Eurocode 1: Actions on structures

EN 1991, Part 1-4: Wind actions

Stanko Brčić

Faculty of Civil Engineering
University of Belgrade

Computational Engineering Course, 2006

Outline of presentation

General remarks about Eurodode 1-4

EC 1-4 applies to:

- Buildings and civil engineering works with heights < 200 m
- Bridges with spans < 200 m

EC 1-4 does not apply to:

- Torsional vibrations of buildings
- Bridge deck vibrations
- Cable supported bridges
- Vibrations where more then 1^{st} mode needs to be considered
- Local thermal effects on the wind, e.g. arctic thermal surface inversion, or tornadoes

Basic definitions in Eurocode 1-4

Definitions related to wind velocity

- Fundamental basic wind velocity
- Basic wind velocity
- Mean wind velocity

Other basic definitions

- Pressure coefficient
- Force coefficient
- Background response factor
- Resonance response factor

Basic definitions in Eurocode 1-4

Fundamental basic wind velocity

the 10 minute mean wind velocity with return period of 50 years, irrespective of wind direction, at height of 10 m above flat open country terrain and accounting to altitude effects (if needed)

Basic wind velocity

the fundamental basic wind velocity modified to account for the direction of the wind and the season (if required)

Mean wind velocity

the basic wind velocity modified to account for the terrain roughness and orography

Basic definitions in Eurocode 1-4

Pressure coefficient

- external and internal pressure coefficients
- overall coefficient (loaded area > 10 m^2)
- local coefficient (loaded area < 1 m^2)
  - design of small elements and fixings

Pressure coefficient

Net pressure coefficients give the resulting wind effect on a structure, structural element, or component per unit area

Basic definitions in Eurocode 1-4

Force coefficient

Force coefficients give the overall effect of the wind on a structure, structural element or component as a whole, including friction, if not explicitely excluded

Bacground response factor

The background factor allowing for the lack of full correlation of the pressure on the structure surface

Resonance response factor

The resonance response factor allowing for turbulence in resonance with the vibration mode (of a structure)

Nature of the wind

Stochastic nature of the wind

- Wind actions fluctuate with time
- Wind action act directly on external surfaces
- Wind action act indirectly on internal surfaces (due to porosity of external surfaces)
- Wind action may act directly on internal surfaces of opened structures
- Resulting forces act normal to the surface of structures or individual components
- Also, friction wind forces acting tangentially to the surface may be significant

Representations of wind actions

Equivalent wind forces

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

Classification of wind actions

Unless otherwise speciffied, wind actions are classified as variable fixed actions

Characteristic values

The wind actions are characteristic values calculated from the basic values of wind velocity or wind pressure (based on the mean return period of 50 years)

Structural models

Structural response

The effect of the wind upon the structure (i.e. response of the structure), depends on

- size
- shape
- dynamic properties of the structure

Along-wind response

EC1, Part 4, covers dynamic response due to along-wind turbulence in resonance with the along-wind vibrations of the fundamental flexural mode shape (with constant sign)

Structural models

Structural response

Structural response is calculated from the

- peak velocity pressure, q_P, at the reference height,
- force and pressure coefficients
- structural factor $c_s c_d$

Peak velocity pressure, q_P depends on:

- wind climate
- terrain roughness and orography
- reference height

Structural models

Peak velocity pressure, q_P is equal to:

the mean velocity preassure plus the contribution from short-term pressure fluctuations

Aeroelastic response

should be considered for flexible structures like:

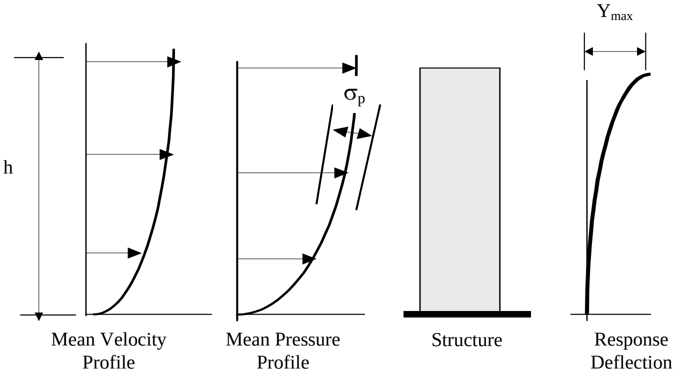
- cables
- chimneys
- masts
- bridges

(Simplified guidance on aeroelastic response given in Annex E)

