EU-Russia Regulatory Dialogue: Construction Sector Subgroup

Seminar ' Bridge Design with Eurocodes'

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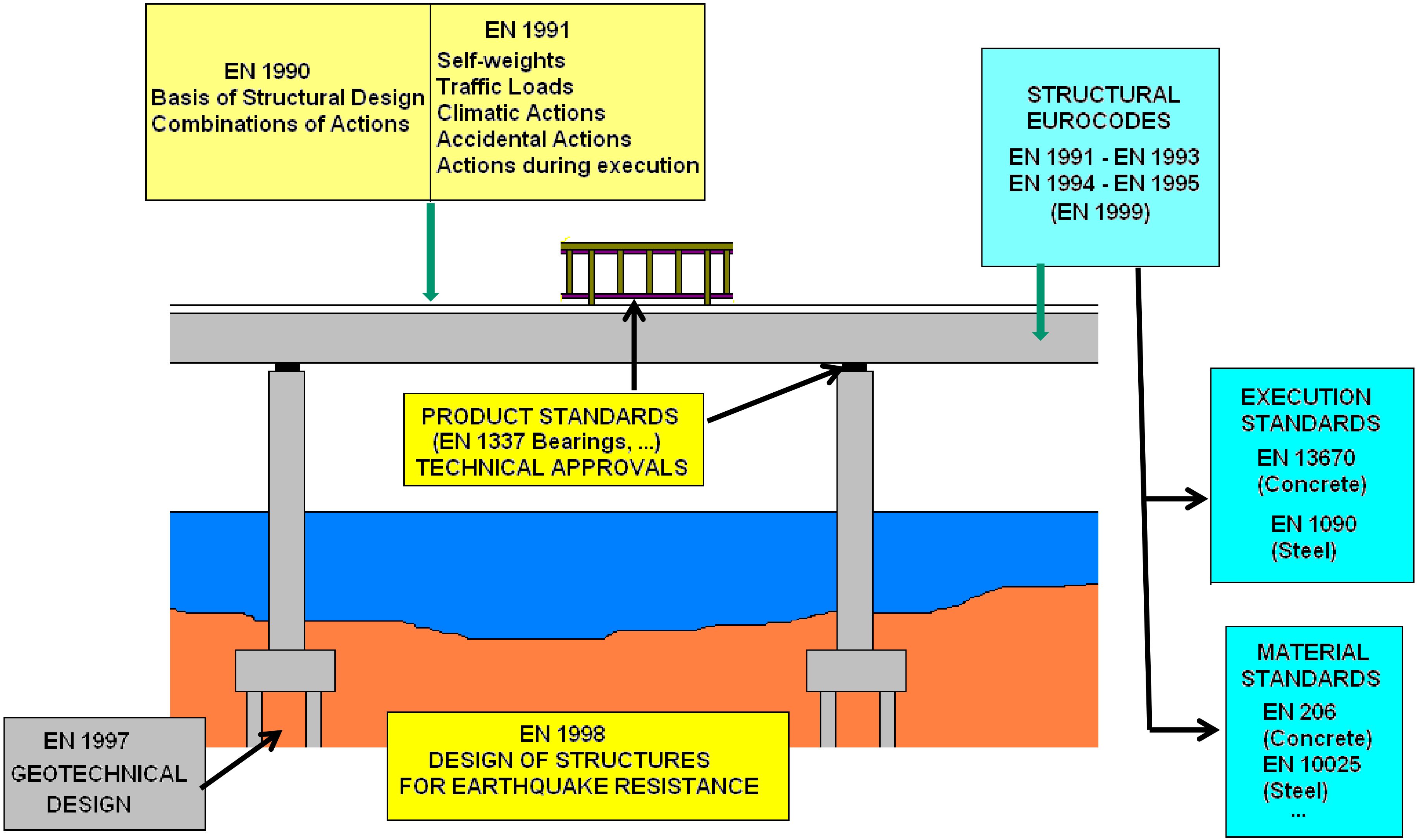
TC250 Structural Eurocodes

Actions (loading) on bridges

N. Malakatas
Chairman of CEN/TC250/SC1
Director for Design & Studies of Road Works
Greek Ministry DCITN

Design and construction of a bridge : EN 1991-2 (Traffic loads on bridges) + other Eurocodes + Construction Stand.



ACTIONS ON A BRIDGE

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**

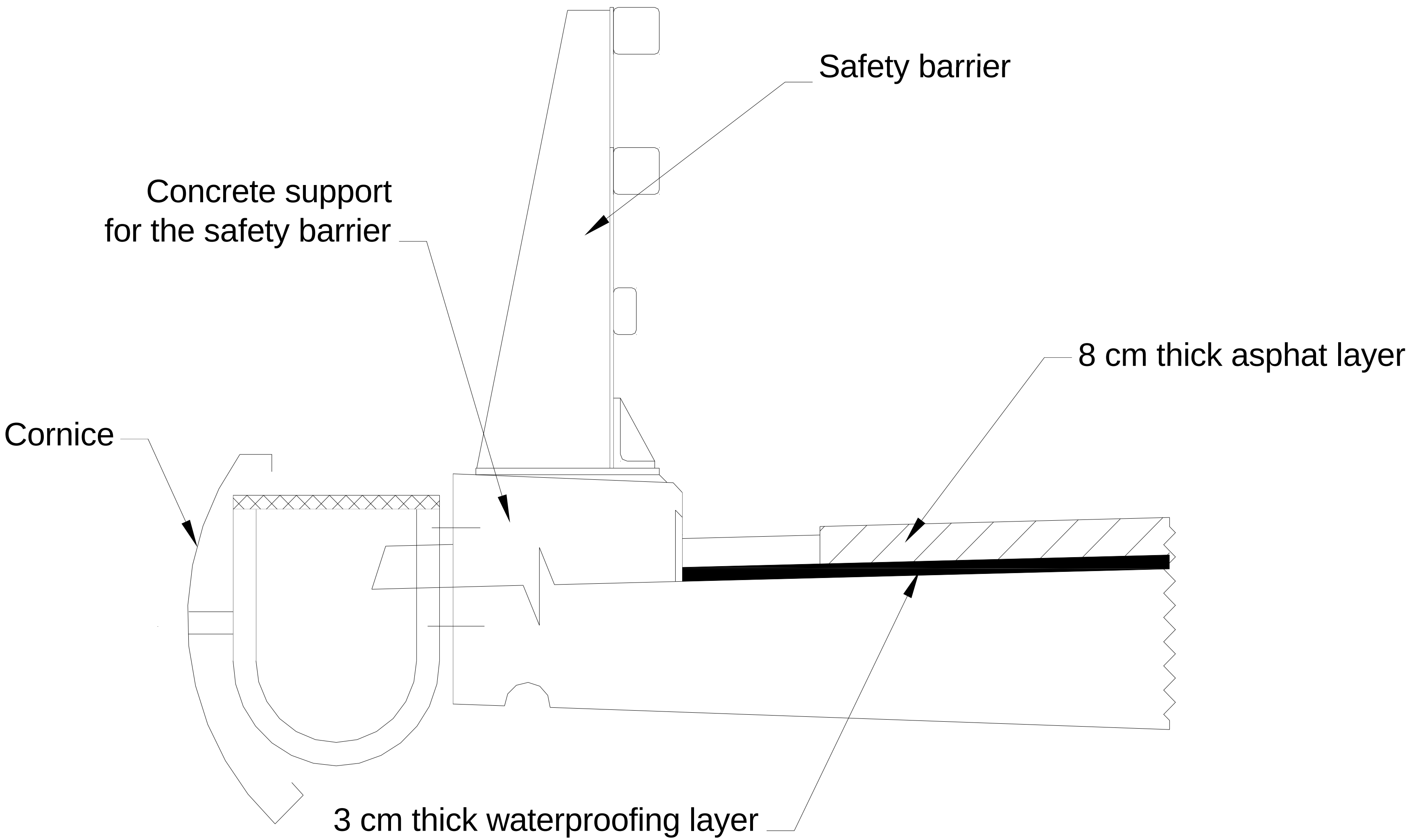
There are also other actions described in EN 1991, such as fire and snow loads, which are usually irrelevant. Additional actions are foreseen in other EN Eurocodes, namely:

- **Concrete creep and shrinkage (EN 1992)**
- **Settlements and earth pressures (EN 1997)**
- **Seismic actions (EN 1998)**

PARTS AND IMPLEMENTATION OF EN 1991

Part of Eurocode 1 : Actions on structures	Title (Subject)	Issued
EN 1991-1-1	General actions – Densities, self-weight, imposed loads for buildings	April 2002
EN 1991-1-2	General actions – Actions on structures exposed to fire	November 2002
EN 1991-1-3	General actions – Snow loads	July 2003
EN 1991-1-4	General actions – Wind actions	April 2005
EN 1991-1-5	General actions – Thermal actions	November 2003
EN 1991-1-6	General actions – Actions during execution	June 2005
EN 1991-1-7	General actions – Accidental actions	July 2006
EN 1991-2	Traffic loads on bridges	September 2003
EN 1991-3	Actions induced by cranes and machinery	July 2006
EN 1991-4	Silos and tanks	May 2006

ACTIONS : SELFWEIGHT



ACTIONS : SELFWEIGHT

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Structural parts:

The density of structural steel is taken equal to 77 kN/m³ *[EN 1991-1-1, Table A.4]*. The density of reinforced concrete is taken equal to 25 kN/m³ *[EN 1991-1-1, Table A.1]*. The selfweight is determined based on the dimensions of the structural elements.

Non-structural parts:

The density of the waterproofing material and of the asphalt is taken as equal to 24-25 kN/m3 *[EN 1991-1-1, Table A.6]*.

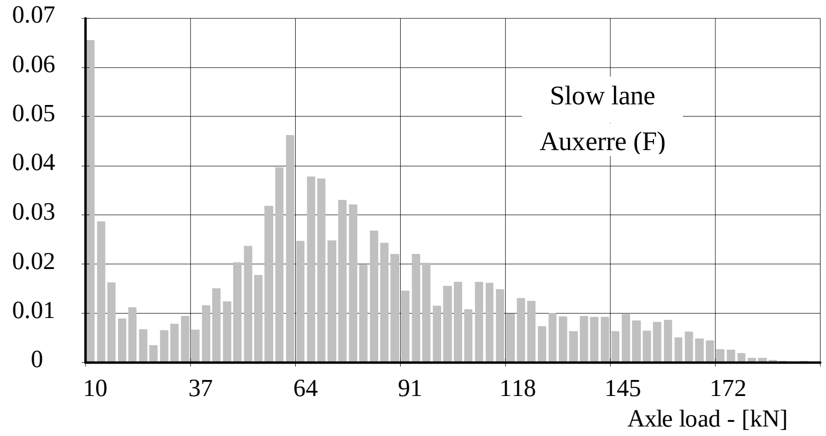
According to *[EN 1991-1-1, 5.2.3(3)]* it is recommended that the nominal value of the waterproofing layer and the asphalt layer is multiplied by +/-20% (if the post-execution coating is taken into account in the nominal value) and by +40% / -20% (if this is not the case)

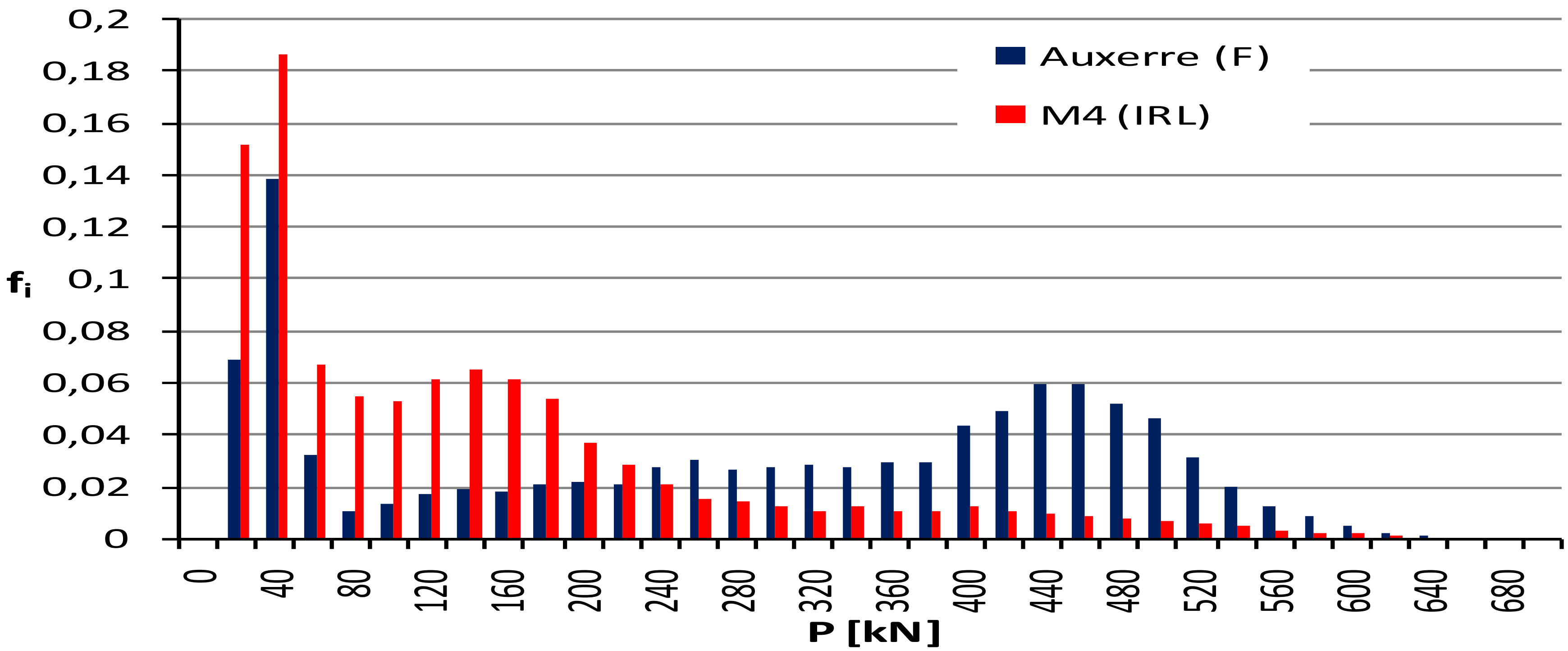
- Forward
- Section 1 – General
- Section 2 – Classification of actions
- Section 3 – Design situations
- Section 4 – Road traffic actions and other actions specifically for road bridges
- Section 5 – Actions on footways, cycle tracks and footbridges
- Section 6 – Traffic actions and other actions specifically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

- **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 + φ 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

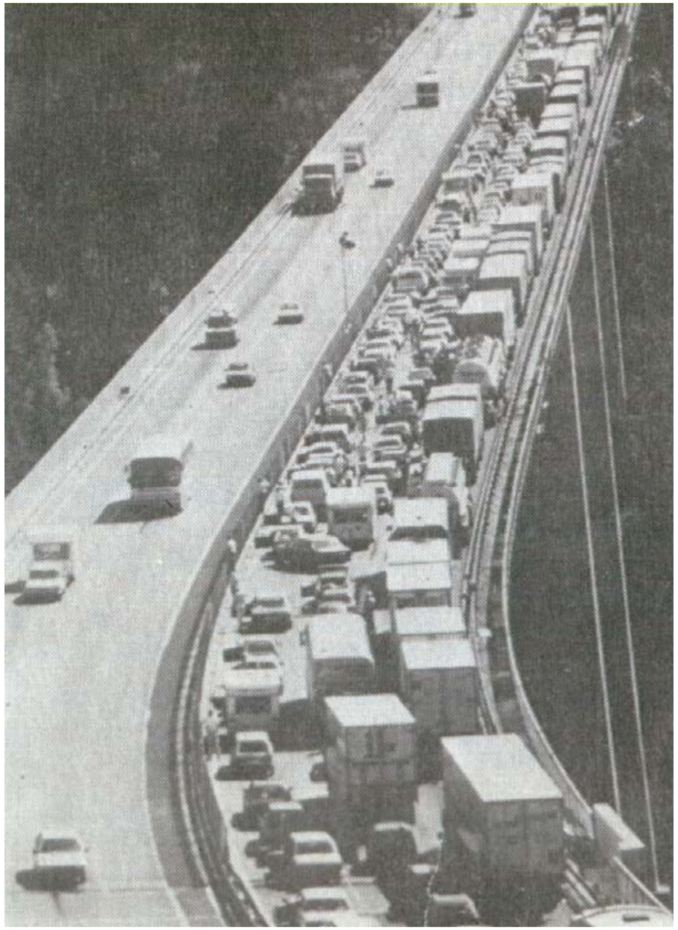
Traffic measurements :

- Axial load
- Total load





Extreme traffic scenarios



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 traffric actions

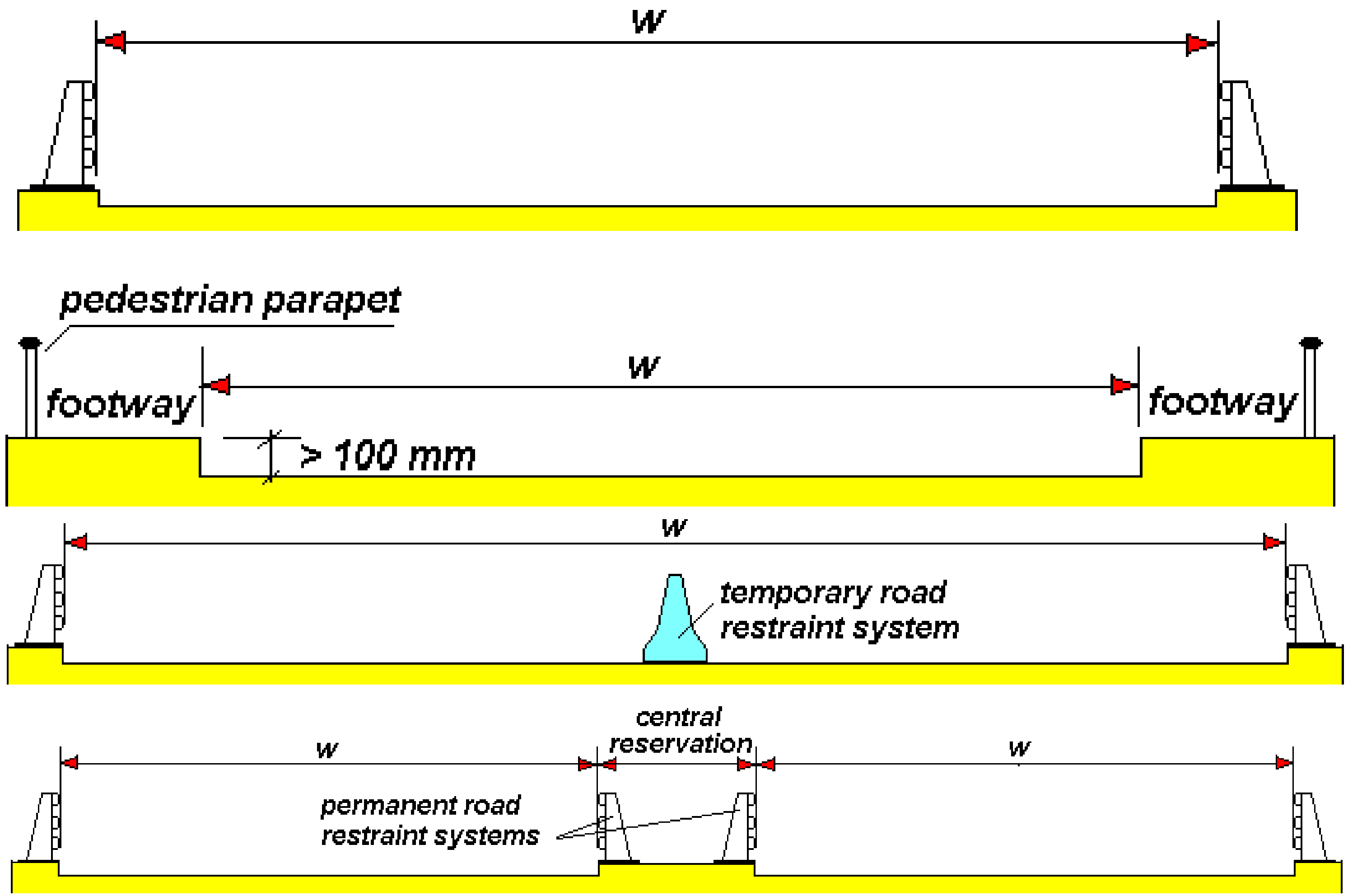
LOAD MODELS FOR LIMIT STATE VERIFICATIONS OTHER THAN FOR FATIGUE LIMIT STATES

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/m^2**

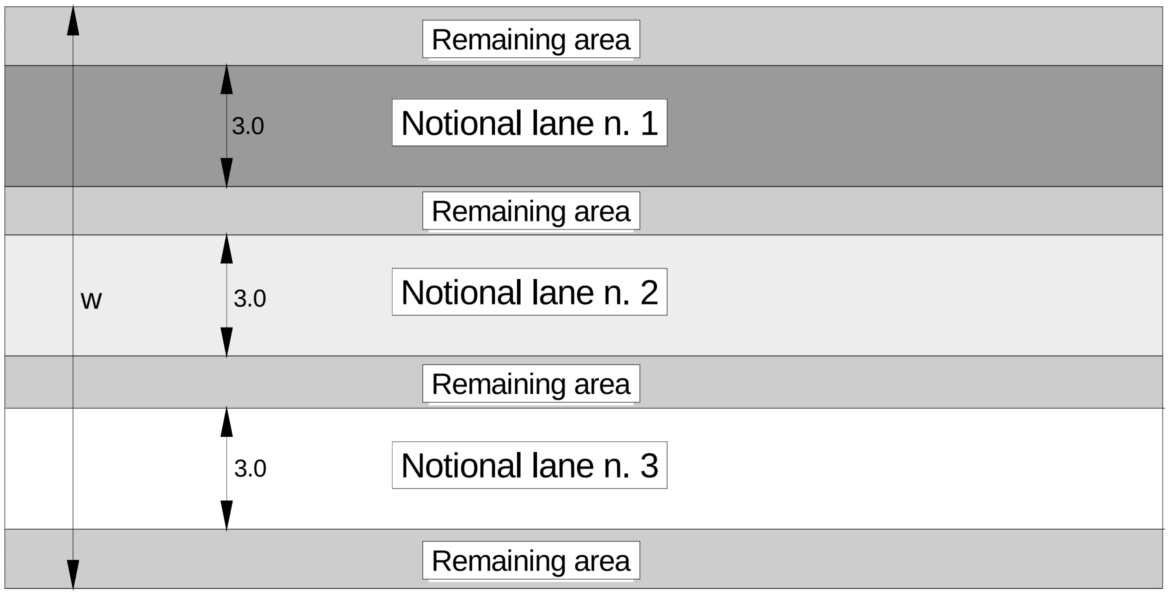
Carriageway width *w*

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

Carriageway width	Number of notional lanes	Notional lane width	Width of the remaining area
$w < 5{,}4$ m	$n_\ell = 1$	3 m	$w - 3$ m
$5{,}4 \text{ m} \leq w < 6$ m	$n_\ell = 2$	$w/2$	0
$6 \text{ m} \leq w$	$n_\ell = \text{int}(w/3)$	3 m	$w - 3 \times n_\ell$



