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Enhanced Regional EU-ASEAN Dialogue Instrument (E-READI)

EN 1991: Actions on Structures;

Part 1-4: General actions - wind actions;

Part 1-5: General actions – thermal actions

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Chairman of CEN/TC 250/SC 1 “Structural Eurocodes-Actions on Structures”

General overview of the evolution of EN 1991:
Eurocode 1 – Actions on structures

A reminder of the scope of EN 1991 (2nd Generation)

0.2 Introduction to the EN 1991 series

The EN 1991 series provides **the actions to be considered for the structural design of buildings, bridges and other civil engineering works, or parts thereof, including temporary structures**, in conjunction with EN 1990 and the other Eurocodes.

The actions on structures, including in some cases geotechnical structures in conjunction with the EN 1997 series as appropriate, **provided in the EN 1991 series are intended to be applied in conjunction with the other Eurocodes** for the verification of safety, serviceability and durability, as well as robustness of structures, including during the execution phase.

EN 1991 **does not cover actions for structures in seismic regions**, unless explicitly prescribed by the EN 1998 series.

A reminder of the scope of EN 1991 (2nd Generation)

The EN 1991 series is also **applicable to existing structures** for their:

— structural assessment,

— retrofitting (strengthening, repair) design,

— assessment for changes of use.

NOTE 1 In this case, additional or amended provisions can be necessary.

The EN 1991 series is applicable to the design of structures where **materials or actions outside the scope of the other Eu**rocodes are involved.

NOTE 2 In this case additional or amended provisions can be necessary.

Contents of EN 1991 (2nd Generation)

Eurocode 1

EN 1991-1 Eurocode 1 – Actions on structures – Part 1-1: Specific weight of materials, self-weight of construction works and imposed loads on buildings
EN 1991-2 Eurocode 1 – Actions on structures – Part 1-2: Actions on structures exposed to fire
EN 1991-3 Eurocode 1 – Actions on structures – Part 1-3: Snow loads
EN 1991-4 Eurocode 1 – Actions on structures – Part 1-4: Wind actions
EN 1991-5 Eurocode 1 – Actions on structures – Part 1-5: Thermal actions
EN 1991-6 Eurocode 1 – Actions on structures – Part 1-6: Actions during execution
EN 1991-7 Eurocode 1 – Actions on structures – Part 1-7: Accidental actions
EN 1991-8 Eurocode 1 – Actions on structures – Part 1-8: Actions from waves and currents on coastal structures
EN 1991-9 Eurocode 1 – Actions on structures – Part 1-9: Atmospheric icing
EN 1991-2 Eurocode 1 – Actions on structures – Part 2: Traffic loads on bridges and other civil engineering works
EN 1991-3 Eurocode 1 – Actions on structures – Part 3: Actions induced by cranes and machinery
EN 1991-4 Eurocode 1 – Actions on structures – Part 4: Silos and tanks

Key changes to EN 1991

- Update of **titles**
- **Common structure** of the core content of practically all EN 1991 parts (design situations; classification of actions; representation of actions)
- Incorporation in EN 1991 of two **new parts** based on relevant ISO standards, namely :
  - EN 1991-1-8 on "Actions from waves and currents on coastal structures"
  - EN 1991-1-9 on "Atmospheric icing"
- Consistency with the relevant Annexes of EN 1990 enhanced

Key changes to EN 1991-1-1

- Clarification/update of some definitions (e.g. “tributary area”)
- Provision of a single table of imposed loads on buildings for all categories of use and a single table for horizontal loads on partition walls and parapets
- Additional sub-category G2 of garages for vehicles with gross weight > 160 kN ; Additional class of helicopter HC3 for 60 kN < Q < 120 kN for category K roof ;Three subcategories S1, S2, S3 for stairs and landings
- Updates on partitions treated as imposed loads
- Updates on reduction factors:
  - Modified formula for the reduction factor $\alpha_A = 0.5 + \frac{10}{A} \leq 1{,}0$
  - Modified formula for the reduction factor $\alpha_n = \min\left\{0.7 + \frac{0.6}{n}\ ;1\right\}$
- Former Annex B (Vehicle barriers and parapets for car parks) removed

Key changes to EN 1991-1-1 (cont'd)

Table 6.1 — (NDP) Categories of use and values for q_k and Q_k

Category	Specific Use	Example	q_k [kN/m²]	Q_k [kN]	Typical dimension of the area loaded by Q_k expressed in (m × m)
A	Areas for domestic and residential activities	**A1** Rooms in residential buildings and houses, including corridors.	2,0	2,0	0,05 × 0,05
		A2 Bedrooms, wards, dormitories, private bathrooms and toilets in hospitals, hotels, hostels and other institutional residential occupancies.	2,0	2,0	0,05 × 0,05
B[a]	Public areas (not susceptible to crowding)	**B1** Office areas for general use including corridors other than archive / storage areas (see Category E)	3,0	3,0	0,05 × 0,05
		B2 Kitchens, communal bathrooms and toilets in hospitals, hotels, hostels and other institutional residential occupancies.	3,0	3,0	0,05 × 0,05
C[b,c,d]	Public areas where people may congregate (with the exception of areas defined under category A, B, and D)	**C1**: Areas with tables, etc. e.g. areas in schools, cafés, restaurants, dining halls, reading rooms, receptions.	3,0	4,0	0,05 × 0,05
		C2: Areas with fixed seats, e.g. areas in churches, theatres, cinemas, conference rooms, lecture halls, assembly halls, waiting rooms.	4,0	4,0	0,05 × 0,05
		C3: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and corridors to areas not belonging to categories A1, B1 and C5.	5,0	4,0	0,05 × 0,05
		C4: Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages.	5,0	7,0	0,05 × 0,05
		C5: Areas susceptible to large crowds, e.g. in buildings for public events including corridors like concert halls, sports halls including stands, and railway platforms.	7,5	4,5	0,05 × 0,05
D	Shopping areas	**D1**: Areas in retail shops	4,0	4,0	0,05 × 0,05
		D2: Areas in department stores	5,0	7,0	0,05 × 0,05
E	Areas for archive, storage and industrial use[e]	**E1**: Areas susceptible to accumulation of goods, including access areas [f]	7,5	7,0	[a]
		E2: Industrial use [g,h,i,j]	[a]		
F	Garages and vehicle traffic areas (excluding ordinary roads and bridges)	Gross vehicle weight ≤ 30 kN: **F1** Traffic and parking areas for light vehicles (≤8 seats not including driver) e.g. garages; parking areas, parking halls	2,5	20	[a]
G		30 kN < Gross vehicle weight ≤ 160 kN: **G1** Traffic and parking areas for medium vehicles (on 2 axles) e.g. access routes, delivery zones, zones accessible to fire engines	5,0	90	0,2 × 0,2
		Gross vehicle weight > 160 kN: **G2** Traffic and parking areas for heavy vehicles [k]	[a]		
H[l]	Roofs not accessible except for normal maintenance and repair		0,4	1,0	0,05 × 0,05
I	Roofs accessible with occupancy according to categories A to G		See categories A to G		
K	Roofs accessible for special services, such as classes HC for helicopter landing areas		5,0	See Table 6.4	
S	Stairs and landings	**S1** Stairs and landings to areas belonging to category A1 and B1.	See categories A1 and B1		0,05 × 0,05
		S2 Stairs and landings for tribunes without fixed seats that are defined as escape ways.	7,5	3,0	0,05 × 0,05
		S3 Stairs and landings not belonging to category S1 or S2.	5,0	2,0	0,05 × 0,05
T	Terraces and balconies	**T1** Roof terraces, access balconies, balconies, loggias, etc.	3,0	2,0	0,05 × 0,05

Key changes to EN 1991-1-1 (cont'd)

Table 6.5 — (NDP) Horizontal loads on partition walls and parapets

Category	Specific Use	q_k [kN/m]
A B C1	Areas for domestic and residential activities Office areas Areas with tables	0,8
C2 C3 C4 D	Areas with fixed seats Areas without obstacles for moving people Areas with possible physical activities Shopping areas	1,0
C5	Areas susceptible to large crowds	3,0
E[a]	Storage and industrial use	2,0
F	Garages and vehicle traffic areas in buildings, for gross vehicle weight ≤ 30 kN	See EN 1991-1-7
G	Garages and vehicle traffic areas in buildings, for gross vehicle weight > 30 kN	See EN 1991-1-7
S	Stairs and landings	See categories A to G
T	Balconies and terraces	

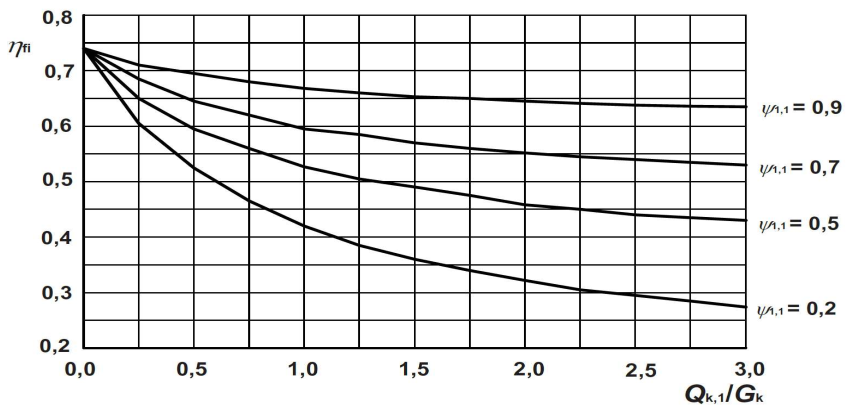
[a] For areas of category E, the horizontal loads depend on the occupancy. Therefore the value of q_k is defined as a minimum value and should be checked for the specific occupancy and actual storage conditions.

Key changes to EN 1991-1-2

- Clarification/update of some definitions
- Scope clarified, in particular the non-coverage of:
  - the possible installation and maintenance of sprinkler systems;
  - conditions on occupancy of building or fire compartment;
  - the use of approved insulation and coating materials, including their maintenance
- Formulae and relevant diagrams are given as simplified rules for the determination of the reduction factor η_{fi}

$$E_{fi,d,t} = E_{fi,d} = \eta_{fi} \cdot E_d \qquad (6.1)$$

$$\eta_{fi} = \frac{G_k + \psi_{fi}\, Q_{k,1}}{\gamma_G\, G_k + \gamma_{Q,1}\, Q_{k,1}} \qquad (6.2)$$



Key changes to EN 1991-1-2 (new content)

- The scope of **Annex C** on the thermal action of a **localised fire** represented by a virtual solid flame as exposed in this annex has been clarified and substantially extended.
- In **Annex G** a model has been introduced for the evaluation of the virtual solid flame used in the determination of the "**configuration factor**" (expressing the diffusely radiated energy of heat transfer from one surface to another)
- A new **Annex H** (informative) on "**Thermal actions for structural fire loads of timber structures**" has been added, to be combined with the Annex A (informative) of EN 1995-1-2 on the "Design of timber structures exposed to physically based design fires"
- All Annexes remain informative

Key changes to EN 1991-1-2 (cont'd)

- The **Annex E** on "**Fire load densities, Fire Growth Rates and Rate of Heat Releases**" has been revisited and led to the introduction of an updated and detailed factor taking into account the different active fire-fighting measures (sprinkler, detection, automatic alarm transmission, firemen …) in the formula (E.1) for the evaluation of the design value of the fire load $q_{f,d}$:

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_{q1} \cdot \delta_{q2} \cdot \delta_{\mathbf{n}} \cdot \delta_{q3} \qquad [\text{MJ/m}^2] \qquad (E.1)$$

Table E.2 — Factors δ_{ni}

Automatic Fire Suppression				Automatic Fire Detection & Alarm				Manual Fire Suppression								
Automatic Water Extinguishing System	Independent Water Supplies			Automatic Fire Detection & Alarm			Automatic Alarm Transmission To Fire Brigade	Fire Brigade		Safe Access Route			Fire Fighting Device		Smoke Exhaust System	
	0	1	2	By heat	By smoke	By heat & smoke		Work FB	Off Site FB	Improved	Standard	Difficult	Present	Not present	Present	Not present
δ_{n1}	δ_{n2}			δ_{n3}			δ_{n4}	δ_{n5}		δ_{n6}			δ_{n7}		δ_{n8}	
0,61	1	0,87	0,7	0,9	0,73	0,73	0,87	0,61	0,78/0,84	0,9	1	1,5	1	1,5	1	1,5

Key changes to EN 1991-1-2 (cont'd)

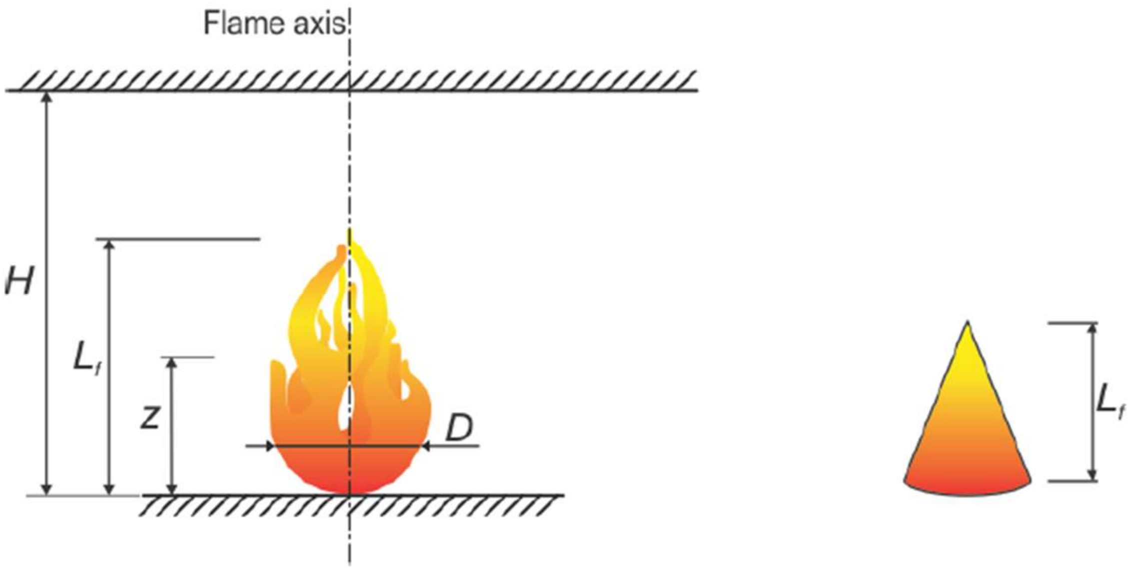


Figure C.1: Height of the virtual flame L_f

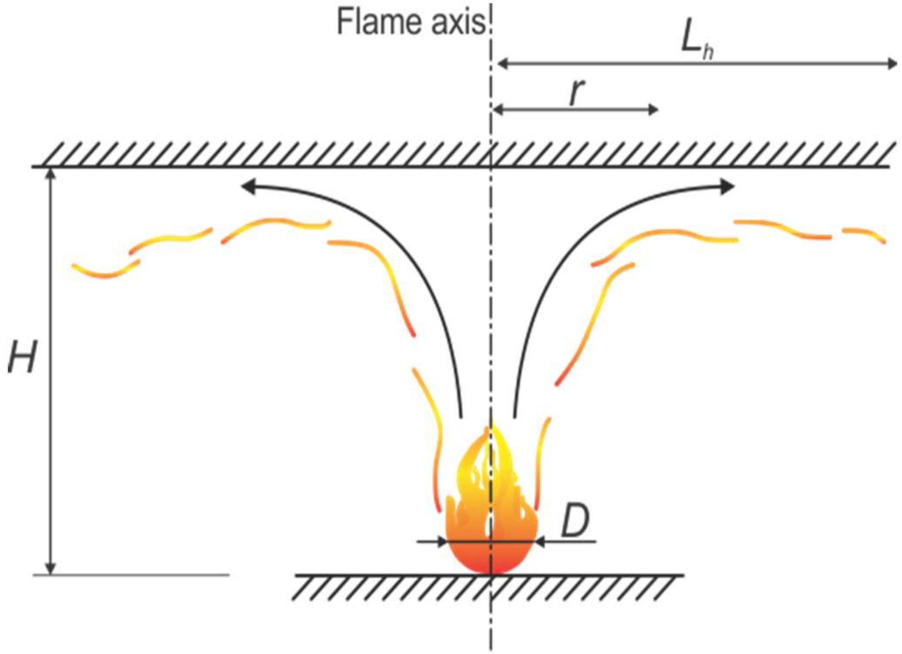


Figure C.5: Flame impacting the ceiling

Annec C: Localised fires

Key changes to EN 1991-1-3 and new content

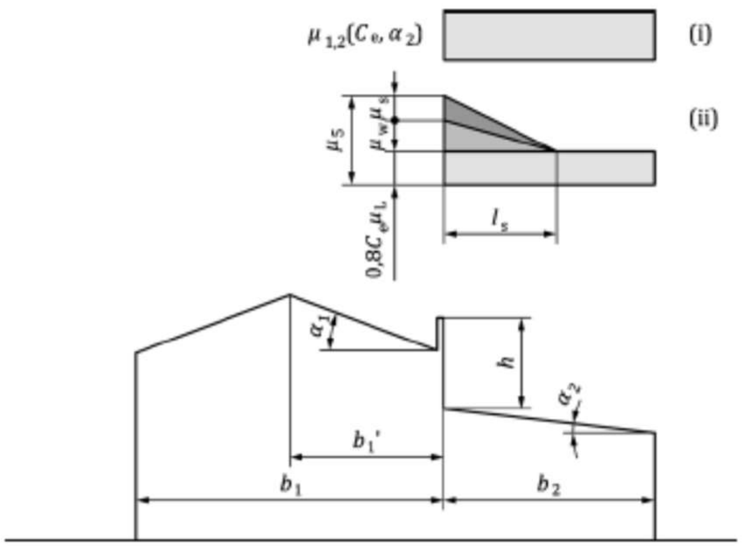
- Implementation of new models closer to the physics and based on state-of-the-art experimental data available for European climates, e.g. an updated model for the snow load on the roofs
- Consideration of snow load for additional types of roofs
- Implementation of updated and specific models for snow local effects
- As an example, the terms **"balanced"** and **"unbalanced"** are used in place of "undrifted" and "drifted". (This terminology is also consistent with ISO 4355:2013 and with ASCE/SEI 7-16)
- The exposure coefficient **Ce** has been updated accordingly, in order to account for the increase of snow load in locally sheltered areas of the roof
- The snow coefficients have been revisited and a **new snow model** for **pitched (gabled) roofs** has been introduced