Wind velocity and velocity pressure

Wind velocity and velocity pressure

Wind velocity and velocity pressure are composed of a mean and fluctuating component



Mean wind velocity v_m

Mean wind velocity v_m

determined from the basic wind velocity v_b which depends on

- wind climate
- terrain roughness and orography (i.e. variation with height)

Fluctuating wind velocity

represented by the turbulence intensity

Mean wind velocity v_m

Fundamental value of basic wind velocity $v_{b,0}$ is

characteristic 10 minute mean velocity, irrespective of wind direction and time of year, at 10 m above ground level of open country terrain with low vegetation (terrain category II)

Basic wind velocity v_b

calculated by:

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

Note: recommended values:

$$c_{dir} = 1.0 \qquad c_{season} = 1.0$$

Mean wind velocity $v_m(z)$

Mean wind velocity $v_m(z)$

Mean wind velocity $v_m(z)$ at height z above ground depends on

- terrain roughness
- orography (hills, cliffs, etc)
- basic wind velocity v_b

Mean wind velocity $v_m(z)$

calculated by:

$$v_m(z) = c_r(z) \cdot c_0(z) \cdot v_b$$

Note: recommended value:

$$c_0 = 1.0$$

Mean wind velocity $v_m(z)$

Terrain roughness $c_r(z)$

Terrain roughness coefficient accounts for wind profile due to

- height above ground
- ground roughness of terrain upwind

Terrain roughness $c_r(z)$

calculated by the logarithmic law:

$$
\begin{aligned}
c_r(z) &= k_r \cdot \ln\left(\frac{z}{z_0}\right) && z_{min} \leq z \leq z_{max} \\
c_r(z) &= c_r(z_{min}) && z \leq z_{min}
\end{aligned}
$$

Mean wind velocity $v_m(z)$

where

- z_0 is the roughness length
- k_r is terrain factor depending on z_0:

$$k_r = 0.19 \cdot (\frac{z_0}{z_{0,II}})^{0.07}$$

- where
  - $z_{0,II} = 0.05\ m$ (terrain category II, Table 4.1)
  - z_{min} is the minimum height defined in Table 4.1
  - $z_{max} = 200\ m$

Terrain roughness - Table 4-1

Table 4.1 — 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
The terrain categories are illustrated in Annex A.1.			

Wind turbulence

Turbulence intensity $I_v(z)$

defined as the ratio of standard deviation and mean wind velocity:

$$I_v(z) = \frac{\sigma_v}{v_m(z)}$$

Standard deviation of wind turbulence is given as

$$\sigma_v = k_r \cdot v_b \cdot k_I$$

where

- k_r is the terrain factor
- v_b is the basic wind velocity
- k_I is the turbulence factor (recommended as 1.0)

Wind turbulence

Turbulence intensity $I_v(z)$

may be obtained as:

$$I_v(z) = \frac{\sigma_V}{v_m(z)} = \frac{k_I}{c_o(z) \cdot \ln(\frac{z}{z_0})} \qquad z_{min} \leq z \leq z_{max}$$