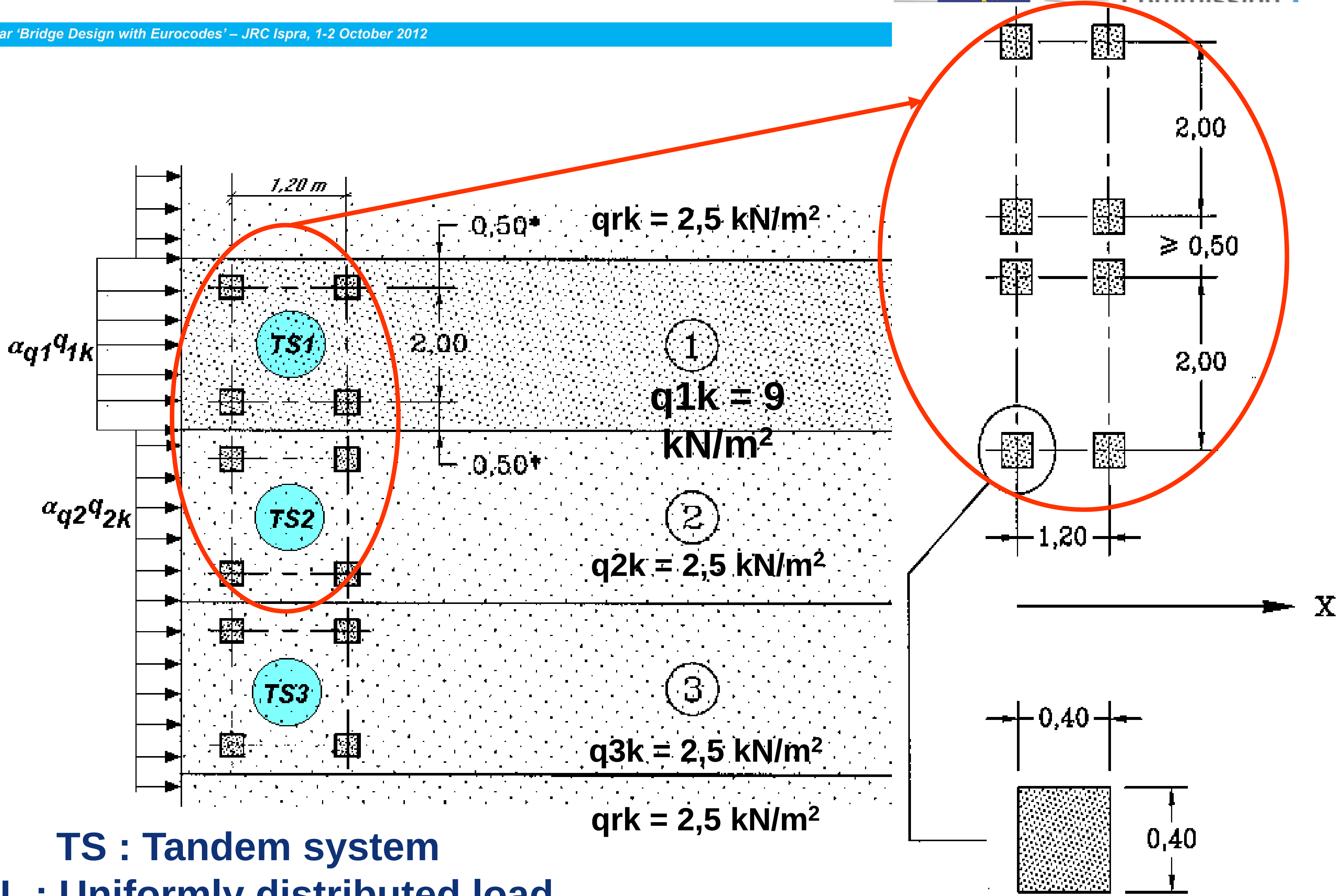
1 – Lane n° 1 (3m)

2 – Lane n° 2 (3m)

3 – Lane n° 3 (3m)

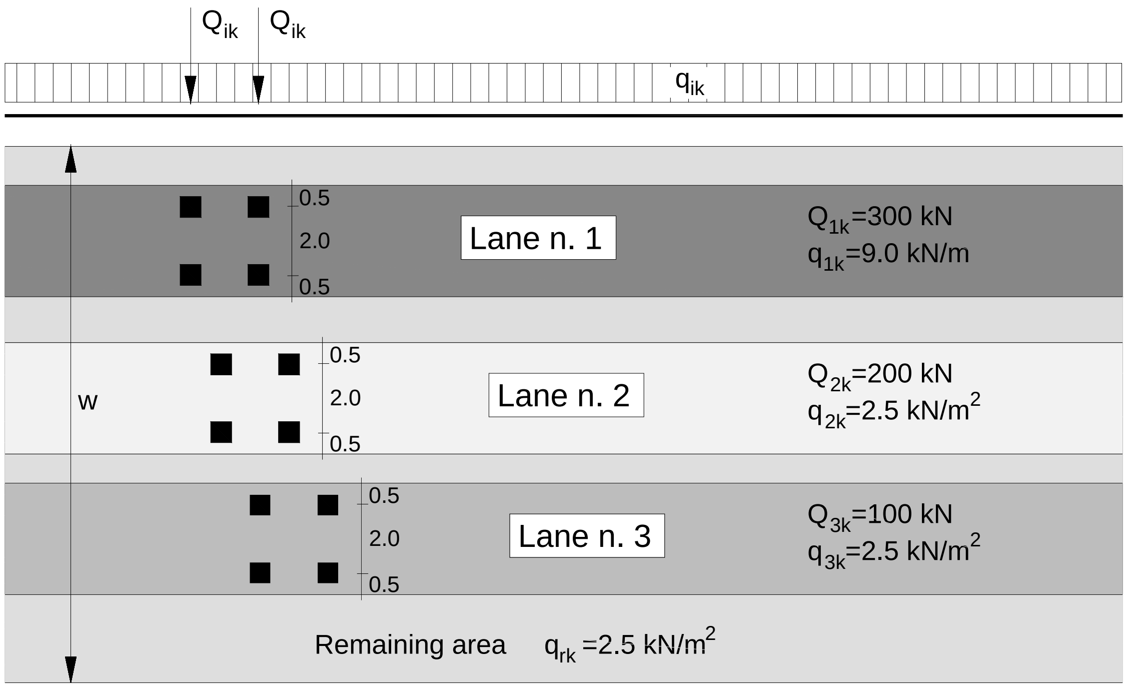
4 – Remaining area

The main load model (LM1)



TS : Tandem system
UDL : Uniformly distributed load

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

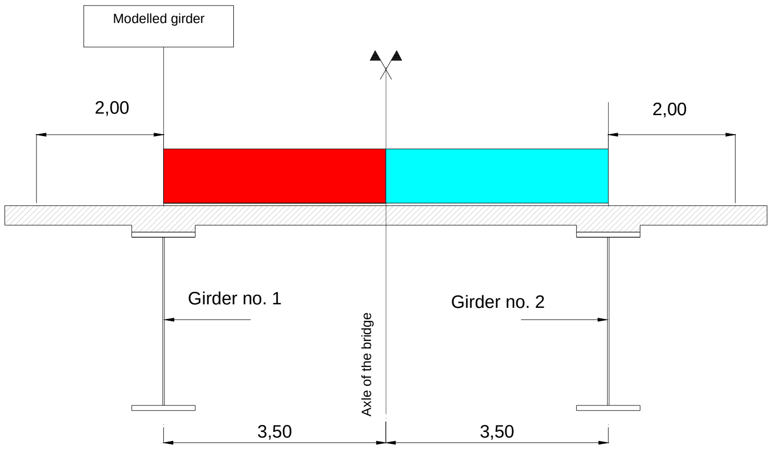


For the determination of general effects, the tandems travel along the axis of the notional lanes

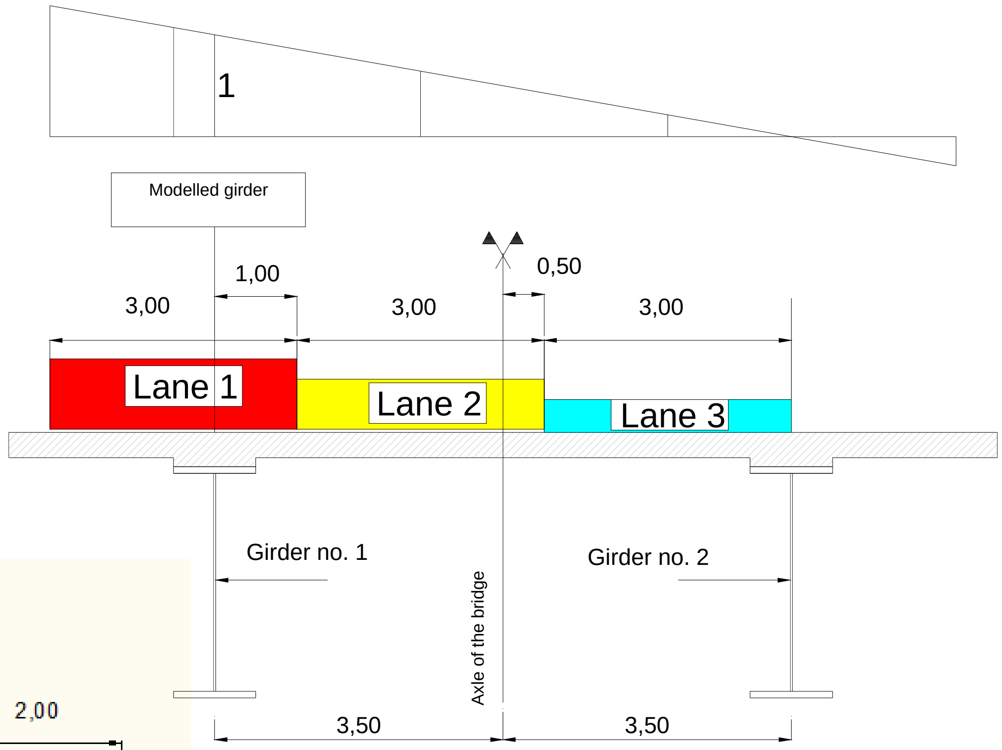
For local verifications, the heaviest tandem should be positioned to get the most unfavourable effect.

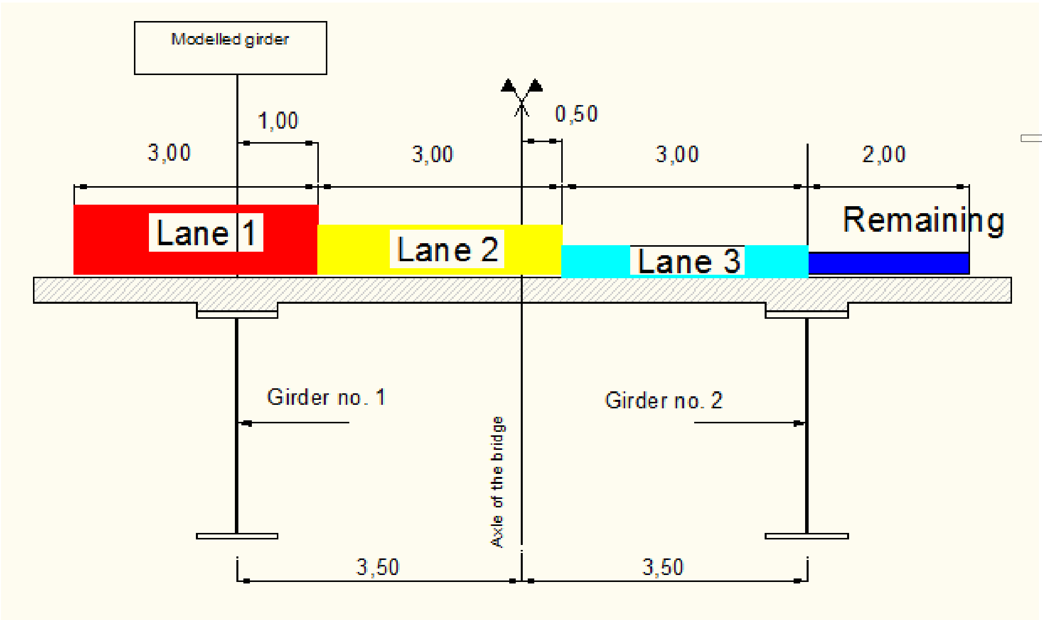
Where two tandems are located in two adjacent notional lanes, they may be brought closer, the distance between axles being not less than 0,50 m

Subdivision of a composite bridge in notional lanes (example)



Physical lanes





Notional lanes

Load Model 1 : Characteristic Values

Location	Tandem system *TS*	*UDL* system
	Axle loads Q_{ik} (kN)	q_{ik} (or q_{ik}) (kN/m^2)
Lane Number 1	300	9
Lane Number 2	200	2,5
Lane Number 3	100	2,5
Other lanes	0	2,5
Remaining area (q_{rk})	0	2,5

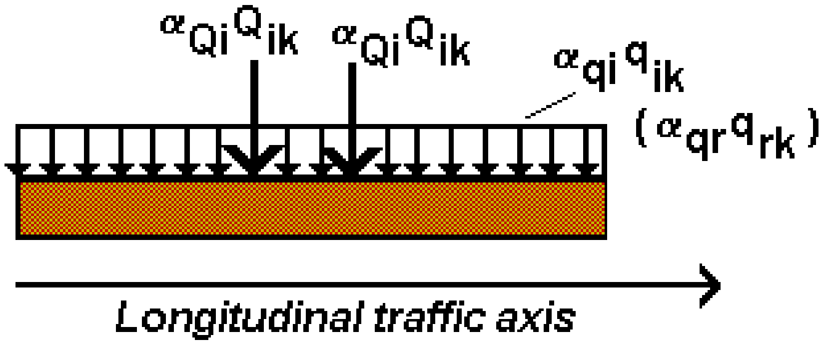
Load models for road bridges: LM1

The main load model (LM1): Concentrated and uniformly distributed loads, covers most of the effects of the traffic of lorries and cars.

$Q_{1k} = 300$ kN

$Q_{2k} = 200$ kN

$Q_{3k} = 100$ kN



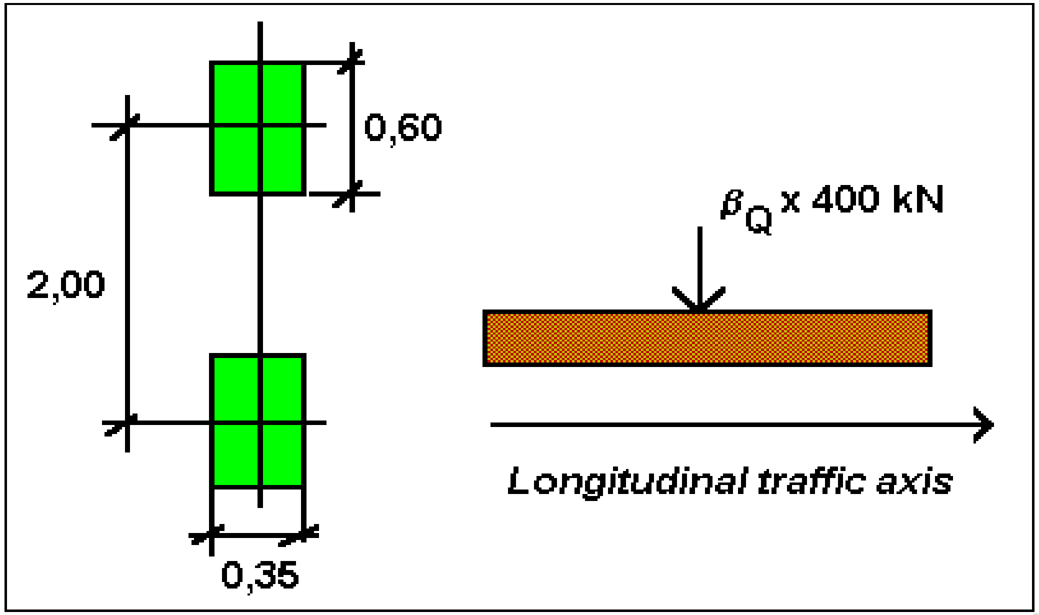
Recommended values of αQi , αqi = 1

***Example* of other values for α factors (NDPs)**

	α_{Q1}	$\alpha_{Qi}\ i \geq 2$	α_{q1}	$\alpha_{qi}\ i \geq 2$	α_{qr}
1st class	1	1	1	1	1
2nd class	0,9	0,8	0,7	1	1
3rd class	0,8	0,5	0,5	1	1

1st class : international heavy vehicle traffic
2nd class : « normal » heavy vehicle traffic
3rd class : « light » heavy vehicle traffic

