULS and SLS
- Launching
- Seismic
It is reminded that according to EN 1991 the following should be considered:

- Selfweight and imposed loads
- Wind
- Thermal actions
- Actions during execution
- Accidental actions (impact loads)
- Traffic loads

There are also other actions described in EN 1991, such as fire and snow loads, which are considered as irrelevant for the example of bridge structure presented. Additional actions are foreseen in other EN Eurocodes, namely:

- Concrete creep and shrinkage (EN 1992)
- Settlements and earth pressures (EN 1997)
- Seismic actions (EN 1998)
### PARTS AND IMPLEMENTATION OF EN 1991

<table>
<thead>
<tr>
<th>Part of Eurocode 1: Actions on structures</th>
<th>Title (Subject)</th>
<th>Issued</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EN 1991-1-1</strong></td>
<td>General actions – Densities, self-weight, imposed loads for buildings</td>
<td>April 2002</td>
</tr>
<tr>
<td><strong>EN 1991-1-2</strong></td>
<td>General actions – Actions on structures exposed to fire</td>
<td>November 2002</td>
</tr>
<tr>
<td><strong>EN 1991-1-3</strong></td>
<td>General actions – Snow loads</td>
<td>July 2003</td>
</tr>
<tr>
<td><strong>EN 1991-1-4</strong></td>
<td>General actions – Wind actions</td>
<td>April 2005</td>
</tr>
<tr>
<td><strong>EN 1991-1-5</strong></td>
<td>General actions – Thermal actions</td>
<td>November 2003</td>
</tr>
<tr>
<td><strong>EN 1991-1-6</strong></td>
<td>General actions – Actions during execution</td>
<td>June 2005</td>
</tr>
<tr>
<td><strong>EN 1991-1-7</strong></td>
<td>General actions – Accidental actions</td>
<td>July 2006</td>
</tr>
<tr>
<td><strong>EN 1991-2</strong></td>
<td>Traffic loads on bridges</td>
<td>September 2003</td>
</tr>
<tr>
<td><strong>EN 1991-3</strong></td>
<td>Actions induced by cranes and machinery</td>
<td>July 2006</td>
</tr>
<tr>
<td><strong>EN 1991-4</strong></td>
<td>Silos and tanks</td>
<td>May 2006</td>
</tr>
</tbody>
</table>
• Forward
• Section 1 – General
• Section 2 – Classification of actions
• Section 3 – Design situations
• Section 4 – Densities of construction and stored materials
• Section 5 – Self-weight of construction works
• Section 6 – Imposed loads on buildings
• Annex A (informative) – Tables for nominal density of construction materials, and nominal density and angles of repose for stored materials.
• Annex B (informative) – Vehicle barriers and parapets for car parks
**ACTIONS : SELFWEIGHT**

**Structural parts:**
The density of structural steel is taken equal to 77 kN/m$^3$ [EN 1991-1-1, Table A.4]. The density of reinforced concrete is taken equal to 25 kN/m$^3$ [EN 1991-1-1, Table A.1]. The selfweight is determined based on the dimensions of the structural elements. For the longitudinal bending global analysis the selfweight of the in-span transverse cross girder is modelled by a uniformly distributed load of 1,5 kN/m applied to each main girder (about 10% of its own weight).

**Non-structural parts:**
The density of the waterproofing material and of the asphalt is taken as equal to 25 kN/m kN/m$^3$ [EN 1991-1-1, Table A.6]. According to [EN 1991-1-1, 5.2.3(3)] it is recommended that the nominal value of the waterproofing layer and the asphalt layer is multiplied by +/-20% (if the post-execution coating is taken into account in the nominal value) and by +40% / -20% (if this is not the case).
ACTIONS : SELFWEIGHT

- Safety barrier
- Concrete support for the safety barrier
- 8 cm thick asphalt layer
- Cornice
- 3 cm thick waterproofing layer
Non-structural parts (cont.):
The key data to evaluate the selfweight are summarized in the following table:

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristics</th>
<th>Maximum multiplier</th>
<th>Minimum multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete support of the safety barrier</td>
<td>Area 0,5 x 0,2 m</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Safety barrier</td>
<td>65 kg/ml</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Cornice</td>
<td>25 kg/ml</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Waterproofing layer</td>
<td>3 cm thick</td>
<td>1,2</td>
<td>0,8</td>
</tr>
<tr>
<td>Asphalt layer</td>
<td>8 cm thick</td>
<td>1,4</td>
<td>0,8</td>
</tr>
</tbody>
</table>
Non-structural parts (cont.):
The values of selfweight (as uniformly distributed load per main steel girder) are summarized in the following table:

<table>
<thead>
<tr>
<th>Item</th>
<th>$q_{nom}$ (kN/ml)</th>
<th>$q_{max}$ (kN/ml)</th>
<th>$q_{min}$ (kN/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete support of the safety barrier</td>
<td>2,5</td>
<td>2,5</td>
<td>2,5</td>
</tr>
<tr>
<td>Safety barrier</td>
<td>0,638</td>
<td>0,638</td>
<td>0,638</td>
</tr>
<tr>
<td>Cornice</td>
<td>0,245</td>
<td>0,245</td>
<td>0,245</td>
</tr>
<tr>
<td>Waterproofing layer</td>
<td>4,2</td>
<td>5,04</td>
<td>3,36</td>
</tr>
<tr>
<td>Asphalt layer</td>
<td>11,0</td>
<td>15,4</td>
<td>8,8</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>18,58</strong></td>
<td><strong>23,82</strong></td>
<td><strong>15,54</strong></td>
</tr>
</tbody>
</table>
EN 1991-1-4: WIND ACTIONS

- Forward
- Section 1 – General
- Section 2 – Design situations
- Section 3 – Modelling of wind actions
- Section 4 – Wind velocity and velocity pressure
- Section 5 – Wind actions
- Section 6 – Structural factor $c_s c_d$
- Section 7 – Pressure and force coefficients
- Section 8 – Wind actions on bridges
- Annex A (informative) – Terrain effects
- Annex B (informative) – Procedure 1 for determining the structural factor $c_s c_d$
- Annex C (informative) – Procedure 2 for determining the structural factor $c_s c_d$
- Annex D (informative) – $c_s c_d$ values for different types of structures
- Annex E (informative) – Vortex shedding and aeroelastic instabilities
- Annex F (informative) – Dynamic characteristics of structures
EXAMPLE OF APPLICATION
WIND ACTIONS ON BRIDGE DECK AND PIERS

Courtesy of GEFYRA S.A. (Rion – Antirion Bridge, Greece)
1. Introduction

The scope of the example handled is to present the wind actions and effects usually applied on a bridge, to both deck and piers. The following cases have been handled in the written text:

• Bridge during its service life, without traffic
• Bridge during its service life, with traffic
• Bridge under construction (finished and most critical case)

Two alternative pier dimensions:
• Squat piers of 10 m height and rectangular cross section 2,5 m x 5,0 m
• “High” piers of 40 m height and circular cross section of 4 m diameter
2. Brief description of the procedure

The general expression of a wind force $F_w$ acting on a structure or structural member is given by the following formula [Eq. 5.3]:

$$F_w = c_s \cdot c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref}$$

Where:
- $c_s \cdot c_d$ is the **structural factor** [6] (= 1.0 when no dynamic response procedure is needed [8.2(1)])
- $c_f$ is the **force coefficient** [8.3.1, 7.6 and 7.13, 7.9.2, respectively, for the deck, the rectangular and the cylindrical pier]
- $q_p(z_e)$ is the **peak velocity pressure** [4.5] at reference height $z_e$, which is usually taken as the height $z$ above the ground of the C.G. of the structure subjected to the wind action
- $A_{ref}$ is the **reference area** of the structure [8.3.1, 7.6, 7.9.1, respectively, for the deck, the rectangular and the cylindrical pier]
EXAMPLE OF APPLICATION
WIND ACTIONS ON BRIDGE DECK AND PIERS

2. Brief description of the procedure (continued)

The peak velocity pressure \( q_p(z) \) at height \( z \), includes the mean and the short-term (turbulent) fluctuations and is expressed by the formula [4.8]:

\[
q_p(z) = [1 + 7 \cdot I_v(z)] \cdot \frac{1}{2} \cdot \rho \cdot v_m^2(z) = c_e(z) \cdot q_b
\]

Where:

- \( \rho \) is the air density (which depends on the altitude, temperature and barometric pressure to be expected in the region during wind storms; the recommended value used is 1.25 kg/m\(^3\))
- \( v_m(z) \) is the mean wind velocity at a height \( z \) above the ground [4.3]
- \( I_v(z) \) is the turbulence intensity at height \( z \), defined [4.4(1)] as the ratio of the standard deviation of the turbulence divided by the mean velocity, and is expressed by the following formula [4.7]
- \( c_e(z) \) is the exposure factor at a height \( z \).
2. Brief description of the procedure (continued)

\[ I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z) \cdot \ln(z / z_0)} \]

\[ I_v(z) = I_v(z_{\text{min}}) \]

\[ \gamma \alpha \quad z_{\text{min}} \leq z \leq z_{\text{max}} \]

\[ \gamma \alpha \quad z < z_{\text{min}} \]

Where:

- \( k_I \) is the turbulence factor (NDP value). The recommended value, used in the example, is 1.0
- \( c_o(z) \) is the orography factor [4.3.3]
- \( z_0 \) is the roughness length [Table 4.1]
2. Brief description of the procedure (continued)

\[ v_m : \text{mean wind velocity at height } z \text{ above terrain} \]
\[ v_{mf} : \text{mean wind velocity above flat terrain} \]
\[ c_o = v_m / v_{mf} \]

\[ c_o = c_o(s) \]
2. Brief description of the procedure (continued)

The mean wind velocity $v_m (z)$ is expressed by the formula [4.3]:

$$v_m (z) = c_r (z) \cdot c_o (z) \cdot v_b$$

Where:

$c_r (z)$ is the **roughness factor**, which may be an NDP, and is recommended to be determined according to the following formulas [4.3.2]:

$$c_r (z) = k \cdot \ln \left( \frac{z}{z_0} \right)$$

for $z_{min} \leq z \leq z_{max}$

$$c_r (z) = c_r (z_{min})$$

for $z \leq z_{min}$
2. Brief description of the procedure (continued)

Where:

\[ z_0 \] is the roughness length \([Table 4.1]\)

\[ k_r \] terrain factor depending on the roughness length and evaluated according the following formula \([4.5]:\)

\[
k_r = 0.19 \left( \frac{z_0}{z_{0,II}} \right)^{0.07}
\]

with:

\[ z_{0,II} = 0.05 \text{ m (terrain category II, } [Table 4.1]) \]

\[ z_{min} \] is the minimum height defined in \([Table 4.1]\)

\[ z_{max} \] is to be taken as 200m
2. Brief description of the procedure (continued)

The basic wind velocity $v_b$ is expressed by the formula [4.1]:

$$v_b = (c_{prob}) \cdot c_{dir} \cdot c_{season} \cdot v_{b,0}$$

Where:
- $v_b$ is the basic wind velocity, defined at 10 m above ground of terrain category II.
- $v_{b,0}$ is the fundamental value of the basic wind velocity, defined as the characteristic 10 minutes mean wind velocity (irrespective of wind direction and season of the year) at 10 m above ground level in open country with low vegetation and few isolated obstacles (distant at least 20 obstacle heights).
- $c_{dir}$ is the directional factor, which may be an NDP; the recommended value is 1,0.
- $c_{season}$ is the season factor, which may be an NDP; the recommended value is 1,0.
2. Brief description of the procedure (continued)

In addition to that a probability factor $c_{prob}$ should be used, in cases where the return period for the design defers from $T = 50$ years. This is usually the case, when the construction phase is considered. Quite often also for bridges $T = 100$ is considered as the duration of the design life, which should lead to $c_{prob} > 1,0$.

The expression of $c_{prob}$ is given in the following formula [4.2], in which the values of $K$ and $n$ are NDPs; the recommended values are 0,2 and 0,5, respectively:

$$c_{prob} = \left( \frac{1 - K \cdot \ln(-\ln(1 - p))}{1 - K \cdot \ln(-\ln(0,98))} \right)^n$$
2. Brief description of the procedure (continued)

To resume:

To determine the wind actions on bridge decks and piers, it seems convenient to follow successively the following steps:

- Determine $v_b$ (by choosing $v_{b,0}$, $c_{dir}$, $c_{season}$ and $c_{prob}$, if relevant); $q_b$ may also be determined at this stage
- Determine $v_m (z)$ (by choosing terrain category and reference height $z$ to evaluate $c_r (z)$ and $c_o (z)$)
- Determine $q_p (z)$ (either by choosing directly $c_e (z)$, where possible, either by evaluating $l_v(z)$, after choosing $c_o (z)$)
- Determine $F_w$ (after evaluating $A_{ref}$ and by choosing $c_f$ and $c_s c_d$, if relevant)
Fig. 8.2 of EN 1991-1-4 (Directions of wind actions on bridges)
3. Numerical application

3.1 Bridge during its service life, **without traffic**
(“high” pier \( z = 40 \) m, wind transversally to the deck)

The fundamental wind velocity \( v_{b,0} \) is an NDP to be determined by each Member State (given in the form of zone/isocurves maps, tables etc.). For the purpose of this example the value \( v_{b,0} = 26 \) m/s (\( = v_b \), since in this case it is considered that \( c_{dir} = 1,0 \) and \( c_{season} = 1,0 \))

The corresponding (basic velocity) pressure may also be computed, according to [Eq. 4.10]:

\[
q_b = \frac{1}{2} \times 1,25 \times 262 = 422,5 \text{ N/m}^2 \text{ (Pa)}
\]
3. Numerical application (cont.)