$$I_v(z) = I_v(z_{min}) \qquad z \leq z_{min}$$

Peak velocity pressure $q_p(z)$

Peak velocity pressure $q_p(z)$

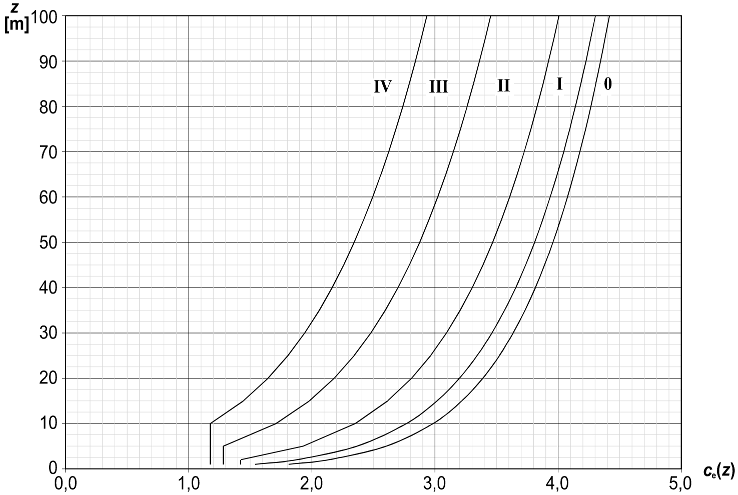
The peak velocity pressure $q_p(z)$ at height z, includes mean and short-term velocity fluctuations
Recommended expression:

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

where

- $c_e(z) = \frac{q_p(z)}{q_b}$ is the exposure factor
- $q_b = \frac{1}{2} \cdot \rho \cdot v_b^2$ is the basic velocity pressure

Exposure factor for $c_0 = 1.0$ and $k_I = 1.0$



Wind pressures of surfaces

Wind actions - general

Wind actions on structures or structural elements shall be determined taking into account of both external and internal pressures

Wind pressures on external surfaces

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

where

- $q_p(z_e)$ is the peak velocity pressure
- z_e is the reference height for the external pressure
- c_{pe} is the pressure coefficient for the external pressure

Wind pressures of surfaces

Wind pressures on internal surfaces

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

where

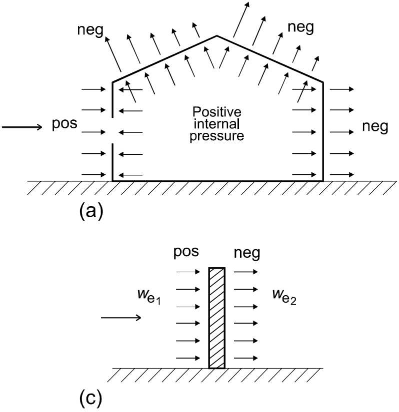
- $q_p(z_i)$ is the peak velocity pressure
- z_i is the reference height for the internal pressure
- c_{pi} is the pressure coefficient for the internal pressure

Net pressure on a wall

difference between the pressures on the opposite surfaces (taking due account of signs):

- pressure - towards the surface (positive)
- suction - away from surface (negative)

Wind pressure on surfaces



Wind forces

Wind forces

The wind force F_w acting on a structure or structural component may be determined as:

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

or by vectorial summation over the structural elements:

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

Wind forces

where

- $c_s c_d$ is the structural factor
- c_f is the force coefficient for the structure or structural element
- $q_p(z_e)$ is the peak velocity pressure at reference height z_e
- A_{ref} is the reference area of the structure or structural element

Wind forces - alternative

Wind forces based on pressures

The wind force F_w may be determined by vectorial summation of the forces $F_{w,e}$, $F_{w,i}$, calculated from external and internal pressures and the frictional forces F_{fr}:

- external forces

$$F_{w,e} = c_s c_d \cdot \sum_{surf} w_e \cdot A_{ref}$$

- internal forces

$$F_{w,i} = \sum_{surf} w_i \cdot A_{ref}$$

- frictional forces

$$F_{fr} = c_{fr} \cdot q_p(z_e) \cdot A_{fr}$$

Wind forces

where

- $c_s c_d$ is the structural factor
- w_e is the external pressure on the individual surface at height z_e
- w_i is the internal pressure on the individual surface at height z_i
- A_{ref} is the reference area of the individual surface
- c_{fr} is the friction coefficient
- A_{fr} is the area of external surface parallel to the wind

Structural factor $c_s c_d$

General principle

The structural factor $c_s c_d$ takes into account:

- the effect of spatial correlation of wind action
- the effect of structural vibration due to wind turbulence

Note

The structural factor $c_s c_d$ may be separated (according to National Annex) into the:

- size factor c_s
- dynamic factor c_d

Structural factor $c_s c_d$

Determination of $c_s c_d$

The structural factor $c_s c_d$ should be determined as follows:

(a) For buildings with H < 15 m the value of $c_s c_d$ may be 1.0

(b) For fasade and roof elements with natural frequencies $T_1 > 5Hz$, the value of $c_s c_d$ may be 1.0