Load models for road bridges : LM2 – isolated single axle



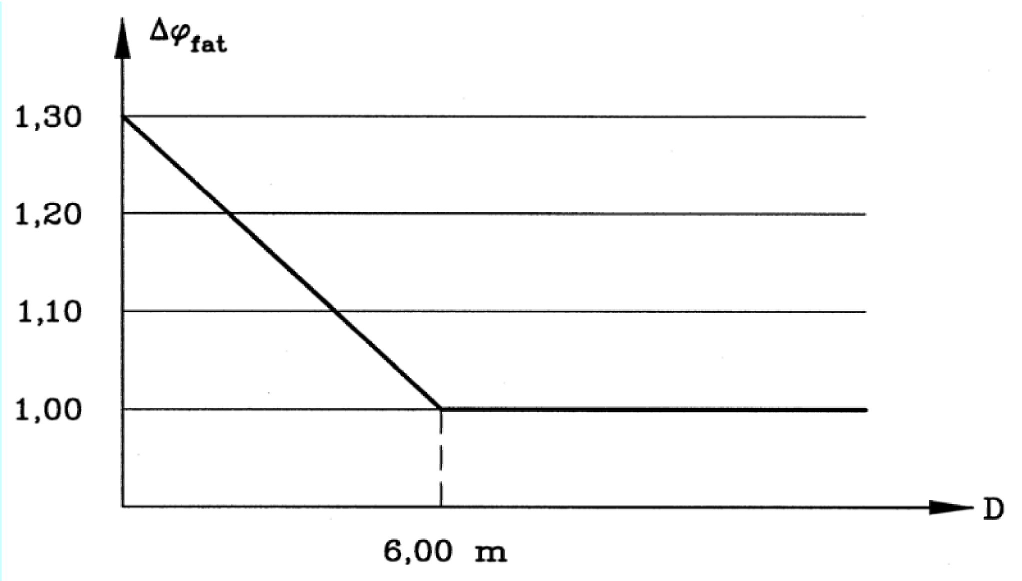
Recommended value

$\beta_Q = \alpha_{Q1}$

in the vicinity of expansion joints, an additional dynamic amplification factor equal to the value

when relevant, only one wheel of 200 (kN) may be taken into account

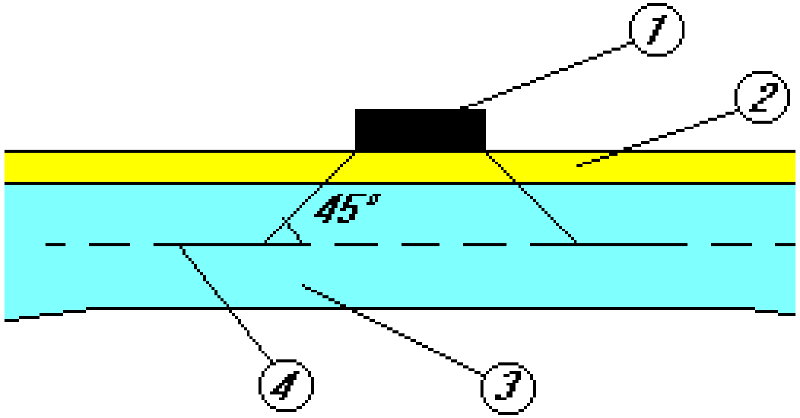
Representation of the additional amplification factor

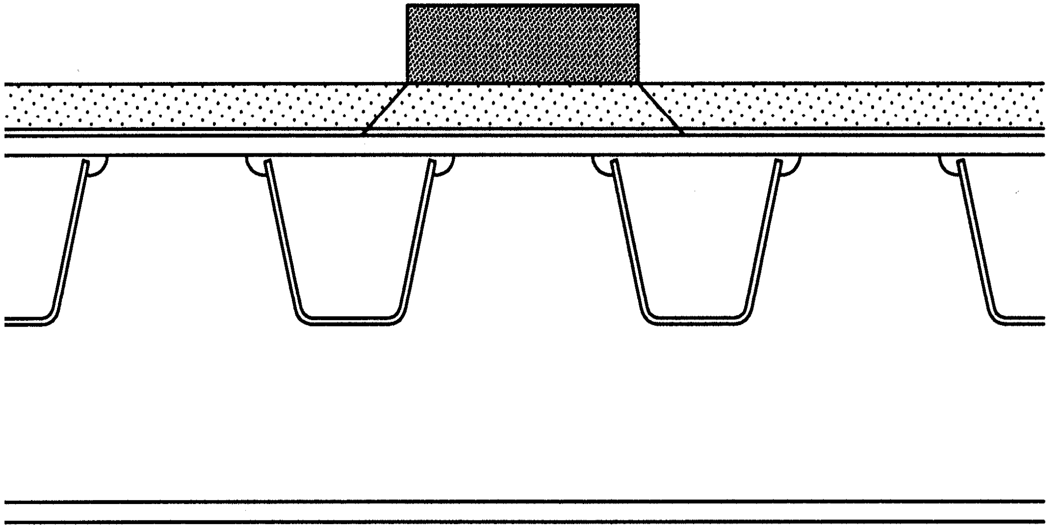


$\Delta\varphi_{fat}$: Additional amplification factor

D **: Distance of the cross-section under consideration from the expansion joint**

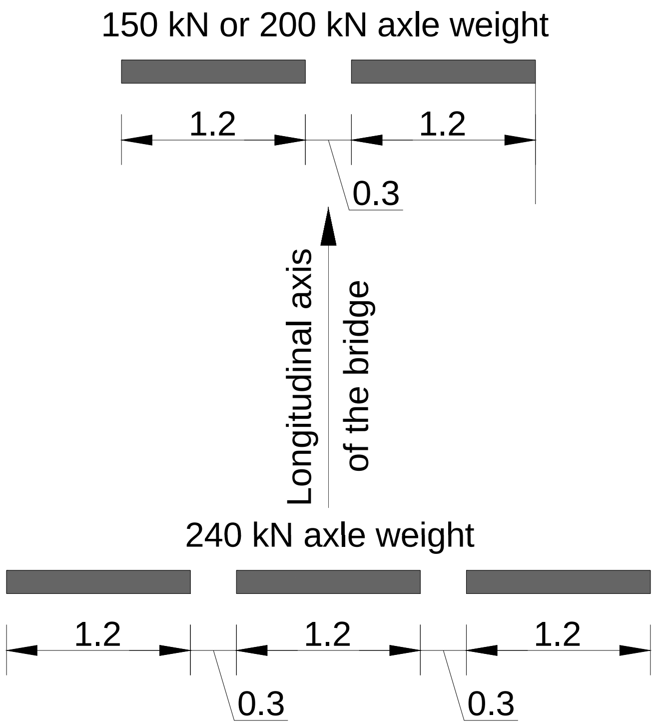
Dispersal of concentrated loads





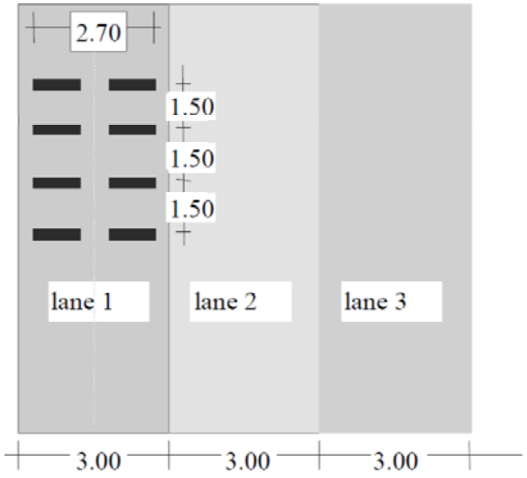
1 – Contact pressure of the wheel
2 – Surfacing
3 – Concrete slab
4 – Slab neutral axis

Load models for road bridges : LM3 – Special vehicles

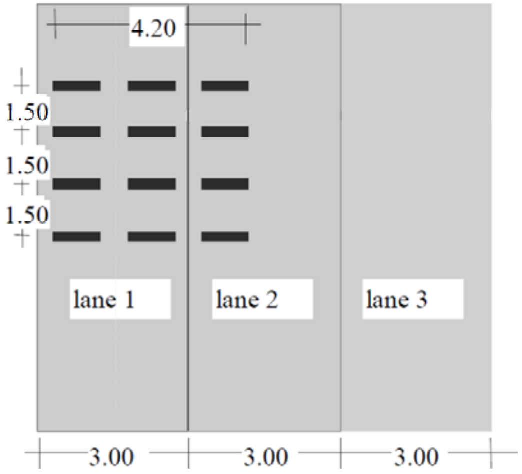


Axle lines and wheel contact areas for special vehicles

Load models for road bridges : LM3 – Special vehicles

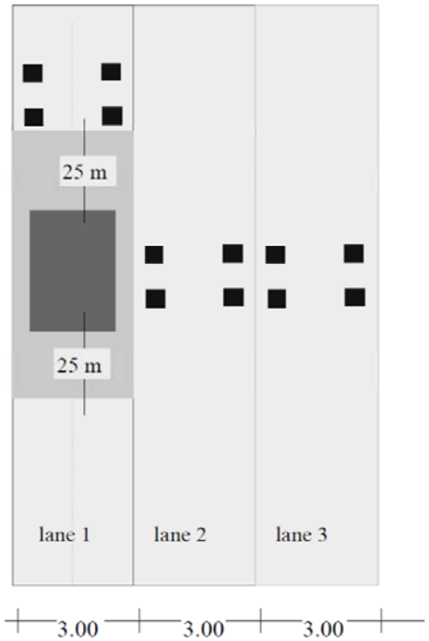


150 or 200 kN axle weight

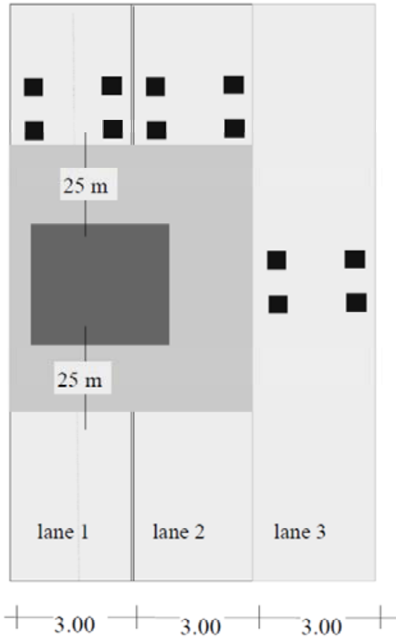


240 kN axle weight

Arrangement of special vehicle on the carriageway



150 or 200 kN axle weight



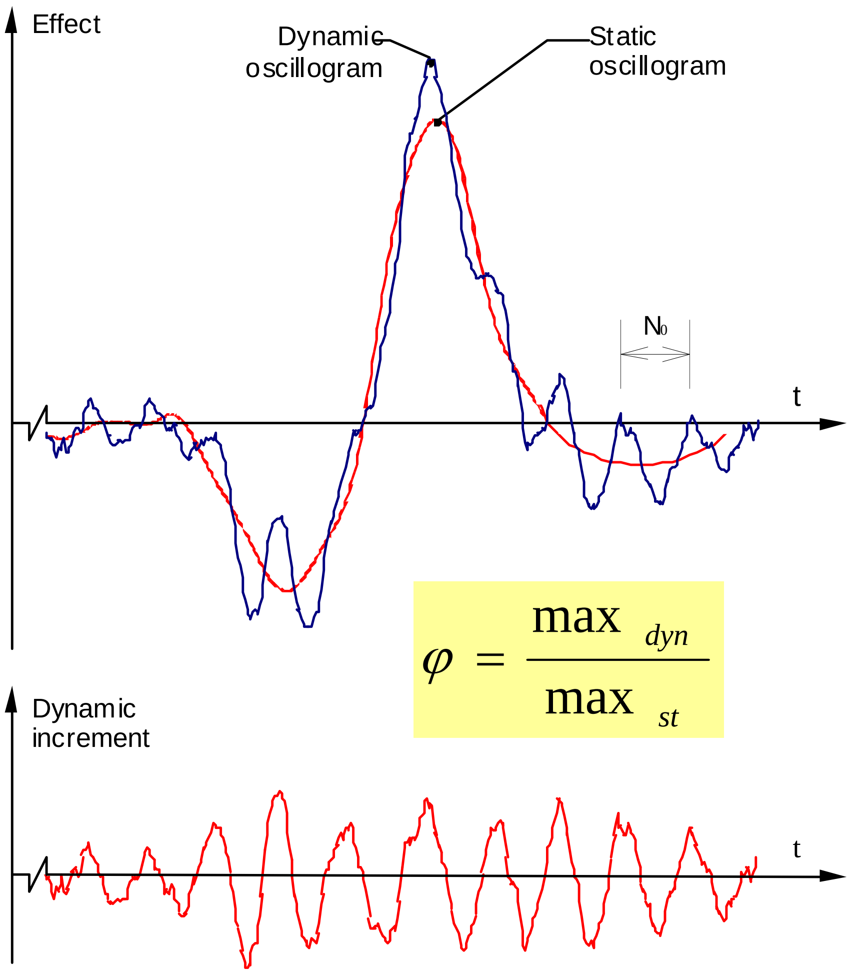
240 kN axle weight

Simultaneity of special vehicles and load model n. 1

Load models for road bridges : LM4 – Crowd loading

- distributed load 5 kN/m^2 (dynamic effects included)
- combination value 3 kN/m^2 (dynamic effects included)
- to be specified per project
- for global effects
- transient design situation

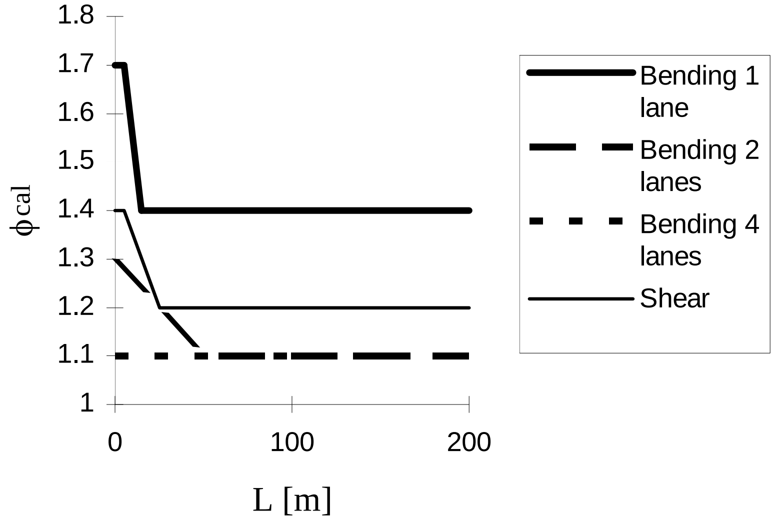
Load models for road bridges : Dynamics



$$\varphi = \frac{\max_{dyn}}{\max_{st}}$$

Physical impact factor φ

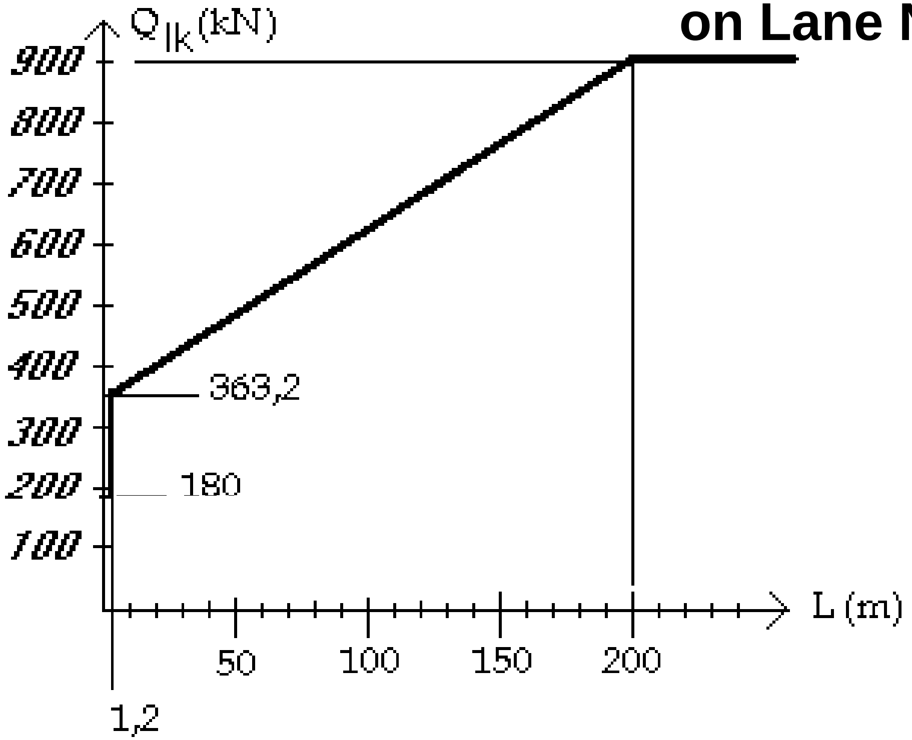
$$E_{dyn(x-fractile)} = \frac{\varphi_{cal} \cdot \varphi_{local}}{\varphi_{in}} \cdot E_{st(x-fractile)}$$



Calibration value of the impact factor φ_{cal} (EN 1991-2).

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

A characteristic braking force, *Qlk*, is a longitudinal force acting at the surfacing level of the carriageway. *Qlk*, 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.



$$Q_{\ell k} = 0{,}6\alpha_{Q1}(2Q_{1k}) + 0{,}10\alpha_{q1}q_{1k}w_1L$$

$$180\alpha_{Q1}kN \le Q_{\ell k} \le 900\ kN$$

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

$Q_{1k} = 180 + 2{,}7L$ for $0 \le L \le 1{,}2$ m

$Q_{1k} = 360 + 2{,}7L$ for $L > 1{,}2$ m

L = length of the deck or of the part of it under consideration

HORIZONTAL FORCES : Centrifugal forces

$Q_{fk} = 0{,}2Q_v \quad kN$	for r < 200 m
$Q_{fk} = 40Q_v / r \quad kN$	for 200 ≤ r < 1500 m
$Q_{fk} = 0$	for r > 1500 m

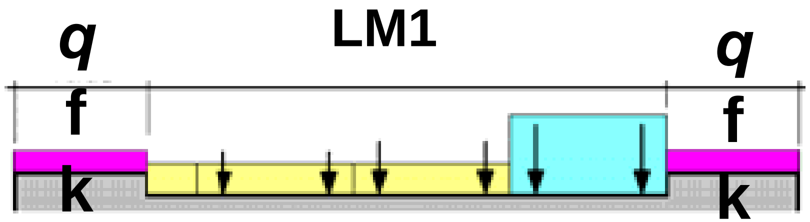
r **: horizontal radius of curvature of the carriageway centreline [m]**

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

$$\sum_i \alpha_{Qi}(2Q_{ik})$$

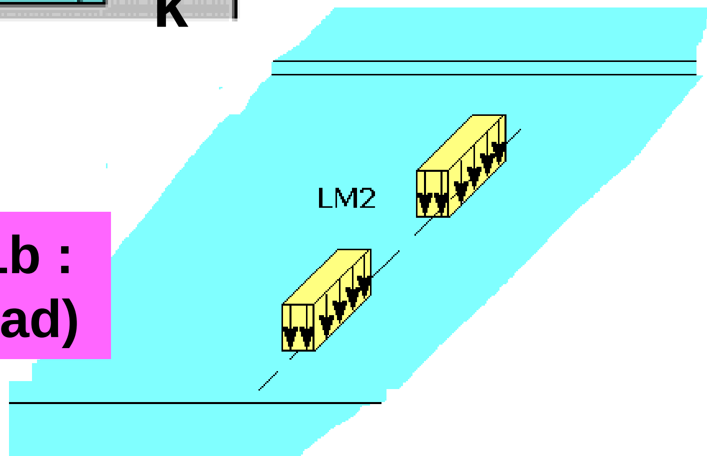
Qfk **should be taken as a transverse force acting at the finished carriageway level and radially to the axis of the carriageway.**

Definition of groups of loads

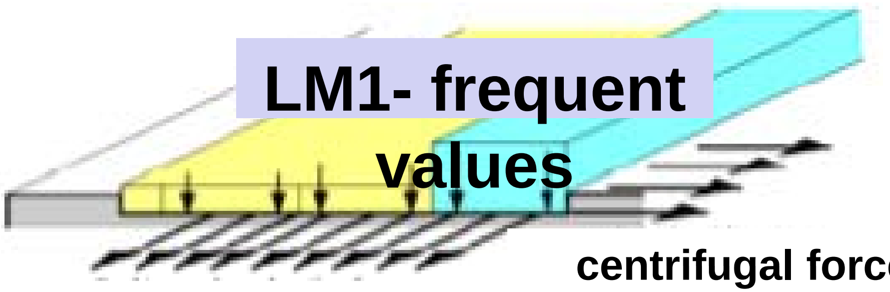


Group of loads gr1a : LM1 + *combination value* of pedestrian load on footways or cycle tracks

Group of loads gr1b : LM2 (single axle load)