In the present example a very flat valley will be considered with a roughness category II:
*low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights*

Concerning the **reference height** of the deck $z_e$, it may be considered more or less as equal to the mean distance $z$ between the centre of the bridge deck and the soil surface [8.3.1(6)]

$$Z_e = z$$
3. Numerical application (cont.)

For terrain category II:

<table>
<thead>
<tr>
<th>Terrain category</th>
<th>$z_0$ (m)</th>
<th>$z_{min}$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0,003</td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>0,01</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>0,05</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>0,3</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>1,0</td>
<td>10</td>
</tr>
</tbody>
</table>

thus: $k_r = 0,19 \cdot \left( \frac{z_0}{z_{0,II}} \right)^{0,07} = 0,19 \cdot \left( \frac{0,05}{0,05} \right)^{0,07} = 0,19$

and: $c_r (40) = 0,19 \cdot \ln \left( \frac{40,00}{0,05} \right) = 0,19 \cdot \ln 800 = 0,19 \cdot 6,6846 = 1,27$
3. Numerical application (cont.)

For a flat valley the orography factor $c_0(40) = 1,0$. Hence:

$v_m(40) = 1,27 \times 1,0 \times 26 = 33,02 \text{ m/s} \approx 33 \text{ m/s}$

The turbulence intensity is:

$I_v(40) = \frac{1,0}{1,0 \times \ln(40 / 0,05)} = \frac{1}{6,6846} = 0,15$

And

$q_p(40) = \left[1 + 7 \cdot 0,15\right] \times \frac{1}{2} \times 1,25 \times 33^2 = 2,05 \times 680,6 = 1395,28 \text{ in N/m}^2$

$c_e(40) = 2,05 \times 1,27^2 \times 1,0^2 = 2,05 \times 1,61 \times 1,0 = 3,30$

($= 1395,28 / 422,5 = q_p(40) / q_b$, [Eq. 4.9])
3. Numerical application (cont.)

[Fig. 4.2]

Exposure coefficient $c_e(z)$
(for $c_o=1,0$, $k_i=1,0$)
3. Numerical application (cont.)

Further calculations are needed to determine the wind force on the deck [5.3].

\[ F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \]

Both the force coefficient \( c_f \) and the reference area \( A_{ref} \) of the bridge deck [8.3.1] depend on the width to (total) depth ratio \( b/d_{tot} \) of the deck, where \( d_{tot} \) represents the depth of the parts of the deck which are considered to be subjected to the wind pressure.

In the case of the bridge in service, without consideration of the traffic, according to [8.3.1(4) and Table 8.1], \( d_{tot} \) is the sum of the projected (windward) depth of the structure, including the projecting solid parts, such as footway or safety barrier base, plus 0.3m for the open safety barrier BN4 in each side of the deck.
3. Numerical application (cont.)

<table>
<thead>
<tr>
<th>Road restraint system</th>
<th>on one side</th>
<th>on both sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open parapet or open safety barrier</td>
<td>$d + 0,3,m$</td>
<td>$d + 0,6,m$</td>
</tr>
<tr>
<td>Solid parapet or solid safety barrier</td>
<td>$d + d_1$</td>
<td>$d + 2d_1$</td>
</tr>
<tr>
<td>Open parapet and open safety barrier</td>
<td>$d + 0,6,m$</td>
<td>$d + 1,2,m$</td>
</tr>
</tbody>
</table>

*[Fig 8.5 & Table 8.1] Depth $d_{tot}$ to be used for $A_{ref,x}$*
3. Numerical application (cont.)
3. Numerical application (cont.)

Consequently:

\[ d_{tot} = 2.800 + 0.400 - 0.025 \times 2.500 + 0.200 + 2 \times 0.300 = 3.1375 + 0.200 + 0.600 = 3.9375 \approx 4.00 \, \text{m} \]

Hence:

\[ \frac{b}{d_{tot}} = \frac{12.00}{4.00} = 3 \quad \left(\frac{12.00}{3.94} \approx 3.05\right) \]

\[ A_{ref} = d_{tot} \cdot L = 4.00 \times 200.00 = 800.00 \, \text{m}^2 \]

\[ c_{fx,0} \approx 1.55 \quad \text{[Fig. 8.3]} \]

\[ c_{fx} = c_{fx,0} \approx 1.55 \quad \text{[Eq. 8.1]} \]

Finally:

\[ F_w = 1.0 \times 1.55 \times 1395.28 \times 800.00 = 2162.68 \times 800.00 = 1730147 \, \text{N} \approx 1730 \, \text{kN} \]

Or “wind load” in the transverse (x-direction): \( w = 1730/200 \approx 8.65 \, \text{kN/m} \)
EXAMPLE OF APPLICATION
WIND ACTIONS ON BRIDGE DECK AND PIERS

[Fig. 8.3] Force coefficient $c_{fx,0}$ for bridges
3. Numerical application (cont.)

Simplified Method [8.3.2]

Formula [5.3] is slightly modified as follows:

\[ F_w = \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x} \]

Where the force factor \( C = c_e \cdot c_{f,x} \) is given in [Tab. 8.2]

<table>
<thead>
<tr>
<th>( b/d_{tot} )</th>
<th>( z_e \leq 20 \text{ m} )</th>
<th>( z_e = 50 \text{ m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 0,5 )</td>
<td>6,7</td>
<td>8,3</td>
</tr>
<tr>
<td>( \geq 4,0 )</td>
<td>3,6</td>
<td>4,5</td>
</tr>
</tbody>
</table>

This table is based on the following assumptions:
- terrain category II according to Table 4.1
- force coefficient \( c_{f,x} \) according to 8.3.1 (1)
- \( c_0=1,0 \)
- \( k_l=1,0 \)

For intermediate values of \( b/d_{tot} \), and of \( z_e \) linear interpolation may be used.
3. Numerical application (cont.)

Simplified Method [8.3.2] (cont.)

By double interpolation, since $20 \, \text{m} < (z_e =) \, 40 \, \text{m} < 50 \, \text{m}$ and $0,5 < (b/d_{tot}) = 3,0 < 4,0$ one gets $C = 5,23$

Using the interpolated value of $C$ one gets:

$$F_w = 0,5 \times 1,25 \times 262 \times 5,23 \times 800,00 = 2209,67 \times 800,00 = 767740 \, \text{N}$$

$$\approx 1768 \, \text{kN}$$

which is almost identical (a bit greater) than the “exact” value 1730 kN
3. Numerical application (cont.)

3.2 Bridge during its service life, with traffic
(“high” pier $z = 40$ m, wind transversally to the deck)

The magnitude which is differentiated, compared to the case without traffic, is the reference depth $d_{tot}$ of exposure on wind action transversally to the deck. In that case:

$$d_{tot} = 3,1375 + 0,200 + 2,0 = 5,3375 \approx 5,34 \text{ m}$$

and

$$\frac{b}{d_{tot}} = 12,00/5,34 = 2,25, \quad A_{ref} = 5,34 \times 200,00 = 1068 \text{ m}^2, \quad c_{fx} = c_{fx,0} \approx 1,83$$

Hence:

$$F_w = 1,0 \times 1,83 \times 1395,28 \times 1068,00 = 2553,36 \times 1068,00 = 2726991 \text{ N} \approx 2727 \text{ kN}$$

Or “wind load” in the transverse (x-direction): $w \approx 13,64 \text{ kN/m}$
3. Numerical application (cont.)

Additional heights for the calculation of \( A_{\text{ref},x} \) \( (d^* = 2 \text{ m} ; d^{**} = 4 \text{ m}) \) for bridges during their service life with traffic.
3. Numerical application (cont.)

3.3 Bridge **under construction** (launched steel alone - cantilever at P2; “high” pier \( z = 40 \) m, wind transversally to the deck)

It has been agreed to use the value \( v_b = 50 \) km/h (\( = 50/3.6 \approx 14 \) m/s)

More generally, given that the construction phase has a limited duration and subsequently the associated return period of the actions considered is lesser than the service design life of the structure, \( c_{prob} \) may be modified accordingly. In several cases this might also be the case for \( c_{season} \) for a time period up to 3 months [EN 1991-1-6, Table 3.1]. In the same table the return periods for (up to) 3 months and (up to) 1 year are given, \( T = 5 \) and 10 years, respectively. The corresponding probabilities for exceedence of the extreme event once, are \( p = 1/5 = 0.20 \) and \( 1/10 = 0.10 \), respectively
3. Numerical application (cont.)

<table>
<thead>
<tr>
<th>Duration</th>
<th>Return periods (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 3</td>
<td>2</td>
</tr>
<tr>
<td>≤ 3 months (but &gt; 3 days)</td>
<td>5</td>
</tr>
<tr>
<td>≤ 1 year (but &gt; 3 months)</td>
<td>10</td>
</tr>
<tr>
<td>&gt; 1 year</td>
<td>50</td>
</tr>
</tbody>
</table>

Extracts from [*Table 3.1 of EN 1991-1-6*]
3. Numerical application (cont.)

In the specific case of this example one might reasonably assume 3 months for the duration of the construction, before casting the concrete slab, leading to $c_{prob} = 0.85$. Nevertheless, a more conservative approach would be to assume virtual delays, thus leading to a value of $c_{prob} = 0.9$, as it may be seen below:

$$c_{prob} = \left( \frac{1 - 0.2 \cdot \ln(-\ln(1 - 0.10))}{1 - 0.2 \cdot \ln(-\ln(0.98))} \right)^{0.5} = \left( \frac{1 - 0.2 \cdot \ln(-\ln(0.98))}{1 - 0.2 \cdot \ln(-\ln(1 - 0.10))} \right)^{0.5} = (1.45/1.78)^{0.5} = 0.8146^{0.5} = 0.902 \approx 0.9$$

It is to note however that the phase of launching has usually a duration that does not exceed 3 days
3. Numerical application (cont.)

The case considered is, when the steel structure pushed (without addition of a nose-girder) from one side (abutment A0) is about to reach as cantilever the pier P2. In that specific case:

\[ L = 60,00 + 80,00 = 140,00 \text{ m} \] and \[ d_{\text{tot}} = 2 \cdot d_{\text{main beam}} = 2 \times 2,80 = 5,60 \text{ m} \]

Hence:
\[ \frac{b}{d_{\text{tot}}} = \frac{12,00}{5,60} = 2,14, \quad A_{\text{ref}} = 5,60 \times 140,00 = 784 \text{ m}^2, \quad c_{f_x} = c_{f_x,0} \approx 1,9 \]

Consequently:
\[ v_m (10) = 1,27 \times 1,0 \times 14 = 17,78 \approx 18 \text{ m/s} \]
\[ q_p (10) = [1 + 7 \times 0,15] \cdot \frac{1}{2} \times 1,25 \times 18^2 = 2,05 \times 202,5 = 415,125 \approx 415 \text{ in N/m}^2 \]

Finally:
\[ F_w = 1,0 \times 1,9 \times 415 \times 784,00 = 788,5 \times 784,00 = 618184 \text{ N} \approx 618 \text{ kN} \]

Or “wind load” in the transverse (x-direction): \[ w \approx 4,4 \text{ kN/m} \]
### 3. Numerical application (cont.)