(c) For framed buildings with structural walls and height < 100 m and if the height is $\leq 4\times$ along-wind depth, the value of $c_s c_d$ may be 1.0

(d) For chimneys with height H and circular cross-section with diameter D, if:

- H < 60 m
- H $\leq 6.5\times$ D

the value of $c_s c_d$ may be 1.0

Structural factor $c_s c_d$

Determination of $c_s c_d$

(e) Alternatively, for cases (a) - (d) the value for $c_s c_d$ may be calculated according to expression:

$$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_e) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_e)}$$

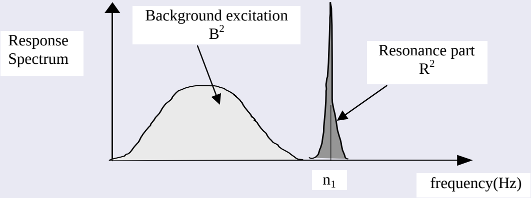
where

- z_e is the reference height
- k_p is the peak factor denoted as the ratio of the maximum value of the fluctuating part of the response to its standard deviation
- $I_v(z_e)$ is the turbulence intensity

Determination of $c_s c_d$

and also

- B^2 is the background factor, allowing the lack of full correlation of wind pressure on the structure surface
- R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode



Structural factor $c_s c_d$

Separation of c_s and c_d: $c_s c_d = c_s \cdot c_d$

- Size factor c_s takes into account lack of correlation of wind pressure (i.e. the background factor):

$$c_s = \frac{1 + 7 \cdot I_v(z_e) \cdot \sqrt{B^2}}{1 + 7 \cdot I_v(z_e)}$$

- Dynamic factor c_d takes into account effect from vibrations due to turbulence in resonance with the vibration mode (i.e. the resonance response factor):

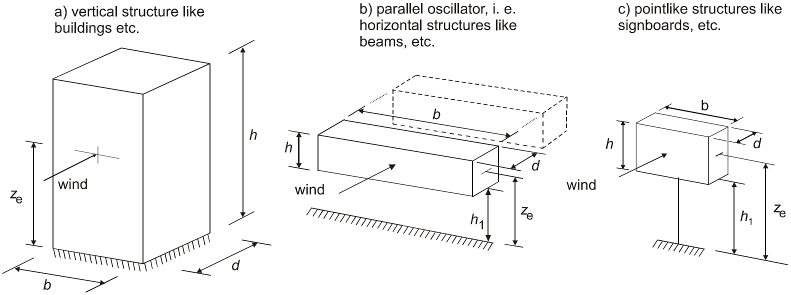
$$c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_e) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_e) \cdot \sqrt{B^2}}$$

Structural factor $c_s c_d$

Notes about $c_s c_d$

- National Annex may define procedures to determine k_p, B and R
- Recommended procedure is given in EC1, Annex B and Annex C (alternative, $\Delta_{max} = 5\%$)
- Given formulae may be used if structure corresponds to given general shapes
- and only the along-wind vibration in the fundamental mode is significant

Reference height z_e



NOTE Limitations are also given in 1.1 (2)

$$z_e = 0{,}6 \cdot h \geq z_{min}$$

$$z_e = h_1 + \frac{h}{2} \geq z_{min}$$

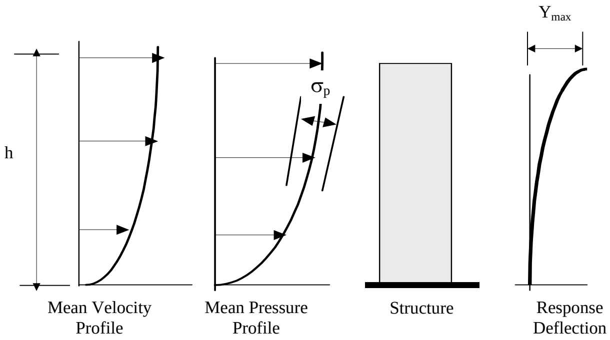
$$z_e = h_1 + \frac{h}{2} \geq z_{min}$$