Key changes to EN 1991-1-3 and new content (cont'd)

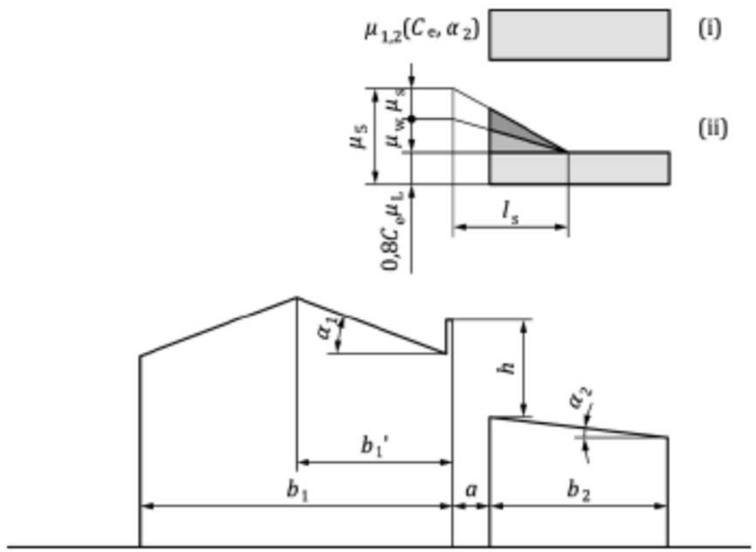
- For **flat roofs**, the influence of the roof dimensions is now taken into account, as well as the presence of rows of tilted (solar) panels
- For **cylindrical roofs** slightly updated model to account for variations in drifted snow load based on varying exposure coefficient.
- For **domes** a new snow load model is introduced, as a simplification of the relevant models of ISO 4355:2013 and with ASCE/SEI 7-16
- For **multi-span roofs** the model is revised to account for realistic snow load depths in the valley (not exceeding the ridge of the roof) and the effect of sliding in the valley
- Update to the snow load shape to account for the **drifting at obstructions** (snow load shape coefficient and drift length of obstructions are made dependent on the exposure coefficient)
- New snow load shape coefficients for **intersecting pitched roofs**

Key changes to EN 1991-1-3 and new content (cont'd)

- **For roof abutting and close to taller construction works a new model for "unbalanced" snow load on the lower roof is introduced**, in order to correct inconsistencies detected in the current standard. The new model accounts for three different contributions: the load pertaining to the balanced condition (**μ_L**), the sliding part from the upper roof (**μ_s**) and the wind driven accumulated snow (**μ_w**)

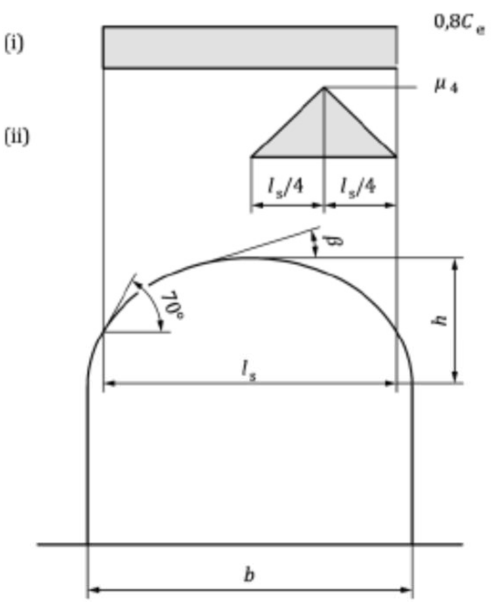


a) This load arrangement applies where $a = 0$ and $b_2 \geq l_s$



b) This load arrangement applies where $0 < a < l_s$

Key changes to EN 1991-1-3 and new content (cont'd)

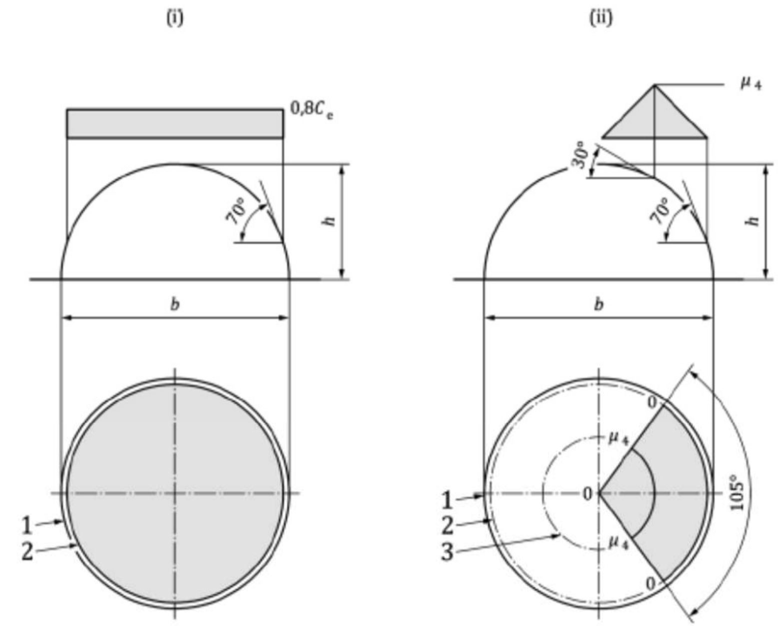


Key

(i) Balanced load arrangement

(ii) Unbalanced load arrangement

Figure 7.8 — Snow load arrangements for cylindrical roofs



Key

(i) Balanced load arrangement

(ii) Unbalanced load arrangement

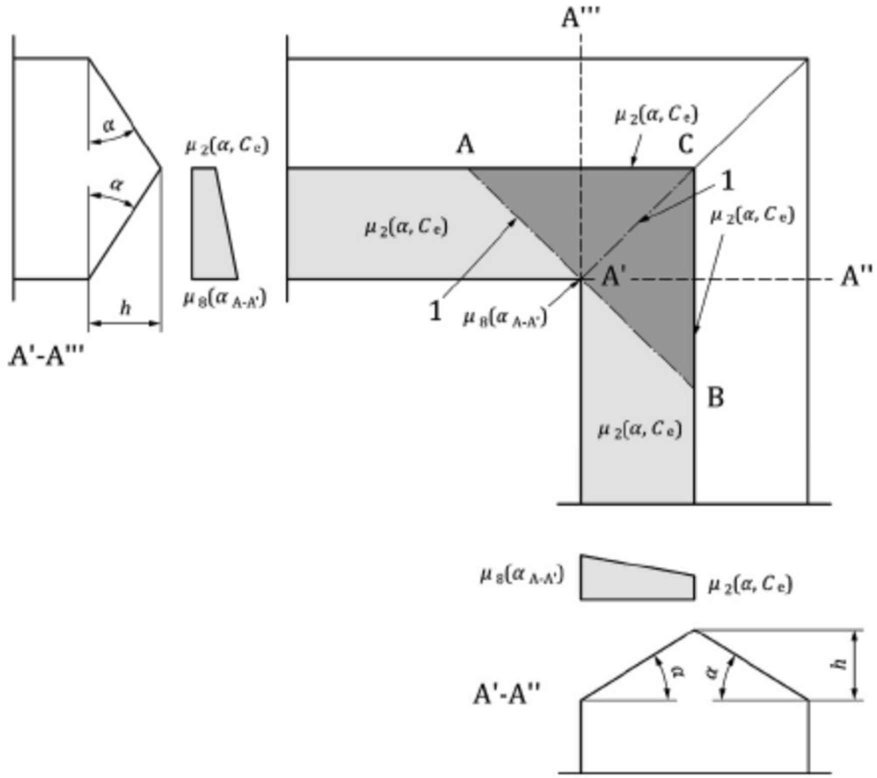
1 Structural Perimeter

2 70 degrees tangent

3 30 degrees tangent

Figure 7.9 — Snow load arrangements for domes

Key changes to EN 1991-1-3 and new content (cont'd)



Key
1 Linear variation of the shape coefficients along lines A'-A, A'-B and A'-C

Figure 8.5 — Snow load shape coefficients for intersecting pitched roofs

Key changes to EN 1991-1-6 and new content

- Update and clarification of the scope and the assumptions
- Proper delimitation vis-à-vis the use of product standards relevant for auxiliary structures and equipment (e.g. falsework, temporary works equipment, scaffolds)
- Design of auxiliary structures clarified
- Improved description of the design situations and limited update of the classification and representation of actions
- Update of the guidance for the determination of the characteristic values of the climatic actions (new Table 6.1, former Table 3.1)
- Additional considerations on actions during execution (imperfections, lateral stability, dynamically applied actions)
- Former Annex B (Actions on structures during alteration, reconstruction or demolition) removed

Key changes to EN 1991-1-6 and new content (cont'd)

Table 6.1(NDP) — Guidance for the determination of the characteristic values of the climatic actions

Duration of the activities	Method for determining characteristic values
≤ 5 days	The characteristic values are determined based on reliable meteorological data covering a period that extends over the entire planned maximum duration of the activity under analysis.
≤ 1 year (but > 5 days)	The characteristic values are taken as specified in the applicable part of EN 1991 (i.e. based on an annual probability of exceedance of 0,02), accounting, when applicable, for seasonal variations by seasonal factors.
> 1 year	The characteristic values are taken as specified in the applicable part of EN 1991 (i.e. based on an annual probability of exceedance of 0,02), but neglecting seasonal factors.

(2) Threshold values (or a range of values) of a specific climatic action may be used if specified by the relevant authority and agreed for a specific project by the relevant parties.

NOTE Providing a threshold value (or a range of values) of a climatic action can be relevant in cases where the decision to start or continue an execution activity is made dependent on checking whether values of that action meet the threshold value.

Key changes to EN 1991-1-7 and new content

- Limited changes as compared to the actual version
- Clarification and improvement of some clauses
- Improvement of the compatibility with EN 1990 (Annex E, in particular, related to strategies for accidental design situations)
- Rearrangement of the categorization of consequence classes
- Clarifications for the impact from river, canal and seagoing vessels
- Addition of ship impact formulas for non-ice-classed vessels
- Clarification about internal explosions
- Addition of a new Annex E on actions from debris

Key changes to EN 1991-1-7 and new content (cont'd)

Table 4.1 — Strategies for Accidental Design Situations

Design for accidental actions (EN 1991) **Explicit design of the structure (e.g. against explosion, impact)**		**Design for enhanced robustness (EN 1990)** **Strategies based on limiting the extent of damage**		
Design structure to resist the action[a]	Prevent or reduce the action e.g. protective measures, control of events	Alternative load paths either providing adequate deformation capacity and ductility or applying prescriptive design rules	Key elements i.e. designing selected members to resist notional action(s)	Segmentation i.e. separation into parts
[a] Structural design against identified accidental actions can incorporate specifically designed members, which fall partially or fully, provided their failure does not lead to further structural collapse as agreed with the authorities (for strategies and methods to limit the extent of damages, see E.3 and E.4 in **EN 1990**:2023)				

Key changes to EN 1991-1-8 (new standard)

- There has not been so far an EN 1991-1-8, therefore this aspect could only make sense if comparison is made against ISO 21650:2007 upon which (as background) EN 1991-1-8 is based
- As compared with ISO 21650 the following key differences can be stated:
  - EN 1991-1-8 is intended to be a standard referring to actions (only) while ISO 21650 covers actions and modelling (actions effects) and also touches some resistance aspects of the design.
  - ISO 21650 is only briefly covering aspects of reliability, while partial factors and combinations of actions are missing. Achieving full consistency with EN 1990 and the Eurocodes framework in general is hardly feasible in view of some design provisions of ISO 21650
  - For breakwaters, **severe displacement of armour units** and **severe overtopping ultimate limit states** are introduced
- Structures that have only the purpose of flood risk management were not incorporated, notably dykes, as requested by some NSBs

Key changes to EN 1991-1-8 (new standard) (cont'd)

Contents .... Page

- **Annexes A to H** with additional guidance on the key topics of the main text

Key changes to EN 1991-1-8 (new standard) (cont'd)

- As most significant items of the standard can be considered the following:
  - A comprehensive definition of design **"Environmental sea conditions"** (essentially water level, wave conditions, currents). Detailed guidance is provided in Annex A
  - The implementation of the **"Hydrodynamic Estimate Approach""** **(HEA)**, which is defined as : "methodology to assess metocean parameters that relates to the consequence class of the structure and the local hydrodynamic conditions"
  - The implementation of **"Design Approaches" (DA)**

The purpose is that methods and requirements for the design can be outlined depending on the HEA-level, the DA-Level and the Consequence Classes (CC).

Key changes to EN 1991-1-8 (new standard) (cont'd)

Table 4.3 — Design approach selection matrix

HEA level	Low-to medium structure design/ response uncertainty[a]	High structure design/ response uncertainty[a]
HEA1	DA1	Not applicable
HEA2	DA1 or DA2[b]	DA1 + DA4 or DA2 + DA4
HEA3	DA1 or DA2 or DA3 or any previous with DA4	DA1[c] + DA4 or DA2 + DA4 or DA3 + DA4

NOTE 1 As explained in 4.2:

- DA1: Semi-probabilistic partial factors approach (loads and resistances) with appropriate sensitivity testing of key parameters based on the application of semi-empirical structure response formulae;
- DA2: Probabilistic (reliability based) approach with allowable probabilities of failure or β indexes;
- DA3: Risk-informed approach with a socio-economic optimisation to determine optimum probability of failure of the considered structure;
- DA4: Design assisted by testing approach, in combination with DA1, DA2 or DA3.

NOTE 2 Guidance and limitation of use of DA2 and DA3 are given in FprEN 1990:2022, C.3.1.