<table>
<thead>
<tr>
<th></th>
<th>Service life without traffic</th>
<th>Service life with traffic</th>
<th>Construction phase (steel alone – end of pushing)</th>
<th>Construction phase (steel alone - cantilever at P2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$z = z_e (\text{m})$</td>
<td>10 40</td>
<td>10 40</td>
<td>10 40</td>
<td>10 40</td>
</tr>
<tr>
<td>$v_{b,0} (\text{m/s})$</td>
<td>26 26</td>
<td>26 26</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>$v_b (\text{m/s})$</td>
<td>26 26</td>
<td>26 26</td>
<td>14 14</td>
<td>14 14</td>
</tr>
<tr>
<td>$v_m (\text{m/s})$</td>
<td>26 33</td>
<td>26 33</td>
<td>14 18</td>
<td>14 18</td>
</tr>
<tr>
<td>$q_b (\text{N/m}^2)$</td>
<td>422,5 422,5</td>
<td>422,5 422,5</td>
<td>122,5 122,5</td>
<td>122,5 122,5</td>
</tr>
<tr>
<td>$q_m (\text{N/m}^2)$</td>
<td>422,5 680,6</td>
<td>422,5 680,6</td>
<td>122,5 202,5</td>
<td>122,5 202,5</td>
</tr>
<tr>
<td>$q_p (\text{N/m}^2)$</td>
<td>980,2 1395,3</td>
<td>980,2 1395,3</td>
<td>284,2 415</td>
<td>284,2 415</td>
</tr>
<tr>
<td>$c_e$</td>
<td>2,32 3,30</td>
<td>2,32 3,30</td>
<td>2,32 3,30</td>
<td>2,32 3,30</td>
</tr>
<tr>
<td>$d_{tot} (\text{m})$</td>
<td>4,00 4,00</td>
<td>5,34 5,34</td>
<td>5,60 5,60</td>
<td>5,60 5,60</td>
</tr>
<tr>
<td>$L (\text{m})$</td>
<td>200 200</td>
<td>200 200</td>
<td>140 140</td>
<td>140 140</td>
</tr>
<tr>
<td>$A_{\text{ref},x} (\text{m}^2)$</td>
<td>800 800</td>
<td>1068 1068</td>
<td>1120 1120</td>
<td>784 784</td>
</tr>
<tr>
<td>$b/d_{tot}$</td>
<td>3,00 3,00</td>
<td>2,25 2,25</td>
<td>2,14 2,14</td>
<td>2,14 2,14</td>
</tr>
<tr>
<td>$c_{f,x}$</td>
<td>1,55 1,55</td>
<td>1,83 1,83</td>
<td>1,9 1,9</td>
<td>1,9 1,9</td>
</tr>
<tr>
<td>$F_w (\text{kN})$</td>
<td>1215 1730</td>
<td>1916 2727</td>
<td>605 883</td>
<td>423 618</td>
</tr>
<tr>
<td>$w (\text{kN/m})$</td>
<td>6 8,65</td>
<td>9,6 13,64</td>
<td>3 4,4</td>
<td>3 4,4</td>
</tr>
</tbody>
</table>
3. Numerical application (cont.)

3.4 Vertical wind forces on bridge deck (z-direction)

- Use of [8.3.3] with recommended value for $c_{f,z} = \pm 0,9$, or
- Use the adjacent [Fig. 8.6]. The recommended value excentricity is $e = b/4$

- In the present example, both the wind angle $\alpha$ and the transverse slope of the bridge are taken = 0
3. Numerical application (cont.)

3.5 Wind forces along bridge deck (y-direction)

- [8.3.4] refers to the wind action on bridge decks in the longitudinal direction, to be taken into account, where relevant.

- The values are also left as NDPs, but it is recommended that a 25% percentage of the wind forces in x-direction is considered, in the case of plated bridges, and a 50% in the case of truss bridges.

- These two additional cases (wind action in y- and z-direction) are not treated in this example of application.
4. Wind actions on piers

“High” circular pier (4 m diameter, 40 m height)

According to [8.4.2] simplified rules for the evaluation of wind effects on piers may be given in the National Annexes. Otherwise the procedures described in [7.6], [7.8] and [7.9], should be applied, respectively for rectangular, regular polygonal and circular cross sections.

\[ F_w = c_s c_d \cdot c_f \cdot q_p (z_e) \cdot A_{ref} \]

The general formula [5.3] already used for the deck is also valid for structural elements like free standing piers. In this case \( c_s c_d = 1,0 \) and \( c_f \) are given by the following formula [7.19] of [7.9.2]:

\[ c_f = c_{f,0} \psi_\lambda \]

Where:
\( c_{f,0} \) is the force coefficient of circular sections (finite cylinders) without free-end flow [Fig. 7.28]
\( \psi_\lambda \) is the end-effect factor (for elements with free-end flow [7.13] )
4. Wind actions on piers (cont.)

For the use of [Fig. 7.28] the Reynolds number [Eq. 7.15] based on the peak wind velocity according to [4.5, Eq. 4.8] and the equivalent surface roughness $k$ [Tab. 7.13] need first to be computed.

The combination of formulas [7.15] and [4.8] leads to the following expression: $v(z_e) = v_m(z_e) \cdot \{1 + 7 \cdot l_v(z_e)\}^{0.5}$

For $z_e = 40$ m one gets:
$v(40) = 33 \times \{1 + 7 \times 0.15\}^{0.5} = 33 \times 2.05^{0.5} = 33 \times 1.432 = 47.25$ m/s

$Re = b \cdot v(z_e) / \nu = 4.00 \times 47.25 / (15 \times 10^{-6}) = 12.6 \times 10^6 = 1.26 \times 10^7$

This value is a bit further than the limiting value of [Fig. 7.28].

The equivalent roughness is 0.2 mm for smooth and 1.0 mm for rough concrete. Smooth concrete surface will be assumed. This leads to $k/b = 0.2/4000 = 5 \times 10^{-5}$. From Fig 7.28 a value greater than 0.7 is expected.
4. Wind actions on piers (cont.)

[Fig. 7.28] Force coefficient $c_{f,0}$ for circular cylinders without end-flow and for different equivalent roughness $k/b$
4. Wind actions on piers (cont.)

By using the relevant formula one gets:

\[
\begin{align*}
c_{f,0} &= 1,2 + \{0,18 \cdot \log(10 \ k/b)\} / \{1 + 0,4 \cdot \log (Re/106)\} = \\
&= 1,2 + \{0,18 \cdot \log(10 \times 5 \times 10^{-5})\} / \{1 + 0,4 \cdot \log (12,6 \times 106/106)\} = \\
&= 1,2 - 0,594 / 1,44 = 1,2 - 0,413 = 0,787 \approx 0,79
\end{align*}
\]

In the case of rough concrete one would get: \(c_{f,0} = 0,875\)

Concerning the evaluation of \(\psi_\lambda\) one should use interpolation, while using \([Tab. 7.16]\) and \([Fig. 7.36]\) since \(15 \ m < l = 40 \ m < 50 \ m\).

For \(l = 15 \ m\) the effective slenderness \(\lambda\) is given as follows: \(\lambda = \min \{ l/b ; 70\} = \min \{ 40,00/4,00 ; 70\} = 10\)

For \(l = 50 \ m\) the effective slenderness \(\lambda\) is given as follows: \(\lambda = \min \{ 0,7 \ l/b ; 70\} = \min \{ 0,7 \times 40,00/4,00 ; 70\} = 7\)

Interpolation gives \(\lambda = 0,786 \ l/b = 0,786 \times 40,00 / 4,00 = 7,86\)
4. Wind actions on piers (cont.)

[Fig. 7.36] — Indicative values of the end-effect factor $\psi_\lambda$ as a function of solidity ratio $\varphi$ versus slenderness $\lambda$
EXAMPLE OF APPLICATION
WIND ACTIONS ON BRIDGE DECK AND PIERS

4. Wind actions on piers (cont.)

By using [Fig. 7.36] with \( \varphi = 1,0 \) one gets \( \psi_\lambda \approx 0,685 \)
And: \( c_f = 0,79 \times 1,0 \times 0,685 \approx 0,54 \)
\( A_{\text{ref}} = l. b = 40,00 \times 4,00 = 160,00 \text{ m}^2 \)
\( q_p (40) = 1395,3 \text{ N/m}^2 (415 \text{ N/m}^2 \text{ for the construction phase}) \)

According to [7.9.2(5)] the reference height \( z_e \) is equal to the maximum height above the ground of the section being considered. As a conservative approach the value for \( z_e = 40 \text{ m} \) may be consider, given that [Fig. 7.4] is not directly applicable. Nevertheless, a splitting of the pier in adjacent strips with various \( z_e \) and the associated values for \( v, q_p \) etc. might be considered, as a more realistic and less conservative approach.

Finally: \( F_w = 1,0 \times 0,54 \times 1295,3 \times 160,00 = 753,46 \times 160,00 = 120554 \text{ N} \approx 120,5 \text{ kN} \)
4. Wind actions on piers
(cont.)

[Fig. 7.4] — Reference height, $z_e$, depending on $h$ and $b$, and corresponding velocity pressure profile (for rectangular piers)
EN 1991-1-5: THERMAL ACTIONS

• Forward
• Section 1 – General
• Section 2 – Classification of actions
• Section 3 – Design situations
• Section 4 – Representation of actions
• Section 5 – Temperature changes in buildings
• Section 6 – Temperature changes in bridges
• Section 7 – Temperature changes in industrial chimneys, pipelines, silos, tanks and cooling towers
• Annex A (normative) – Isotherms of national minimum and maximum shade air temperatures.
• Annex B (normative) – Temperature differences for various surfacing depths
• Annex C (informative) – Coefficients of linear expansion
• Annex D (informative) – Temperature profiles in buildings and other construction works
Diagrammatical representation of constituent components of a temperature profile \([EN 1991-1-5, \text{Fig. 4.1}]\)
Consideration of thermal actions on bridge decks \[\text{EN 1991-1-5, 6.1.2}\]:

- Representative values of thermal actions should be assessed by the uniform temperature component (\(\Delta T_N\)) and the temperature difference components (\(\Delta T_M\)).
- The vertical temperature difference component (\(\Delta T_M\)) should generally include the non-linear component. Either Approach 1 (Vertical linear component) or Approach 2 (Vertical temperature components with non linear effects) may be used.
Uniform temperature component:

This component induces a variation in length of the bridge (when the longitudinal displacements are free on supports) which is not studied for the design example.

The uniform temperature component ($\Delta T_N$) depends on the minimum ($T_{min}$) and maximum ($T_{max}$) temperature which a bridge will achieve.

Minimum shade air temperature ($T_{min}$) and maximum shade air temperature ($T_{max}$) for the site are derived from isotherms.

The minimum and maximum uniform bridge temperature components $T_{e.min}$ and $T_{e.max}$ need to be determined.
Type 1  Steel deck
- steel box-girder
- steel truss or plate girder

Type 2  Composite deck

Type 3  Concrete deck
- concrete slab
- concrete beam
- concrete box-girder
ACTIONS : THERMAL ACTIONS
Determination of thermal effects

**Type 1 - steel**
**Type 2 - composite**
**Type 3 - concrete**

Correlation between
min/max shade air temperature \( (T_{\text{min}}/T_{\text{max}}) \)

And
min/max uniform bridge temperature component \( (T_{\text{e.min}}/T_{\text{e.max}}) \)
ACTIONS : THERMAL ACTIONS

Uniform temperature component

$T_0$ is the initial bridge temperature at the time that the structure is restrained.

The characteristic value of the maximum contraction range of the uniform bridge temperature component, $\Delta T_{N,\text{con}}$ should be taken as: $\Delta T_{N,\text{con}} = T_0 - T_{e.\text{min}}$

The characteristic value of the maximum expansion range of the uniform bridge temperature component, $\Delta T_{N,\text{exp}}$ should be taken as: $\Delta T_{N,\text{exp}} = T_{e.\text{max}} - T_0$

The overall range of the uniform bridge temperature component is: $\Delta T_N = T_{e.\text{max}} - T_{e.\text{min}}$
The National Annex of EN1991-1-5 should choose to one of the two following definitions for this thermal component in a bridge (see next figure):

- a **linear thermal gradient** over the entire depth of the bridge deck [6.1.4.1 of EN 1991-1-5]

- a **non-linear thermal gradient** which can be defined by two methods, continuous or discontinuous. The values $\Delta T_1$ and $\Delta T_2$ are defined according to the type of deck surfacing in Annex B to EN1991-1-5 [6.1.4.2 and Annex B of EN 1991-1-5]

The option adopted in this example is a variation of the second approach (simplified procedure), i.e. the **non-linear discontinuous thermal gradient** with a temperature difference of +/- 10°C between the slab concrete and the structural steel. The linear temperature difference components are noted $\Delta T_{M,\text{heat}}$ (heating) and $\Delta T_{M,\text{cool}}$ (cooling).
This thermal gradient is classified as a variable action (like traffic load) and is applied to composite cross-sections which are described with the short-term modular ratio.
Over a prescribed time period heating and cooling of a bridge deck's upper surface will result in a maximum heating (top surface warmer) and a maximum cooling (bottom surface warmer) temperature variation.

The vertical temperature difference may produce, for example, effects within a structure due to:

- Restraint of free curvature due to the form of the structure (e.g. portal frame, continuous beams etc.);
- Friction at rotational bearings;
- The effect of vertical temperature differences should be considered by using an equivalent linear temperature difference component with $\Delta T_{M,\text{heat}}$ and $\Delta T_{M,\text{cool}}$. These values are applied between the top and the bottom of the bridge deck.
Table 6.1: Recommended values of linear temperature difference component for different types of bridge decks for road, foot and railway bridges

<table>
<thead>
<tr>
<th>Type of Deck</th>
<th>Top warmer than bottom</th>
<th>Bottom warmer than top</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta T_{M,\text{heat}}$ ($^\circ$C)</td>
<td>$\Delta T_{M,\text{cool}}$ ($^\circ$C)</td>
</tr>
<tr>
<td>Type 1: Steel deck</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Type 2: Composite deck</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>Type 3: Concrete deck:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- concrete box girder</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>- concrete beam</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>- concrete slab</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>

**NOTE 1:** The values given in the table represent upper bound values of the linearly varying temperature difference component for representative sample of bridge geometries.