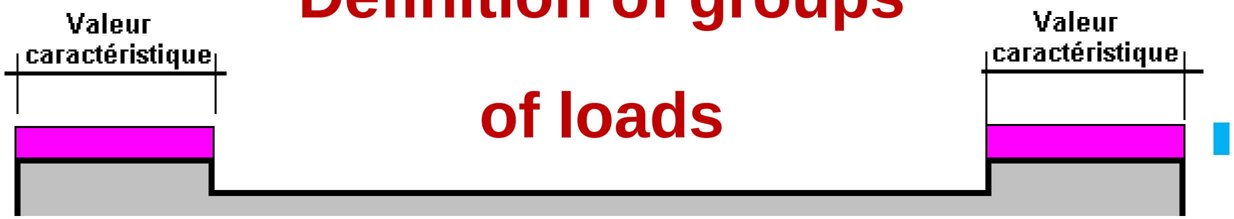


Group of loads gr2 : *characteristic values* of horizontal forces, *frequent values* of LM1



Definition of groups of loads

Group of loads gr3 : loads on footways and cycle tracks




Crowds packed Sydney Harbour Bridge yesterday to celebrate the sixtieth anniversary o
three-hour closure to traffic, people were shoulder to shoulder from the north to the south

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)

		CARRIAGEWAY						FOOTWAYS AND CYCLE TRACKS
Load type		Vertical forces				Horizontal forces		Vertical forces only
Reference		4.3.2	4.3.3	4.3.4	4.3.5	4.4.1	4.4.2	5.3.2-(1)
Load system		LM1 (TS and UDL systems)	LM2 (Single axle)	LM3 (Special vehicles)	LM4 (Crowd loading)	Braking and acceleration forces	Centrifugal and transverse forces	Uniformly Distributed load
Groups of Loads	gr1a	Characteristic values				[a]	[a]	Combination value [b]
	gr1b		Characteristic value					
	gr2	Frequent values[b]				Characteristic value	Characteristic value	
	gr3 [d]							Characteristic value [c]
	gr4				Characteristic value			Characteristic value [b]
	gr5	See Annex A		Characteristic value				

(shaded cell) 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 : $3\ kN/m^2$.
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 γG and γQ - EN 1990, A2, Tables A2.4(A) to (C)

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Limit states	Load effects	γG	γQ
A-EQU	Unfavourable	1,05	1,50
	Favourable	0,95	0,00
B-STR/GEO	Unfavourable	1,35	1,50 [1)]
	Favourable	1,00	0,00
C- STR/GEO	Unfavourable	1,00	1,30
	Favourable	1,00	0,00

1) For road traffic 1,35,

for railway traffic 1,45

ψ factors for road bridges

Action	Symbol	ψ_0	ψ_1	ψ_2
Traffic loads (see EN 1991-2, Table 4.4)	gr 1a (LM1) TS	0,75	0,75	0
	gr 1a (LM1) UDL	0,40	0,40	0
	gr1b (single axle)	0	0,75	0
	gr2 (horizontal forces)	0	0	0
	gr3 (pedestrian loads)	0	0,4	0
	gr4 (LM4 crowd)	0	0	0
	gr5 (LM3 spec.vehicl.)	0	1	0
Wind forces	F_w persistent (execut.)	0,6 (0,8)	0,2	0
Thermal actions	T	0,6	0,6	0,5
Snow loads	S_n (during execution)	0,8	-	0
Construction loads	Q_{ca}	1	-	1

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**

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

- **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**

$$\sum_{j\geq 1} G_{kj} + P_{k} + Q_{k1} + \sum_{i>1} \psi_{0i} Q_{ki} \qquad (6.14)$$

- **Frequent – local effects**

$$\sum_{j\geq 1} G_{kj} + P_{k} + \psi_{11} Q_{k1} + \sum_{i>1} \psi_{2i} Q_{ki} \qquad (6.15)$$

- **Quasi-permanent – long-term effects**

$$\sum_{j\geq 1} G_{kj} + P_{k} + \sum_{i\geq 1} \psi_{2i} Q_{ki} \qquad (6.16)$$

- **Infrequent – concrete bridges**

$$\sum_{j\geq 1} G_{k,j} \text{"+"} P \text{"+"} \psi_{1,\mathrm{infq}} Q_{k,1} \text{"+"} \sum_{i>1} \psi_{1,i} Q_{k,i} \quad ($$

Fundamental combination of actions

Leading action, accompanying

Eq. (6.10)

$$\sum_{j\geq 1}(1{,}35\,G_{\mathrm{kj,sup}}\ \text{ or }\ 1{,}00\,G_{\mathrm{kj,inf}})\ "+"\ (1{,}00\ \text{or}\ 0)\times S\ "+"\begin{cases} 1{,}35\times\overbrace{\left(TS+UDL+q^*_{fk}\right)}^{gr_{1a}}+1{,}5\times\begin{cases}\min\left(0{,}6\,F_{Wk},F^*_w\right)\\ or\ \ 0{,}6\,T_k\end{cases}\\ 1{,}35\,\mathrm{gr1b}\\ 1{,}35\,\mathrm{gr2}+1{,}5\times 0{,}6\,T_k\\ 1{,}35\left(\mathrm{gr3}\ or\ \mathrm{gr4}\right)+1{,}5\times 0{,}6\,T_k\\ 1{,}35\,\mathrm{gr5}\\ 1{,}5T_k+1{,}35\times\underbrace{(0{,}75TS+0{,}4UDL+0{,}4q^*_{fk})}_{\psi_0 gr_{1a}}\\ 1{,}5F_{Wk}\\ 1{,}5Q_{Sn,k}\end{cases}$$

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)

Leading action, accompanying

$$\sum_{j\geq 1}(G_{\text{kj,sup}} \text{ or } G_{\text{kj,inf}})\text{"+"}(1{,}00 \text{ or } 0)\times S\text{"+"}\begin{cases}\overbrace{\left(TS+UDL+q^{*}_{fk}\right)}^{gr_{1a}}+\begin{cases}\min\left(0{,}6\,F_{Wk},F^{*}_{w}\right)\\ or\;\;0{,}6\,T_k\end{cases}\\ \text{gr1b}\\ \text{gr2}+0{,}6\,T_k\\ \left(\text{gr3 } or \text{ gr4}\right)+0{,}6\,T_k\\ \text{gr5}\\ T_k+\underbrace{(0{,}75TS+0{,}4UDL+0{,}4q^{*}_{fk})}_{\psi_0 gr_{1a}}\\ F_{Wk}\\ Q_{Sn,k}\end{cases}$$

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)

Leading action, accompanying

$\psi_1 gr_{1a}$

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

***TS* tandem system, *UDL* uniformly distributed load**

Quasi permanent-combination of actions (SLS)

Leading action (no accompanying)

$$\sum_{j \geq 1} (G_{\mathrm{kj,sup}} \text{ or } G_{\mathrm{kj,inf}}) \text{ "+" } (1{,}00 \text{ or } 0) \times S \text{ "+" } 0{,}5\, T_k$$

Fatigue Load Models for road bridges

- **Load Model Nr. 1 (FLM1) : Similar to characteristic Load Model Nr. 1**

$$0{,}7 \times Q_{ik} - 0{,}3 \times q_{ik} - 0{,}3 \times q_{rk}$$

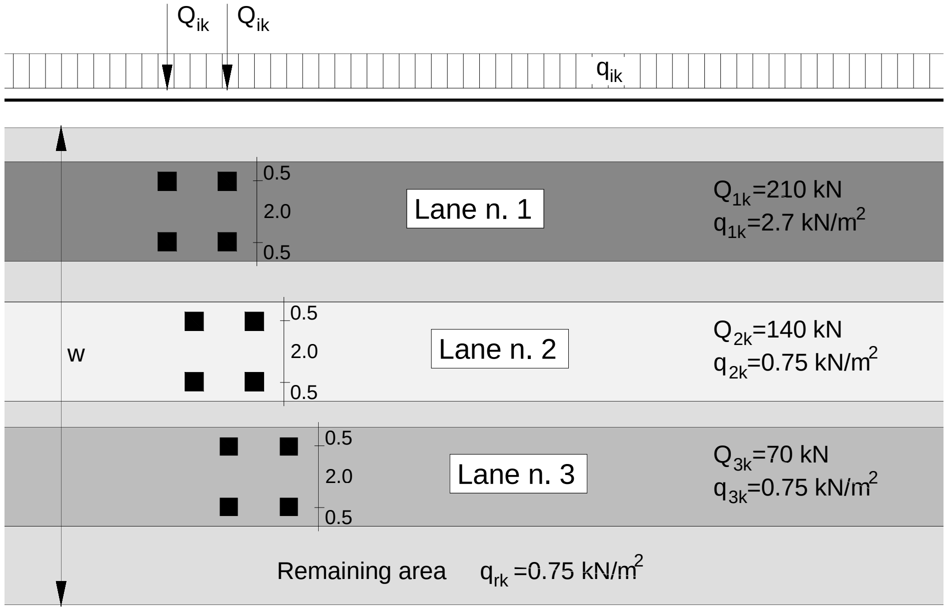
- **Load Model Nr. 2 (FLM2) : Set of « fequent » lorries**
- **Load Model Nr. 3 (FLM3) : Single vehicle**
- **Load Model Nr. 4 (FLM4) : Set of « equivalent » lorries**
- **Load M/odel Nr. 5 (FLM5) : Recorded traffic**

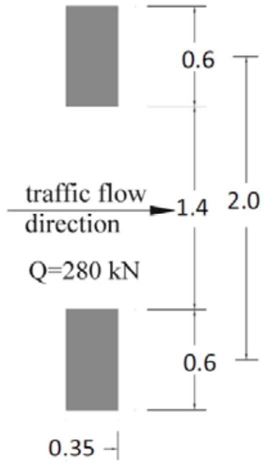
models 1-2: just check whether max stress range S < fatigue limit

models 3-4: damage assessment

model 5 - general (additional assumptions might be necessary)

Fatigue LM 1



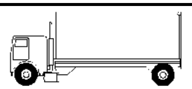
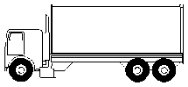
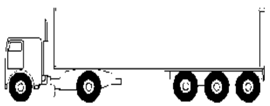
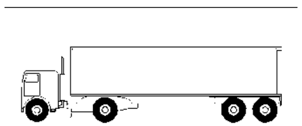
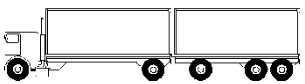


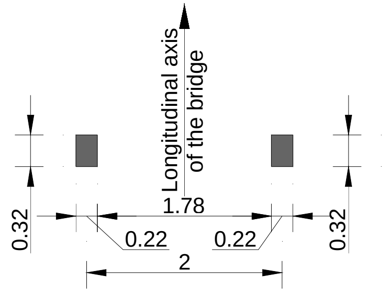
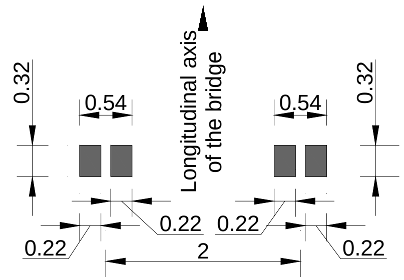
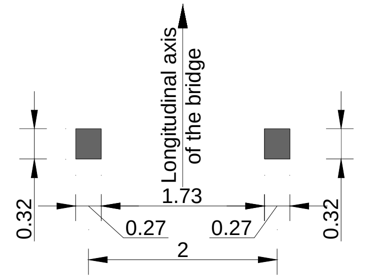
Fatigue load model 1

Fatigue load model 1
for local verifications

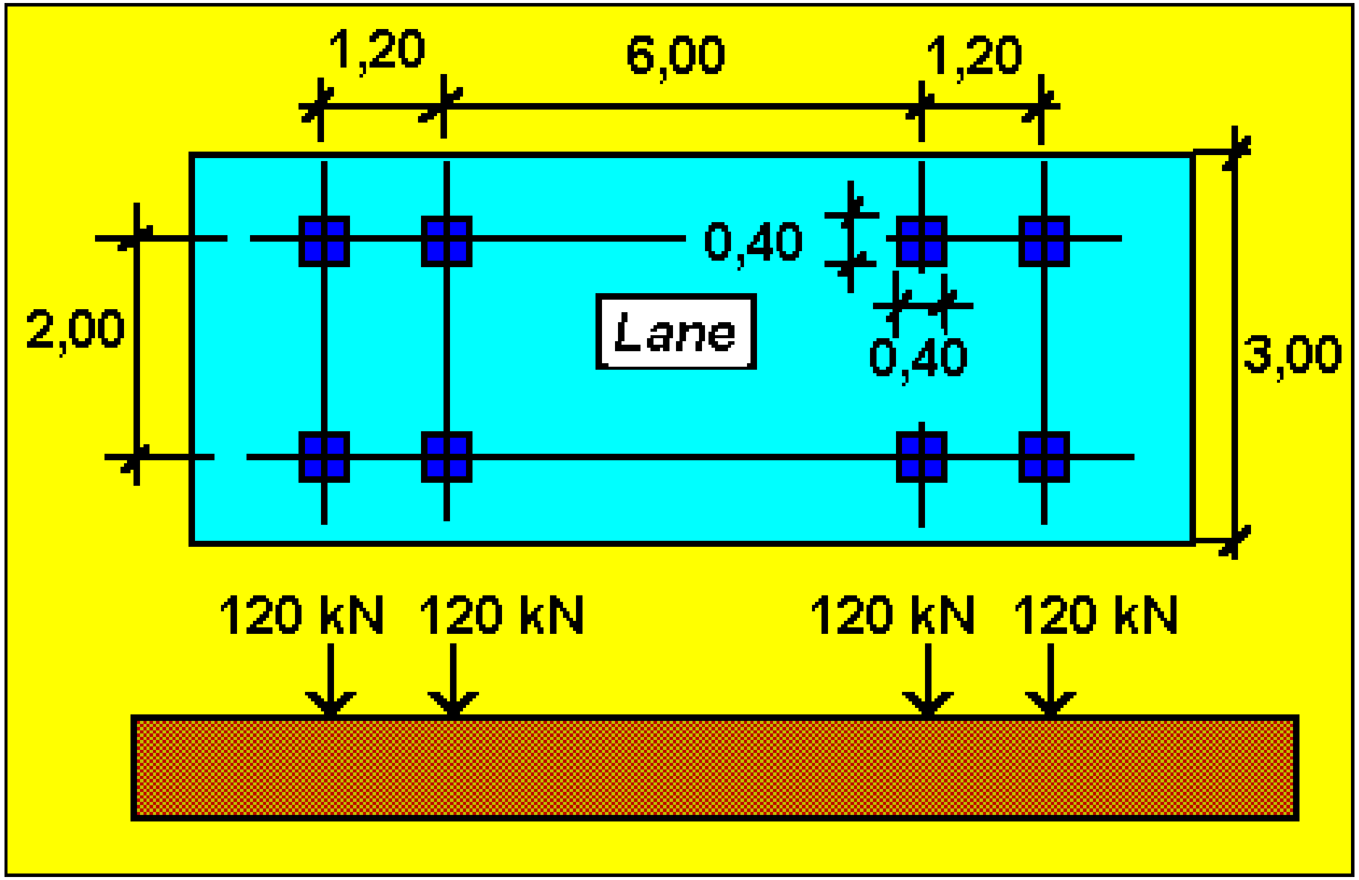
Fatigue LM 2

Fatigue load model n. 2 – frequent set of lorries

LORRY SILHOUETTE	*Interaxles [m]*	*Frequent axle loads [kN]*	*Wheel type (see table 3)*
	4.5	90 190	A B
	4.20 1.30	80 140 140	A B B
	3.20 5,20 1.30 1.30	90 180 120 120 120	A B C C C
	3.40 6.00 1.80	90 190 140 140	A B B B
	4.80 3.60 4.40 1.30	90 180 120 110 110	A B C C C

Wheel axle type	*Geometrical definition*
A	
B	
C	

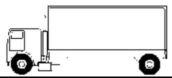
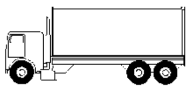
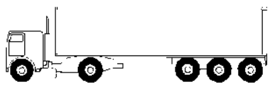
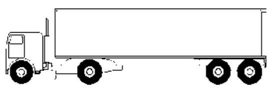
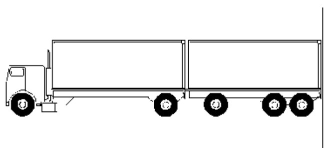
Fatigue Load Model Nr.3 (FLM3)



A second vehicle may be taken into account : Recommended axle load value Q = 36 kN - Minimum distance between vehicles : 40 m - See National Annex

Fatigue LM 4

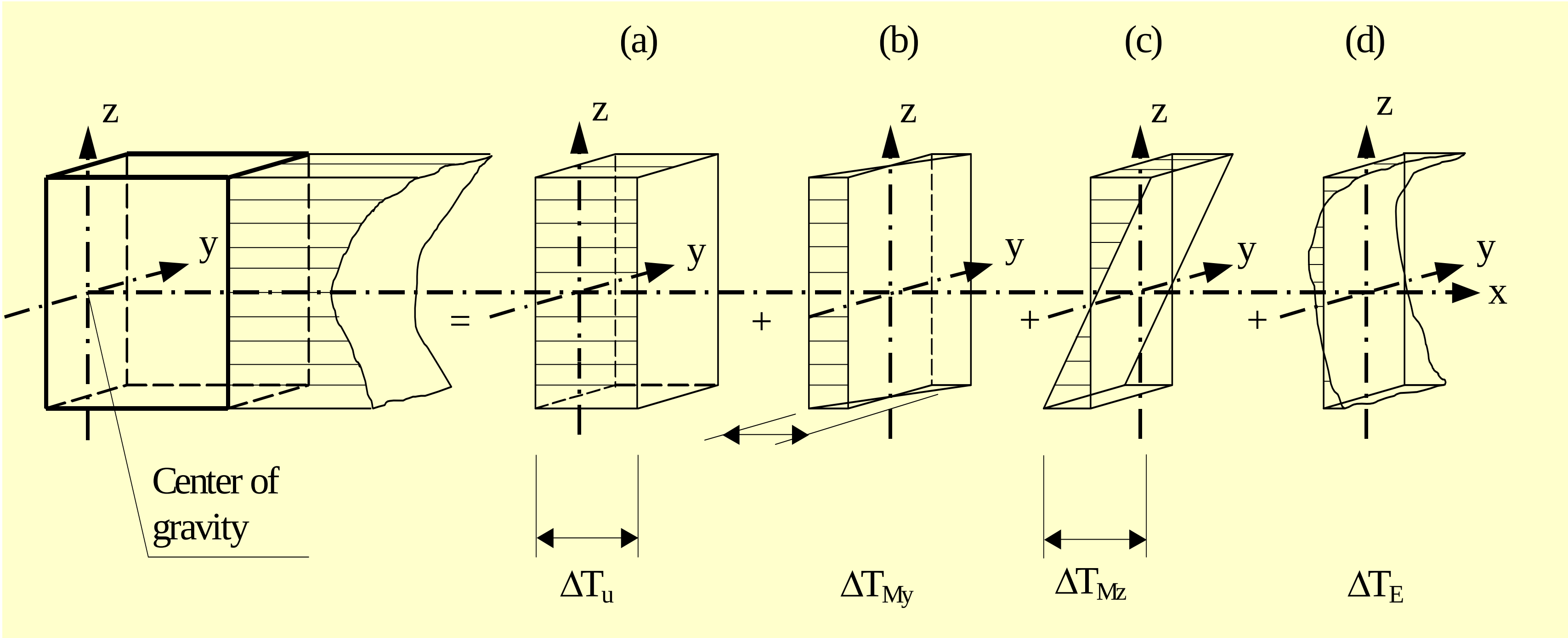
Fatigue load model n. 4 – equivalent set of lorries

LORRY SILHOUETTE			*TRAFFIC TYPE*		
			Long distance	*Medium distance*	*Local traffic*
LORRY	*Axle spacing* [*m*]	*Equivalent Axle loads* [*kN*]	*Lorry percentage*	*Lorry percentage*	*Lorry percentage*
	4.5	70 130	20.0	40.0	80.0
	4.20 1.30	70 120 120	5.0	10.0	5.0
	3.20 5.20 1.30 1.30	70 150 90 90 90	50.0	30.0	5.0
	3.40 6.00 1.80	70 140 90 90	15.0	15.0	5.0
	4.80 3.60 4.40 1.30	70 130 90 80 80	10.0	5.0	5.0