Serviceability assesments

Serviceability assesments

The maximum along-wind displacement and the standard deviation of maximum along-wind accceleration of the structure:

$$Y_{max}(h) = Y_{max}(h) + k_p \sigma_Y(h)$$



Wake buffeting

Wake buffeting

- For slender buildings ($\frac{H}{B} > 4$) and chimneys ($\frac{H}{B} > 6.5$) in grouped arrangement the effect of increased turbulence, due to wake buffeting, should be considered
- Wake buffeting may be considered as negligible if (at least one condition)
  - the distance of 2 buildings or chimneys is > then 25 x the cross wind dimension of upstream building or chimney
  - the natural frequency of downstream building or chimney is $T_1 > 1$ Hz
- If conditions are not fulfilled, wind tunnel tests or specialist advice is necessary

Pressure and force coefficients

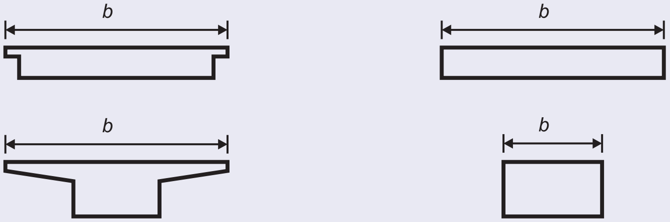
Pressure and force coefficients

- Choice of aerodynamic coefficient
- Effects of ice and snow
- Pressure coefficients for buildings
- Various configuration of roofs
- Friction coefficients
- Elements with rectangular and sharp edged sections
- Circular cylinders
- Spheres
- Lattice structures
- etc ...

Wind actions on bridges

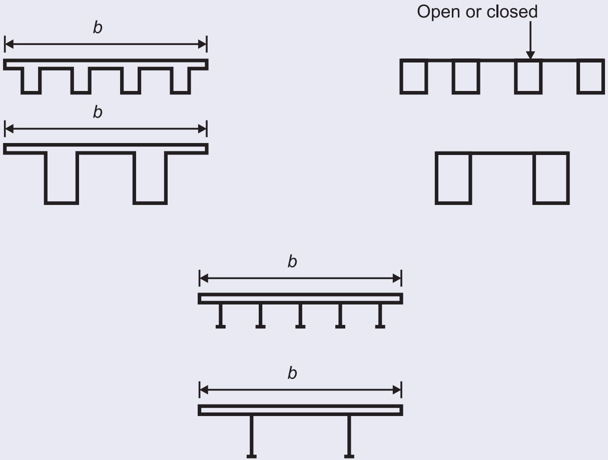
Wind actions on bridges - applies to:

- Bridges of constant depth
- Cross sections shown
- Single deck with one ore more spans