**NOTE 2:** The values given in the table are based on a depth of surfacing of 50 mm for road and railway bridges. For other depths of surfacing these values should be multiplied by the factor $k_{\text{sur}}$. Recommended values for the factor $k_{\text{sur}}$ is given in Table 6.2.
**Table 6.2: Recommended values of $k_{\text{sur}}$ to account for different surfacing thickness**

<table>
<thead>
<tr>
<th>Surface Thickness</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top warmer than bottom</td>
<td>Bottom warmer than top</td>
<td>Top warmer than bottom</td>
</tr>
<tr>
<td>[mm]</td>
<td>$k_{\text{sur}}$</td>
<td>$k_{\text{sur}}$</td>
<td>$k_{\text{sur}}$</td>
</tr>
<tr>
<td>unsurfaced</td>
<td>0.7</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>waterproofed 1)</td>
<td>1.6</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>50</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>100</td>
<td>0.7</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>150</td>
<td>0.7</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>ballast (750 mm)</td>
<td>0.6</td>
<td>1.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>

1) These values represent upper bound values for dark colour.
Vertical temperature components with non-linear effects (Approach 2)

The effect of the vertical temperature differences should be considered by including a non-linear temperature difference component.

Recommended values of vertical temperature differences for bridge decks are given in next 3 Figures. In these figures “heating” refers to conditions such that solar radiation and other effects cause a gain in heat through the top surface of the bridge deck. Conversely, “cooling” refers to conditions such that heat is lost from the top surface of the bridge deck as a result of re-radiation and other effects.

The temperature difference $\Delta T$ incorporates $\Delta T_M$ and $\Delta T_E$ together with a small part of component $\Delta T_N$; this latter part is included in the uniform bridge temperature component.
1a. Steel deck on steel box girders

\[ h_1 = 0.1\, \text{m} \quad \Delta T_1 = 24^\circ\text{C} \]
\[ h_2 = 0.2\, \text{m} \quad \Delta T_2 = 14^\circ\text{C} \]
\[ h_3 = 0.3\, \text{m} \quad \Delta T_3 = 8^\circ\text{C} \]
\[ h_4 = \text{unknown} \quad \Delta T_4 = 4^\circ\text{C} \]

1b. Steel deck on steel truss or plate girders

\[ h_1 = 0.5\, \text{m} \quad \Delta T_1 = 21^\circ\text{C} \]
\[ h_4 = -5^\circ\text{C} \quad h_1 = 0.1\, \text{m} \]
STEEL-CONCRETE COMPOSITE BRIDGES

Normal Procedure

<table>
<thead>
<tr>
<th>$h$</th>
<th>$\Delta T_1$</th>
<th>$\Delta T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>$^\circ C$</td>
<td>$^\circ C$</td>
</tr>
<tr>
<td>0.2</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>0.3</td>
<td>16</td>
<td>4</td>
</tr>
</tbody>
</table>

Simplified Procedure

$\Delta T_1 = 10^\circ C$

$\Delta T_1 = -10^\circ C$
**Type of Construction**

<table>
<thead>
<tr>
<th>100mm surfacing</th>
<th>100mm surfacing</th>
<th>100mm surfacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a. Concrete slab</td>
<td>3b. Concrete beams</td>
<td>3c. Concrete box girder</td>
</tr>
</tbody>
</table>

**Temperature Difference (ΔT)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Heating</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a)</td>
<td>(b)</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>Cooling</td>
</tr>
<tr>
<td></td>
<td>ΔT₁₃</td>
<td>ΔT₂₃</td>
</tr>
<tr>
<td></td>
<td>ΔT₆₃</td>
<td>ΔT₇₃</td>
</tr>
</tbody>
</table>

(a) Heating

- \( h₁ = 0.3h \) but ≤ 0.15m
- \( h₂ = 0.3h \) but ≥ 0.10m ≤ 0.25m
- \( h₃ = 0.3h \) but (0.10m + surfacing depth in metres)
- (for thin slabs, \( h₃ \) is limited by \( h₁ - h₂ - h₃ \))

(b) Cooling

- \( h₁ = h₄ = 0.20h \) but ≤ 0.25m
- \( h₂ = h₃ = 0.25h \) but ≤ 0.20m

<table>
<thead>
<tr>
<th>( h )</th>
<th>ΔT₁</th>
<th>ΔT₂</th>
<th>ΔT₃</th>
<th>ΔT₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 0.2</td>
<td>8.5</td>
<td>3.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>12.0</td>
<td>3.0</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>13.0</td>
<td>3.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>≥ 0.8</td>
<td>13.0</td>
<td>3.0</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 6.2c: Temperature differences for bridge decks – Type 3: Concrete Decks*

*Note: The temperature difference \( ΔT \) incorporates \( ΔT₆ \) and \( ΔT₇ \) (see 4.3) together with a small part of component \( ΔT₈ \); this latter part has been included in the uniform bridge temperature component (see 6.1.3).*
Simultaneity of uniform and temperature difference components (recommended values)

\[
\Delta T_{M,heat}(or\Delta T_{M,cool}) + 0,35\Delta T_{N,exp}(or\Delta T_{N,con})
\]
\[
0,75\Delta T_{M,heat}(or\Delta T_{M,cool}) + \Delta T_{N,exp}(or\Delta T_{N,con})
\]

Differences in the uniform temperature component between different structural elements:
- 15°C between main structural elements (e.g. tie and arch); and
- 10°C and 20°C for light and dark colour respectively between suspension/stay cables and deck (or tower).

Temperature differences between the inner and outer web walls of large concrete box girder bridges:
Recommended value 15°C
• Forward
• Section 1 – General
• Section 2 – Classification of actions
• Section 3 – Design situations and limit states
• Section 4 – Representation of actions
• Annex A1 (normative) – Supplementary rules for buildings
• Annex A2 (normative) – Supplementary rules for bridges
• Annex B (informative) – Actions on structures during alteration, reconstruction or demolition
Actions during execution are classified in accordance with EN 1990, and may include

- those actions that are not construction loads;

  and

- construction loads

In the following only construction loads will be treated
**Construction Loads - $Q_c$**

*Six different sources*

<table>
<thead>
<tr>
<th>$Q_{ca}$</th>
<th>Personnel and hand tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{cb}$</td>
<td>Storage of movable items</td>
</tr>
<tr>
<td>$Q_{cc}$</td>
<td>Non-permanent equipment in position for use</td>
</tr>
<tr>
<td>$Q_{cd}$</td>
<td>Movable heavy machinery and equipment</td>
</tr>
<tr>
<td>$Q_{ce}$</td>
<td>Accumulation of waste materials</td>
</tr>
<tr>
<td>$Q_{cf}$</td>
<td>Loads from part of structure in a temporary state</td>
</tr>
</tbody>
</table>

*Construction loads* $Q_c$ may be represented in the appropriate design situations (see EN 1990), either, as one single variable action, or where appropriate different types of construction loads may be grouped and applied as a single variable action. Single and/or a grouping of construction loads should be considered to act simultaneously with non construction loads as appropriate.
## ACTIONS DURING EXECUTION: CONSTRUCTION LOADS

<table>
<thead>
<tr>
<th>Relate Clause In this standard</th>
<th>Action</th>
<th>Classification / Origin</th>
<th>Spatial Variation</th>
<th>Nature (Static/ Dynamic)</th>
<th>Remarks</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Variation in time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction loads:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.11</td>
<td>Personnel and handtools</td>
<td>Variable</td>
<td>Direct</td>
<td>Free</td>
<td>Static</td>
<td></td>
</tr>
<tr>
<td>4.11</td>
<td>Storage movable items</td>
<td>Variable</td>
<td>Direct</td>
<td>Free</td>
<td>Static / dynamic</td>
<td>Dynamic in case of dropped loads</td>
</tr>
<tr>
<td>4.11</td>
<td>Non permanent equipment</td>
<td>Variable</td>
<td>Direct</td>
<td>Fixed / Free</td>
<td>Static / dynamic</td>
<td>EN 1991-3</td>
</tr>
<tr>
<td>4.11</td>
<td>Movable heavy machinery and equipment</td>
<td>Variable</td>
<td>Direct</td>
<td>Free</td>
<td>Static / dynamic</td>
<td>EN 1991-3, EN 1992-1</td>
</tr>
<tr>
<td>4.11</td>
<td>Accumulation of waste materials</td>
<td>Variable</td>
<td>Direct</td>
<td>Free</td>
<td>Static/dynamic</td>
<td>Can impose loads on e.g. vertical surfaces also</td>
</tr>
<tr>
<td>4.11</td>
<td>Loads from parts of structure in temporary states</td>
<td>Variable</td>
<td>Direct</td>
<td>Free</td>
<td>Static</td>
<td>Dynamic effects are excluded</td>
</tr>
</tbody>
</table>
## ACTIONS DURING EXECUTION: CONSTRUCTION LOADS $Q_{ca}$

### Representation of construction loads

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel and handtools</strong></td>
<td>$Q_{ca}$</td>
<td>Working personnel, staff and visitors, possibly with hand tools or other small site equipment</td>
</tr>
<tr>
<td><strong>Storage of movable items</strong></td>
<td>$Q_{cb}$</td>
<td>Storage of moveable items, e.g. building and construction materials, precast elements, and equipment</td>
</tr>
<tr>
<td><strong>Non permanent equipment</strong></td>
<td>$Q_{cc}$</td>
<td>Non permanent equipment in position for use during execution, either: static (e.g. formwork panels, scaffolding, falsework, machinery, containers) or during movement (e.g. travelling forms, launching girders and nose, counterweights)</td>
</tr>
<tr>
<td><strong>Moveable heavy machinery and equipment</strong></td>
<td>$Q_{cd}$</td>
<td>Moveable heavy machinery and equipment, usually wheeled or tracked, (e.g. cranes, lifts, vehicles, lift trucks, power installations, jacks, heavy lifting devices)</td>
</tr>
<tr>
<td><strong>Accumulation of waste materials</strong></td>
<td>$Q_{ce}$</td>
<td>Accumulation of waste materials (e.g. surplus construction materials, excavated soil, or demolition materials)</td>
</tr>
<tr>
<td><strong>Loads from parts of a structure in temporary states</strong></td>
<td>$Q_{cf}$</td>
<td>Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations</td>
</tr>
</tbody>
</table>
ACTIONS DURING EXECUTION: CONSTRUCTION LOADS

Working personnel, staff and visitors, possibly with hand tools or other site equipment

Bridge workers

Modelled as a uniformly distributed load $q_{ca}$ and applied as to obtain the most unfavourable effects

The recommended value is: $q_{ca,k} = 1,0 \text{ kN/m}^2$
**ACTIONS DURING EXECUTION:**

**CONSTRUCTION LOADS \(Q_{cb}\)**

**Representation of construction loads**

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel and handtools</td>
<td>(Q_{ca})</td>
<td>Working personnel, staff and visitors, possibly with hand tools or other small site equipment</td>
</tr>
<tr>
<td><strong>Storage of movable items</strong></td>
<td>(Q_{cb})</td>
<td>Storage of moveable items, e.g. - building and construction materials, precast elements, and equipment</td>
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<tr>
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<td>(Q_{cc})</td>
<td>Non permanent equipment in position for use during execution, either: - static (e.g. formwork panels, scaffolding, falsework, machinery, containers) or - during movement (e.g. travelling forms, launching girders and nose, counterweights)</td>
</tr>
<tr>
<td>Moveable heavy machinery and equipment</td>
<td>(Q_{cd})</td>
<td>Moveable heavy machinery and equipment, usually wheeled or tracked, (e.g. cranes, lifts, vehicles, lifttrucks, power installations, jacks, heavy lifting devices)</td>
</tr>
<tr>
<td>Accumulation of waste materials</td>
<td>(Q_{ce})</td>
<td>Accumulation of waste materials (e.g. surplus construction materials, excavated soil, or demolition materials)</td>
</tr>
<tr>
<td>Loads from parts of a structure in temporary states</td>
<td>(Q_{cf})</td>
<td>Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations</td>
</tr>
</tbody>
</table>
Modelled as a free action and represented by a uniform dead load $Q_{cb}$ and a concentrated load $F_{cb}$

For bridges, the following values are recommended minimum values:

$$q_{cb,k} = 0.2 \text{ kN/m}^2$$

$$F_{cb,k} = 100 \text{ kN}$$
# ACTIONS DURING EXECUTION: CONSTRUCTION LOADS

## Representation of construction loads

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel and handtools</td>
<td>$Q_{ca}$</td>
<td>Working personnel, staff and visitors, possibly with hand tools or other small site equipment</td>
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<td>$Q_{cb}$</td>
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<tr>
<td>Accumulation of waste materials</td>
<td>$Q_{ce}$</td>
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<td>Loads from parts of a structure in temporary states</td>
<td>$Q_{cf}$</td>
<td>Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations</td>
</tr>
</tbody>
</table>
Representation of construction loads
Construction Loads during the casting of concrete

• Actions to be taken into account simultaneously during the casting of concrete may include:
  • working personnel with small site equipment ($Q_{ca}$);
  • formwork and load-bearing members ($Q_{cc}$);
  • the weight of fresh concrete (which is one example of $Q_{cf}$), as appropriate.
**ACTIONS DURING EXECUTION : casting of concrete**

$Q_{ca}$, $Q_{cc}$ and $Q_{cf}$ may be given in the National Annex. Recommended values for fresh concrete ($Q_{cf}$) may be taken from Table 4.2 and EN 1991-1-1, Table A.1. Other values may have to be defined, for example, when using self-levelling concrete or pre-cast products.