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**

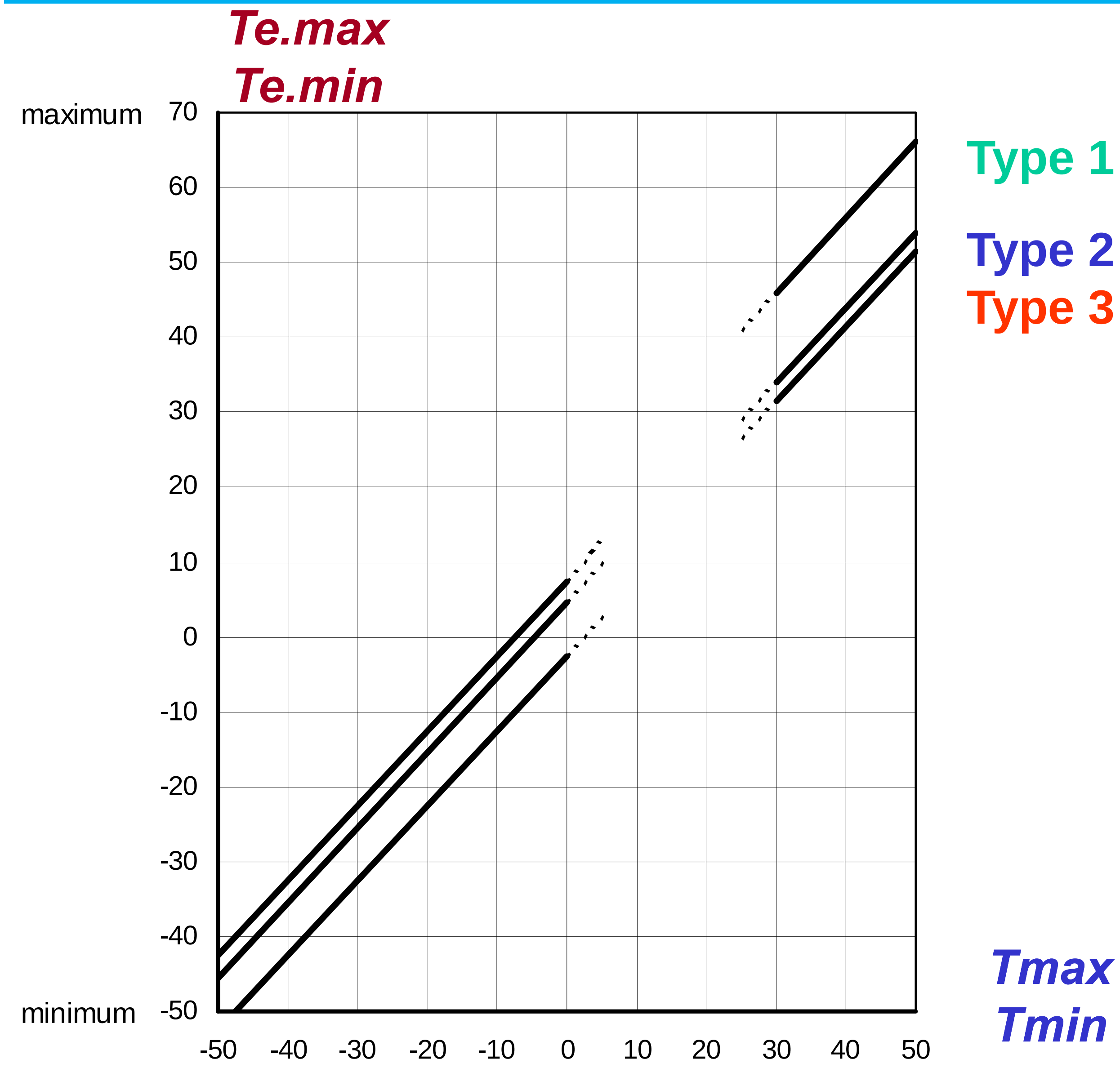
Diagrammatical representation of constituent components of a temperature profile *[EN 1991-1-5, Fig. 4.1]*



EN 1991-1-5: THERMAL ACTIONS - Bridge Types

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**

EN 1991-1-5: THERMAL ACTIONS
Determination of thermal effects



Type 1 - steel

Type 2 - composite

Type 3 - concrete

Correlation between

min/max shade air temperature (*Tmin/Tmax*)

And

min/max uniform bridge temperature component (*Te.min/Te.max*)

Table 6.1: Recommended values of linear temperature difference component for different types of bridge decks for road, foot and railway bridges

Type of Deck	Top warmer than bottom	Bottom warmer than top
	$\Delta T_{M,heat}$ (°C)	$\Delta T_{M,cool}$ (°C)
Type 1: Steel deck	18	13
Type 2: Composite deck	15	18
Type 3: Concrete deck: - concrete box girder - concrete beam - concrete slab	 10 15 15	 5 8 8

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_{sur}. Recommended values for the factor k_{sur} is given in Table 6.2.

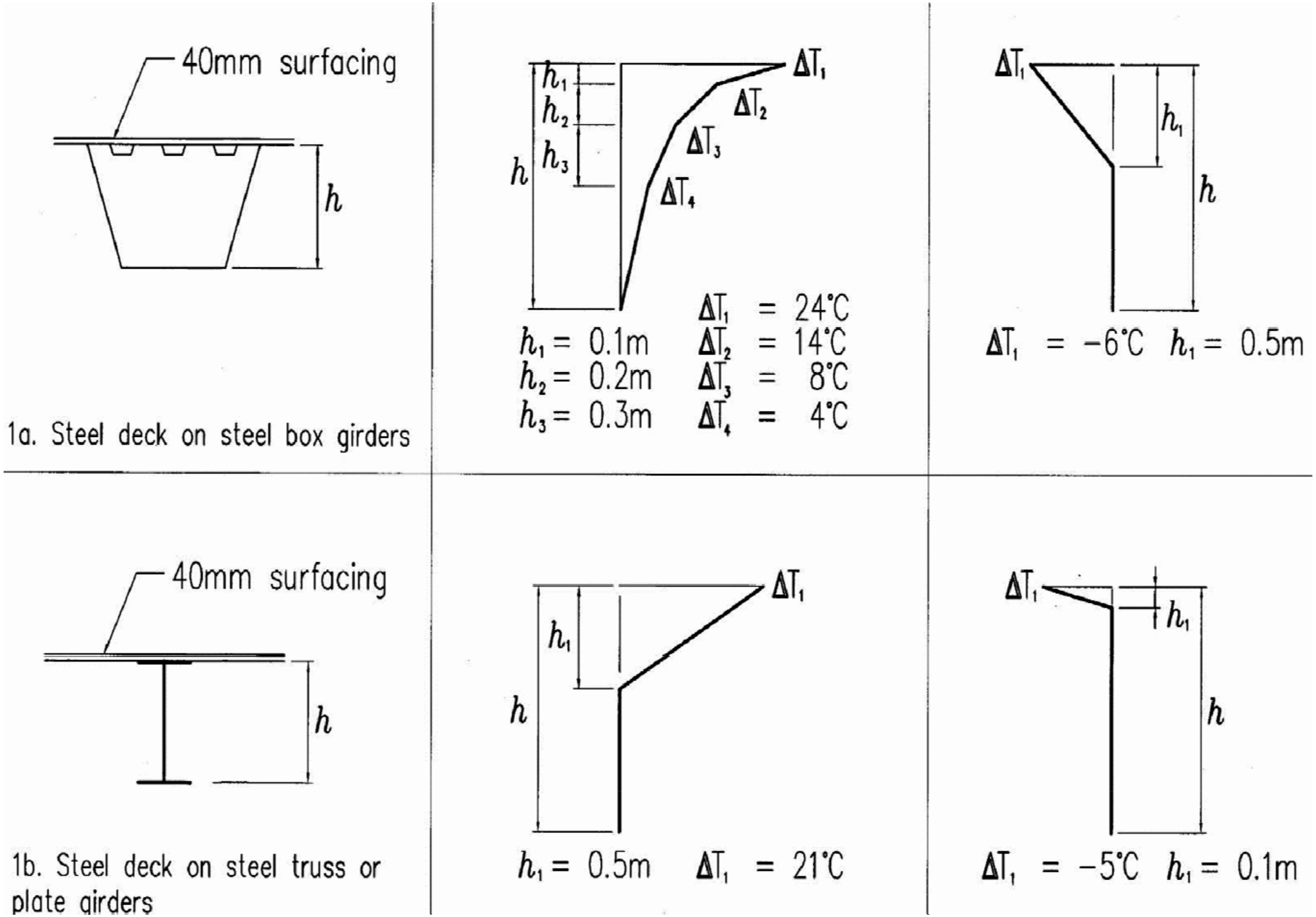
Table 6.2: Recommended values of k_{sur} to account for different surfacing thickness

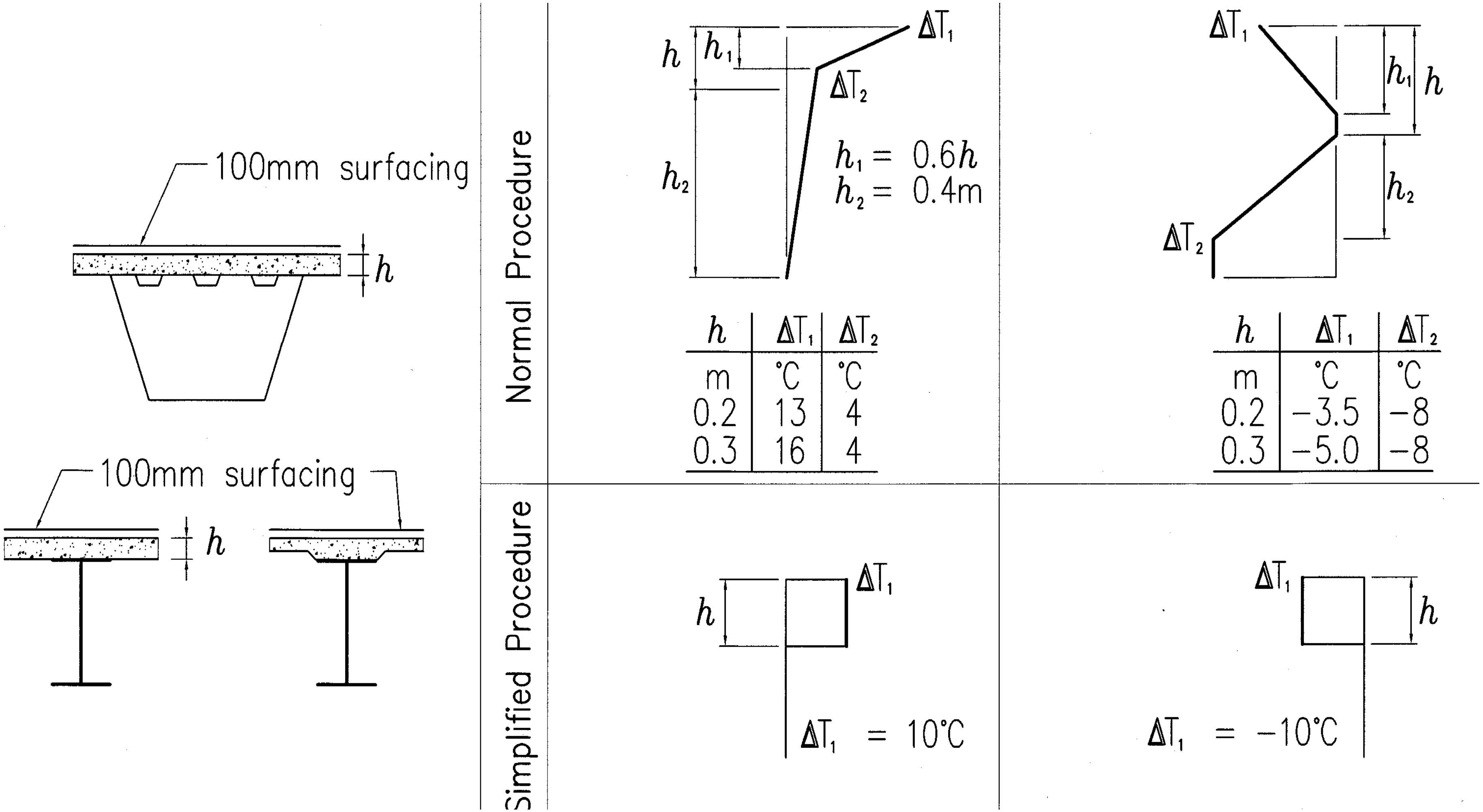
Road, foot and railway bridges						
Surface Thickness	Type 1		Type 2		Type 3	
	Top warmer than bottom	Bottom warmer than top	Top warmer than bottom	Bottom warmer than top	Top warmer than bottom	Bottom warmer than top
[mm]	k_{sur}	k_{sur}	k_{sur}	k_{sur}	k_{sur}	k_{sur}
unsurfaced	0,7	0,9	0,9	1,0	0,8	1,1
water-proofed [1)]	1,6	0,6	1,1	0,9	1,5	1,0
50	1,0	1,0	1,0	1,0	1,0	1,0
100	0,7	1,2	1,0	1,0	0,7	1,0
150	0,7	1,2	1,0	1,0	0,5	1,0
ballast (750 mm)	0,6	1,4	0,8	1,2	0,6	1,0

[1)] These values represent upper bound values for dark colour

STEEL BRIDGES

European Commission





Normal Procedure – heating:

h	ΔT_1	ΔT_2
m	°C	°C
0.2	13	4
0.3	16	4

Normal Procedure – cooling:

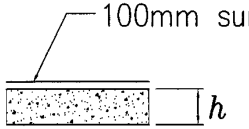
h	ΔT_1	ΔT_2
m	°C	°C
0.2	−3.5	−8
0.3	−5.0	−8

$h_1 = 0.6h$, $h_2 = 0.4\text{m}$

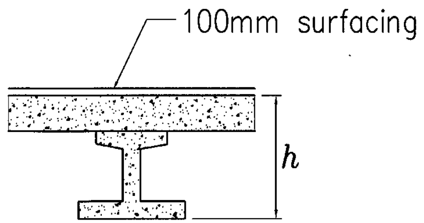
Simplified Procedure: $\Delta T_1 = 10°C$; $\Delta T_1 = -10°C$

CONCRETE BRIDGES

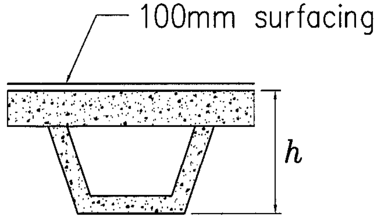
Type of Construction	Temperature Difference (ΔT) (a) Heating	Temperature Difference (ΔT) (b) Cooling



3a. Concrete slab

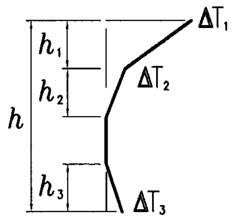


3b. Concrete beams



3c. Concrete box girder

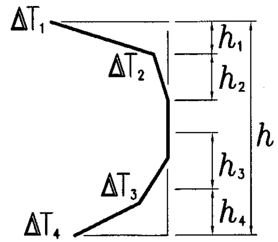
(a) Heating



$h_1 = 0.3h$ but ≤ 0.15m
$h_2 = 0.3h$ but ≥ 0.10m
but ≤ 0.25m
$h_3 = 0.3h$ but $\leq (0.10$m + surfacing depth in metres)
(for thin slabs, h_3 is limited by $h - h_1 - h_2$)

h	ΔT_1	ΔT_2	ΔT_3
m		°C	
≤0.2	8.5	3.5	0.5
0.4	12.0	3.0	1.5
0.6	13.0	3.0	2.0
≥0.8	13.0	3.0	2.5

(b) Cooling



$h_1 = h_4 = 0.20h$ but ≤ 0.25m
$h_2 = h_3 = 0.25h$ but ≤ 0.20m

h	ΔT_1	ΔT_2	ΔT_3	ΔT_4
m		°C		
≤0.2	−2.0	−0.5	−0.5	−1.5
0.4	−4.5	−1.4	−1.0	−3.5
0.6	−6.5	−1.8	−1.5	−5.0
0.8	−7.6	−1.7	−1.5	−6.0
1.0	−8.0	−1.5	−1.5	−6.3
≥1.5	−8.4	−0.5	−1.0	−6.5

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

*Note: The temperature difference ΔT incorporates ΔT_M and ΔT_E (see 4.3) together with a small part of component ΔT_N ; 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).

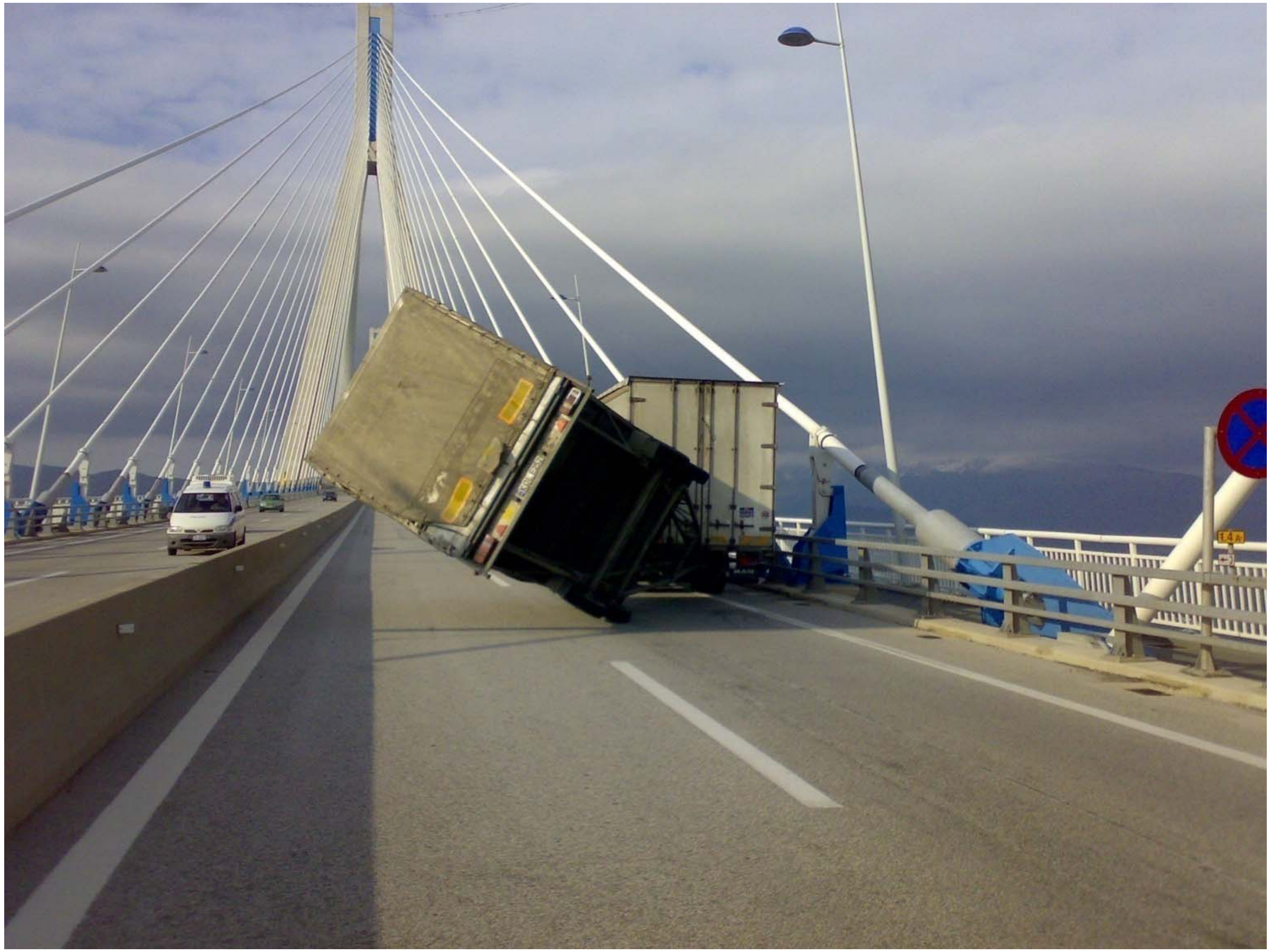
Temperature differences between the inner and outer web walls of large concrete box girder bridges :
Recommended value 15°C

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

EN 1991-1-4: WIND ACTIONS
(ON BRIDGE DECK AND PIERS)

European Commission



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

The following cases should typically be handled :

- **Bridge during its service life, without traffic**
- **Bridge during its service life, with traffic**
- **Bridge under construction (finished and most critical case)**
  This design situation might be critical in case of varying structural system