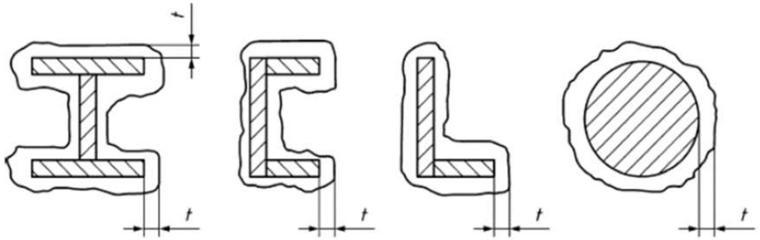
Key changes to EN 1991-1-9 (new standard)

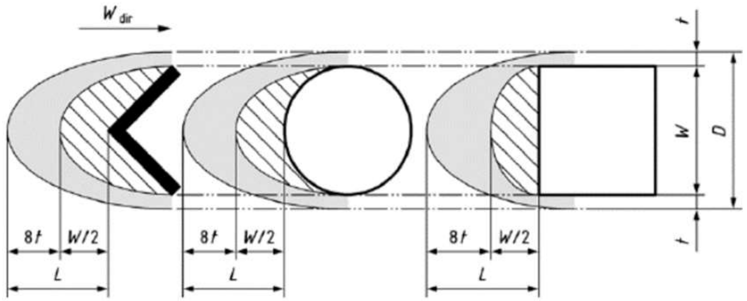
- There has not been so far an EN 1991-1-9, therefore this aspect could only make sense, if comparison is made against ISO 12494:2001 upon which (as background) EN 1991-1-9 is based
- Ice load is determined and classified according to **ice classes** (IC) for both **glaze** (ICG) and **rime** (ICR), because the characteristics for these differ. ICG should be determined for glaze deposits and ICR for rime deposits (see following slide)
- Combination with wind actions considered
- New height factor introduced for glaze ice
- Most information on how to measure and model atmospheric icing left open for the National Annexes
- In sum, EN 1991-1-9 is more compact than ISO 12494 and consistent with EN 1990 and the Eurocode style

Key changes to EN 1991-1-9 (new standard) (cont'd)

- Ice thickness for ICGs **(glaze)**

Ice classes ICG	G1	G2	G3	G4	G5	G6
Characteristic ice thickness *t* (mm)	10	20	30	40	50	*
* To be used for extreme ice accretions NOTE The numbers represent the upper bound for the corresponding ICGs.						





- Ice masses for ICRs **(rime)**

Ice classes for rime	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Characteristic Ice mass *m* (kg/m)	0,5	0,9	1,6	2,8	5,0	8,9	16,0	28,0	50,0	*
* To be used for extreme ice accretions NOTE The numbers represent the upper bound for the corresponding ICRs										

Key changes to EN 1991-2 and new content

- **Extension of the scope and field of application (and associated change of title)** to include other civil engineering works (e.g. geotechnical works, but not buildings)
- Some changes for geotechnical items especially new wording (more accurate/clear technical terms and definitions), mainly related to railway traffic loading
- Addressing the request of ERA (European Railway Agency, now European Union Agency for Railways) for the revision of some clauses in order to achieve consistency with TSI INF and relevant standards (e.g. EN 15528)
- Deleting former Annexes F and G
- Update of Annex E (on limits of validity of Load Model HSLM)
- Adjustments in view of consistency with EN 1990-Annex A.2 and other Eurocodes bridge parts (following HG-B proposals)

Key changes to EN 1991-2 and new content (cont'd)

- **New subclauses 6.9 and 8.10 (Static load models for geotechnical structures – characteristic values), for road and railway traffic, respectively**
- Update of clauses related to the final CEN/TR 17231 for Track-Bridge interaction
- Including the bases of design for noise barriers at railway lines (transfer from EN 16727-2-2)
- Including some new methods and materials (e.g. for footbridges and timber structures)
- Creating an updated clause 7 and a **new Annex G for footbridges** with additional special requirements related to EN 1990 Annex H, in particular on dynamic actions and pedestrian induced vibrations, based on state-of-the-art literature (guidelines and/or largely/commonly accepted methods and results); see next slide

Key changes to EN 1991-2 and new content (cont'd)

- Load model for geotechnical structures (road traffic)

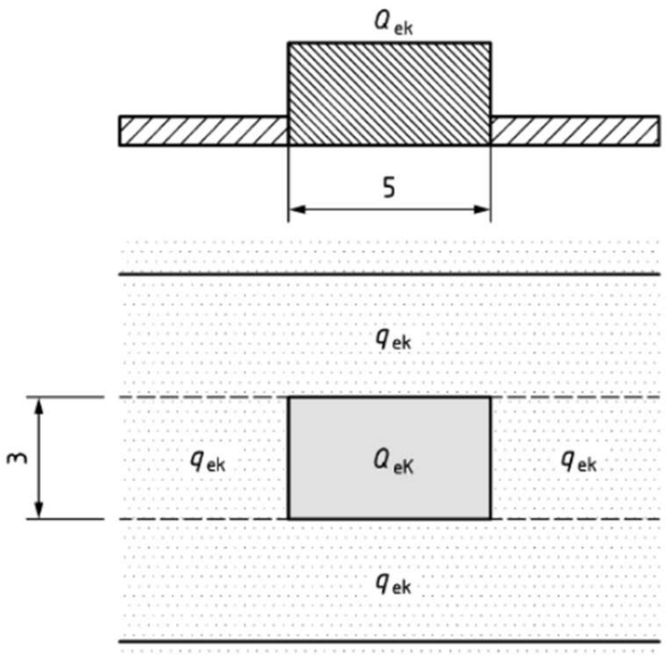


Figure 6.11 — Road traffic load model for geotechnical structures

Key changes to EN 1991-2 and new content (cont'd)

- Static load model for geotechnical structures (railway traffic)

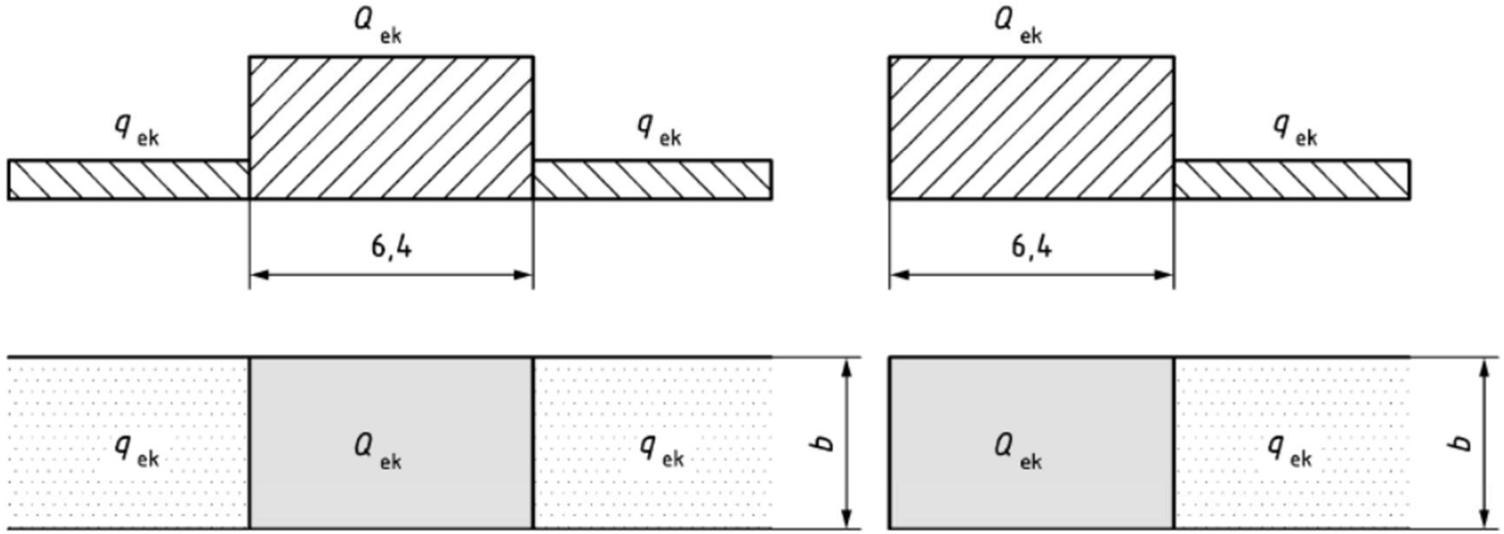


Figure 8.28 — Equivalent load arrangement for Load Model 71 for geotechnical structures (*a*, left) Single concentrated patch load and uniformly distributed load on both sides (*b*, right) Single concentrated patch load and uniformly distributed load on one side only

Key changes to EN 1991-2 and new content (cont'd)

Table G.1 — Traffic classes and harmonic load models

		(G.4)	(G.5)	(G.6)
Traffic Class	Description	Pedestrian stream P/m^2 (A)	Pedestrian group n_w (B)	Jogging group n_j (C)
TC 1	Very weak traffic	0,1	1	0
TC 2	Weak traffic	0,2	2	0
TC 3	Dense traffic	0,5	4	1
TC 4	Very dense traffic	1,0	8	2
TC 5	Exceptionally dense traffic	1,5	16	4

d = density [P/m^2 = pedestrians on loaded surface]

n_w = number of pedestrians in a group

n_j = number of joggers in a group

NOTE 1 As an example:

TC 2(A) = load model of pedestrian stream with pedestrian density of 0,2 × P/m^2

TC 4(B) = load model of group of 8 pedestrians

TC 3(C) = load model of a single jogger

NOTE 2 Further guidance for the selection of design situations, depending on the usage and location of the bridge, is presented in EN 1990:2023, A.2.8.3 and Annex H.

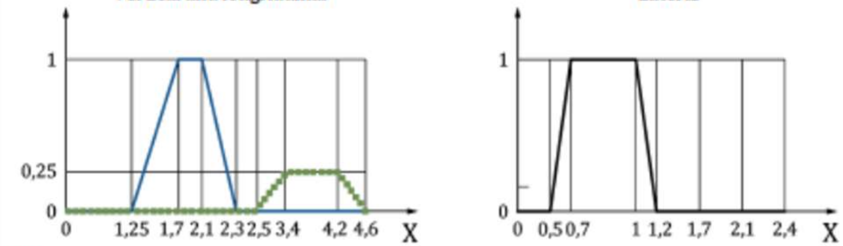
For pedestrian stream load model minimum of 15 persons on the bridge deck should be assumed unless otherwise defined in the National Annex or for the individual project.

Table G.2 — Parameters for load model of TC 1 to TC 5

	P_w N	
Vertical 280	Longitudinal 140	Lateral 35

Reduction coefficient ψ_w

Vertical and longitudinal — Lateral



Key

1. Harmonic
2. Harmonic

X frequency

Equivalent number n' of pedestrians on the loaded surface S for traffic classes TC1 to TC5:

TC 1 to TC 3 (density $d < 1{,}0$ P/m^2):

$$n' = \frac{10{,}8\sqrt{\xi \cdot n}}{S} \ [1/\text{m}^2] \quad \text{(G.2)}$$

TC 4 to TC 5 (density $d \geq 1{,}0$ P/m^2):

$$n' = \frac{1{,}85\sqrt{n}}{S} \ [1/\text{m}^2] \quad \text{(G.3)}$$

where

ξ is the structural damping ratio;

d is the density of pedestrians [P/m^2] (see Table G.1);

n is the number of pedestrians on the loaded surface S ($n = d \times S$);

S is the area of loaded surface.

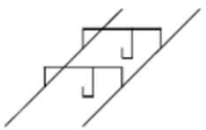
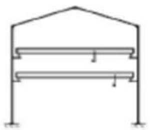
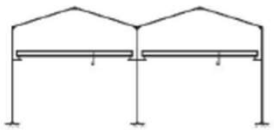
Annex G : Dynamic load models for footbridges

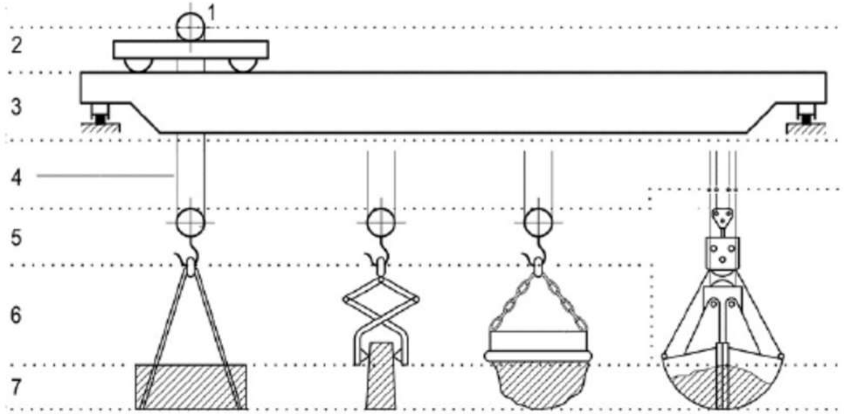
Key changes to EN 1991-3 and new content

- Clarification in the scope that the content concerns the structures supporting **bridge, gantry and wall cranes travelling on fixed runways** and **fixed machines** that cause a harmonic dynamic loading on fixed supporting structures
- Setting some additional principles and requirements on actions transferred from cranes or machines at the interface with their supporting structures
- Update of the definitions, together with Annex A.5 of EN 1990, based on ISO 4306-1, especially on crane-related terms
- Improvement of the multiple crane operation
- Addition and clarification for the handling of in-service wind
- Removal of the former normative Annexes A (practically covered now by the Annex A.5 of EN 1990) and B (practically covered now by cl. 6.9 and new Annex A)

Key changes to EN 1991-3 and new content (cont'd)

Table 6.1 (NDP) — Maximum number of bridge cranes in fundamental (persistent and transient) and fatigue design situations for the verification of the ultimate limit states

Maximum number of cranes for	Crane runway	Crane runway supporting structures	
		Single-bay structures	Multi-bay structures
			
Vertical actions (Q_r)	**3** cranes maximum on the same runway	**4** cranes maximum in the same bay, either: a) 3 on the same runway and 1 on another runway, *or* b) 2 on the same runway and 2 on another runway, *or* c) 2 on the same runway and 2 on separate runways.	**6** cranes maximum, with either: a) 4 positioned in one of the ways listed for single bay structures and 2 in another bay, *or* b) 6 distributed over several bays.
Horizontal crane actions (H_T, H_L, H_S)	**1** crane only, except for two cranes operating in tandem.	**2** cranes maximum on different runways, unless they operate in tandem.	**4** cranes maximum, taking into account the provisions for crane runways and single-bay structure.



Key

1 hoist
2 trolley
3 crane bridge
4 hoist medium
5 fixed load-lifting attachment
6 non-fixed load-lifting attachment
7 payload

Figure 3.2 — Crane-related terms (exemplified for a bridge crane)

Key changes to EN 1991-3 and new content (cont'd)

- More user-friendly guidance on actions from cranes travelling on fixed runways for two important standard cases:
  - Main case of application: Use of the technical data file for cranes designed according to a relevant European crane product standard
  - Minor case of application for existing older cranes: User-friendly guidance on how to determine the crane-induced actions, if no technical data file is available (new Annex B)
- Improved and updated classification of typical bridge and gantry cranes for the fatigue design of their supporting structure that is now consistent with the relevant crane product standard EN 15011 (new Annex A)
- Addition of guidance on the calculation of actions from travelling wall cranes as this information has been missing up to now (new Annex C).