<table>
<thead>
<tr>
<th>Action</th>
<th>Loaded area</th>
<th>Load in kN/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Outside the working area</td>
<td>0,75 covering $Q_{ca}$</td>
</tr>
<tr>
<td>(2)</td>
<td>Inside the working area 3 m x 3 m (or the span length if less)</td>
<td>10 % of the self-weight of the concrete but not less than 0,75 and not more than 1,5 Includes $Q_{ca}$ and $Q_{cf}$</td>
</tr>
<tr>
<td>(3)</td>
<td>Actual area</td>
<td>Self-weight of the formwork, load-bearing element ($Q_{cf}$) and the weight of the fresh concrete for the design thickness ($Q_{cf}$)</td>
</tr>
</tbody>
</table>

Paolo Formichi, University of Pisa Italy
## ACTIONS DURING EXECUTION: CONSTRUCTION LOADS $Q_{cc}$

### Representation of construction loads

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel and handtools</td>
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</tr>
<tr>
<td>Storage of movable items</td>
<td>$Q_{cb}$</td>
<td>Storage of moveable items, e.g. - building and construction materials, precast elements, and - equipment</td>
</tr>
<tr>
<td><strong>Non permanent equipment</strong></td>
<td>$Q_{cc}$</td>
<td>Non permanent equipment in position for use during execution, either: - static (e.g. formwork panels, scaffolding, falsework, machinery, containers) or - during movement (e.g. travelling forms, launching girders and nose, counterweights)</td>
</tr>
<tr>
<td>Moveable heavy machinery and equipment</td>
<td>$Q_{cd}$</td>
<td>Moveable heavy machinery and equipment, usually wheeled or tracked, (e.g cranes, lifts, vehicles, liftrucks, power installations, jacks, heavy lifting devices)</td>
</tr>
<tr>
<td>Accumulation of waste materials</td>
<td>$Q_{ce}$</td>
<td>Accumulation of waste materials (e.g. surplus construction materials, excavated soil, or demolition materials)</td>
</tr>
<tr>
<td>Loads from parts of a structure in temporary states</td>
<td>$Q_{cf}$</td>
<td>Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations</td>
</tr>
</tbody>
</table>
Non permanent in position for use during execution, either: - static (e.g. formwork panels, scaffolding, falsework, machinery, containers) or – during movement (e.g. travelling forms, launching girders and nose, counterweights)

Unless more accurate information is available, they may be modelled by a uniformly distributed load with a recommended minimum characteristic value of $q_{cc,k} = 0.5 \text{kN/m}^2$
### Representation of construction loads

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
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<td>$Q_{ca}$</td>
<td>Working personnel, staff and visitors, possibly with hand tools or other small site equipment</td>
</tr>
</tbody>
</table>
| Storage of movable items         | $Q_{cb}$ | Storage of moveable items, e.g.
- building and construction materials, precast elements, and
- equipment                     |
| Non permanent equipment          | $Q_{cc}$ | Non permanent equipment in position for use during execution, either:
- static (e.g. formwork panels, scaffolding, falsework, machinery, containers) or
- during movement (e.g. travelling forms, launching girders and nose, counterweights) |
| Moveable heavy machinery and equipment | $Q_{cd}$ | Moveable heavy machinery and equipment, usually wheeled or tracked, (e.g. cranes, lifts, vehicles, lifttrucks, power installations, jacks, heavy lifting devices) |
| Accumulation of waste materials  | $Q_{ce}$ | Accumulation of waste materials (e.g. surplus construction materials, excavated soil, or demolition materials) |
| Loads from parts of a structure in temporary states | $Q_{cf}$ | Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations |
Moveable heavy machinery and equipment, usually wheeled or tracked, (e.g. cranes, lifts, vehicles, lifttrucks, power installations, jacks, heavy lifting devices)

Information for the determination of actions due to vehicles when not defined in the project specification, may be found in EN 1991-2, for example
### ACTIONS DURING EXECUTION: CONSTRUCTION LOADS $Q_{ce}$ & $Q_{cf}$

**Representation of construction loads**

<table>
<thead>
<tr>
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<td>$Q_{cf}$</td>
<td>Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations</td>
</tr>
</tbody>
</table>
Accumulation of waste materials (e.g. surplus construction materials excavated soil, or demolition)

These loads are taken into account by considering possible mass effects on horizontal, inclined and vertical elements (such as walls).

These loads may vary significantly, and over short time periods, depending on types of materials, climatic conditions, build-up and clearance rates.
ACTIONS DURING EXECUTION:
CONSTRUCTION LOADS $Q_{ce}$ & $Q_{cf}$

$Q_{cf}$ : Loads from parts of a structure in temporary states (under execution) before the final design actions take effect, such as loads from lifting operations. Taken into account and modelled according to the planned execution sequences, including the consequences of those sequences (e.g. loads and reverse load effects due to particular processes of construction, such as assemblage).
LAUNCHING

Counterweight? EQU

STR

STR

STR
Design values of actions (EQU), Set A

<table>
<thead>
<tr>
<th>Persistent and transient design situation</th>
<th>Permanent actions</th>
<th>Prestress</th>
<th>Leading variable action</th>
<th>Accompanying variable actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavourable</td>
<td>Favourable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq (6.10)</td>
<td>$\gamma_{Gj,\text{sup}} G_{kj,\text{sup}}$</td>
<td>$\gamma_{Gj,\text{inf}} G_{kj,\text{ing}}$</td>
<td>$\gamma_P P$</td>
<td>$\gamma_{Q,1} Q_{k,1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1: Recommended values of partial factors:**

- $\gamma_{Gj,\text{sup}} = 1.05$ for unfavourable effects of permanent actions
- $\gamma_{Gj,\text{inf}} = 0.95$ for favourable effects of permanent actions
- $\gamma_{Q, i} = 1.50$ for all other variable actions in persistent design situations
- $\gamma_{Q, i} = 1.35$ for construction loads during execution

For favourable variable actions, $\gamma_Q = 0.$
Combined approach - EQU and STR

Note 2:

Alternative approach may be used (verification of bearing uplift of continuous bridges, and where verification of static equilibrium involves the resistance of structural members).

**Recommended values of $\gamma$.**

- $\gamma_{Gj, sup} = 1,35$, $\gamma_{Gj, inf} = 1,25$
- $\gamma_Q = 1,50$ for all other variable actions in persistent design situation provided that applying $\gamma_{Gj, inf} = 1,00$ both to the favourable and unfavourable part of permanent actions does not give a more unfavourable effect.
If a counterweight is necessary, the variability of its characteristics can be taken into account considering:

\[ \gamma_{G,\text{inf}} = 0.8 \text{ when the weight is not well defined} \]

\[ \text{variation of its design position (for steel bridges usually } \pm 1 \text{ m)} \]
Actions to be considered during launching

Permanent loads

Wind

Vertical temperature difference between bottom and upper part of the beam

Horizontal temperature difference

Differential deflection between the support in longitudinal direction (±10 mm)

Differential deflection between the support in longitudinal direction (±2.5 mm)

Friction forces:

- total longitudinal friction forces=10% of the vertical loads
- at every pier: the most unfavourable considering max e min value of friction coefficient $\mu$: $\mu_{\text{min}}=0 - \mu_{\text{max}}=0.04$
Theoretically, all possible combinations should be considered, but in most cases their effects are not critical for a bridge of that type. For the example presented the value of $d_{set,1} = 30$ mm has been considered in P1.
EN 1991-1-7: ACCIDENTAL ACTIONS

- Forward
- Section 1 – General
- Section 2 – Classification of actions
- Section 3 – Design situations
- Section 4 – Impact
- Section 5 – Internal explosions
- Annex A (informative) – Design for consequences of localised failure in buildings from an unspecified cause
- Annex B (informative) – Information on risk assessment
- Annex C (informative) – Dynamic design for impact
- Annex D (informative) – Internal explosions
ACCIDENTAL LOADS: Impact

Collisions on the bridge:
- lorries outside the regular position (footpath)
- hitting structural elements (kerbs, barriers, cables, columns, pylons)

Collisions under the bridge (EN 119-1-7):
- on piers
- to the deck
ACCIDENTAL LOADS: Impact on substructure

- Impact from road traffic
  - Type of road and vehicle
  - Distance to the road and clearance
  - Type of structures
    - Soft impact
    - Hard impact

- Impact from train traffic
  - Use of the structure
    - Class A
    - Class B
  - Line maximum speed
ACCIDENTAL LOADS: Impact on substructure

c=1.25 m for lorries
c=0.5 m for cars

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Type of vehicle</th>
<th>Force $F_{d,x}$ [kN]</th>
<th>Force $F_{d,y}$ [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorway</td>
<td>Truck</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>Country road</td>
<td>Truck</td>
<td>750</td>
<td>375</td>
</tr>
<tr>
<td>Urban area</td>
<td>Truck</td>
<td>500</td>
<td>250</td>
</tr>
<tr>
<td>Courtyards/garages</td>
<td>Passengers cars only</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Courtyards/garages</td>
<td>Trucks</td>
<td>150</td>
<td>75</td>
</tr>
</tbody>
</table>
ACCIDENTAL LOADS: Impact on substructure

Statistical parameters for input values

\[ F = v_r \sqrt{km} \]

\[ m=32 \text{ ton}, \ v=90 \text{ km/hr}=25 \text{ m/s} \]

\[ F = 25 (300 \times 32)^{0.5} = 2400 \text{ kN} \]

\[ v_r = (v_0^2 - 2as)^{0.5} \]

\[ \text{if } a=4 \text{ m/s}^2 \quad s=80 \text{ m} \]

\[ \phi=15^\circ \quad d=20 \text{ m} \]

\[ F = F_o \sqrt{1 - d/d_b} \text{ (for } d < d_b). \]

Situation sketch for impact by vehicles (top view and cross sections for upward slope, flat terrain and downward slope)

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Type of vehicle</th>
<th>Force $F_{d,x}$ [kN]</th>
<th>Force $F_{d,y}$ [kN]</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td>Trucks</td>
<td>150</td>
<td>75</td>
</tr>
</tbody>
</table>
ACCIDENTAL LOADS: Impact on substructure

- Impact from ships
  - The type of waterway,
  - The flood conditions,
  - The type and draught of vessels
  - The type of the structures

Impact cases:

A. bow collision with bridge pillar,
B. side collision with bridge pillar,
C. deckhouse (superstructure) collision with bridge span.
ACCIDENTAL LOADS: Impact on substructure

Design forces $F_d$ for inland ships

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1250</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>4500</td>
<td>3</td>
<td>5</td>
<td>10</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>20000</td>
<td>3</td>
<td>5</td>
<td>20</td>
<td>30</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 4.5 of EN 1991-1-7

Design forces $F_d$ for seagoing vessels

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>5</td>
<td>15</td>
<td>50</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td>10000</td>
<td>5</td>
<td>30</td>
<td>80</td>
<td>87</td>
<td>84</td>
</tr>
<tr>
<td>40000</td>
<td>5</td>
<td>45</td>
<td>240</td>
<td>212</td>
<td>238</td>
</tr>
<tr>
<td>100000</td>
<td>5</td>
<td>60</td>
<td>460</td>
<td>387</td>
<td>460</td>
</tr>
</tbody>
</table>

Table 4.6 of EN 1991-1-7
ACCIDENTAL LOADS: Impact on superstructure

Vehicle impact on restraint system

Indicative equivalent static design forces due to impact on superstructures.