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

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

Where:

$c_s.c_d$ **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 *ze*, 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]***

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:

- ***ρ*** — **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 be the mean velocity, and is expressed by the following formula *[4.7]***
- ***$c_e(z)$*** — **is the exposure factor at a height *z***

EN 1991-1-4: WIND ACTIONS (ON BRIDGE DECK AND PIERS)

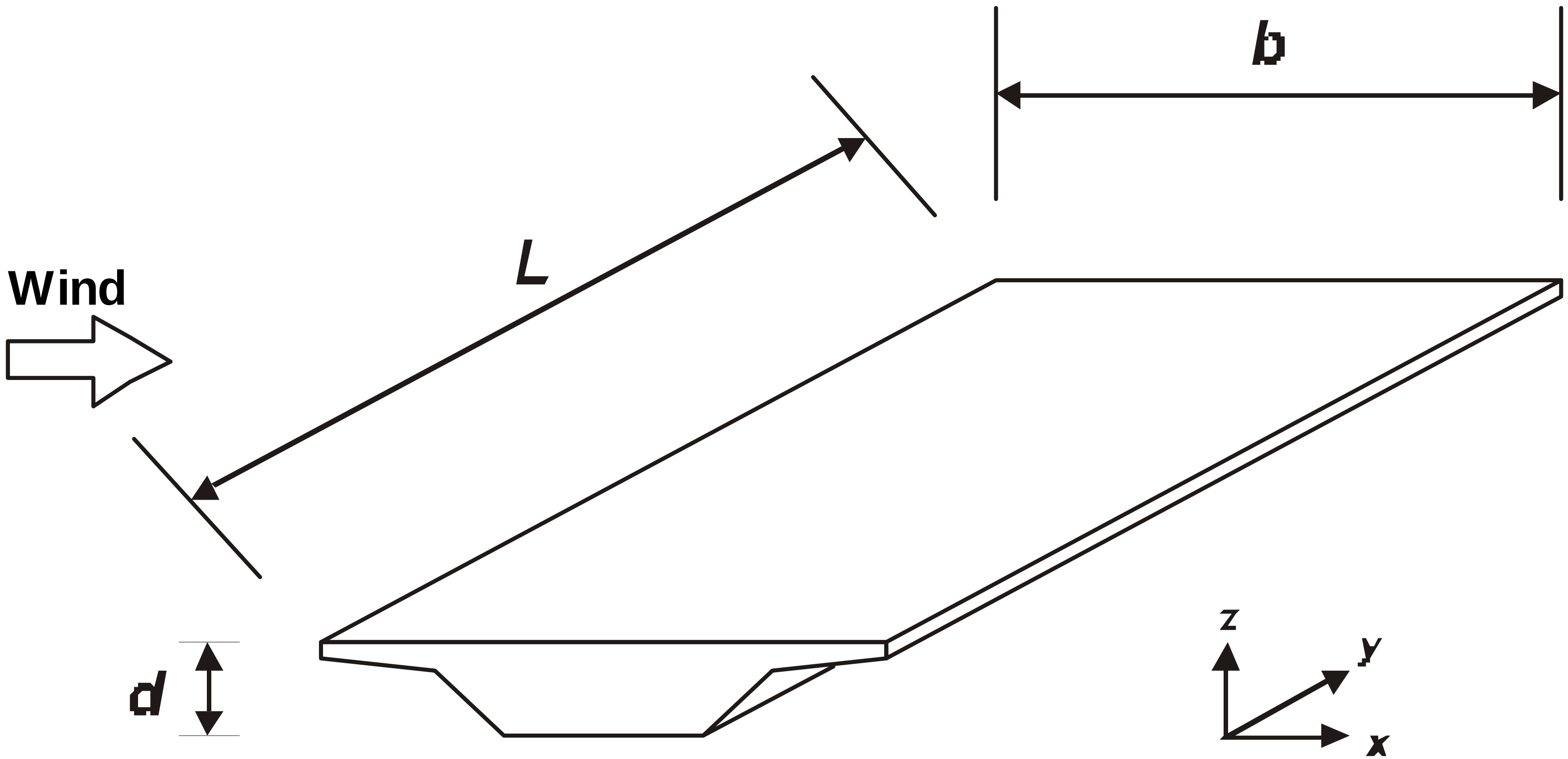
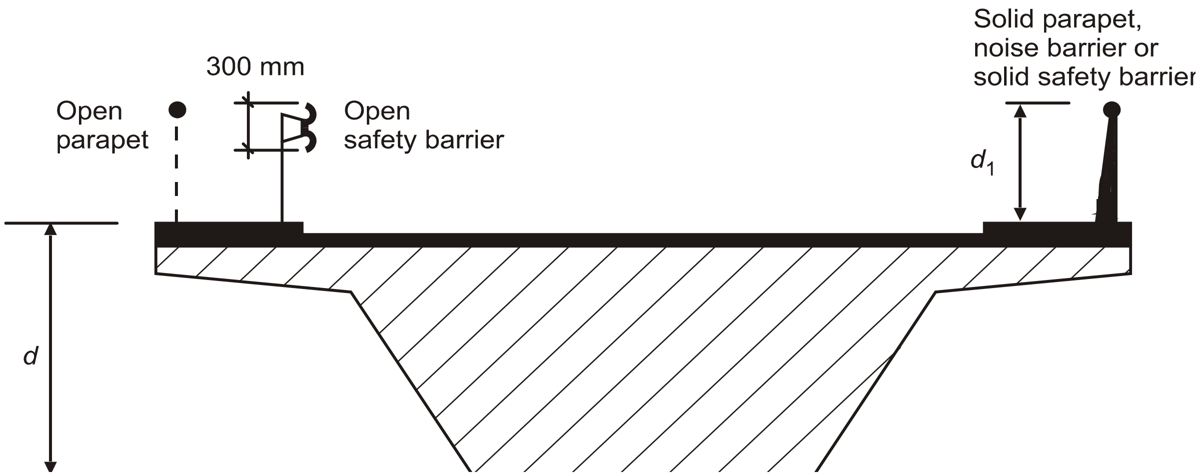
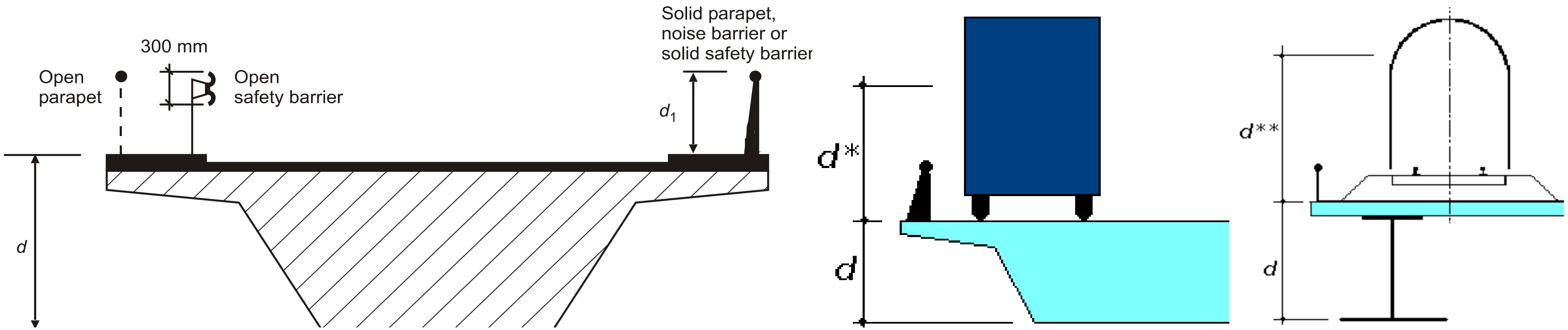


Fig. 8.2 of EN 1991-1-4 (Directions of wind actions on bridges)



Road restraint system	on one side	on both sides
Open parapet or open safety barrier	d + 0,3 m	d + 0,6 m
Solid parapet or solid safety barrier	$d + d_1$	$d + 2d_1$
Open parapet and open safety barrier	d + 0,6 m	d + 1,2 m

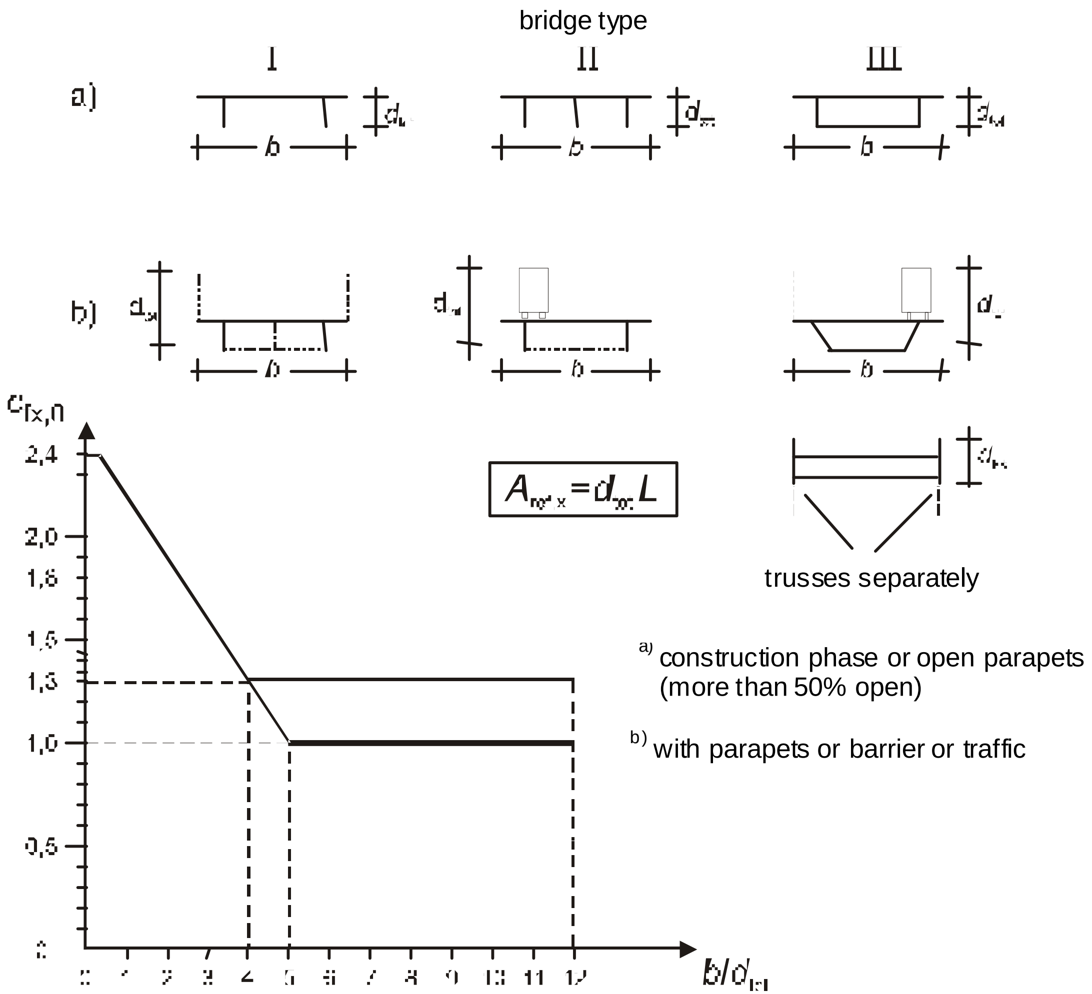
[Fig 8.5 & Table 8.1]* Depth *dtot* to be used for *Aref,x



Additional heights for the calculation of $A_{ref,x}$ (d* = 2 m ; d = 4 m)**

for bridges during their service life with traffic

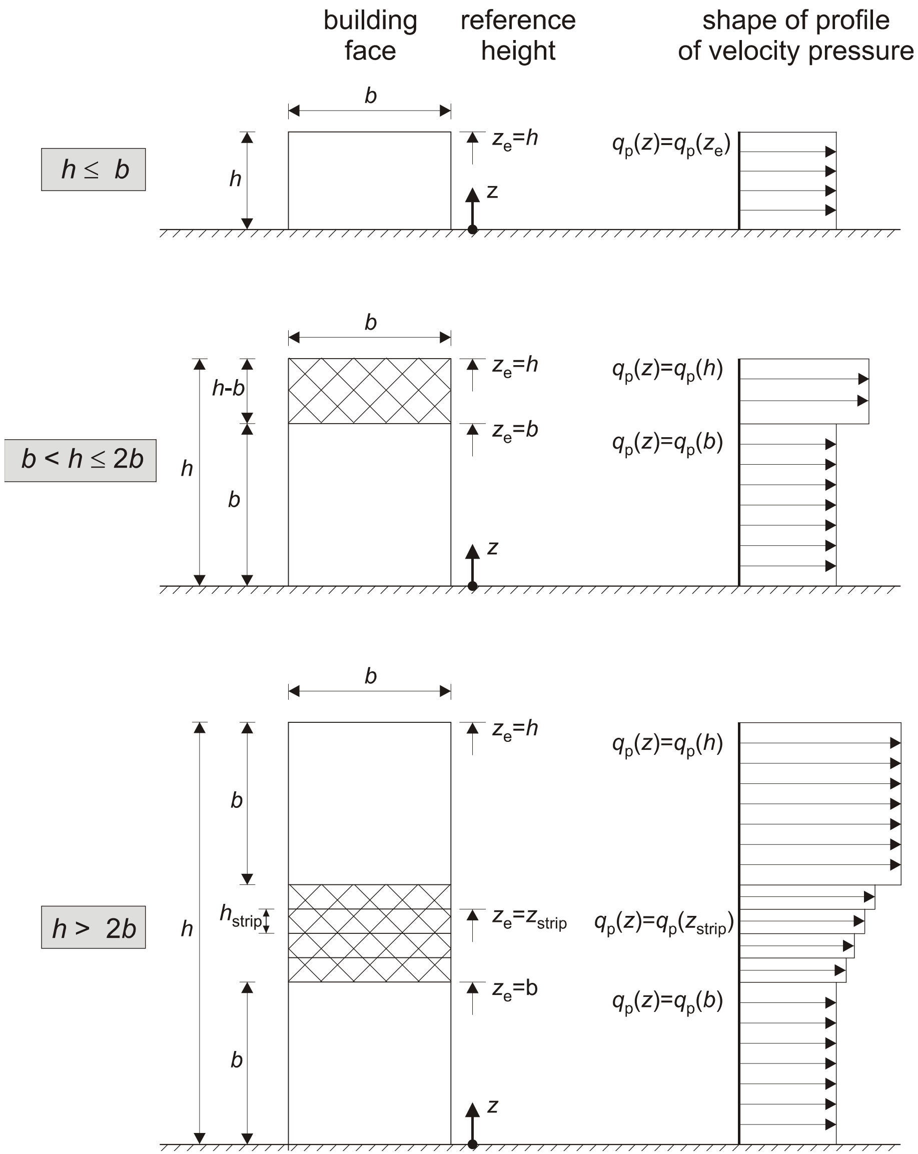
EN 1991-1-4: WIND ACTIONS (ON BRIDGE DECK AND PIERS)



[Fig. 8.3] Force coefficient $c_{fx,0}$ for bridges

Wind actions on piers

[Fig. 7.4] — Reference height, z_e, depending on *h* and *b*, and corresponding velocity pressure profile (for rectangular piers)



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* $I_v(z)$, after choosing $c_o(z)$)
- Determine F_w (after evaluating A_{ref} and by choosing c_f *and* $c_s.c_d$, if relevant)

EN 1991-1-6: ACTIONS DURING EXECUTION

- 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

Construction Loads - Q_c
Six different sources

Q_{ca}	*Personnel and hand tools*
Q_{cb}	*Storage of movable items*
Q_{cc}	*Non-permanent equipment in position for use*
Q_{cd}	*Movable heavy machinery and equipment*
Q_{ce}	*Accumulation of waste materials*
Q_{cf}	*Loads from part of structure in a temporary state*

*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.

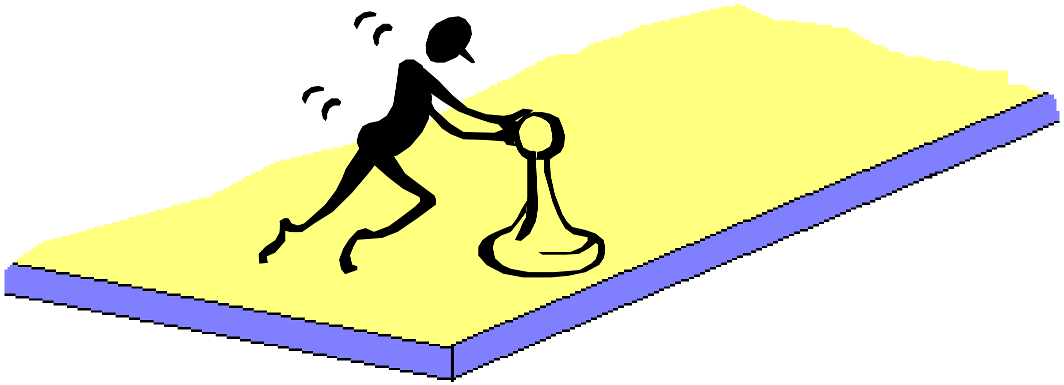
ACTIONS DURING EXECUTION : CONSTRUCTION LOADS *Qca*

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

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 kN/m²

ACTIONS DURING EXECUTION : CONSTRUCTION LOADS: *Qcb*



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:

$q_{cb,k} = 0,2$ kN/m^2

$F_{cb,k} = 100$ kN

ACTIONS DURING EXECUTION : CONSTRUCTION LOADS: *Qcc*

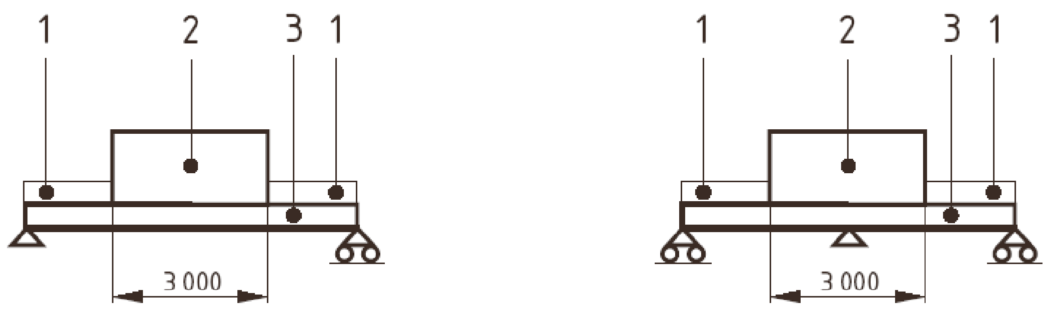
- **Actions to be taken into account simultaneously during the casting of concrete may include:**
- **working personnel with small site equipment (*Q*ca);**
- **formwork and load-bearing members (*Qcc*);**
- **the weight of fresh concrete (which is one example of Q*cf*), as appropriate.**

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.