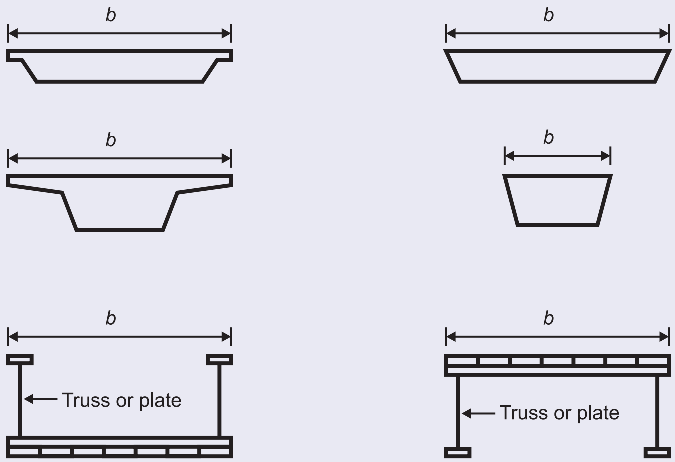
Wind actions on bridges

Wind actions on bridges



Wind actions on bridges

Wind actions on bridges



Wind actions on bridges

Coordinate system

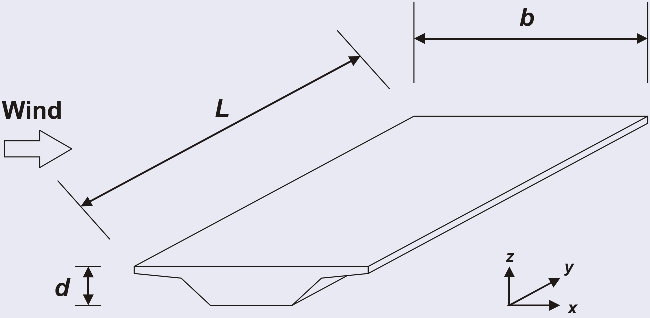


Figure 8.2 — Directions of wind actions on bridges

Wind actions on bridges

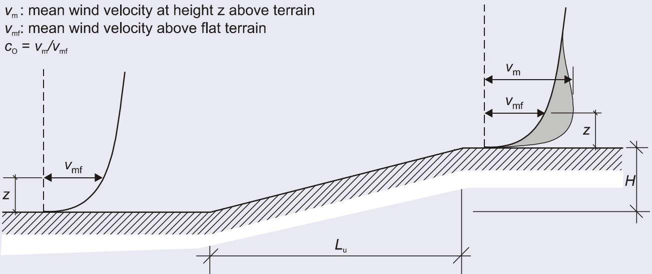
Wind action on bridges

- Choice of the response calculation procedure
- Force coefficients in x direction (general and simplified method)
- Wind forces on bridge deck in z direction
- Wind forces on bridge deck in y direction
- Wind effects on piers

Annex A (informative)

Terrain effects

- Upper roughness of each terrain category
- Transitions between terrain categories
- Calculation of orography coefficients
- Neighbouring structures
- Displacement heights

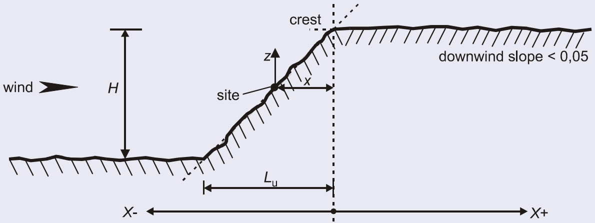


Annex A (informative)

Orography: factor *s* for cliffs and escarpments

$$c_0 = \frac{v_m}{v_{mf}} \qquad \Phi = \frac{H}{L_u}$$

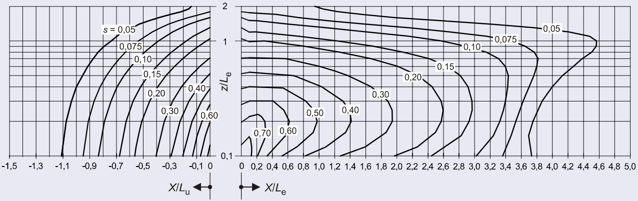
- v_m - mean wind velocity at height z
- v_{mf} - mean wind at height z above flat terrain
- Φ - upwind slope (in wind direction)



Annex A (informative)

Orography: factor *s* for cliffs and escarpments

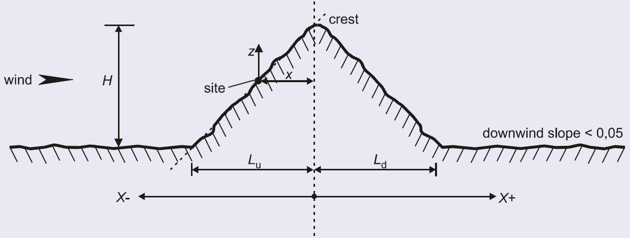
- $c_0 = 1 + 2 \cdot s \cdot \Phi$, etc (similar expressions)



Annex A (informative)

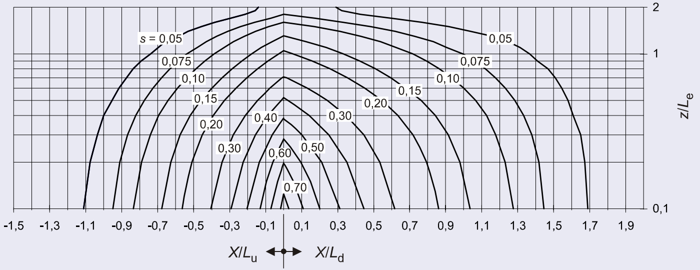
Orography: factor s for hills and ridges

$$c_0 = 1 \qquad \Phi < 0.05$$
$$c_0 = 1 + 2 \cdot s \cdot \Phi \qquad 0.05 < \Phi < 0.3$$
$$c_0 = 1 + 0.6 \cdot s \qquad \Phi > 0.3$$