<table>
<thead>
<tr>
<th>Category of traffic</th>
<th>Equivalent static design force $F_{dx}$ [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways and country national and main roads</td>
<td>500</td>
</tr>
<tr>
<td>Country roads in rural area</td>
<td>375</td>
</tr>
<tr>
<td>Roads in urban area</td>
<td>250</td>
</tr>
<tr>
<td>Courtyards and parking garages</td>
<td>75</td>
</tr>
</tbody>
</table>

$a$ $x$ = direction of normal travel.
EN 1991-2: TRAFFIC LOADS ON BRIDGES

- Forward
- Section 1 – General
- Section 2 – Classification of actions
- Section 3 – Design situations
- Section 4 – Road traffic actions and other actions specifically for road bridges
- Section 5 – Actions on footways, cycle tracks and footbridges
- Section 6 – Traffic actions and other actions specifically for railway bridges
EN 1991-2: TRAFFIC LOADS ON BRIDGES

- Annex A (informative) – Models of special vehicles for road bridges
- Annex B (informative) – Fatigue life assessment for road bridges assessment method based on recorded traffic
- Annex C (normative) – Dynamic factors $1 + \phi$ for real trains
- Annex D (normative) – Basis for the fatigue assessment of railway structures
- Annex E (informative) – Limits of validity of load model HSLM and the selection of the critical universal train from HSLM-A
- Annex F (informative) – Criteria to be satisfied if a dynamic analysis is not required
- Annex G (informative) – Method for determining the combined response of a structure and track to variable actions
- Annex F (informative) – Load models for rail traffic loads in transient design situations
Traffic measurements:

Histogram of the axle load frequency – Auxerre slow lane – lorries
Traffic measurements:

Histograms of the truck gross weight – Auxerre slow lane and M4 motorway (Ireland)
EN 1991-2: TRAFFIC LOADS ON BRIDGES

Load models should:

- be easy to use
- produce main load effects correctly
- be the same for local and global verifications
- cover all possible situations (traffic scenarios)
- correspond to the target reliability levels
- include dynamic effects
Extreme traffic scenarios

Traffic jam on the Europa Bridge (from Tschermmenegg)
Traffic load models

- Vertical forces: LM1, LM2, LM3, LM4
- Horizontal forces: braking and acceleration, centrifugal, transverse

Groups of loads

- gr1a, gr1b, gr2, gr3, gr4, gr5
- characteristic, frequent and quasi-permanent values

Combination with actions other than traffic actions
LOAD MODELS FOR LIMIT STATE VERIFICATIONS OTHER THAN FOR FATIGUE LIMIT STATES

Field of application: loaded lengths less than 200 m (maximum length taken into account for the calibration of the Eurocode) and width less than 42 m (for L>200 m they result safe-sided)

- Load Model Nr. 1 - Concentrated and distributed loads (main model)
- Load Model Nr. 2 - Single axle load
- Load Model Nr. 3 - Set of special vehicles (*Can be specified by NA*)
- Load Model Nr. 4 - Crowd loading: 5 kN/m²
Carriageway width $w$ : width measured between kerbs (height more than 100 mm – recommended value) or between the inner limits of vehicle restraint systems
## Division of the carriageway into notional lanes

<table>
<thead>
<tr>
<th>Carriageway width</th>
<th>Number of notional lanes</th>
<th>Notional lane width</th>
<th>Width of the remaining area</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w &lt; 5.4$ m</td>
<td>$n_{\ell} = 1$</td>
<td>3 m</td>
<td>$w - 3$ m</td>
</tr>
<tr>
<td>$5.4 \leq w &lt; 6$ m</td>
<td>$n_{\ell} = 2$</td>
<td>$w/2$</td>
<td>0</td>
</tr>
<tr>
<td>$6 \leq w$</td>
<td>$n_{\ell} = \text{int}(w/3)$</td>
<td>3 m</td>
<td>$w - 3 \times n_{\ell}$</td>
</tr>
</tbody>
</table>

**Diagram:**

1 – Lane n° 1 (3m)
2 – Lane n° 2 (3m)
3 – Lane n° 3 (3m)
4 – Remaining area
The main load model (LM1)

\[ q_{r_k} = 2,5 \text{ kN/m}^2 \]

\[ q_{1k} = 9 \text{ kN/m}^2 \]

\[ q_{2k} = 2,5 \text{ kN/m}^2 \]

\[ q_{3k} = 2,5 \text{ kN/m}^2 \]

TS : Tandem system

UDL : Uniformly distributed load
The main load model for road bridges (LM1): diagrammatic representation

For the determination of general effects, the tandems travel along the axis of the notional lanes.

<table>
<thead>
<tr>
<th>Lane</th>
<th>Qk</th>
<th>qk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane n. 1</td>
<td>300 kN</td>
<td>9.0 kN/m</td>
</tr>
<tr>
<td>Lane n. 2</td>
<td>200 kN</td>
<td>2.5 kN/m²</td>
</tr>
<tr>
<td>Lane n. 3</td>
<td>100 kN</td>
<td>2.5 kN/m²</td>
</tr>
<tr>
<td>Remaining area</td>
<td>qrk = 2.5 kN/m²</td>
<td></td>
</tr>
</tbody>
</table>

For local verifications, the heaviest tandem should be positioned to get the most unfavourable effect.

Where two tandems are located in two adjacent notional lanes, they may be brought closer, the distance between axles being not less than 0,50 m.
## Load model 1: characteristic values

<table>
<thead>
<tr>
<th>Location</th>
<th>Tandem system TS</th>
<th>UDL system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( Q_{ik} ) (kN)</td>
<td>( q_{ik} ) (or ( q_{ik} )) (kN/m(^2))</td>
</tr>
<tr>
<td>Lane Number 1</td>
<td>300</td>
<td>9</td>
</tr>
<tr>
<td>Lane Number 2</td>
<td>200</td>
<td>2,5</td>
</tr>
<tr>
<td>Lane Number 3</td>
<td>100</td>
<td>2,5</td>
</tr>
<tr>
<td>Other lanes</td>
<td>0</td>
<td>2,5</td>
</tr>
<tr>
<td>Remaining area ( q_{rk} )</td>
<td>0</td>
<td>2,5</td>
</tr>
</tbody>
</table>
The main load model (LM1): Concentrated and uniformly distributed loads, covers most of the effects of the traffic of lorries and cars.

**Recommended values of** $\alpha_{Qi}$, $\alpha_{qi} = 1$

**Example** of other values for $\alpha$ factors (NDPs)

<table>
<thead>
<tr>
<th></th>
<th>$\alpha_{Q1}$</th>
<th>$\alpha_{Qi} \geq 2$</th>
<th>$\alpha_{q1}$</th>
<th>$\alpha_{qi} \geq 2$</th>
<th>$\alpha_{qr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st class</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd class</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3rd class</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1<sup>st</sup> class: international heavy vehicle traffic
2<sup>nd</sup> class: « normal » heavy vehicle traffic
3<sup>rd</sup> class: « light » heavy vehicle traffic
Load models for road bridges: LM2 – isolated single axle

Recommended value: \( \beta_Q = \alpha_{Q1} \)

In the vicinity of expansion joints, an additional dynamic amplification factor equal to the value defined in 4.6.1(6) should be applied.

When relevant, only one wheel of 200 (kN) may be taken into account.
Representation of the additional amplification factor

\[ \Delta \varphi_{\text{fat}} : \text{Additional amplification factor} \]

\[ D : \text{Distance of the cross-section under consideration from the expansion joint} \]
Dispersal of concentrated loads

1 – Contact pressure of the wheel
2 – Surfacing
3 – Concrete slab
4 – Slab neutral axis
Load models for road bridges: LM3 – Special vehicles

Axle lines and wheel contact areas for special vehicles

150 kN or 200 kN axle weight

240 kN axle weight

Longitudinal axis of the bridge
Load models for road bridges: LM3 – Special vehicles

Arrangement of special vehicle on the carriageway

Simultaneity of special vehicles and load model n. 1
Load models for road bridges: LM4 – Crowd loading

- distributed load 5 kN/m² (dynamic effects included)
- combination value 3 kN/m² (dynamic effects included)
- to be specified per project
- for global effects
- transient design situation
Load models for road bridges: Dynamics

\[ E_{\text{dyn}(x-\text{fractile})} = \frac{\varphi_{\text{cal}} \cdot \varphi_{\text{local}}}{\varphi_{\text{in}}} \cdot E_{\text{st}(x-\text{fractile})} \]

Calibration value of the impact factor \( \varphi_{\text{cal}} \) (EN 1991-2).
Load models for road bridges

**HORIZONTAL FORCES: Braking and acceleration (Lane Nr. 1)**

A characteristic braking force, $Q_{lk}$, is a longitudinal force acting at the surfacing level of the carriageway. $Q_{lk}$, limited to 900 kN for the total width of the bridge, is calculated as a fraction of the total maximum vertical loads corresponding to Load Model 1 and applied on Lane Number 1.

$$Q_{lk} = 0.6\alpha_{Q1}(2Q_{1k}) + 0.10\alpha_{q1}q_{1k} w_1 L$$

$$180\alpha_{Q1} kN \leq Q_{lk} \leq 900 \text{ kN}$$

$\alpha_{Q1} = \alpha_{q1} = 1$

$Q_{1k} = 180 + 2.7L$ for $0 \leq L \leq 1.2$ m

$Q_{1k} = 360 + 2.7L$ for $L > 1.2$ m

$L = \text{length of the deck or of the part of it under consideration}$
Load models for road bridges

**HORIZONTAL FORCES: Centrifugal forces**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r &lt; 200$ m</td>
<td>$Q_{fk} = 0.2Q_v$ kN</td>
</tr>
<tr>
<td>$200 \leq r &lt; 1500$ m</td>
<td>$Q_{fk} = 40Q_v / r$ kN</td>
</tr>
<tr>
<td>$r &gt; 1500$ m</td>
<td>$Q_{fk} = 0$</td>
</tr>
</tbody>
</table>

$r$: horizontal radius of curvature of the carriageway centreline [m]

$Q_v$: total maximum weight of vertical concentrated loads of the tandem systems of LM1

$Q_{fk}$ should be taken as a transverse force acting at the finished carriageway level and radially to the axis of the carriageway.
Definition of groups of loads

Group of loads gr1a: LM1 + *combination value* of pedestrian load on footways or cycle tracks

Group of loads gr1b: LM2 (single axle load)

Group of loads gr2: *characteristic values* of horizontal forces, *frequent values* of LM1

*LM1, qfk, LM2*
Group of loads gr3: loads on footways and cycle tracks

Group of loads gr4: crowd loading

Group of loads gr5: special vehicles (+ special conditions for normal traffic)
## Table 4.4a – Assessment of groups of traffic loads (characteristic values of the multi-component action)

<table>
<thead>
<tr>
<th>Load type</th>
<th>Vertical forces</th>
<th>Horizontal forces</th>
<th>Vertical forces only</th>
<th>CARRIAGEWAY</th>
<th>FOOTWAYS AND CYCLE TRACKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>4.3.2</td>
<td>4.3.3</td>
<td>4.3.4</td>
<td>4.3.5</td>
<td>4.4.1</td>
</tr>
<tr>
<td>Load system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM1 (TS and UDL systems)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2 (Single axle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM3 (Special vehicles)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM4 (Crowd loading)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Braking and acceleration forces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrifugal and transverse forces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uniformly Distributed load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groups of Loads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gr1a</td>
<td>Characteristic values</td>
<td>a)</td>
<td>a)</td>
<td>Combination value b)</td>
<td></td>
</tr>
<tr>
<td>gr1b</td>
<td>Characteristic value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gr2</td>
<td>Frequent values b)</td>
<td>Characteristic value</td>
<td>Characteristic value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gr3 c)</td>
<td>Characteristic value</td>
<td></td>
<td></td>
<td>Characteristic value c)</td>
<td></td>
</tr>
<tr>
<td>gr4</td>
<td>Characteristic value</td>
<td></td>
<td></td>
<td>Characteristic value b)</td>
<td></td>
</tr>
<tr>
<td>gr5</td>
<td>See Annex A</td>
<td>Characteristic value</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Dominant component action (designated as component associated with the group)**

- a) If specified, may be defined in the National Annex.
- b) May be defined in the National Annex. Recommended value: 3 kN/m².
- c) See 5.3.2.1-(3). One footway only should be considered to be loaded if the effect is more unfavourable than the effect of two loaded footways.
- d) This group is irrelevant if gr4 is considered.
Partial factors $\gamma_G$ and $\gamma_Q$ - EN 1990, A2, Tables A2.4(A) to (C)

<table>
<thead>
<tr>
<th>Limit states</th>
<th>Load effects</th>
<th>$\gamma_G$</th>
<th>$\gamma_Q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-EQU</td>
<td>Unfavourable</td>
<td>1,05</td>
<td>1,50</td>
</tr>
<tr>
<td></td>
<td>Favourable</td>
<td>0,95</td>
<td>0,00</td>
</tr>
<tr>
<td>B-STR/GEO</td>
<td>Unfavourable</td>
<td>1,35</td>
<td>1,50  (^1)</td>
</tr>
<tr>
<td></td>
<td>Favourable</td>
<td>1,00</td>
<td>0,00</td>
</tr>
<tr>
<td>C- STR/GEO</td>
<td>Unfavourable</td>
<td>1,00</td>
<td>1,30</td>
</tr>
<tr>
<td></td>
<td>Favourable</td>
<td>1,00</td>
<td>0,00</td>
</tr>
</tbody>
</table>

\(^1\) For road traffic 1,35, for railway traffic 1,45
### Factors for Road Bridges