Key changes to EN 1991-4 and new content

- A clear differentiation between silos with very different requirements is provided by classifying according to action assessment, construction complexity, consequences of failure and stored bulk solid behavior
- A user-friendly structure with simple routes throughout the document and easy access to loads in silos designed for symmetrical conditions
- A more rational basis for prescribing characteristic loads
- The revised standard is based in more physics and less empirical work
- Important steps towards consistency with EN1990 Annex A4
- A new section added on silos with inverted cone
- Additional rules have been added on rectangular silos with flexible walls
- New clauses have been added on **pressures in asymmetrical conical hoppers (mass flow)** and on **overpressure factors under mixed flow**, as well as on **thermal differential causing pressures** in different geometries

Key changes to EN 1991-4 and new content (cont'd)

- A clear distinction is made between:
  - symmetrical loads on vertical silos (**S**ilo **F**undamental **L**oad **C**ases - **SFLC**), in the case of symmetrical filling and discharge loads for silos of various slenderness and retaining silos, silo hoppers and bottoms (in Sections 7 and 9); and
  - (**S**ilo **S**pecial **L**oad **C**ases - **SSLC**), in the case of vertical walls, hoppers and silo bases with unsymmetrical pressures and high slenderness, large eccentricities of filling loads for squat or intermediate slender silos or pipe flow and several other special cases (in Sections 8 and 10)

- A **new Annex G with flow charts** to aid the use of the standard has been added

The flow charts are set out in the following sequence:

m) Silo Fundamental Load Cases for vertical walls (SFLC W)

n) Silo Fundamental Load Cases for hoppers and silo bases (SFLC H)

o) Silo Special Load Cases for vertical walls 1 (SSLC W1)

p) Silo Special Load Cases for vertical walls 2 (SSLC W2)

q) Silo Special Load Cases for vertical walls 3 (SSLC W3)

r) Silo Special Load Cases for hoppers and silo bases (SSLC H)

Key changes to EN 1991-4 and new content (cont'd)

Table 5.2 – Eccentricity limits for all silos

Silo Special Load Case depending on the eccentricity	Slender and very slender silos	Intermediate slenderness silos	Squat silos
Small filling eccentricity (FLC rules)	$e_f < 0{,}30d_c$	$e_f < 0{,}20d_c$	$e_f < 0{,}20d_c$
Large filling eccentricity (SSLC Proxy load rules)	$e_f \geq 0{,}30d_c$ (see 5.5.4)	$e_f \geq 0{,}20d_c$ (see 5.5.5)	$e_f \geq 0{,}20d_c$ (see 5.5.5)
Small discharge eccentricity (FLC rules)	$e_e < 0{,}15d_c$	$e_e < 0{,}20d_c$	$e_e < 0{,}30d_c$
Moderate discharge eccentricity (SSLC Proxy load rules)	$0{,}15d_c \leq e_e < 0{,}25d_c$ (see 5.5.6)	$0{,}20d_c \leq e_e < 0{,}30d_c$ (see 5.5.7)	$0{,}30d_c \leq e_e < 0{,}40d_c$ (see 5.5.7)
Large discharge eccentricity (SSLC Pipe flow rules)	$e_e \geq 0{,}25d_c$ (see 5.5.8)	$e_e \geq 0{,}30d_c$ (see 5.5.8)	$e_e \geq 0{,}40d_c$ (see 5.5.8)

NOTE 1 Specific rules on the Silo Special Load Cases associated with large filling eccentricity and moderate and large discharge eccentricity are provided in 5.5.4 to 5.5.8.

NOTE 2 A 'small' eccentricity is deemed to be close to axisymmetric and the Silo Fundamental Load Case applies.

NOTE 3 See Figure 5.6 for the eccentricities of filling e_f and discharge e_o.

Overview of the evolution of EN 1991-1-4:
Eurocode 1 – Actions on structures
Part 1-4: Wind actions

Scope of EN 1991-1-4

(1) EN 1991-1-4 gives **principles and rules for the determination of natural wind actions for the structural design of building and civil engineering works for each of the loaded areas under consideration**. This includes the whole structure or parts of the structure or elements attached to the structure, e.g. components, cladding units and their fixings, safety and noise barriers.

(2) This part is applicable to:

- **buildings and civil engineering works with heights up to 300 m.**

- **bridges having no span greater than 200 m**.

(3) This part is intended to predict **characteristic wind actions on land-based structures, their components and appendages.**

(4) This part is also **applicable to structures less than 1 km offshore from the main coastline**. For offshore structures more than 1 km from the main coastline, the terrain effects defined in this part do not apply.

Scope of EN 1991-1-4 (cont'd)

(5) This part **does not** give guidance on **non-synoptic winds (e.g. thunderstorms, downbursts, microbursts, tornadoes, etc.), mixed wind climates**, nor does it give guidance on how to account for **local effects (e.g. thermal effects, funnelling, strong arctic thermal surface inversion, etc.**).

(6) This document addresses **simplified procedures for dynamic effects, mostly based on the assumption of a dominant single-mode response**. General criteria for performing a full dynamic analysis under aerodynamic excitation are not treated in this standard.

(7) Wind pressure effects of passing vehicles are outside the scope of this document.

NOTE See EN 1991-2:2023 for wind effects from passing trains

Contents of current (left) and future (right) EN 1991-1-4

Contents of current (left) and future (right) EN 1991-1-4

No maps provided in an Annex

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

A. **BLANK** (Formerly "Wind maps", to be removed)

B. Terrain effects

C. **Pressure coefficients for pressures on surface**

D. **Net pressure and force coefficients for walls, roofs and skins**

E. **Force coefficients for structures and structural members**

F. Procedure for along-wind dynamic response

G. Procedure for across-wind and torsional actions on susceptible buildings

H. Procedure for across-wind dynamic and aeroelastic response of slender structures

I. Dynamic characteristics of structures with linear elastic behaviour

J. Response of steel lattice towers and guyed masts

K. Guidance on derivation of design parameters from wind tunnel

L. Guidance on derivation of wind speeds from measurements at meteorological stations

M. Guidance on probabilistic description of wind actions

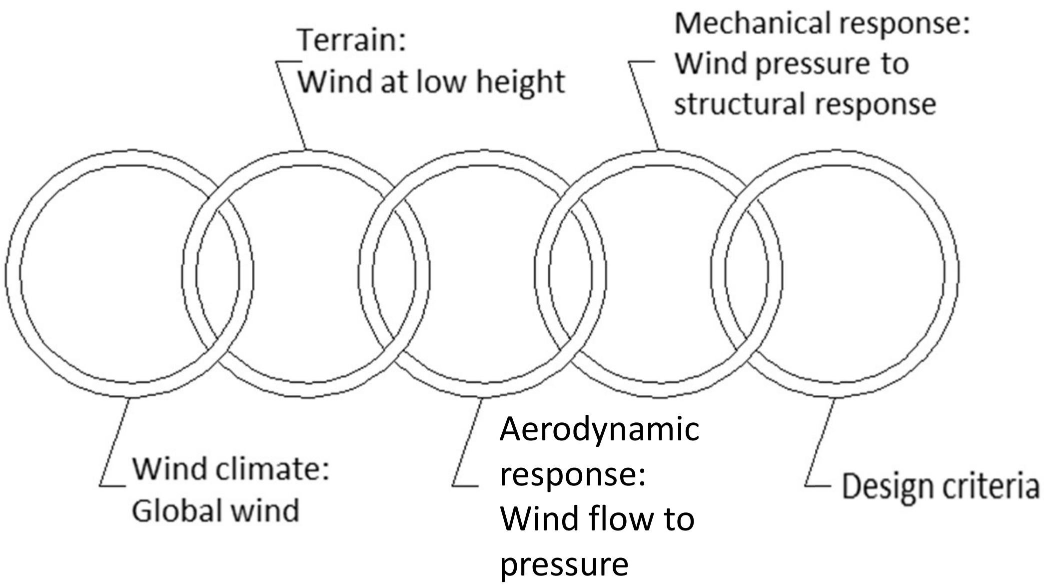
Key changes to EN 1991-1-4 and new content

- **Extension of the field of application of the standard for buildings between 200 m and 300 m high (for slender structures)**
- New formulation for determining the mean velocity and turbulence intensity up to $z = 300\ m$
- The two procedures defined in the current standard for determining the structural factor $c_s c_d$ have been unified, as well as the two approaches for determining the vortex excited cross wind amplitudes, in the informative **Annexes F and H**, respectively
- Treatment of the across-wind and torsional actions on susceptible buildings included in the informative **Annex G**
- Inclusion of the effects of atmospheric icing in the informative **Annex E**
- Inclusion of wind actions on silos and tanks

Key changes to EN 1991-1-4 and new content

- Many values of aerodynamic coefficients have been added for types of structures not considered in the current standard, in order to cover most of the current designs. Considering their large amount, they have been transferred into 3 **new normative Annexes: C** (for pressures on surfaces), **D** (for pressures across walls) and **E** (for forces on structures).
- A **new Annex J** (informative) on the response of steel lattice towers and guyed masts has been added (transferred from EN 1993-3-1).
- Guidance is given in three **new Annexes K, L and M**, respectively:
  - on the derivation of design parameters from wind tunnel tests and numerical simulations
  - on the derivation of wind speeds from measurements at meteorological stations, and
  - on probabilistic models for wind actions.

Basic concept for wind actions (based on Alan Davenport's "wind load chain")



Design situations for wind actions

(1) The relevant wind actions shall be determined **for each design situation identified in accordance with EN 1990**.

(2) In accordance with EN 1990, **other actions (such as snow, traffic, ice or rain) which can modify the effects of wind actions should be taken into account**.

NOTE See also prEN 1991-1-3 for snow, prEN 1991-1-9 for atmospheric icing, and EN 1991-2:2023 for traffic loads on bridges and other civil engineering works

(3) The **changes to the structure during construction stages** (such as different stages of the form of the structure, dynamic characteristics, etc.), **which can modify the effects of wind actions, should be taken into account**.

NOTE See also prEN 1991-1-6 for actions during execution.

(4) **Fatigue due to the effects of wind actions should be considered where relevant**, see EN 1990.

NOTE Stress ranges and number of load cycles can be obtained from Annex F, G and H.

(5) Structures should be designed to resist wind forces in all directions including torsion.

Modelling of wind actions

Representations of wind actions

The wind action shall be represented by a simplified set of pressures or forces whose effects are equivalent to the extreme effects of the turbulent wind.

NOTE 1 Wind actions fluctuate with time and act directly as pressures on the external surfaces of enclosed structures and indirectly on the internal surfaces because of porosity of the external surface. They can also act directly on the internal surface of open structures.

Classification of wind actions

Unless otherwise specified, wind actions should be classified as variable free actions.

NOTE See EN 1990 for the classification of actions.

Characteristic values

The wind actions calculated using EN 1991-1-4 are intended to be characteristic values corresponding to a 2 % probability of being exceeded per year as defined in EN 1990. This is equivalent to a return period of 50 years, see EN 1990.

NOTE 1 EN 1990 provides appropriate partial factors on wind load to reduce the probability of failures to acceptable levels

Modelling of wind actions (cont'd) – Enhancement of the Ease of Use (EoU)

Table 5.1 — Guidance for determination of wind velocity and velocity pressure

Determine fundamental value of the basic wind velocity $v_{b,0}$ from wind map	6.2(1) NOTE 1
Determine:	
altitude factor c_{alt}	6.2(2) NOTE 1
directional factor c_{dir}	6.2(2) NOTE 2
seasonal factor c_{season}	6.2(2) NOTE 3
probability factor c_{prob}	Formula (6.2)
Determine:	
basic wind velocity v_b	Formula (6.1)
reference height z_e	Annex C, D or E
terrain roughness category	6.3.2
Determine whether orography is significant? If orography is significant, determine c_o (otherwise $c_o = 1$)	6.3.3 B.3

Modelling of wind actions (cont'd) – Enhancement of the Ease of Use (EoU)

If the structure height is < 200 m	
Determine:	
basic velocity pressure q_b	Formula (6.3)
If orography is <u>not significant</u>	Figure 6.3
exposure factor $c_e(z)$	Formula (6.11)
	Formula (6.13)
	Figure 6.3
peak velocity pressure $q_p(z)$	
If orography is <u>significant</u>	
roughness factor $c_r(z)$	Formula (6.6)
turbulence intensity $I_u(z)$	Formula (6.10)
mean wind velocity $v_m(z)$	Formula (6.4)
peak wind velocity $v_p(z)$	Formula (6.12)
peak velocity pressure $q_p(z)$	Formula (6.11)
For slender structures up to 300 m height, $c_r(z)$ and $I_u(z)$ can be determined from B.6.	

Modelling of wind actions (cont'd) – Enhancement of the Ease of Use (EoU)

Table 5.2 — Guidance for determination of wind load

Wind pressures and forces for buildings:	
Obtain:	
external pressure coefficient, c_{pe}	Annex C
internal pressure coefficient, c_{pi}	Clause C.5
friction coefficient, c_{fr}	Clause E.7
Determine:	
Wind pressure acting on external surfaces, w_e	Formula (7.2)
Wind pressure acting on internal surfaces, w_i	Formula (7.3)
Determine:	
Forces from external wind pressure, $F_{w,p,e}$	Formula (7.6)
Forces from internal wind pressure, $F_{w,p,i}$	Formula (7.7)
Forces from friction, $F_{p,fr}$	Formula (7.8)
Determine wind force $F_{w,p}$ as vector sum of $F_{w,p,e}$, $F_{w,p,i}$ and $F_{p,fr}$	Clause 7.5(4)

Modelling of wind actions (cont'd) – Enhancement of the Ease of Use (EoU)

Net wind pressures and forces on canopy roofs, porches, balconies, free-standing walls, parapets, fences, and signboards:	
Obtain: net pressure coefficient, $c_{p,net}$	Annex D
Determine: net wind pressure net wind force	 Clause 7.3(3) Formula (7.5)
Wind forces on elongated structures and structural elements:	
Obtain: force coefficient, c_f	Annex E
Determine: wind force, $F_{w,p}$ lattice towers and guyed masts	 Formula (7.4) or Formula (7.5) Annex J

Modelling of wind actions (cont'd) – Enhancement of the Ease of Use (EoU)

Table 5.3 — Guidance for determination of structural factor, c_{sd}

Determine: whether $c_{sd} = 1$ may be used as an appropriate simplifying value	Clause 8.2
Or: Evaluate c_{sd} by a more rigorous method	Annex F

Table 5.4 — Guidance for determination of across-wind dynamic response

For buildings where $h/\sqrt{b \cdot d} < 3$, calculation of across-wind dynamic response is not necessary.	–
For buildings where $3 \leq h/\sqrt{b \cdot d} \leq 6$, calculate across-wind response.	Clause 9 Annex G
For buildings where $6 < h/\sqrt{b \cdot d} \leq 8$, calculate across-wind response.	Clause 9 Annex G – Annex H
For buildings where $h/\sqrt{b \cdot d} > 8$, calculate across-wind response.	Clause 9 – Clause 10 Annex H
For other flexible, slender structures (e.g. chimneys, bridge decks, etc.), calculate across-wind response.	Clause 10 Annex H

Wind velocity and velocity pressure

6.1Basis for calculation

(1) The wind velocity and the velocity pressure should be considered to be composed of a **mean** and a **fluctuating** component.

(2) The **mean wind velocity** v_m should be determined from the basic wind velocity v_b which depends on the wind climate as described in 6.2, and on height above ground level, as described in 6.3.

NOTE 1 Procedures for terrain roughness are set out in 6.3.2 for structures not exceeding 200 m.

NOTE 2 Orography is explained in 6.3.3 and procedures calculating orography are set out in B.3.

NOTE 3 The peak velocity pressure is determined from 6.5.

(3) The **fluctuating component** of the wind should be represented by the turbulence intensity defined in 6.4.

NOTE 1 Annex B provides guidance for slender structures taller than 200 m and up to 300 m.

NOTE 2 The National Annex can give guidance on the application of Annex B for structures lower than 200 m.

NOTE 3 The National Annex can provide National climatic information from which the mean wind velocity v_m and the peak velocity pressure q_p can be directly obtained for the terrain categories considered.

NOTE 4 Table 5.1 contains a design process to assist in the determination of the peak velocity pressure.

NOTE 5 The basis for calculation covers structures less than 1 km offshore from the main coastline.

Wind velocity and velocity pressure (cont'd)

The **basic wind velocity** should be calculated form Formula (6.1)

$$\boldsymbol{v}_{\mathbf{b}} = c_{\text{prob}} \cdot c_{\text{dir}} \cdot c_{\text{season}} \cdot c_{alt} \cdot \boldsymbol{v}_{\mathbf{b,0}} \qquad (6.1)$$

where

$v_{\mathbf{b,0}}$ **is the fundamental value of the basic wind velocity**;
c_{alt} is the altitude factor;
c_{dir} is the directional factor;
c_{season} is the seasonal factor,;
c_{prob} is the probability factor

The values of the various coefficients are taken 1,0, unless the National Annex gives a different value

Wind velocity and velocity pressure (cont'd)

It is reminded that **the fundamental value of the basic wind velocity $v_{b,0}$**, is defined as the characteristic 10-minute mean wind velocity with an annual probability of being exceeded of 0,02, irrespective of wind direction and time of year, at a height of 10 m above ground level in flat open country terrain with large windward fetch of low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

The probability factor, c_{prob} should be calculated from Formula (6.2):

$$c_{\text{prob}} = \left(\frac{1 - K \cdot \ln(-\ln(1-p))}{1 - K \cdot \ln(-\ln(0{,}98))}\right)^n = \left(\frac{1 + K \cdot \ln(T)}{1 + K \cdot \ln(50)}\right)^n \qquad (6.2)$$

where

- K is the shape parameter depending on the coefficient of variation of the extreme-value distribution;
- n is the exponent;
- p is the annual probability of exceedance;
- T is the return period in years where $T \geq 1$.