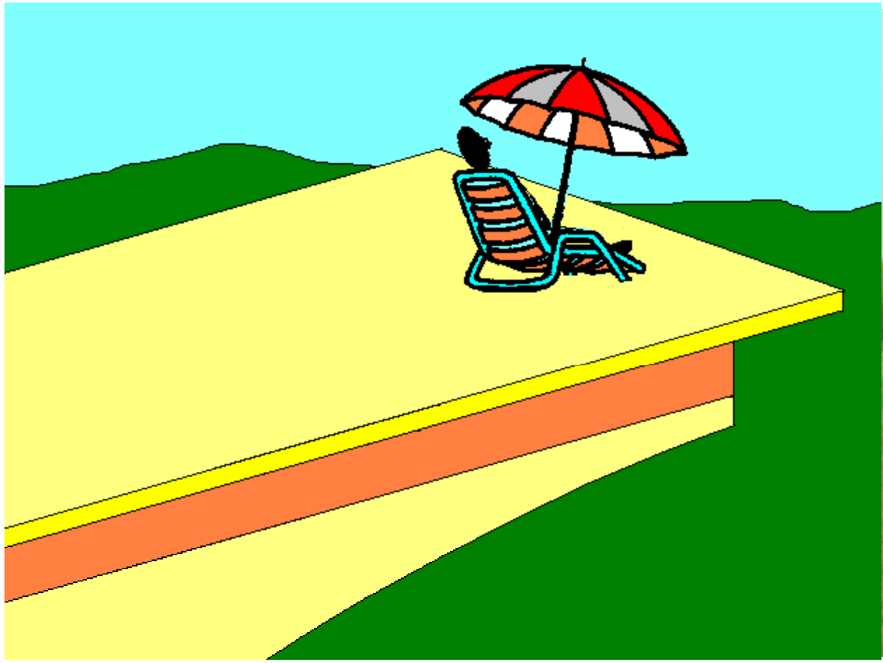
Table 4.2 : Recommended characteristic values of actions due to construction loads during casting of concrete

Action	Loaded area	Load in kN/m^2
(1)	Outside the working area	0,75 covering Q_{ca}
(2)	Inside the working area 3 m x 3 m (or the span length if less)	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}
(3)	Actual area	Self-weight of the formwork, load-bearing element (Q_{cc}) and the weight of the fresh concrete for the design thickness (Q_{cf})



ACTIONS DURING EXECUTION: CONSTRUCTION LOADS *Qcc*

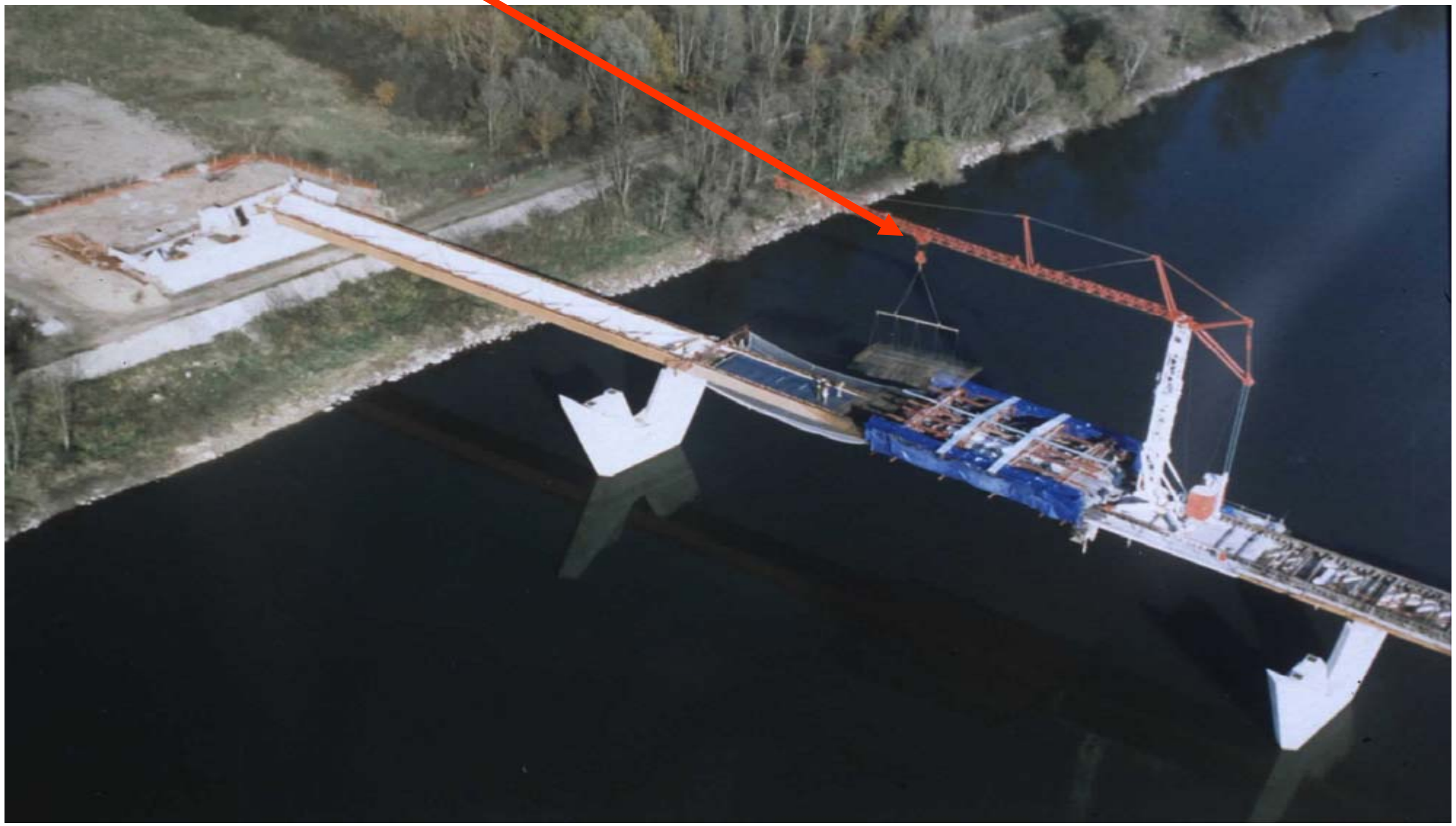
Non permanent in position for use during exectuion, either: - static (e.g. formwork panels, scaffolding, falsework, machinery, containers) or – during movement (e.g. travelling forms, launching girders and nose, counterweights



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 kN/m^2

ACTIONS DURING EXECUTION : CONSTRUCTION LOADS *Qcd*

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

Accumulation of waste materials (e.g. surplus construction materials excavated soil, or demolition Q_{ce} : materials

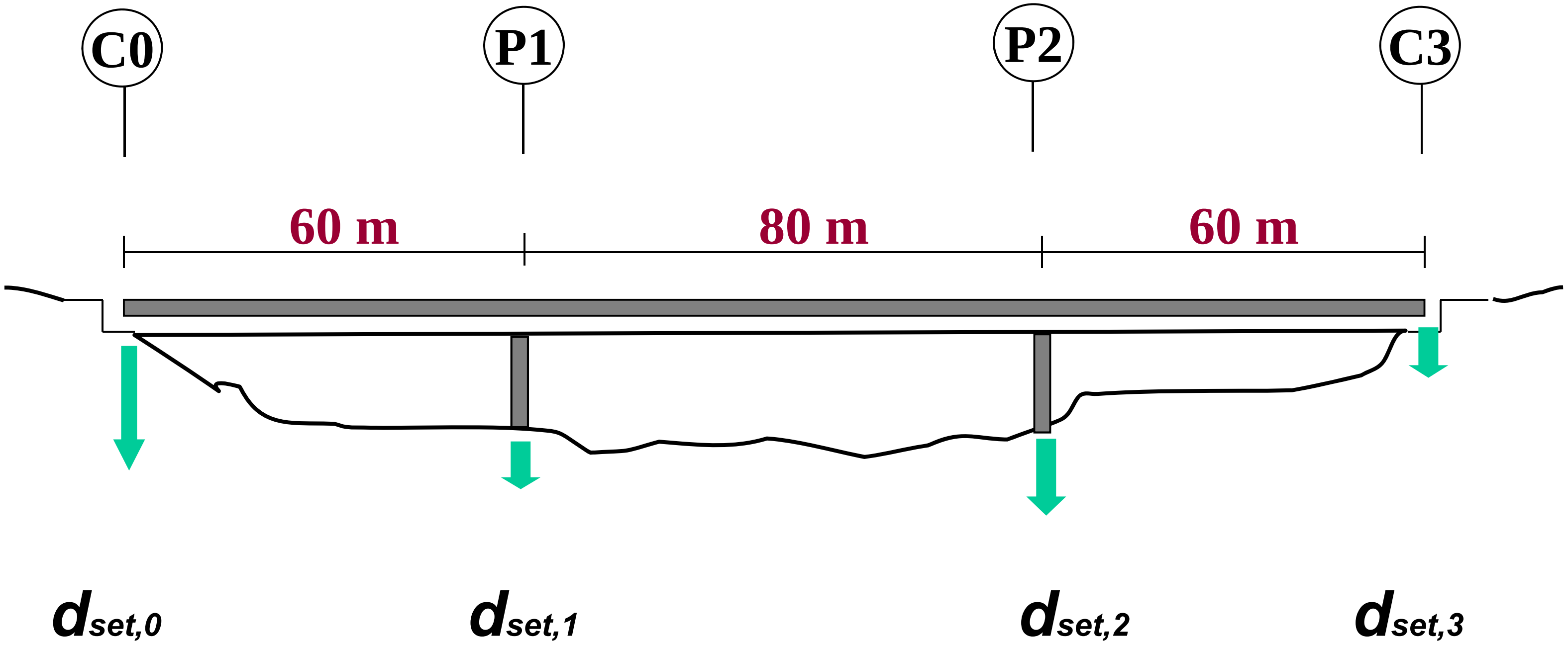
These loads are taken into account by considering possible mass effects on horizontal, inclined and vertical elements (such as walls).
These loads may vary significantly, and over short time periods, depending on types of materials, climatic conditions, build-up and clearance rates.

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).

ACTIONS : SETTLEMENTS

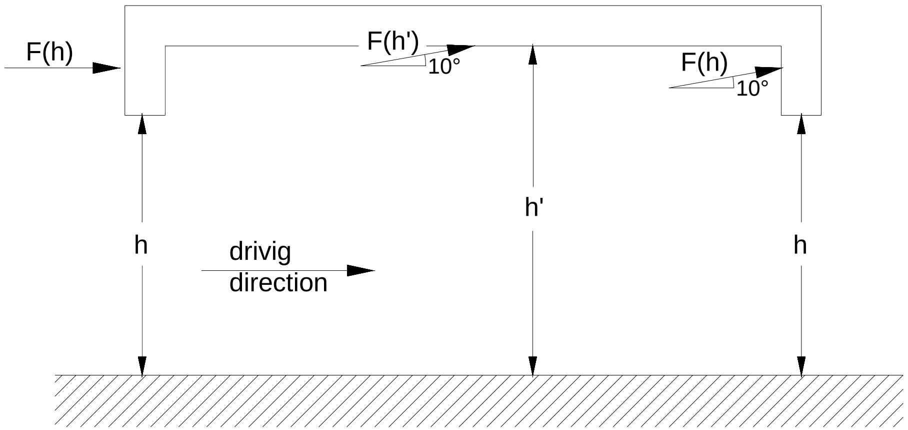


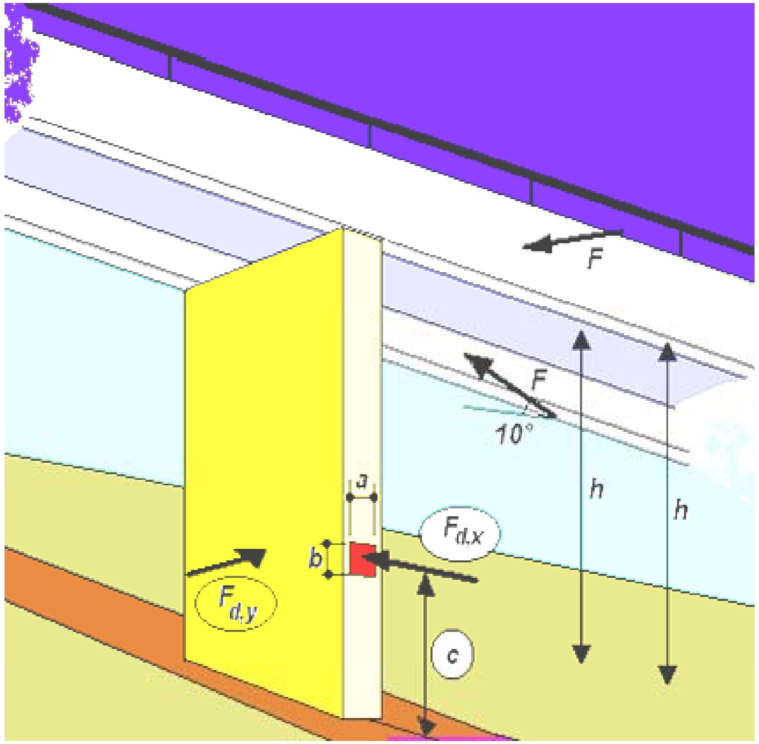
Theoritically, all possible combinations should be considered, but in most cases their effects are not critical for a bridge of that type.

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 on substructure



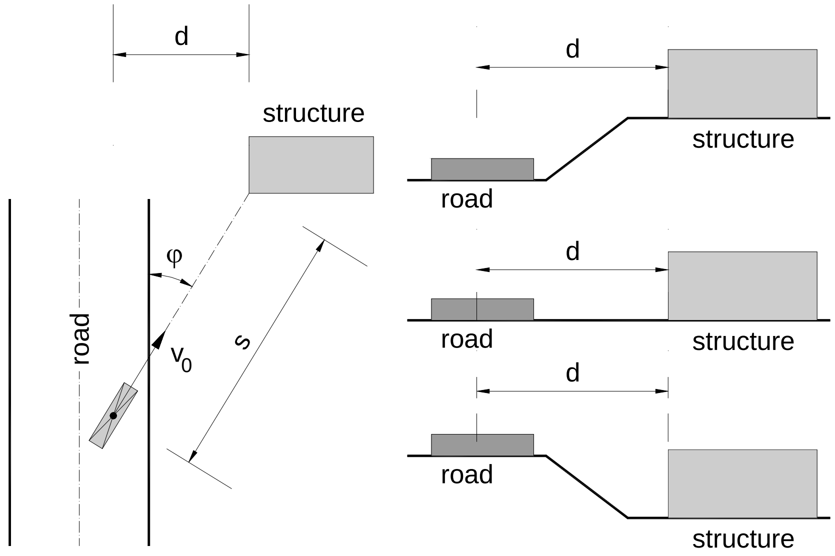


c=1.25 m for lorries

c=0.5 m for cars

Type of road	*Type of vehicle*	*Force $F_{d,x}$ [kN]*	*Force $F_{d,y}$ [kN]*
Motorway	Truck	1000	500
Country road	Truck	750	375
Urban area	Truck	500	250
Courtyards/garages	Passengers cars only	50	25
Courtyards/garages	Trucks	150	75

ACCIDENTAL LOADS: Impact on substructure



		mean value	standard deviation
m	mass	20 ton	12 ton
v	velocity	80 km/hr	10 km/hr
k	equivalent stiffness	300 kN/m	

Statistical parameters for input values

$$F = v_r \sqrt{km}$$

***m*=32 ton, *v*= 90 km/hr=25 m/s**
***F* = 25 (300 ×32)$^{0.5}$ = 2400 kN**

$$v_r = (v_0^2 - 2\,a\,s)^{0.5} \qquad \text{if } a=4\ m/s^2 \quad s=80\ m$$

$$\varphi=15° \qquad d=20\ m$$

$$F = F_0\sqrt{1-d/d_b} \quad (\text{for } d < d_b).$$

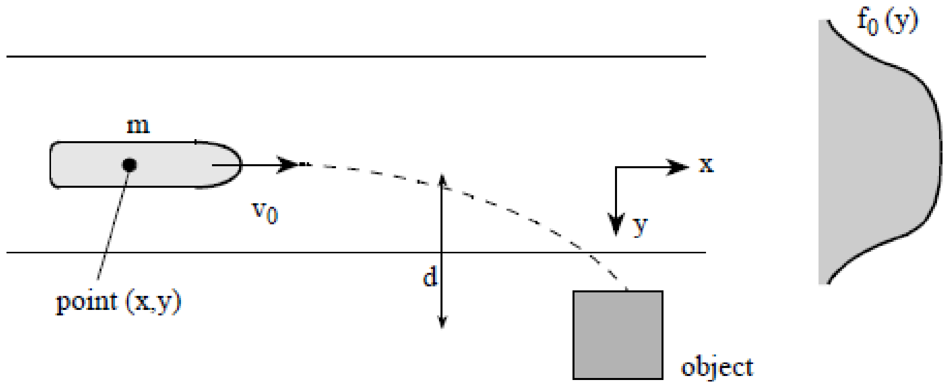
Situation sketch for impact by vehicles (top view and cross sections for upward slope, flat terrain and downward slope)

Type of road	*Type of vehicle*	*Force $F_{d,x}$ [kN]*	*Force $F_{d,y}$ [kN]*
Motorway	Truck	1000	500
Country road	Truck	750	375
Urban area	Truck	500	250
Courtyards/garages	Passengers cars only	50	25
Courtyards/garages	Trucks	150	75

ACCIDENTAL LOADS: Impact on substructure

Impact from ships

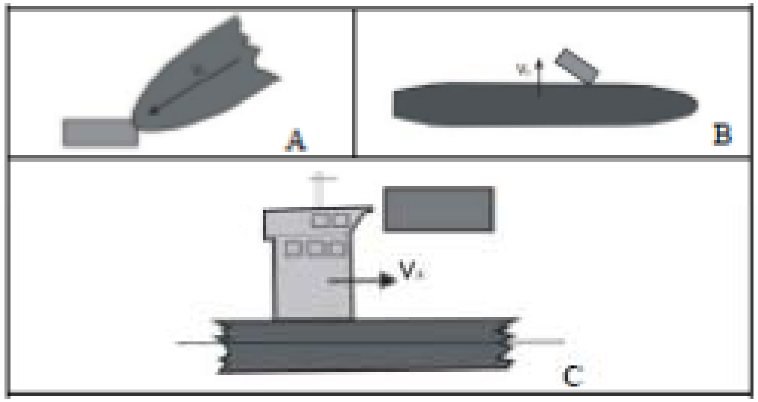
- The type of waterway,
- The flood conditions,
- The type and draught of vessels
- The type of the structures



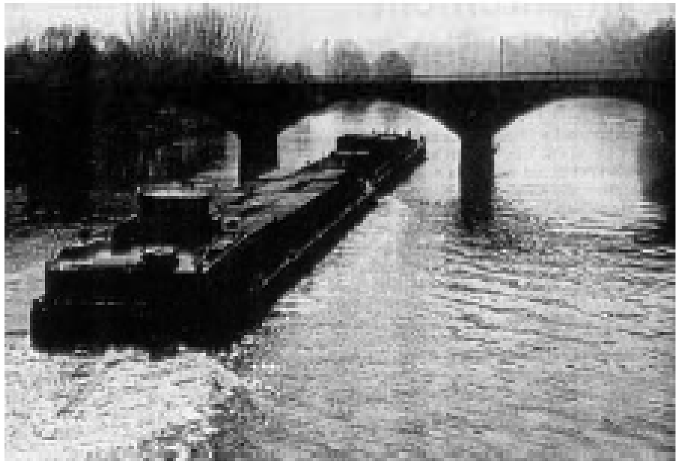
Parameters governing a ship collision model

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



m [ton]	*v* [m/s]	*k* [MN/m]	F_d [MN]	F_d [MN]	F_d [MN]
			Table 4.5 of EN 1991-1-7	eq (C.1) of EN 1991-1-7	eq (C.9) of EN 1991-1-7
300	3	5	2	4	5
1250	3	5	5	8	7
4500	3	5	10	14	9
20000	3	5	20	30	18

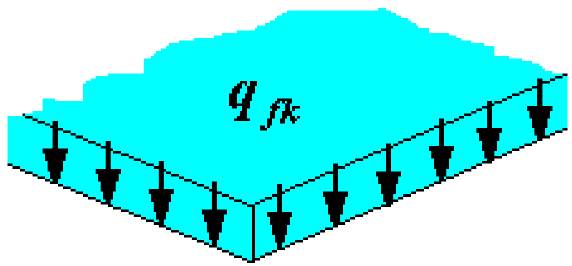
Design forces F_d for inland ships

m [ton]	*v* [m/s]	*k* [MN/m]	F_d [MN]	F_d [MN]	F_d [MN]
			Table 4.6 of EN 1991-1-7	eq(C.1) of EN 1991-1-7	eq (C.11) of EN 1991-1-7
3000	5	15	50	34	33
10000	5	30	80	87	84
40000	5	45	240	212	238
100000	5	60	460	387	460

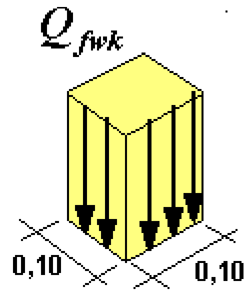
Design forces F_d for seagoing vessels

Load models for footbridges

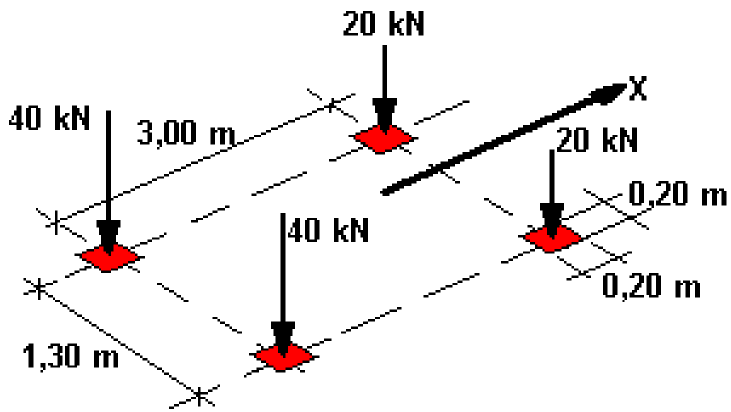
- **LOAD MODEL Nr.1**
  Uniformly distributed load q_{fk}