<table>
<thead>
<tr>
<th>Action</th>
<th>Symbol</th>
<th>$\psi_0$</th>
<th>$\psi_1$</th>
<th>$\psi_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic loads</strong> (see EN 1991-2, Table 4.4)</td>
<td>gr 1a (LM1) TS</td>
<td>0,75</td>
<td>0,75</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>gr 1a (LM1) UDL</td>
<td>0,40</td>
<td>0,40</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>gr1b (single axle)</td>
<td>0</td>
<td>0,75</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>gr2 (horizontal forces)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>gr3 (pedestrian loads)</td>
<td>0</td>
<td>0,4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>gr4 (LM4 crowd loading)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>gr5 (LM3 spec. vehicles)</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Wind forces</strong></td>
<td>$F_w$ persistent (execution)</td>
<td>0,6 (0,8)</td>
<td>0,2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Thermal actions</strong></td>
<td>$T$</td>
<td>0,6</td>
<td>0,6</td>
<td>0,5</td>
</tr>
<tr>
<td><strong>Snow loads</strong></td>
<td>$S_n$ (during execution)</td>
<td>0,8</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td><strong>Construction loads</strong></td>
<td>$Q_{ca}$</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Combinations of actions in EN 1990

Ultimate limit states:
- EQU – static equilibrium (6.7)
- STR, GEO (6.10)
- Accidental (6.11)
- FAT - fatigue

Serviceability limit states:
- characteristic - irreversible (6.14)
- frequent - reversible (6.15)
- quasi-permanent – long-term (6.16)

\[ E_{d,dst} \leq E_{d,stm} \]
\[ E_d \leq R_d \]
\[ E_d \leq C_d \]
Combination rules for ULS

• Persistent and transient design situation – fundamental action combinations

(A) \[
\sum_{j \geq 1} \gamma_{Gj} G_{kj} + \gamma_P P_k + \gamma_{Q1} Q_{k1} + \sum_{i > 1} \gamma_{Qi} \psi_{0i} Q_{ki} \quad (6.10)
\]

or

(B) \[
\sum_{j \geq 1} \gamma_{Gj} G_{kj} + \gamma_P P_k + \sum_{i \geq 1} \gamma_{Qi} \psi_{0i} Q_{ki} \quad (6.10a)
\]

\[
\sum_{j \geq 1} \xi_j \gamma_{Gj} G_{kj} + \gamma_P P_k + \gamma_{Q1} Q_{k1} + \sum_{i > 1} \gamma_{Qi} \psi_{0i} Q_{ki} \quad (6.10b)
\]

• Accidental design situation

\[
\sum_{j \geq 1} G_{kj} + P_k + A_d + (\psi_{11} \text{ or } \psi_{21}) Q_{k1} + \sum_{i \geq 1} \psi_{2i} Q_{ki} \quad (6.11b)
\]

• Seismic design situation

\[
\sum_{j \geq 1} G_{kj} + P_k + A_{Ed} + \sum_{i \geq 1} \psi_{2i} Q_{ki} \quad (6.12b)
\]
Combination rules for SLS

• Characteristic – permanent (irreversible) changes

\[
\sum_{j \geq 1} G_{kj} + P_k + Q_{k1} + \sum_{i > 1} \psi_{0i} Q_{ki} \quad (6.14)
\]

• Frequent – local effects

\[
\sum_{j \geq 1} G_{kj} + P_k + \psi_{1i} Q_{k1} + \sum_{i > 1} \psi_{2i} Q_{ki} \quad (6.15)
\]

• Quasi-permanent – long-term effects

\[
\sum_{j \geq 1} G_{kj} + P_k + \sum_{i \geq 1} \psi_{2i} Q_{ki} \quad (6.16)
\]

• Infrequent – concrete bridges

\[
\sum_{j \geq 1} G_{kj} + P_k + \psi_{1,\text{infq}} Q_{k1} + \sum_{i > 1} \psi_{1,i} Q_{k,i} \quad (A2.1b)
\]
### Design values of actions (EQU), Set A

<table>
<thead>
<tr>
<th>Persistent and transient design situation</th>
<th>Permanent actions</th>
<th>Prestress</th>
<th>Leading variable action</th>
<th>Accompanying variable actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavourable</td>
<td>Favourable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq (6.10)</td>
<td>( \gamma_{Gj,\text{sup}} G_{kj,\text{sup}} )</td>
<td>( \gamma_{Gj,\text{inf}} G_{kj,\text{inf}} )</td>
<td>( \gamma_P P )</td>
<td>( \gamma_{Q,1} Q_{k,1} )</td>
</tr>
</tbody>
</table>

**Note 1: Recommended values of partial factors:**

\[ \gamma_{Gj,\text{sup}} = 1,05 \text{ for unfavourable effects of permanent actions} \]
\[ \gamma_{Gj,\text{inf}} = 0,95 \text{ for favourable effects of permanent actions} \]
\[ \gamma_{Q,1} = 1,35 \text{ for road and pedestrian traffic actions} \]
\[ \gamma_{Q,1} = 1,45 \text{ for rail traffic actions} \]
\[ \gamma_{Q, i} = 1,50 \text{ for all other variable actions in persistent design situations} \]
\[ \gamma_{Q, i} = 1,35 \text{ for construction loads during execution} \]

For favourable variable actions, \( \gamma_Q = 0 \).
Note 2:

Alternative approach may be used (verification of bearing uplift of continuous bridges, and where verification of static equilibrium involves the resistance of structural members).

**Recommended values of $\gamma$.**

- $\gamma_{Gj,\text{sup}} = 1.35$, $\gamma_{Gj,\text{inf}} = 1.25$
- $\gamma_Q = 1.35$ for road and pedestrian traffic actions
- $\gamma_Q = 1.45$ for rail traffic actions
- $\gamma_Q = 1.50$ for all other variable actions in persistent design situation provided that applying $\gamma_{Gj,\text{inf}} = 1.00$ both to the favourable and unfavourable part of permanent actions does not give a more unfavourable effect.
### Design values of actions (STR/GEO), Set B

<table>
<thead>
<tr>
<th>Persistent and transient design situation</th>
<th>Permanent actions</th>
<th>Press-tress</th>
<th>Leading variable action</th>
<th>Accompanying variable actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unfavourable</td>
<td>Favourable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq(6.10)</td>
<td>$\gamma_{Gj,\text{sup}} G_{kj,\text{sup}}$</td>
<td>$\gamma_{Gj,\text{inf}, G_{kj,\text{inf}}}$</td>
<td>$P$</td>
<td>$\gamma_{Q,1} Q_{k,1}$</td>
</tr>
<tr>
<td>Eq(6.10a)</td>
<td>$\gamma_{Gj,\text{sup}} G_{kj,\text{sup}}$</td>
<td>$\gamma_{Gj,\text{inf}, G_{kj,\text{inf}}}$</td>
<td>$P$</td>
<td>$\gamma_{Q,1} \psi_{0,1} Q_{k,1}$</td>
</tr>
<tr>
<td>Eq(6.10b)</td>
<td>$\xi G_{j,\text{sup}} G_{kj,\text{sup}}$</td>
<td>$\gamma_{Gj,\text{inf}, G_{kj,\text{inf}}}$</td>
<td>$P$</td>
<td>$\gamma_{Q,1} Q_{k,1}$</td>
</tr>
<tr>
<td></td>
<td>$\gamma_{Gj,\text{sup}} G_{kj,\text{sup}}$</td>
<td>$\gamma_{Gj,\text{inf}, G_{kj,\text{inf}}}$</td>
<td>$P$</td>
<td>$\gamma_{Q,1} \psi_{0,1} Q_{k,1}$</td>
</tr>
</tbody>
</table>

**Notations:****

- $\gamma_{Gj,\text{sup}} = 1,35$ unfavourable effects of permanent actions
- $\gamma_{Gj,\text{inf}} = 1$ favourable effects of permanent actions
- $\gamma_{Q,1} = 1,35$ unfavourable actions due to road or pedestrian traffic
- $\gamma_{Q,1} = 1,45 \ (1,20)$ for specific actions due to rail traffic
- $\gamma_{Q, i} = 1,50$ for other variable actions in persistent design situations
- $\xi = 0,85$
# Design values of actions (STR/GEO), set C

<table>
<thead>
<tr>
<th>Persistent and transient design situation</th>
<th>Permanent actions</th>
<th>Prestress</th>
<th>Leading variable action</th>
<th>Accompanying variable actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavourable</td>
<td>Favourable</td>
<td>$\gamma P$</td>
<td>$\gamma Q,1 \ Q_{k,1}$</td>
<td>$\gamma Q, i \ \psi_{0,i} \ Q_{k,i}$</td>
</tr>
</tbody>
</table>

**Eq (6.10)**

$\gamma_{Gj, sup} = \gamma_{Gj, inf} = 1,0$ for permanent actions

$\gamma_{Q,1} = 1,15$ for unfavourable effects of variable actions due to road and pedestrian traffic

$\gamma_{Q,1} = 1,25$ for unfavourable effects of variable actions due to rail traffic

$\gamma_{Q, i} = 1,3$ for variable actions due to horizontal earth pressures (soil, ground water) in persistent design situations

$\gamma_{Q, i} = 1,3$ for all other unfavourable effects of variable actions
## Design values of actions in accidental and seismic design situations

<table>
<thead>
<tr>
<th>Design situation</th>
<th>Permanent actions</th>
<th>Pres- tress</th>
<th>Accidental or seismic action</th>
<th>Accompanying variable actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unfavourable</td>
<td>Favourable</td>
<td></td>
<td>Main</td>
</tr>
<tr>
<td>Eq (6.11a/b)</td>
<td>$G_{kj, \text{sup}}$</td>
<td>$G_{kj, \text{inf}}$</td>
<td>$P$</td>
<td>$A_d$</td>
</tr>
<tr>
<td>Eq (6.12 a/b)</td>
<td>$G_{kj, \text{sup}}$</td>
<td>$G_{kj, \text{inf}}$</td>
<td>$P$</td>
<td>$A_{Ed} = \gamma A_{Ek}$</td>
</tr>
</tbody>
</table>
## Design values of actions in the serviceability limit states

<table>
<thead>
<tr>
<th>Combination</th>
<th>Permanent actions</th>
<th>Variable actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
<td>$G_{kj, \text{sup}}$</td>
<td>$G_{kj, \text{inf}}$</td>
</tr>
<tr>
<td><strong>Frequent</strong></td>
<td>$G_{kj, \text{sup}}$</td>
<td>$G_{kj, \text{inf}}$</td>
</tr>
<tr>
<td><strong>Quasi-permanent</strong></td>
<td>$G_{kj, \text{sup}}$</td>
<td>$G_{kj, \text{inf}}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fundamental combination of actions

Leading action, accompanying

\[ \psi_{0gr1a} \]

\[ \sum_{j \geq 1} (1,35 G_{kj,\text{sup}} \text{ or } 1,00 G_{kj,\text{inf}})^+ (1,00 \text{ or } 0) \times S^+ \]

\[ 1,35 \times (TS + UDL + q_{fk}^*) + 1,5 \times \min \left( 0,6 F_{Wk}, F_w^* \right) \text{ or } 0,6 T_k \]

\[ 1,35 \text{ gr1b} \]

\[ 1,35 \text{ gr2} + 1,5 \times 0,6 T_k \]

\[ 1,35 \text{ (gr3 or gr4)} + 1,5 \times 0,6 T_k \]

\[ 1,35 \text{ gr5} \]

\[ 1,5T_k + 1,35 \times (0,75TS + 0,4UDL + 0,4q_{fk}^*) \]

\[ 1,5F_{Wk} \]

\[ 1,5Q_{Sn,k} \]

TS tandem system, UDL uniformly distributed load

The \( \psi_0 \) value for thermal actions may in most cases be reduced to 0 for ultimate limit states EQU, STR and GEO.
Characteristic combination of actions (SLS)

\[
\sum_{j \geq 1} (G_{kj,\text{sup}} \text{ or } G_{kj,\text{inf}})"+" (1,00 \text{ or } 0) \times S"+"
\]

\[
\begin{align*}
\text{Leading action, accompanying} & \\
\psi_0 \text{gr1a} & \\
\{TS + UDL + q^*_f\} & + \left\{ \min \left(0,6 F_{Wk}, F_w^* \right) \right. \\
\text{gr1b} & \\
\text{gr2} + 0,6 T_k & \\
\left( \text{gr3 or gr4} \right) + 0,6 T_k & \\
\text{gr5} & \\
T_k + (0,75TS + 0,4 UDL + 0,4 q^*_f) & \\
F_{Wk} & \\
Q_{S_n,k} & \\
\end{align*}
\]