Basic wind velocity and pressure

The basic velocity pressure q_b shall be calculated from Formula (6.3):

$$q_b = \frac{1}{2} \cdot \rho \cdot v_b^2 \qquad (6.3)$$

where

ρ is the air density.

NOTE The value for ρ is 1,25 kg/m^3 unless the National Annex gives different values

Mean wind velocity and pressure

The mean wind velocity $v_{\mathrm{m}}(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, v_{b}, and should be determined using Formula (6.4):

$$v_{\mathrm{m}}(z) = c_{\mathrm{r}}(z) \cdot c_{\mathrm{o}}(z) \cdot v_{\mathrm{b}} \tag{6.4}$$

where

$c_{\mathrm{r}}(z)$ is the roughness factor, given in 6.3.2;

$c_{\mathrm{o}}(z)$ is the orography factor, taken as 1,0 unless otherwise specified in 6.3.3.

NOTE 1 If the orography is accounted for in the basic wind velocity, the value of c_{o} is 1,0, unless a different value is given in the National Annex.

NOTE 2 Design charts or tables for $v_{\mathrm{m}}(z)$ can be given in the National Annex.

The mean velocity pressure $q_{\mathrm{m}}(z)$ at height z, should be determined using Formula (6.5):

$$q_{\mathrm{m}}(z) = \frac{1}{2} \cdot \rho \cdot v_{\mathrm{m}}^2(z) = c_{\mathrm{r}}^2(z) \cdot c_{\mathrm{o}}^2(z) \cdot q_{\mathrm{b}} \tag{6.5}$$

where

ρ is the air density.

Terrain roughness

The procedure for the determination of the roughness factor at height z, $c_r(z)$, should be taken as defined in Formula (6.6) and is based on a logarithmic velocity profile.

$$c_r(z) = k_r \cdot \ln\left(\frac{z}{z_0}\right) \quad \text{for} \quad z_{min} \leq z \leq z_{max} \tag{6.6}$$

$$c_r(z) = c_r(z_{min}) \quad \text{for} \quad z \leq z_{min}$$

where

z_0 is the roughness length;

k_r terrain factor depending on the roughness length z_0 calculated using Formula (6.7)

$$k_r = 0{,}19 \cdot \left(\frac{z_0}{z_{0,II}}\right)^{0{,}07} \tag{6.7}$$

where

$z_{0,II}$ = 0,05 m (terrain category II, Table 6.1);

z_{min} is the minimum height defined in Table 6.1;

z_{max} is to be taken as 200 m.

z_0, z_{min} depend on the terrain category. Values are given in Table 6.1 depending on five representative terrain categories.

Terrain roughness (cont'd)

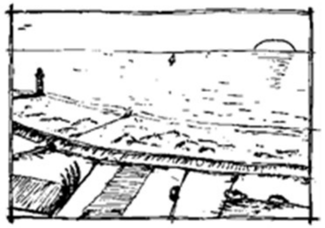
Table 6.1 — Terrain categories and terrain parameters

Terrain category		z_0 [m]	z_{min} [m]
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE The terrain categories are illustrated in Figure B.1.			

Terrain categories (Annex B)

Terrain category 0

Sea, coastal area exposed to the open sea



Terrain category I

Lakes or area with negligible vegetation and without obstacles

Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights

Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)

Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m

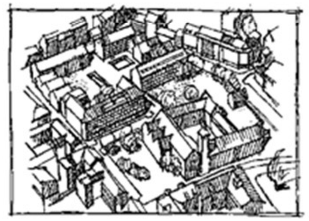


Figure B.1 — Terrain categories.

Wind turbulence

(1) The turbulence intensity $I_u(z)$ at height z should be taken equal to the standard deviation of the turbulence divided by the mean wind velocity.

(2) The turbulent component of wind velocity has a mean value of 0 and a standard deviation σ_u. The standard deviation of the turbulence σ_u may be determined using Formula (6.9).

$$\sigma_u = k_\mathrm{r} \cdot v_\mathrm{b} \cdot k_\mathrm{I} \qquad (6.9)$$

NOTE 1 For the terrain factor k_r see Formula (6.7), for the basic wind velocity v_b see Formula (6.1), k1 is the turbulence factor.

NOTE 2 The value for turbulence factor k_I is 1.0 unless the National Annex gives a different value.

(3) $I_u(z)$ may be calculated from Formula (6.10).

$$I_u(z) = \frac{\sigma_u}{v_\mathrm{m}(z)} = \frac{k_\mathrm{I}}{c_\mathrm{o}(z) \cdot \ln\left(\frac{z}{z_0}\right)} \quad \text{for} \quad z_\mathrm{min} \leq z \leq z_\mathrm{max} \qquad (6.10)$$

$$I_u(z) = I_u(z_\mathrm{min}) \quad \text{for} \quad z < z_\mathrm{min}$$

where

k_I is the turbulence factor.

NOTE The value of k_I is 1.0 unless the National Annex gives a different value.

Peak wind velocity and pressure

(1) The peak velocity pressure $q_{\mathrm{p}}(z)$ at height z, which includes mean and short-term velocity fluctuations, should be determined by using the Formula (6.11).

$$q_{\mathrm{p}}(z) = \frac{1}{2} \cdot \rho \cdot v_{\mathrm{p}}^{2}(z) \qquad (6.11)$$

where

ρ is the air density;

$v_{\mathrm{p}}(z)$ is the peak wind velocity given in Formula (6.12);

NOTE 1 A different rule can be given in the National Annex.

$$v_{\mathrm{p}}(z) = v_{\mathrm{m}}(z) \cdot \left(1 + k_{u} \cdot I_{u}(z)\right) \qquad (6.12)$$

NOTE 2 The value of the peak factor for turbulence k_{u} is 2,8 unless the National Annex gives a different value. The peak factor for turbulence is consistent with the values of the aerodynamic coefficients specified in Annexes C to E.

Wind pressure on surfaces

(1) The wind pressure acting on the external surfaces, w_e, should be obtained from Formula (7.2).

$$w_e = q_p(z_e) \cdot c_{pe} \tag{7.2}$$

where

$q_p(z_e)$ is the peak velocity pressure defined in 6.5;

z_e is the reference height for the external pressure given in Annex C;

c_{pe} is the pressure coefficient for the external pressure, given in Annex C.

(2) The wind pressure acting on the internal surfaces of a structure, w_i, should be obtained from Formula (7.3)

$$w_i = q_p(z_i) \cdot c_{pi} \tag{7.3}$$

where

$q_p(z_i)$ is the peak velocity pressure defined in 6.5;

z_i is the reference height for the internal pressure given in Annex C;

c_{pi} is the pressure coefficient for the internal pressure given in Annex C.

Wind forces (based on force coefficients)

The wind force $F_{w,p}$ acting on a structure or a structural member as a whole or per unit length may be determined directly by using Formula (7.4)

$$F_{w,p} = c_{sd} \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \tag{7.4}$$

or by vector summation over the individual structural member by using Formula (7.5)

$$F_{w,p} = c_{sd} \cdot \sum_{\text{elements}} c_f \cdot q_p(z_e) \cdot A_{ref} \tag{7.5}$$

where

c_{sd} is the structural factor as defined in Clause 8;

c_f is the force coefficient for the structure or structural member, given in Annex E;

$q_p(z_e)$ is the peak velocity pressure defined in 6.5 at reference height z_e of the structure or the member defined in Annex E;

A_{ref} is the reference area of the structure or structural member as a whole or per unit length, given in Annex E.

NOTE Annex E gives c_f values for structures or structural members such as prisms, cylinders, roofs, signboards, plates and lattice structures etc.

Wind forces (based on surface pressures)

The wind force, $F_{w,p}$ acting on a structure or a structural member may be determined by vector summation of the forces $F_{w,p,e}$, $F_{w,p,i}$ and $F_{p,fr}$ calculated from the external and internal pressures using Formulae (7.6) and (7.7) and the frictional forces resulting from the friction of the wind parallel to the external surfaces, calculated using Formula (7.8).

external forces:

$$F_{w,p,e} = c_{sd} \cdot \sum_{\text{surfaces}} w_e \cdot A_{ref} \qquad (7.6)$$

internal forces:

$$F_{w,p,i} = \sum_{\text{surfaces}} w_i \cdot A_{ref} \qquad (7.7)$$

where

c_{sd} is the structural factor as defined in Clause 8;

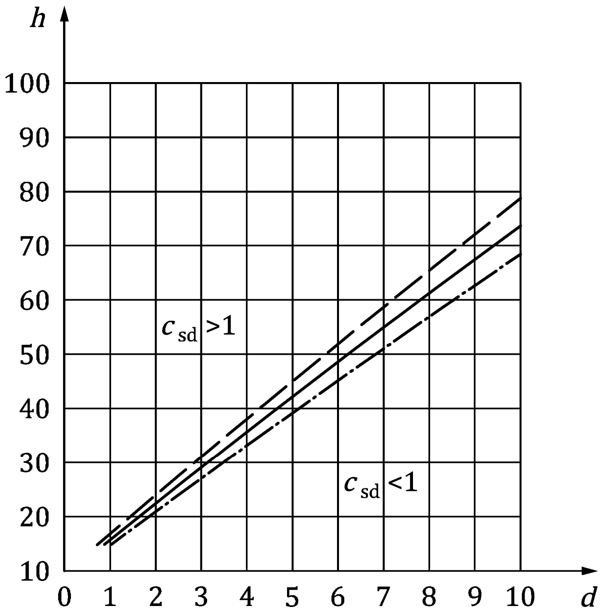
w_e is the external pressure on the individual surface at height z_e, given in Formula (7.2);

w_i is the internal pressure on the individual surface at height z_i, given in Formula (7.3);

A_{ref} is the reference area of the individual surface;

Structural factor c_{sd}

Figure 8.1 — $\boldsymbol{c_{sd}} = 1{,}0$ for multi-storey steel and concrete buildings as function of across-wind width



Key

——— Steel chimneys without liners

— — Concrete chimneys without liners

—·— Steel chimneys with liners

Dimensions of h and d are given in m

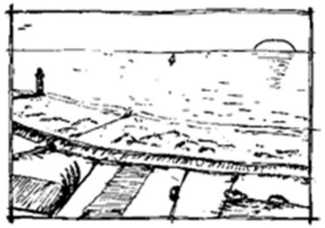
NOTE 1 Figure 8.2 based on:

Roughness length	$z_0 = 0{,}05$ m
Basic wind velocity	$v_b = 28$ m/s
Logarithmic decrement of aerodynamic damping	$\delta_a = 0$

Annex B – Effects of terrain roughness

Terrain category 0

Sea, coastal area exposed to the open sea



Terrain category I

Lakes or area with negligible vegetation and without obstacles

Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights

Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)

Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m

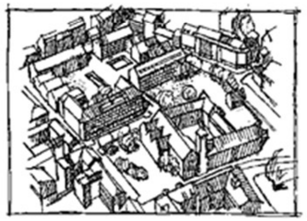
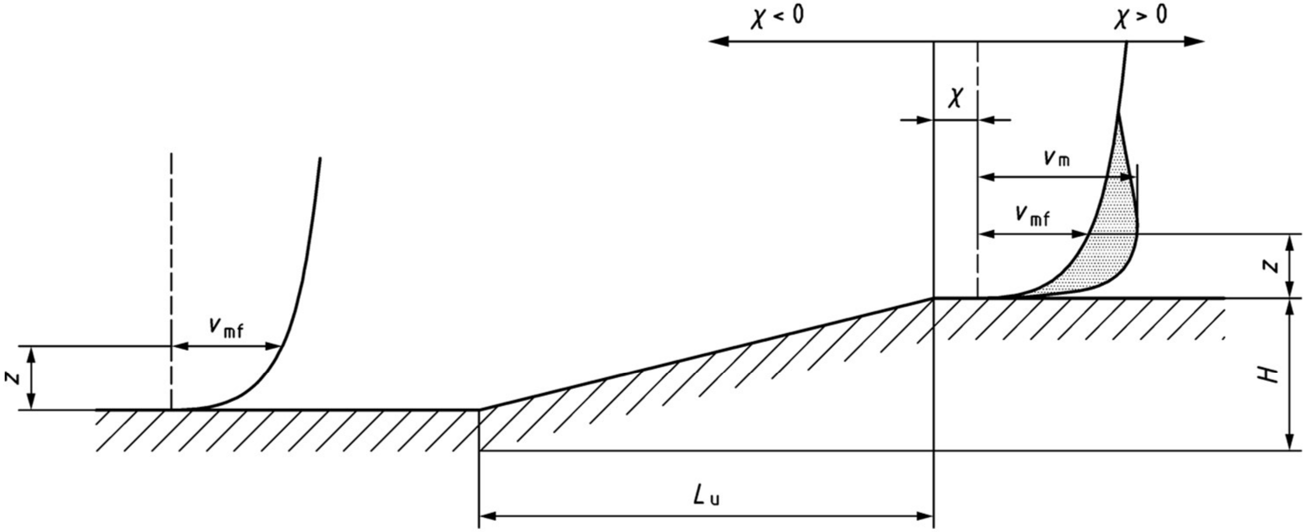


Figure B.1 — Terrain categories.

Annex B – Effects of orography

In the vicinity of isolated hills and ridges or cliffs and escarpments, mean wind velocities will increase, dependent on the upstream slope $\Phi = H/L_u$ in the wind direction, where the height H and the length L_u should be taken as defined in Figure B.2.



Key

v_m Mean wind velocity at height z above terrain

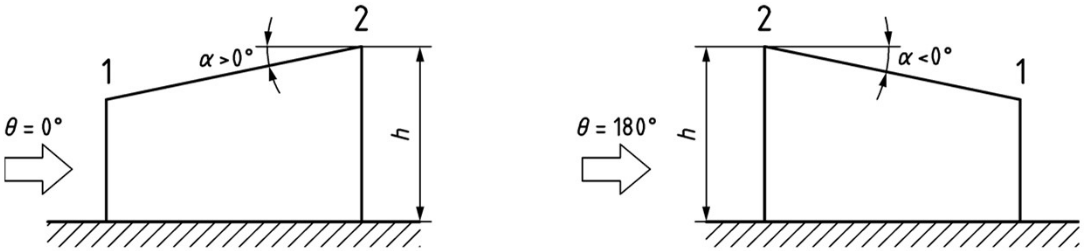
v_{mf} Mean wind velocity above flat terrain

c_o $= v_m/v_{mf}$

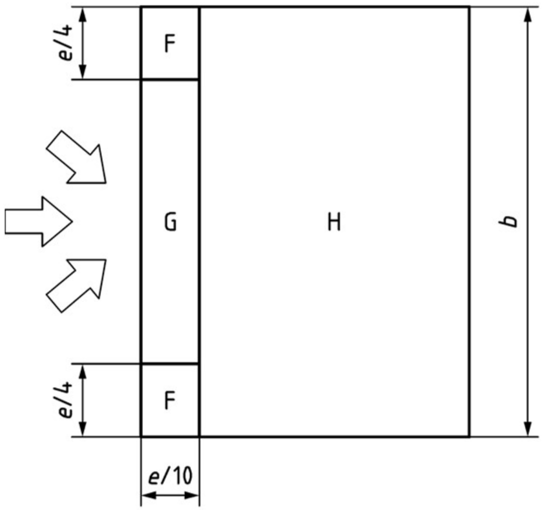
Figure B.2 — Illustration of increase of wind velocities over orography