Annex A (informative)

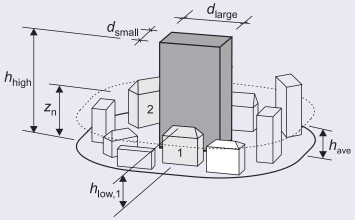
Orography: factor *s* for hills and ridges

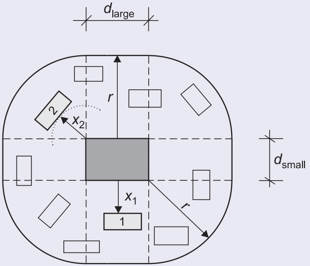


Annex A (informative)

Orography: influence of neighbouring structures

for buildings with $H \geq 2h_{ave}$

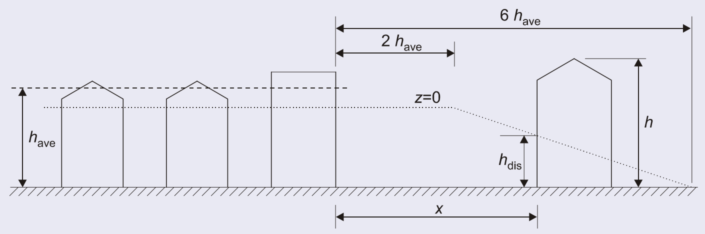




Annex A (informative)

Orography: obstruction height and upwind spacing

for buildings in terrain category IV



Annex B (informative): Procedure 1 for $c_s c_d$

Procedure 1 for determining structural factor $c_s c_d$

- Wind turbulence (turbulent length scale L)
- Structural factor $c_s c_d$
- Number of loads for dynamic response
- Service displacement and accelerations for serviceability assesments

Annex B (informative): Procedure 1 for $c_s c_d$

Wind turbulence

Turbulence length scale L(z):
average gust size for natural winds

$$L(z) = L_t \cdot (\frac{z}{z_t})^{\alpha} \qquad z \geq z_{min}$$
$$L(z) = L(z_{min}) \qquad z < z_{min}$$

- $z_t = 200\ m$ ...reference height
- $L_t = 300\ m$ ...reference length scale
- $\alpha = 0.67 + 0.05 \cdot \ln(z_0)$ ...(z_0 - roughness length [m])

Annex B (informative): Procedure 1 for $c_s c_d$

Power spectral density function

Power spectral density function:
non-dimensional representation of wind distribution over frequencies

$$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6.8 \cdot f_L(z,n)}{[1 + 10.2 \cdot f_L(z,n)]^{\frac{5}{3}}}$$

Annex B (informative): Procedure 1 for $c_s c_d$

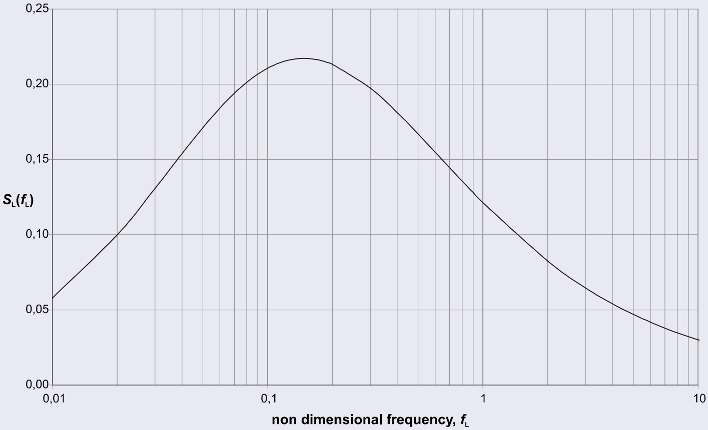
Power spectral density function

where

- $S_v(z,n)$ ...one-sided variance spectrum
- $f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$ ...non-dimensional frequency, where
  - $n = n_{1,x}$ ...the 1^{st} natural frequency of structure, in Hz
  - $L(z)$ ...turbulence length scale
  - $v_m(z)$ ...the mean wind velocity