\text{TS tandem system, UDL uniformly distributed load}

The \(\psi_0\) value for thermal actions may in most cases be reduced to 0 for ultimate limit states EQU, STR and GEO.
Frequent combination of actions (SLS)

\[ \sum_{j \geq 1} (G_{kj,\text{sup}} \text{ or } G_{kj,\text{inf}}) "+" (1,00 \text{ or } 0) \times S"+" \left\{ \begin{array}{l}
(0,75TS + 0,4\text{UDL}) + 0,5 T_k \\
0,75 \text{ gr1b} \\
0,4 \text{ gr3} + 0,5 T_k \\
0,75 \text{ gr4} + 0,5 T_k \\
0,2 F_{Wk} \\
0,6 T_k 
\end{array} \right. \]

*TS tandem system, UDL uniformly distributed load*
Quasi permanent-combination of actions (SLS)

Leading action (no accompanying)

\[
\sum_{j \geq 1} (G_{kj,\text{sup}} \text{ or } G_{kj,\text{inf}}) ^+ (1,00 \text{ or } 0) \times S ^+ 0,5 \times T_k
\]
Subdivision of the composite bridge in notional lanes

Physical lanes

Notional lanes
Horizontal forces (braking and acceleration)

\[ Q_{lk} = 0.6(2 \times 300) + 0.10 \times 27.0 \times L \text{ [kN]} \]

- \( L = 60 \text{ m} \)
  \( Q_{lk} = 522 \text{ kN} \)

- \( L = 80 \text{ m} \)
  \( Q_{lk} = 577 \text{ kN} \)

- \( L = 120 \text{ m} \)
  \( Q_{lk} = 685 \text{ kN} \)

- \( L = 140 \text{ m} \)
  \( Q_{lk} = 739 \text{ kN} \)
Fatigue verification

model 1 = reduced LM1
model 2 = frequent loads
model 3 = N vehicles (1 type)
model 4 = N vehicle (5 types, equivalent loads)
model 5 = real traffic

\[ N = 0.05 \text{ – 2 million on lane 1 depending on road type} \]

models 1-2: just check whether max stress range \( S < \) fatigue limit
models 3-4: damage assessment
model 5 - general (additional assumptions might be necessary)
## Fatigue LM 1

### Fatigue load model n. 1

<table>
<thead>
<tr>
<th>Lane n. 1</th>
<th>$Q_{ik}$</th>
<th>$q_{ik}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

- $Q_{ik} = 210$ kN
- $q_{ik} = 2.7$ kN/m

### Fatigue load model n. 1 for local verifications

<table>
<thead>
<tr>
<th>Lane n. 2</th>
<th>$Q_{ik}$</th>
<th>$q_{ik}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

- $Q_{ik} = 140$ kN
- $q_{ik} = 0.75$ kN/m

<table>
<thead>
<tr>
<th>Lane n. 3</th>
<th>$Q_{ik}$</th>
<th>$q_{ik}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

- $Q_{ik} = 70$ kN
- $q_{ik} = 0.75$ kN/m

<table>
<thead>
<tr>
<th>Remaining area</th>
<th>$q_{ik}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.75 kN/m^2</td>
</tr>
</tbody>
</table>

### Fatigue load model n. 1 for local verifications

- Traffic flow direction
- $Q = 280$ kN
### Fatigue load model n. 2 – frequent set of lorries

<table>
<thead>
<tr>
<th>LORRY SILHOUETTE</th>
<th>Interaxes [m]</th>
<th>Frequent axle loads [kN]</th>
<th>Wheel type (see table 3)</th>
<th>Wheel axle type</th>
<th>Geometrical definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.5</td>
<td>90</td>
<td>190</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.20</td>
<td>80</td>
<td>140</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>120</td>
<td>120</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.20</td>
<td>90</td>
<td>120</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.20</td>
<td>120</td>
<td>120</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>180</td>
<td>180</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>120</td>
<td>120</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.40</td>
<td>90</td>
<td>120</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.00</td>
<td>190</td>
<td>140</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.80</td>
<td>120</td>
<td>120</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.80</td>
<td>90</td>
<td>120</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.60</td>
<td>180</td>
<td>120</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.40</td>
<td>120</td>
<td>110</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>110</td>
<td>110</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>
Fatigue LM 3

Fatigue load model n. 3 – Axle load 120 kN

Indicative number of lorries expected per year on a slow lane

<table>
<thead>
<tr>
<th>Traffic categories</th>
<th>Nobs per year and per slow lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Roads and motorways with 2 or more lanes per direction with high flow rates of lorries</td>
<td>$2.0 \cdot 10^6$</td>
</tr>
<tr>
<td>2 Roads and motorways with medium flow rates of lorries</td>
<td>$0.5 \cdot 10^6$</td>
</tr>
<tr>
<td>3 Main roads with low flow rates of lorries</td>
<td>$0.125 \cdot 10^6$</td>
</tr>
<tr>
<td>4 Local roads with low flow rates of lorries</td>
<td>$0.05 \cdot 10^6$</td>
</tr>
</tbody>
</table>
Equivalent damage coefficient $\lambda$

$$\gamma_{F, \text{fat}} \Delta \sigma_{s, \text{equ}} = \gamma_{F, \text{fat}} \lambda_s \Delta \sigma_{s, \text{EC}} \leq \frac{\Delta \sigma_{s, Rsk}}{\gamma_{s, \text{fat}}}$$

$$\lambda_s = \phi_{\text{fat}} \lambda_1 \lambda_2 \lambda_3 \lambda_4$$

Table 3.1: Recommended values for partial factors for fatigue strength

<table>
<thead>
<tr>
<th>Assessment method</th>
<th>Consequence of failure</th>
<th>Low consequence</th>
<th>High consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage tolerant</td>
<td>1,00</td>
<td>1,15</td>
<td></td>
</tr>
<tr>
<td>Safe life</td>
<td>1,15</td>
<td>1,35</td>
<td></td>
</tr>
</tbody>
</table>

$\Delta \sigma_{s, EC} = \Delta \sigma_{\text{max}}$ induced by LM 3 - Problem: calibration of $\lambda$ values
Damage assessment

Palmgren Miner rule

\[ D = \frac{\sum_{i} n_i}{\sum_{i} N_i} \]

Table 3.1: Recommended values for partial factors for fatigue strength

<table>
<thead>
<tr>
<th>Assessment method</th>
<th>Consequence of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low consequence</td>
</tr>
<tr>
<td>Damage tolerant</td>
<td>1.00</td>
</tr>
<tr>
<td>Safe life</td>
<td>1.15</td>
</tr>
</tbody>
</table>
## Fatigue load model n. 4 – equivalent set of lorries

<table>
<thead>
<tr>
<th>LORRY SILHOUETTE</th>
<th>TRAFFIC TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lorry spacing [m]</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>4.20</td>
</tr>
<tr>
<td></td>
<td>3.20</td>
</tr>
<tr>
<td></td>
<td>3.40</td>
</tr>
<tr>
<td></td>
<td>4.80</td>
</tr>
</tbody>
</table>
Rainflow method

Traffic flow: 500 000 lorries per years per slow lane
500 000 lorries per year on lane 1
500 000 lorries per year on lane 2
Fatigue life: 100 years
# S-N curves for steel reinforcement in concrete

<table>
<thead>
<tr>
<th>Steel reinforcement</th>
<th>S-N curve n.</th>
<th>N*</th>
<th>k₁</th>
<th>k₂</th>
<th>Δσ(N*) [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight bars</td>
<td>2</td>
<td>$10^6$</td>
<td>5</td>
<td>9</td>
<td>162.5</td>
</tr>
<tr>
<td>Welded bars and meshes</td>
<td>4</td>
<td>$10^7$</td>
<td>3</td>
<td>5</td>
<td>58.5</td>
</tr>
<tr>
<td>Jointing devices</td>
<td>7</td>
<td>$10^7$</td>
<td>3</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>Prestressing steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-tensioning</td>
<td>1</td>
<td>$10^6$</td>
<td>5</td>
<td>9</td>
<td>185</td>
</tr>
<tr>
<td>Post tensioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>single strands in plastic ducts</td>
<td>1</td>
<td>$10^6$</td>
<td>5</td>
<td>9</td>
<td>185</td>
</tr>
<tr>
<td>straight tendons or curved tendons in plastic ducts</td>
<td>3</td>
<td>$10^6$</td>
<td>5</td>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>curved tendons in plastic ducts</td>
<td>5</td>
<td>$10^6$</td>
<td>5</td>
<td>7</td>
<td>120</td>
</tr>
<tr>
<td>Jointing devices</td>
<td>6</td>
<td>$10^6$</td>
<td>3</td>
<td>5</td>
<td>80</td>
</tr>
</tbody>
</table>

**Diagram:**

- **Δσ [MPa]**
- **N**
- **$10^4$**
- **$10^5$**
- **$10^6$**
- **$10^7$**
- **$10^8$**
- **$10^9$**

**Graphical Representation:**

- Linear scale for Δσ [MPa]
- Logarithmic scale for N

**Key:**

- **k₁ = 5**
- **k₂ = 3**
- **k₃ = 10**
- **k₄ = 9**
- **k₅ = 7**
- **k₆ = 5**

*Note: The values in the table are approximate and based on typical engineering data.*
S-N curves for steel details

1 Detail category $\Delta \sigma_c$
2 Constant amplitude fatigue limit $\Delta \sigma_d$
3 Cut-off limit $\Delta \sigma_l$
S-N curves for steel details

for \( t = 40 \text{ mm} \) it results

\[
k_s = \left( \frac{25}{40} \right)^{0.2} = 0.91
\]

Effective detail class
\( (t=40 \text{ mm}) \Delta \sigma_C = 72.8 \)

9) The effect of welded shear studs on base material.
S-N curves for steel details

<table>
<thead>
<tr>
<th>80</th>
<th>0 ≤ l ≤ 50 mm</th>
</tr>
</thead>
</table>

6) Welded to plate.

7) Vertical stiffeners welded to a beam or plate girder.

8) Diaphragm of box girders welded to the flange or the web. May not be possible for small hollow sections.

| 71 | 50 < l ≤ 80 mm |

Transverse attachments:

Ends of welds to be carefully ground to remove any undercut that may be present.

7) $\Delta \sigma$ to be calculated using principal stresses if the stiffener terminates in the web, see left side.

The values are also valid for ring stiffeners.
Cross sections taken into account for fatigue assessments

support

midspan

x=35 m

x=72 m
Notional lanes for fatigue assessments

Case 1
Physical lanes (more realistic)

Case 2
Notional lanes (very severe)
Bending moment history - section x=35 m (uncracked)

- Influence line for bending moment - section x=35 m – [m]

<table>
<thead>
<tr>
<th>Case</th>
<th>$\gamma_{Mf} \Delta M_1$ [kNm]</th>
<th>$\gamma_{Mf} \Delta M_2$ [kNm]</th>
<th>$\gamma_{Mf} \Delta M_3$ [kNm]</th>
<th>$\gamma_{Mf} \Delta M_4$ [kNm]</th>
<th>D (upper flange)</th>
<th>D (lower flange)</th>
<th>D (straight rebar)</th>
<th>D (mesh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>6160.4</td>
<td>1680.1</td>
<td>372.5</td>
<td>101.6</td>
<td>0.000E+00</td>
<td>7.470E-01</td>
<td>6.444E-11</td>
<td>2.054E-04</td>
</tr>
<tr>
<td>Case 2</td>
<td>8400.5</td>
<td>5040.3</td>
<td>507.9</td>
<td>304.7</td>
<td>0.000E+00</td>
<td>3.522E+00</td>
<td>1.061E-09</td>
<td>1.042E-03</td>
</tr>
</tbody>
</table>

Bending moment history (\( \eta = 1 \))
Bending moment history - section x=60 m (support) – (cracked)

Influence line for bending moment - section x=60 m – [m]

Bending moment history (η=1)
Bending moment history - section x=72 m (cracked)

**Case 1**

<table>
<thead>
<tr>
<th>$\gamma_{Mf}$</th>
<th>$\Delta M_1$ [kNm]</th>
<th>$\Delta M_2$ [kNm]</th>
<th>$\Delta M_3$ [kNm]</th>
<th>$\Delta M_4$ [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{Mf}$</td>
<td>3819.0</td>
<td>1041.5</td>
<td>699.5</td>
<td>190.8</td>
</tr>
</tbody>
</table>

**Case 2**

<table>
<thead>
<tr>
<th>$\gamma_{Mf}$</th>
<th>$\Delta M_1$ [kNm]</th>
<th>$\Delta M_2$ [kNm]</th>
<th>$\Delta M_3$ [kNm]</th>
<th>$\Delta M_4$ [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{Mf}$</td>
<td>5207.7</td>
<td>3124.6</td>
<td>953.8</td>
<td>572.3</td>
</tr>
</tbody>
</table>

D (upper flange) 0.000E+00 0.000E+00
D (lower flange) 0.000E+00 0.000E+00
D (straight rebar) 2.664E-08 4.387E-07
D (mesh) 5.838E-03 2.962E-02

Influence line for bending moment - section x=72 m – [m]
Bending moment history – midspan (uncracked)

Influence line for bending moment - midspan – [m]
Thank you for your kind attention!