Annex C – Pressure coefficients for pressures on surface

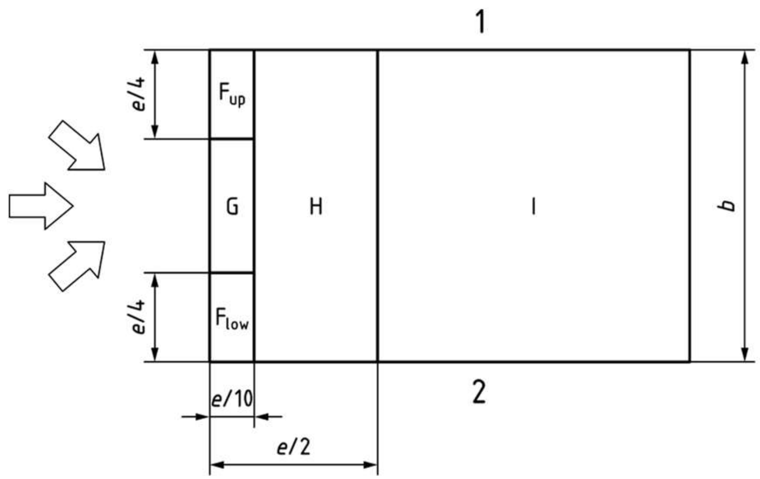
The detailed and local pressure coefficients $c_{\mathrm{pe},10}$ and $c_{\mathrm{pe},1}$ for zones $\mathrm{F_{up}}$, $\mathrm{F_{low}}$, G, H and I should be taken from Table C.7 and Table C.8, including protruding parts.



a) General eave to eave



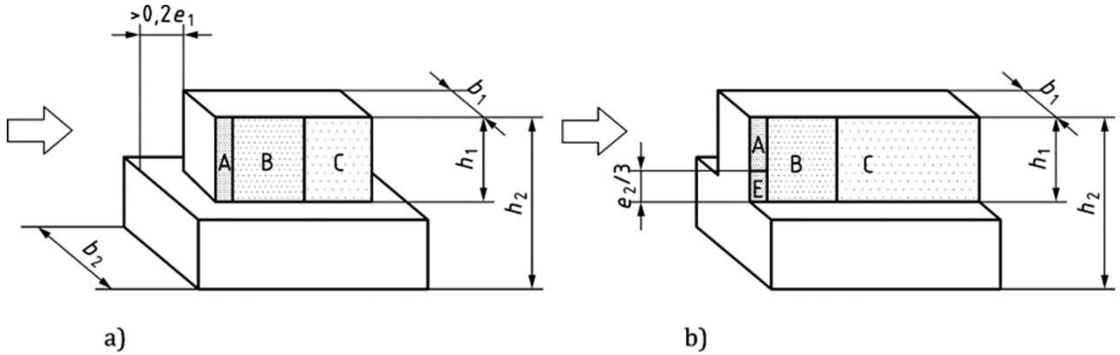
b) Plan view – wind directions $\boldsymbol{\theta} = \mathbf{0}°$ and $\boldsymbol{\theta} = \mathbf{180}°$

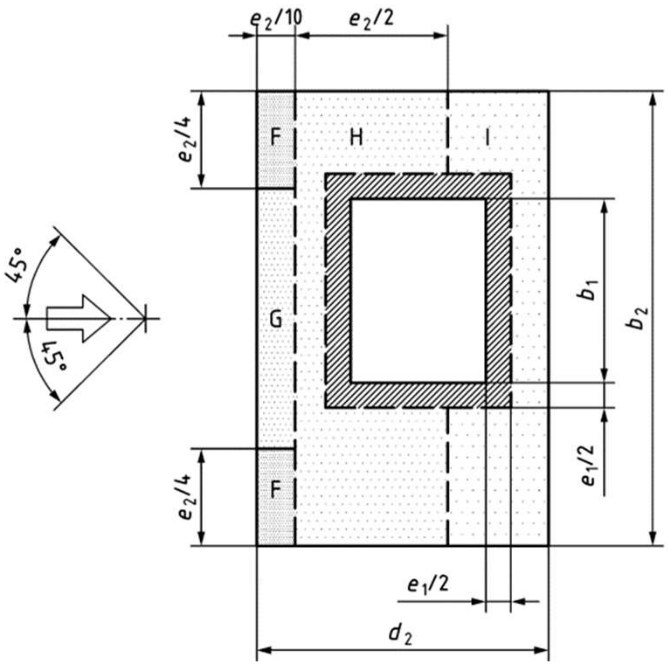


c) Plan view – wind direction $\boldsymbol{\theta} = \mathbf{90}°$

Example of zoning for the detailed and local pressure coefficients on a monopitch roof

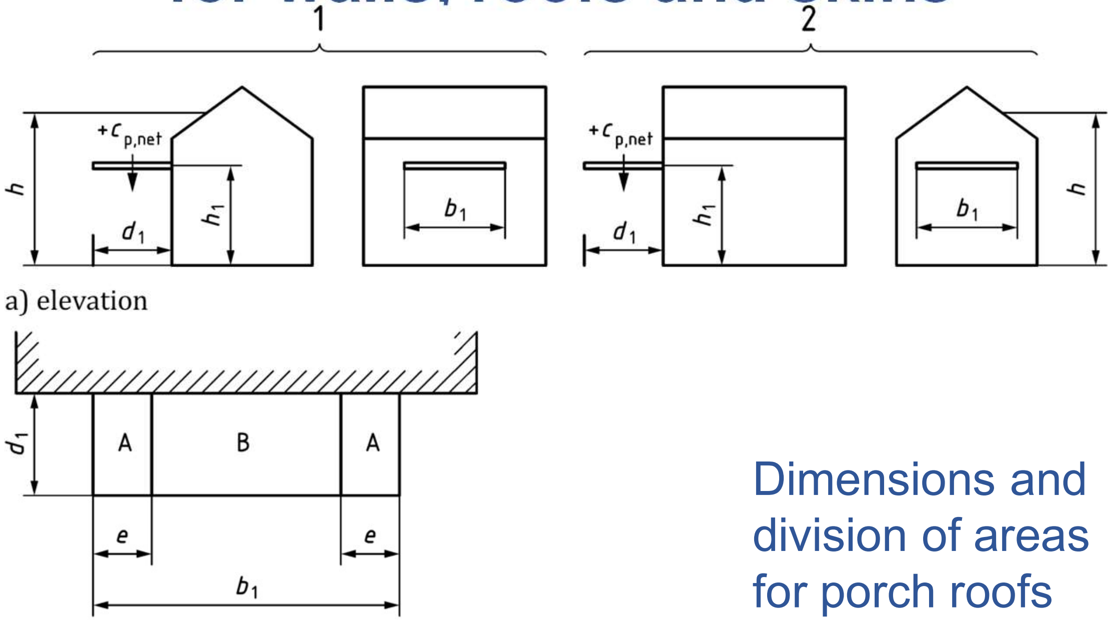
Annex C – Pressure coefficients for pressures on surface (cont’d)





Pressure distribution on the roof of a building with non-uniform height

Annex D – Net pressure and force coefficients for walls, roofs and skins



a) elevation

b) plan

Key

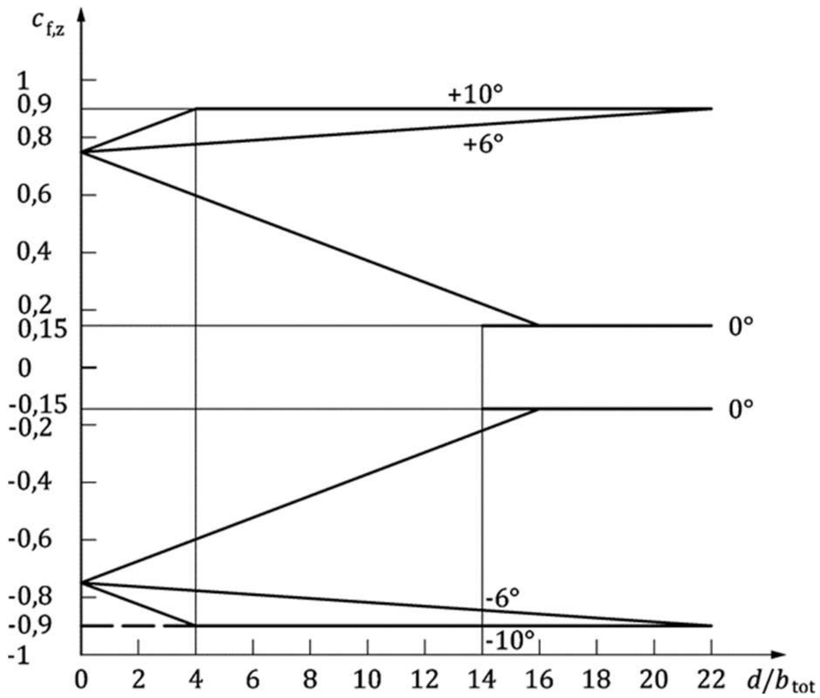
1 Porch roof on a gable wall

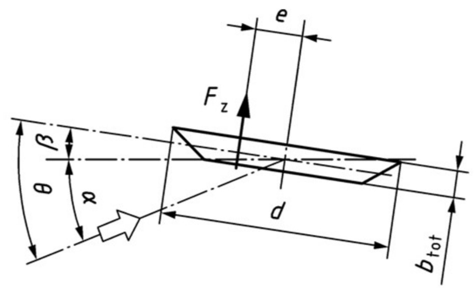
2 Porch roof on a side wall

e $= d_1/4$ or $b_1/2$, whichever is smaller

Dimensions and division of areas for porch roofs

Annex E – Force coefficients for structures and structural members





$A_{ref,z} = d \cdot L$

Key

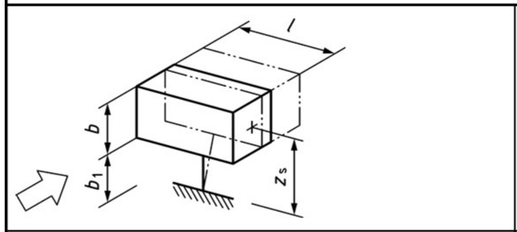
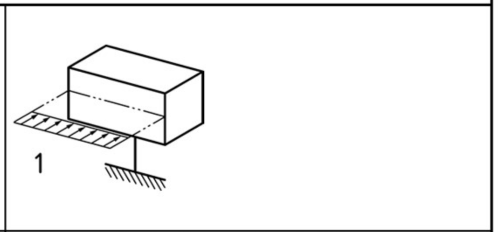
α Angle of the wind with the horizontal

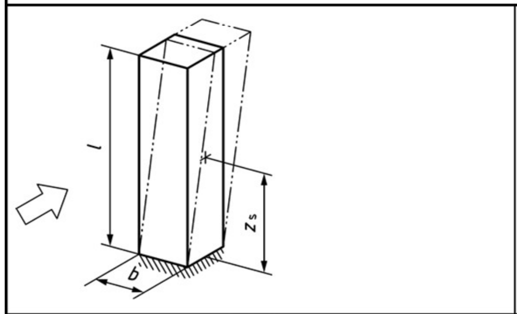
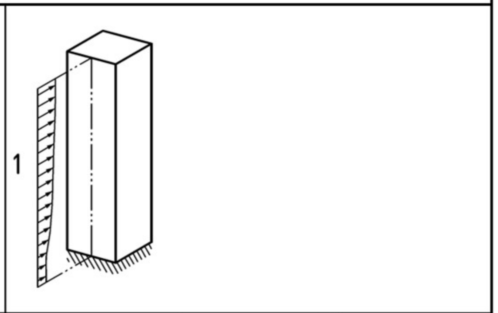
β Superelevation

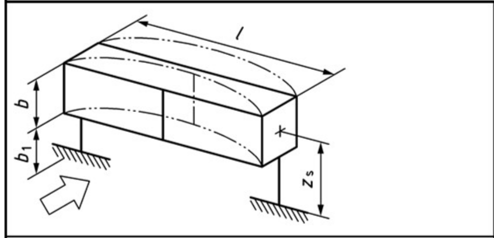
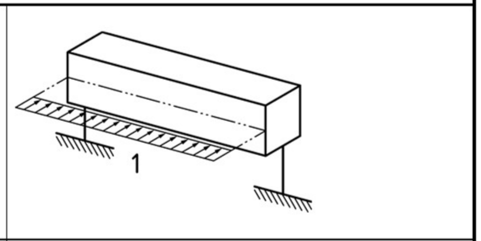
θ $= \alpha + \beta$

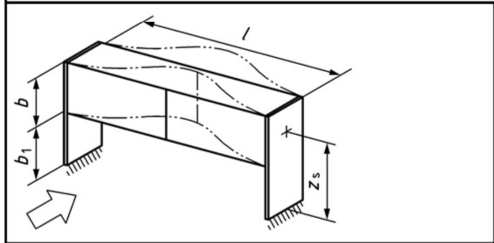
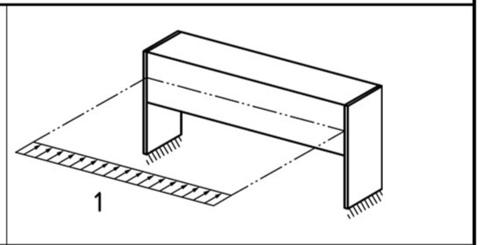
Force coefficient $c_{f,z}$ for bridges with transversal slope and wind inclination

Annex F – Procedure for along-wind aerodynamic response

a. Parallel oscillator or point-like structures such as signboards.	
	
$z_s = b_1 + b/2 \geq z_{min}$	Equivalent static wind force

b. Vertical structures such as buildings.	
	
$z_s = 0{,}6 \cdot l \geq z_{min}$	Equivalent static wind force

c. Horizontal structures such as bridges simply supported.	
	
$z_s = b_1 + b/2 \geq z_{min}$	Equivalent static wind force

d. Horizontal structures such as bridges clamped at the supports.	
	
$z_s = b_1 + b/2 \geq z_{min}$	Equivalent static wind force

Structures with constant sign mode shapes covered by the procedure

Annex G – Procedure for across-wind and torsional actions on susceptible buildings

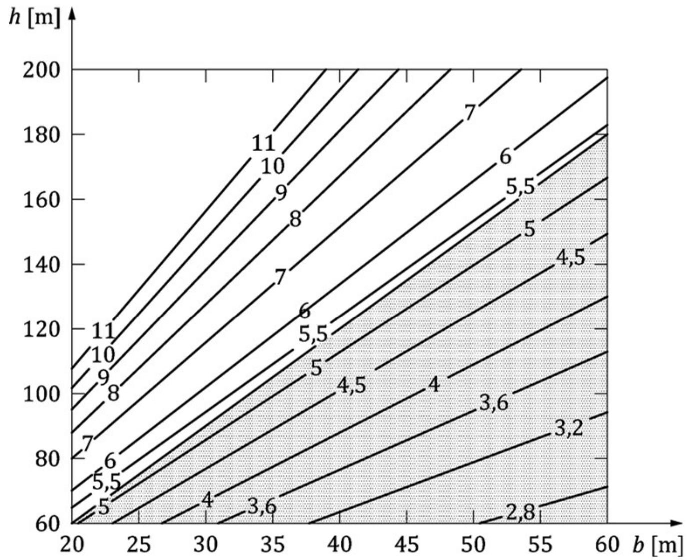


Figure G.8 — Values for the across-wind dynamic factor c_{dL} for square plan steel buildings

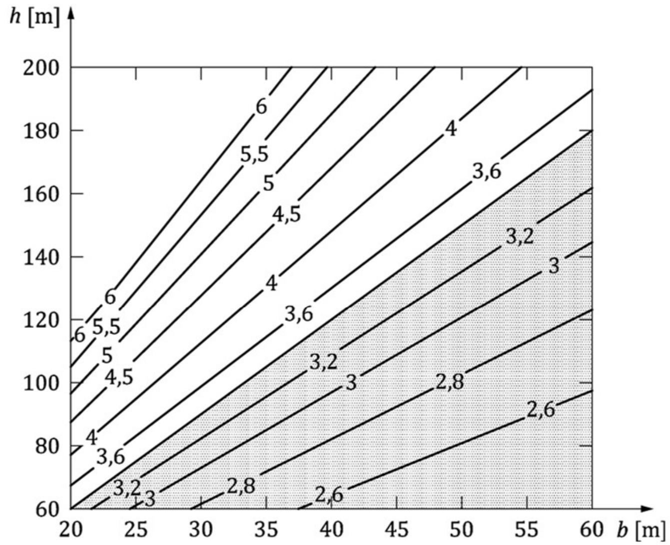


Figure G.9 — Values for the across-wind dynamic factor c_{dL} for square plan reinforced concrete or composite buildings

c_{dL} is the across-wind dynamic factor, given by Formula (G.6):

$$c_{dL} = k_L \cdot \sqrt{1 + R_L^2} \tag{G.6}$$

where

k_L is the across-wind peak factor;