- **LOAD MODEL Nr.2**
  Concentrated load Q_{fwk}
  (10 kN recommended)



- **LOAD MODEL Nr.3**
  Service vehicle Q_{serv}



Load models for footbridges

Recommended characteristic value for :
- footways and cycle tracks on road bridges,
- short or medium span length footbridges :

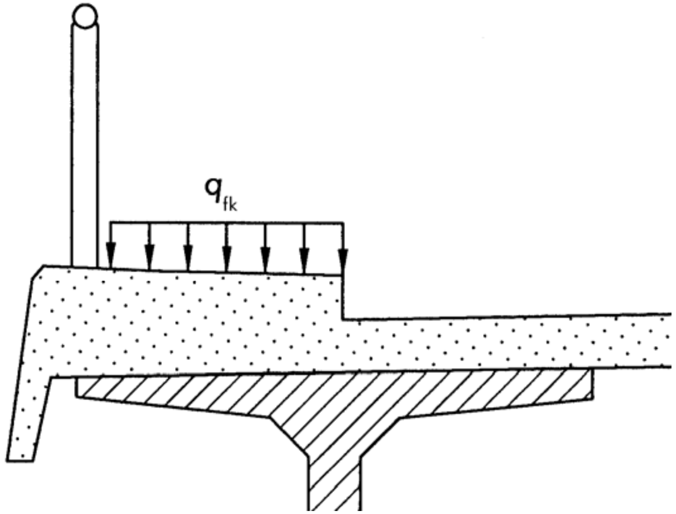
$$q_{fk} = 5,0 \ \text{kN/m}^2$$

Recommended expression for long span length footbridges :

$$q_{fk} = 2,0 + \frac{120}{L+30} \quad \text{kN/m}^2$$

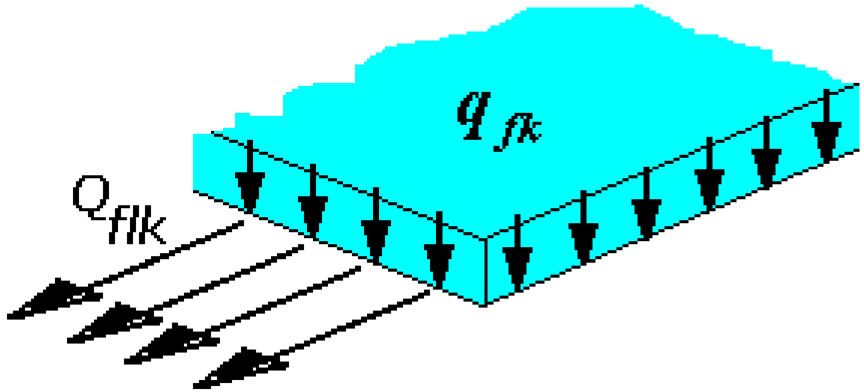
$$q_{fk} \geq 2,5 \ \text{kN/m}^2 \qquad q_{fk} \leq 5,0 \ \text{kN/m}^2$$

***L* is the loaded length [m]**

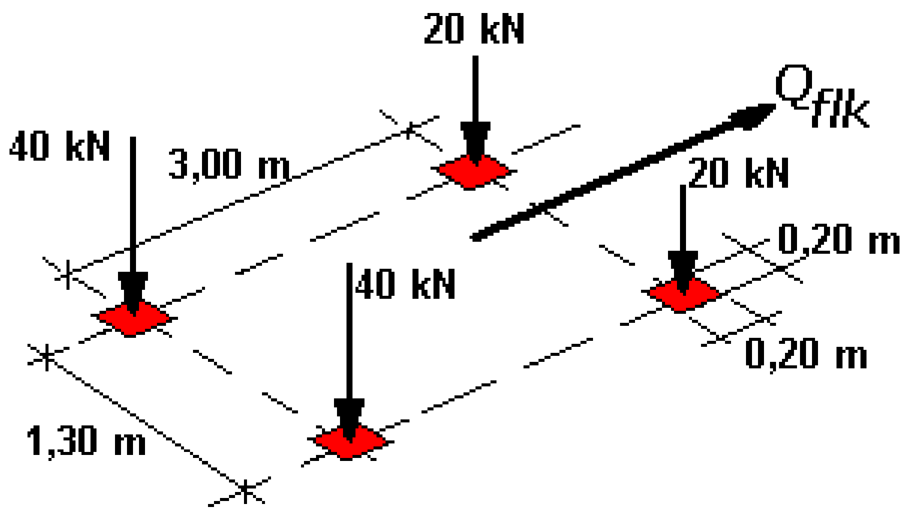


Groups of loads for footbridges

Group of loads gr1



Group of loads gr2

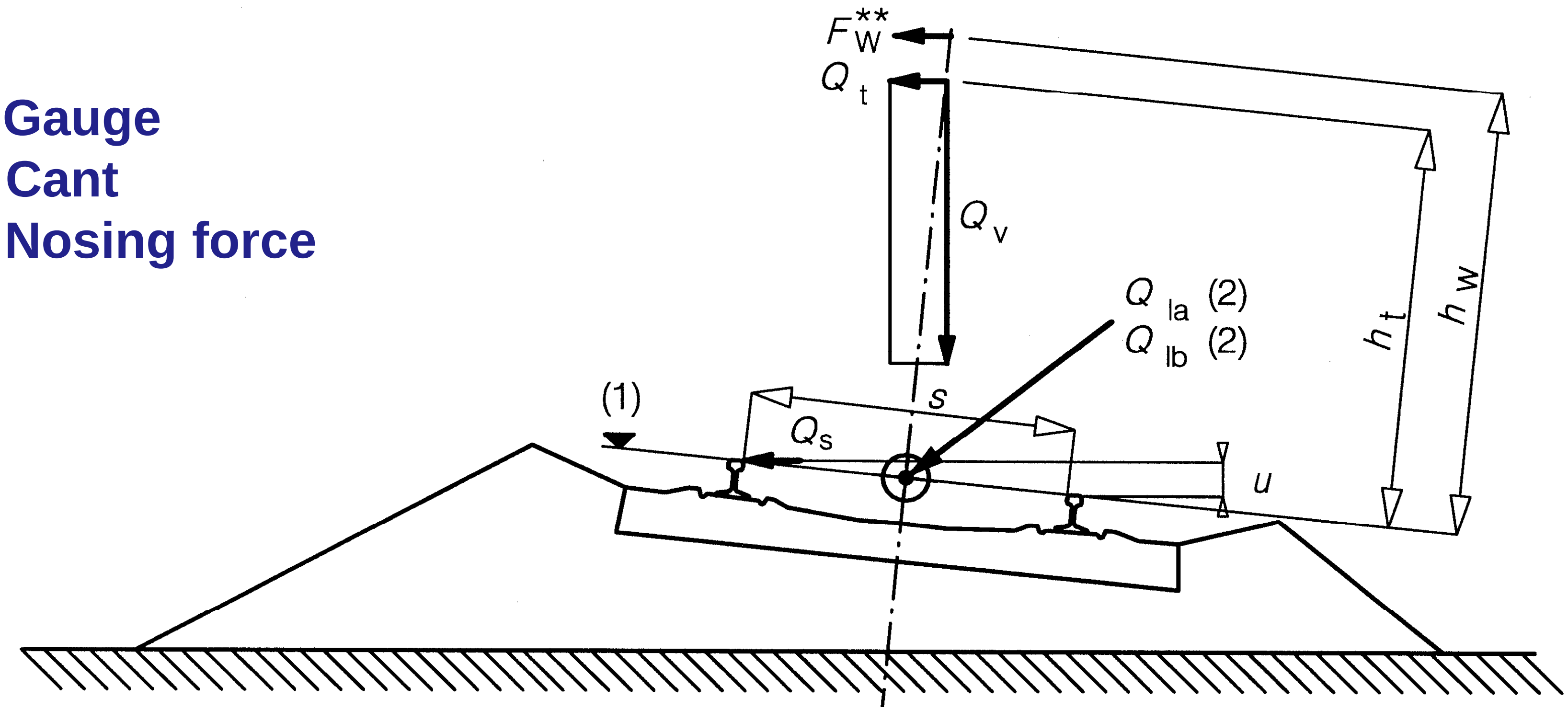


Railway bridges - Notation and dimensions specifically for rail tracks – Section 6

s : Gauge

u : Cant

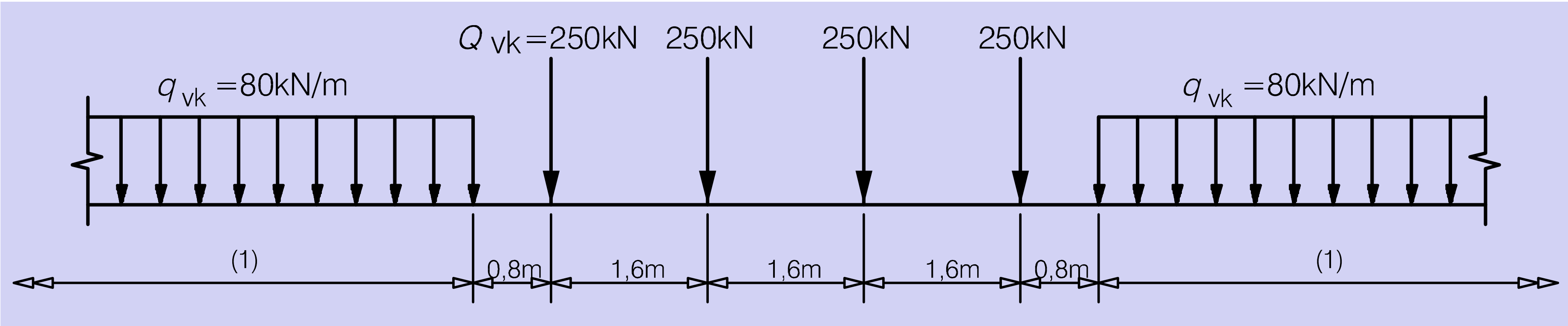
Q_s : Nosing force



(1) Running surface

(2) Longitudinal forces acting along the centreline of the track

Load Model LM 71



The characteristic values may be adjusted to the expected traffic on the bridge by a multiplication factor α which shall be one of the following :

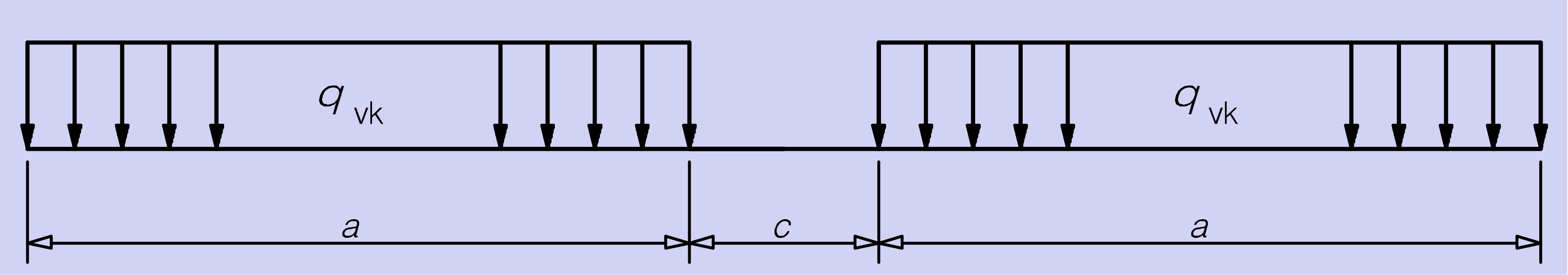
0,75 - 0,83 - 0,91 - 1,00 - 1,10 - 1,21 - 1,33 – 1,46

1,33 is the recommended value for important and international lines.

When selected, the same factor α shall be applied to the other rail traffic action components, in particular to centrifugal forces, nosing forces, and acceleration and braking.

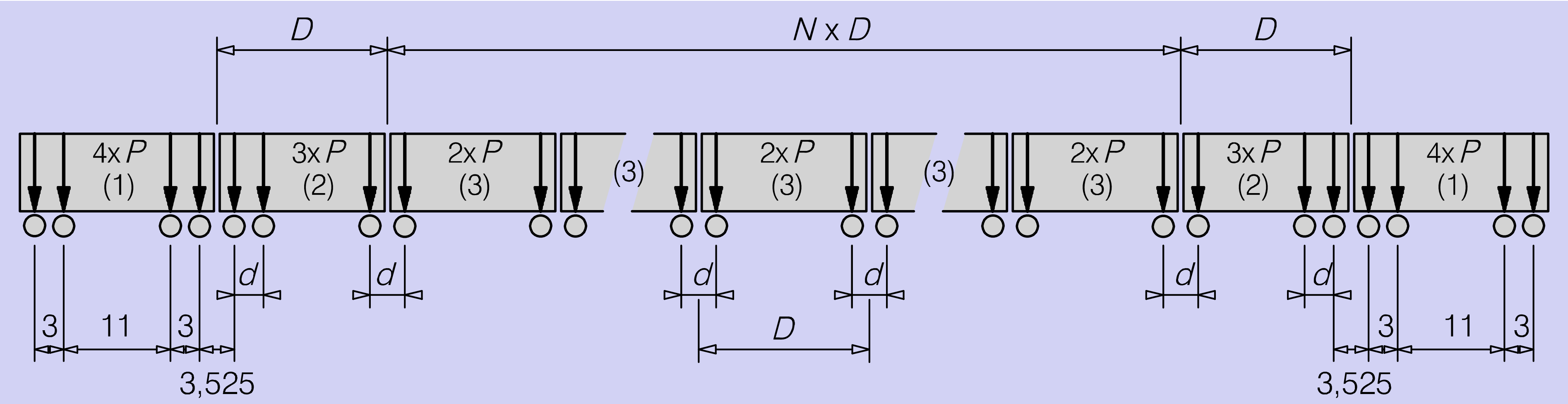
Load Models SW/0 and SW/2

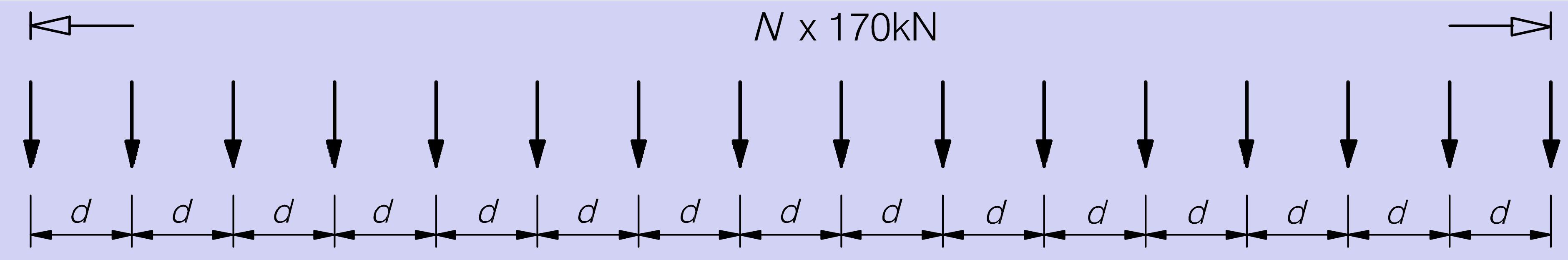
(Heavy rail traffic)



Load models	q_{vk} [kN/m]	*a* [m]	*c* [m]
SW/0	133	15,0	5,3
SW/2	150	25,0	7,0

Models HSLM-A et HSLM-B for international high speed lines





Dynamic effects

Stresses and strains in a bridge deck due to rail traffic (including the associated acceleration) are amplified or reduced by the following phenomena :

- Loading celerity due to the speed of rail traffic crossing the bridge and the bridge inertia,

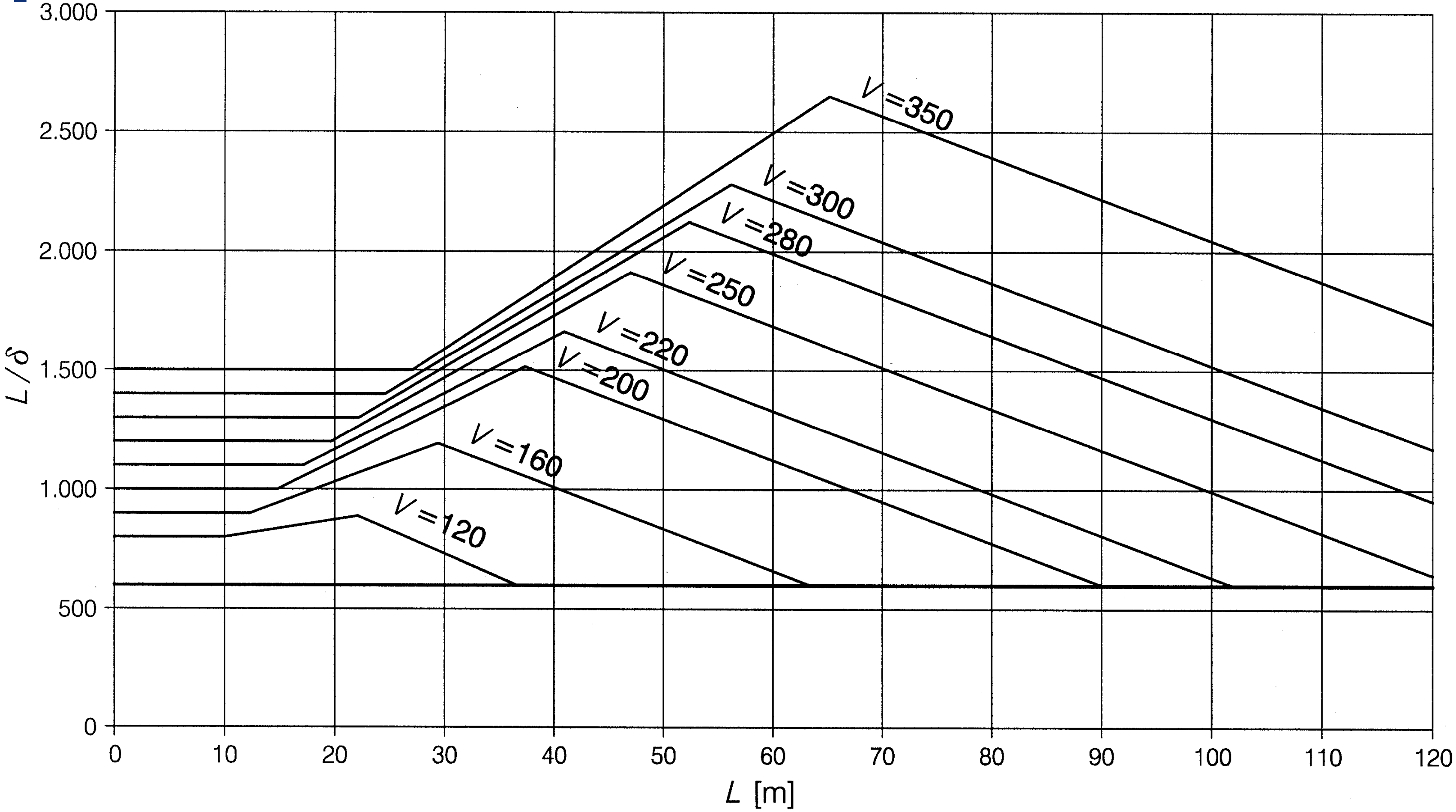
- Successive loads crossing the bridge with more or less regular spacings, which can excite the structure and, in some cases, lead to resonance,

- Variations of wheel loads due to imperfection of tracks or of the vehicle (including wheel irregularities).

To cover these effects, EN 1991-2 defines 3 dynamic amplification factors

Load models for railway bridges

Maximum permissible vertical deflection δ for railway bridges with 3 or more successive simply supported spans corresponding to a permissible vertical acceleration of b_v = 1 m/s² in a coach for speed V [km/h]



THANK YOU FOR YOUR ATTENTION