R_L is the across-wind resonant response factor;

Annex H – Procedure for across-wind dynamic and aeroelastic response of slender structures

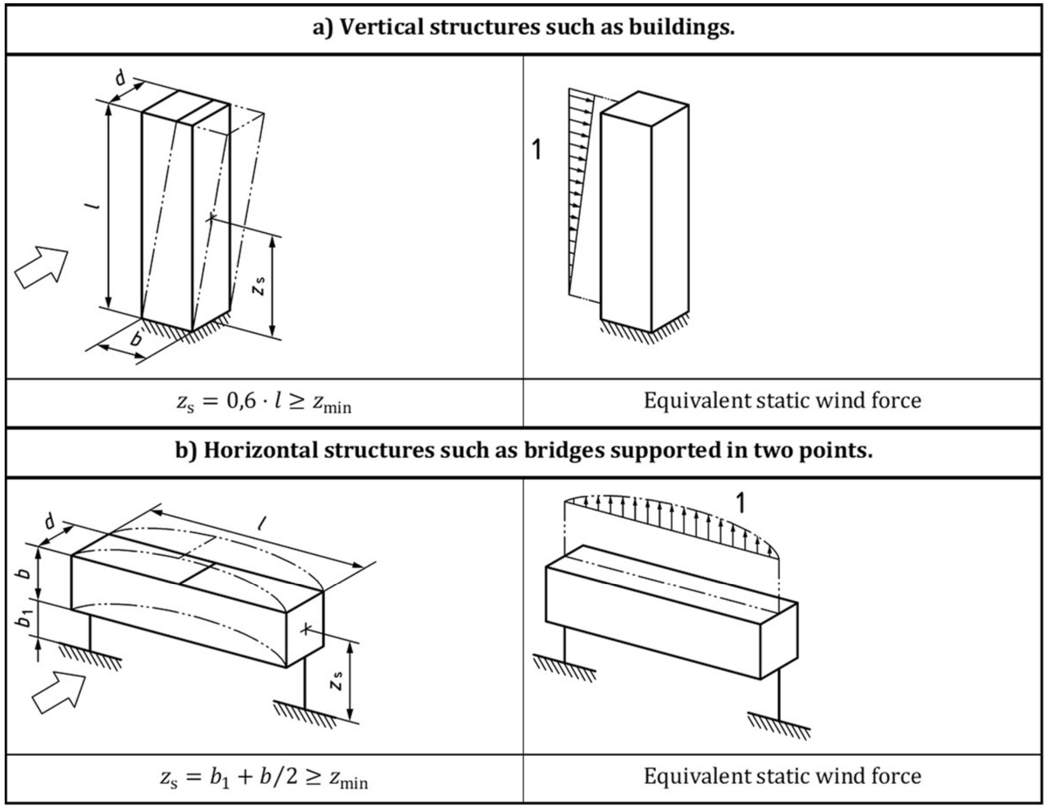


Figure H.1 — The structural dimensions and reference heights for structures where $\boldsymbol{l} > \boldsymbol{b}$ used in the procedure for across-wind dynamic response for cases a) and b)

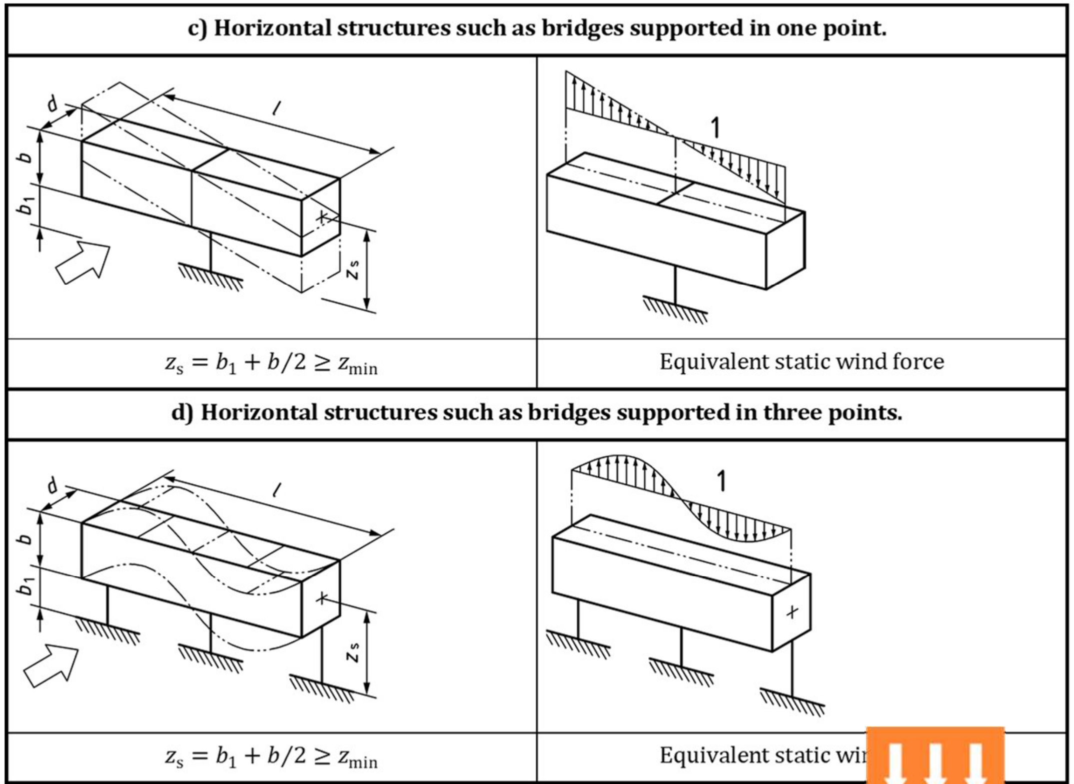
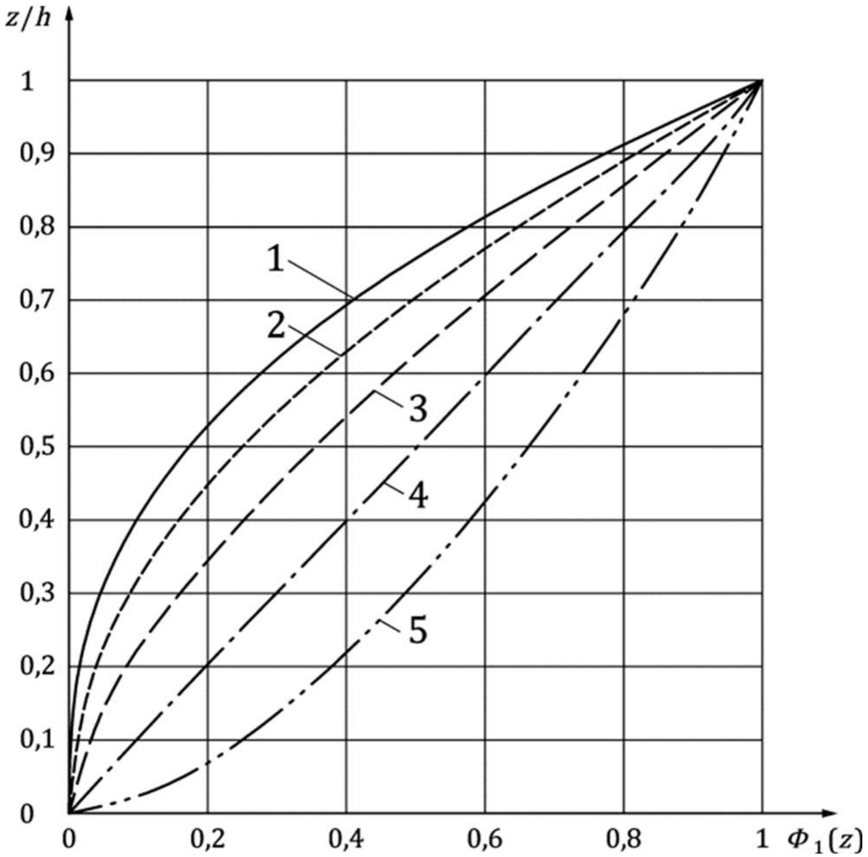


Figure H.2 — The structural dimensions and reference heights for structures wher in the procedure for across-wind dynamic response for cases c) and d)

Annex I – Dynamic characteristics of structures with linear elastic behaviour

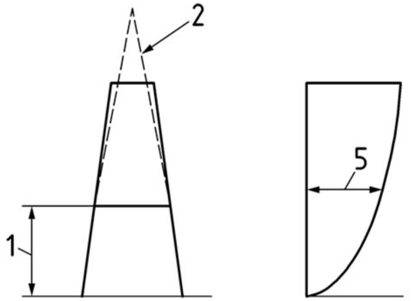


Key

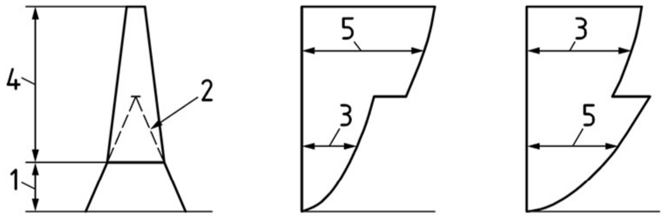
1	= 2,5
2	= 2
3	= 1,5
4	= 1
5	= 0,6
$\phi_1(z)$	Normalised Modal Displacement

Figure I.6 — Fundamental flexural mode shape for buildings, towers and chimneys cantilevered from the ground

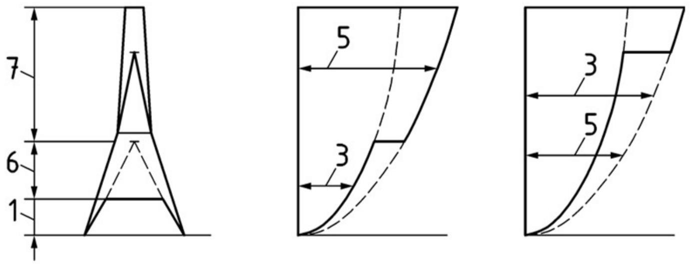
Annex J – Response of steel lattice towers and guyed mast



a) Case 1 All shears determined from mean loading and gust response factor



b) Case 2 Patch loading for panel "A"



c) Case 3 Patch loading for panel "A":
patch 1 ________
patch 2 _ _ _ _ _

Patch loading for panel "B":
patch 1 ________
patch 2 _ _ _ _ _

Key

1 Panel "A"

2 Projection of legs from panel "A"

3 mean

4 Panel "A" as case 1, treat panels above

5 "gust"

6 Panel "B"

7 Panel "B" as case 1, treat panels above

Figure J.1 — Shear patch loading

Annex K – Guidance on derivation of design parameters from wind tunnel tests and numerical simulations

Table K.1 — Fields of applicability of WTT and CWE (A: advised, N: not advised)

Class of problem	WTT		CWE	
	Prelim. stage	Detailed Design	Prelim. stage	Detailed Design
Topographic effects	A	A	A	A
Local pressures	A	A	A	N
Overall forces	A	A	A	N
Gust buffeting response	A	A	A	N
Vortex shedding response	A	A	A	N
Galloping	A	A	A	N
Flutter	A	A	A	N

Key

A: advised

N: not advised

Annex L – Guidance on derivation of wind speeds from measurements at meteorological stations

Wind speed records :

Before undertaking an extreme value or parent population analysis, anemometer data should be audited to ensure it is of sufficient and consistent quality. Issues to address may include changes in:

- surroundings over the record period (e.g. construction, tree growth, etc.)
- anemometer type (e.g. from pressure tube to rotating cup)
- recording methodology (e.g. from manual to automatic)
- anemometer location
- self-consistency of the data (e.g. unexplainable variability).

Calibration of anemometers should also be verified

Annex M – Guidance on probabilistic description of wind actions

The basic velocity pressure q_{b} is its annual extreme value having a 2 % probability of being exceeded.

Its probability distribution function is a Type I extreme-value distribution should be taken from Formula (M.1):

$$F_{\mathrm{q}}(\mathrm{q}) = \exp\left(-\exp\left(-\left(\mathrm{q} - \alpha_{\mathrm{q}}\right)/\beta_{\mathrm{q}}\right)\right) \quad \text{(M.1)}$$

its mean value should be taken from Formula (M.2):

$$\mu_{\mathrm{q}} = \alpha_{\mathrm{q}} + 0{,}5772 \cdot \beta_{\mathrm{q}} \quad \text{(M.2)}$$

and its standard deviation should be taken from Formula (M.3):

$$\sigma_{\mathrm{q}} = \left(\pi/\sqrt{6}\right) \cdot \beta_{\mathrm{q}} \quad \text{(M.3)}$$

where α_{q} and β_{q} are the mode and the scale parameters of the distribution.

Overview of the evolution of EN 1991-1-5:
Eurocode 1 – Actions on structures
Part 1-5: Thermal actions

Contents of the revised EN 1991-1-5

Scope of EN 1991-1-5

(1) EN 1991-1-5 gives principles and rules for calculating **thermal actions on buildings, bridges and other structures including their structural members**. Principles needed for cladding and other attachments of buildings are also provided.

(2) This Part describes the changes in the temperature of structural members. Characteristic values of thermal actions are presented for use in the design of structures which are exposed to daily and seasonal climatic changes.

(3) This Part also gives principles for changes in the temperature of structural members due to the paving of hot asphalt on bridge decks.

(4) This Part also provides principles and rules for **thermal actions acting in structures which are mainly a function of their use (e.g. cooling towers, silos, tanks, warm and cold storage facilities, hot and cold services etc)**.

NOTE Supplementary guidance for thermal actions on chimneys is provided in EN 13084-1.

Key changes to EN 1991-1-5

- Some definitions and rules of application clarified and improved
- Guidance provided on how to determine the temperature components and temperature differences of different structural members within a structure
- For buildings a new presentation of temperatures - merging of tables for inner and outer temperatures
- New approach for the consideration of uncertainties related to the initial bridge temperature T_0 of a structural member at the relevant stage of its restraint (completion) and its range ΔT_0 especially important for the design of bearings and joints
- For the evaluation of the vertical components of temperature differences with non-linear effects on bridge decks an improved presentation in the form of figures and tables has been provided, together with a couple of corrections of values

Design situations for thermal actions

4 Design situations

(1) Thermal actions shall be determined for the relevant design situation identified in accordance with prEN 1990:2021.

(2) The effects of thermal actions shall be allowed for in the design of load bearing members of structures, either by providing movement joints or by including the effects in design verifications.

5 Classification of actions

(1) Thermal actions shall be classified as variable and indirect actions, as defined within EN 1990:2023.

(2) All values of thermal actions given in this Part are characteristic values, see EN 1990:2023.

(3) For design situations where the annual probability of exceedance is other than 0,02 the values of thermal actions should be derived using the calculation method given in Annex A.

Representation of thermal actions

6 Representation of actions

(1) The temperature distribution within an individual structural member should be resolved into the following four basic components, as illustrated in Figure 6.1:

a) A uniform temperature component, ΔT_N

b) A linearly varying temperature difference component about the *z-z* axis, ΔT_{MZ} ;

c) A linearly varying temperature difference component about the *y-y* axis, ΔT_{MY} ;

d) A non-linear temperature difference component, ΔT_E. This results in a system of self-equilibrated stresses which produce no net load effect on the member

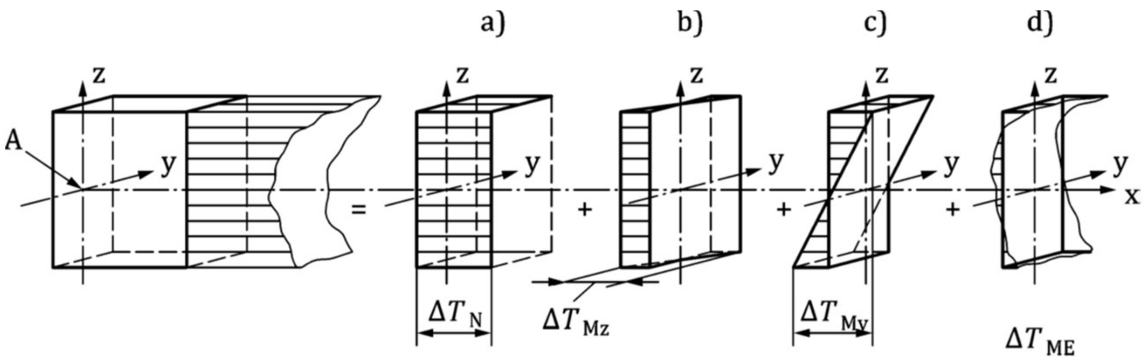


Figure 6.1 — Diagrammatic representation of components of a temperature profile

Thermal actions on buildings

Table 7.1 (NDP) — Indicative temperatures for structural members in buildings

Area		$T_{N,max}$ (C°) (Summer)		$T_{N,min}$ (C°) (Winter)
Temperatures T_{in} of inner environment		$T_1 = 20$		$T_2 = 25$
Temperatures T_{out} for buildings above the ground level[1)]	North-East facing members	Bright light surfaces	$T_{max} + 0$	T_{min}
		Light coloured surfaces	$T_{max} + 2$	
		Dark surfaces	$T_{max} + 4$	
	South-West facing members	Bright light surfaces	$T_{max} + 18$	
		Light coloured surfaces	$T_{max} + 30$	
		Dark surfaces	$T_{max} + 42$	
Temperatures T_{out} for underground parts of buildings		6		– 4

[1)] For intermediate member orientation, the value may be determined by interpolating the angular direction.

Uniform bridge temperature component

(1) The minimum shade air temperature (T_{min}) and the maximum shade air temperature (T_{max}) for the site shall be derived in accordance with 8.1.3.2.

NOTE The uniform temperature component depends on the minimum and maximum temperature which a bridge could achieve. This results in a range of uniform temperature changes which, in an unrestrained structure would result in a change in member length.

(2) The minimum and maximum uniform bridge temperatures $T_{N.min}$ and $T_{N.max}$ should be determined for the relevant bridge deck type.

NOTE The minimum and maximum uniform bridge temperatures $T_{N.min}$ and $T_{N.max}$ are given in Table 8.1 (NDP) unless the National Annex gives different values. Table 8.1 (NDP) is based on typical daily shade air temperature ranges of 10 °C.

(3) For steel truss and plate girders, the maximum values given for Type 1 may be reduced by 3 °C.

Bridge deck type	$T_{N,max}$	$T_{N,min}$
1	$T_{max} + 16$	$T_{min} - 3$
2	$T_{max} + 4$	$T_{min} + 4$
3	$T_{max} + 2$	$T_{min} + 8$

Uniform bridge temperature component (cont'd)

8.1.3.3 Uniform bridge temperature component

(1) The values of the minimum $(\Delta T_{N,min})$ and maximum $(\Delta T_{N,max})$ uniform bridge temperature components for determination of movements and restraining forces shall be derived from the minimum (T_{min}) and maximum (T_{max}) shade air temperatures, see 8.1.3.1(3).

(2) The **initial bridge temperature T_0** should be taken as the temperature of a structural member at the relevant stage of its restraint (completion).

NOTE In the absence of site specific data, the value of initial bridge temperature T_0 can be given by the mean value of minimum/maximum shade air temperature (T_{min} and T_{max}) unless the National Annex gives a different value.

(3) The effects of both contraction over the range from $T_{0,sup}$ down to $T_{N,min}$ and expansion over the range from $T_{0,inf}$ up to $T_{N,max}$ should be considered. Upper and lower bound values of the initial bridge temperature ($T_{0,sup}$ and $T_{0,inf}$) should be used given as:

$$T_{0,sup} = T_0 + \Delta T_0 \tag{8.3}$$

$$T_{0,inf} = T_0 - \Delta T_0 \tag{8.4}$$

ΔT_0 is a range of initial bridge temperature.

NOTE The value of ΔT_0 can be set by the National Annex.

Uniform bridge temperature component (cont'd)

(5) The characteristic value of the maximum contraction range of the uniform bridge temperature component, $\Delta T_{N,con}$ (see Figure 8.1) should be taken as:

$$\Delta T_{N,con} = T_{0,sup} - T_{N.min} \quad (8.5)$$

and the characteristic value of the maximum expansion range of the uniform bridge temperature component, $\Delta T_{N,exp}$ (see Figure 8.1) should be taken as:

$$\Delta T_{N,exp} = T_{N,max} - T_{0,inf} \quad (8.6)$$

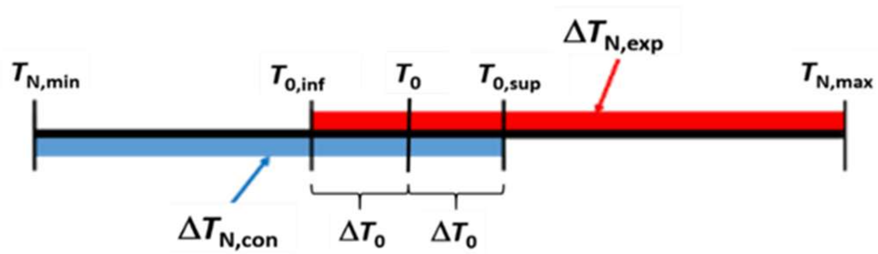


Figure 8.1 — Characteristic value of the maximum contraction ($\Delta T_{N,con}$) and expansion ($\Delta T_{N,exp}$) range of the uniform bridge temperature component

NOTE The maximum expansion range, and the maximum contraction range of the uniform bridge temperature component can be set by the National Annex.

Vertical linear temperature component (Approach 1)

(1) The effect of vertical temperature differences should be considered by using an equivalent linear temperature difference component with $\Delta T_{M,heat}$ and $\Delta T_{M,cool}$. The values $\Delta T_{M,heat}$ and $\Delta T_{M,coo}$l should be applied between the top and the bottom of the bridge deck.

(2) The vertical linear component should be defined taking into account different types of bridge decks and the surfacing thickness.

NOTE 1 For 50 mm surfacing thickness, the values of $\Delta T_{M,heat}$ and $\Delta T_{M,cool}$ are given in Table 8.2 (NDP) unless the National Annex gives different values.

NOTE 2 For other thicknesses of surfacing, a factor ksur is applied. The values of factor k_{sur} are given in Table 8.3 (NDP) unless the National Annex gives different values

Table 8.2 (NDP) — Values of linear temperature difference component for different types of bridge decks for road, pedestrian 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	10	5
- concrete beam	15	8
- concrete slab	15	8

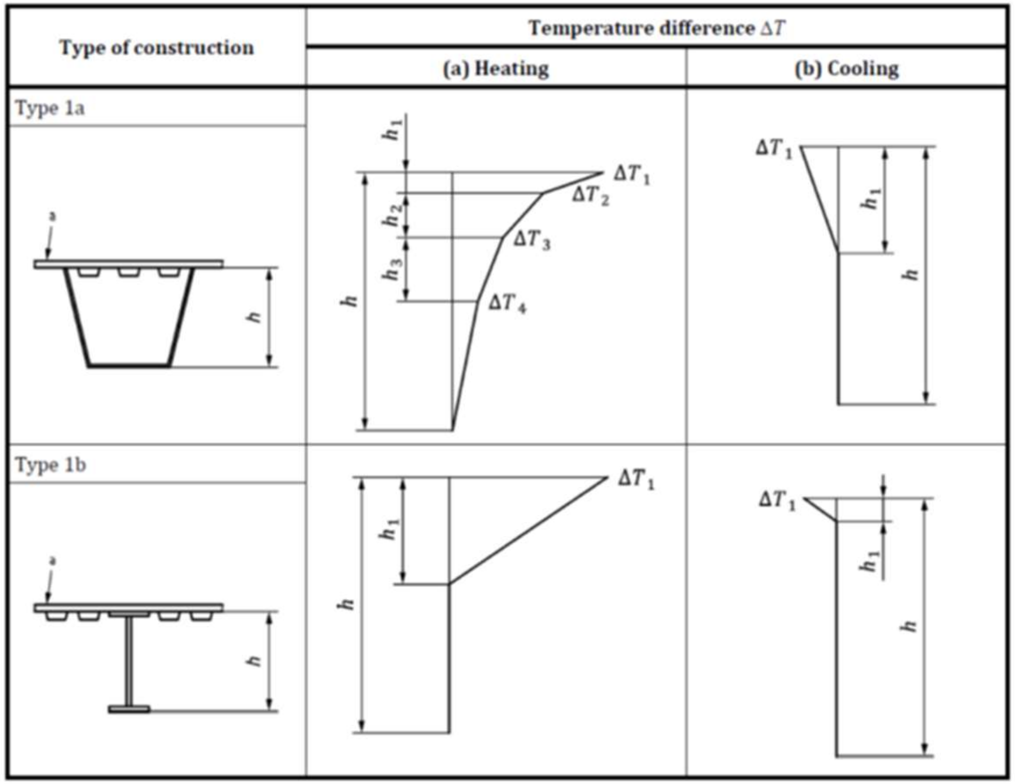
NOTE The values given in the table could be considered as an upper bound values of the linearly varying temperature difference component for representative sample of bridge geometries.

Vertical linear temperature component (Approach 1)

Road, pedestrian and railway bridges						
Surfacing 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}
0	0,7	0,9	0,9	1,0	0,8	1,1
waterproofed[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	0,6	1,4	0,8	1,2	0,6	1,0
[1)] These values could be considered as upper bound values for dark colour.						

Table 8.3 (NDP) — Values of k_{sur} to account for different surfacing thickness

Vertical temperature components with non-linear effects (Approach 2)

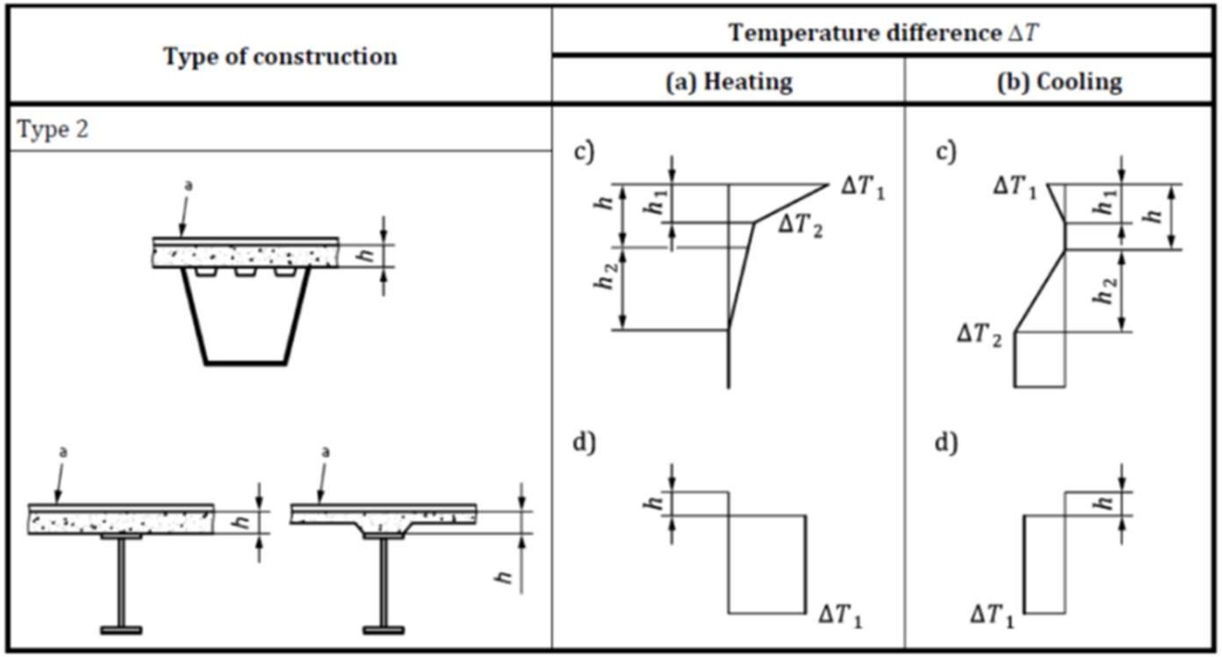


Key

Type 1a	Steel deck on steel box girders
Type 1b	Steel deck on steel truss or plate girders
a	40 mm surfacing

Figure 8.2 — Temperature differences for bridge decks — Type 1: Steel decks

Vertical temperature components with non-linear effects (Approach 2)



Key

Type 2 Concrete deck on steel box, truss or plate girders

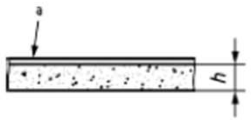
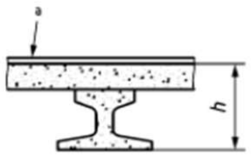
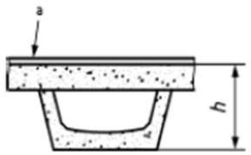
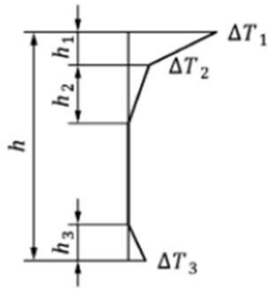
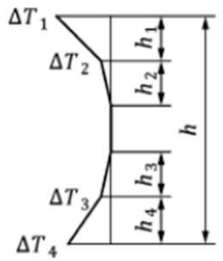
a 100 mm surfacing

c) normal procedure

d) simplified procedure

Figure 8.3 — Temperature difference for bridge decks — Type 2: Composite decks

Vertical temperature components with non-linear effects (Approach 2)

Type of construction	Temperature difference ΔT	
	(a) Heating	(b) Cooling
Type 3a  Type 3b  Type 3c 		

Key

Type 3a	Concrete slab
Type 3b	Concrete beam
Type 3c	Concrete box girder
a	100 mm surfacing

Figure 8.4 — Temperature difference for bridge decks — Type 3: Concrete decks

Thermal actions on bridges – Climate change considerations

Climate change effects may be considered by means of the **change factor** $\Delta \boldsymbol{T}_{cc}$ in terms of differences obtained from the analysis of future climate projections. Considering the current characteristic values of shade air temperatures $T_{\text{Max,k}}$ / $T_{\text{Min,k}}$ based on past observations, the updated values $T'_{\text{Max},k}$ / $T'_{\text{Max},k}$ covering climate change impacts can be obtained as follows

$$T'_{\text{Max},k} = T_{\text{Max},k} + \max\,(\,\Delta T_{\text{Max,cc}}) \quad (8.1)$$

$$T'_{\text{Min},k} = T_{\text{Min},k} + \min(\,\Delta T_{\text{Min,cc}}) \quad (8.2)$$

NOTE The framework for the re-evaluation of the characteristic values of shade air temperature, as well the change factors reflecting the climate change effects can be specified in the **National Annex.**

Thermal actions on industrial chimneys, silos, tanks and cooling towers

(1) Industrial chimneys, silos, tanks and cooling towers shall be designed for

— thermal actions from climatic effects due to the variation of shade air temperature and solar radiation;

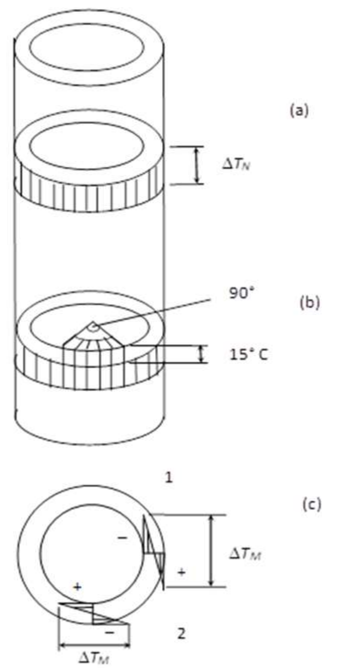
— temperature distribution for normal and abnormal process conditions;

— effects arising from **interaction** between the structure and its contents during thermal changes (e.g. shrinkage of the structure against stiff solid contents or expansion of solid contents during heating or cooling);

— the effect of temperature differences between adjacent members.

(2) Values of maximum and minimum flue gas, liquids and materials with different temperatures should be **agreed for a specific project by the relevant parties**.

NOTE Containment structures can be subjected to thermally induced changes in shape arising from heating/cooling effects of either the contents or their surrounding external environment



THANK YOU FOR YOUR ATTENTION !

Rion – Antirrion (Greece)
multispan cable-stayed bridge
in a high seismicity region
and deep sea water