Annex B (informative): Procedure 1 for $c_s c_d$

Power spectral density function



Annex B (informative): Procedure 1 for $c_s c_d$

Structural factor $c_s c_d$, defined by:

$$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_e) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_e)}$$

- z_e ... the reference height
- k_p ... the peak factor denoted as the ratio of the maximum value of the fluctuating part of the response to its standard deviation
- $I_v(z_e)$ ... the turbulence intensity
- B^2 ... the background factor, allowing the lack of full correlation of wind pressure on the structure surface
- R^2 ... the resonance response factor, allowing for turbulence in resonance with the vibration mode

Annex B (informative): Procedure 1 for $c_s c_d$

The background factor B^2

$$B^2 = \frac{1}{1 + 0.9 \cdot \left(\frac{b+h}{L(z_e)}\right)^{0.63}}$$

- b, h ... width and height of the structure
- $L(z_e)$ ... turbulence length scale at reference height z_e

Annex B (informative): Procedure 1 for $c_s c_d$

The peak factor k_p

The ratio of the max value of fluctuating part of the response to its standard deviation

$$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}} \qquad \text{or } k_p = 3.0$$

where:

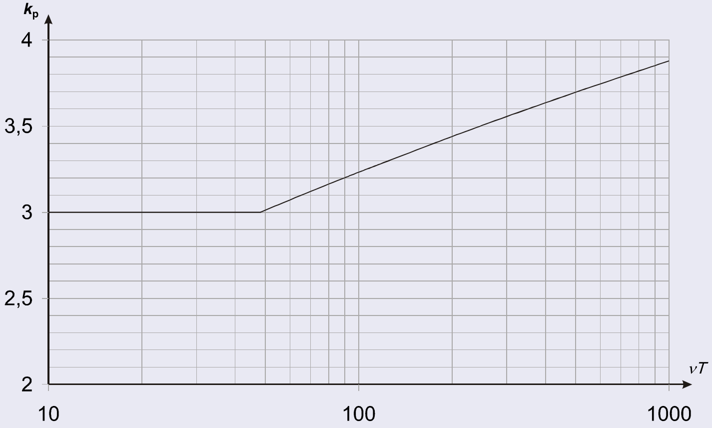
- ν ...upcrossing frequency, in Hz
- T ...averaging time for mean wind velocity: T = 600 s

$$\nu = n_{1,x} \cdot \sqrt{\frac{R^2}{B^2 + R^2}}$$

or, $\nu \geq 0.08$ Hz (corresponds to $k_p = 3.0$)

Annex B (informative): Procedure 1 for $c_s c_d$

The peak factor k_p



Annex B (informative): Procedure 1 for $c_s c_d$

The resonance response factor R^2

R^2 ... the resonance response factor, allowing for turbulence in resonance with the considered vibration mode:

$$R^2 = \frac{\pi^2}{2\delta} \cdot S_L(z_e, n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$$

- δ ... logarithmic decrement of damping
- S_L ... non-dimensional power spectral density function
- R_h, R_b ... aerodynamic admittance functions

Annex B (informative): Procedure 1 for $c_s c_d$

The aerodynamic admittance functions R_h, R_b:

aerodynamic admittance functions R_h, R_b for fundamental mode shape:

$$R_h = \frac{1}{\eta_h} - \frac{1}{2\eta_h^2} \cdot (1 - e^{-2\eta_h}) \qquad R_h = 1 \text{ for } \eta_h = 0$$

$$R_b = \frac{1}{\eta_b} - \frac{1}{2\eta_b^2} \cdot (1 - e^{-2\eta_b}) \qquad R_b = 1 \text{ for } \eta_b = 0$$

with

$$\eta_h = \frac{4.6 \cdot h}{L(z_e)} \cdot f_L(z_e, n_{1,x}) \qquad \eta_b = \frac{4.6 \cdot b}{L(z_e)} \cdot f_L(z_e, n_{1,x})$$

Annex B (informative): Procedure 1 for $c_s c_d$

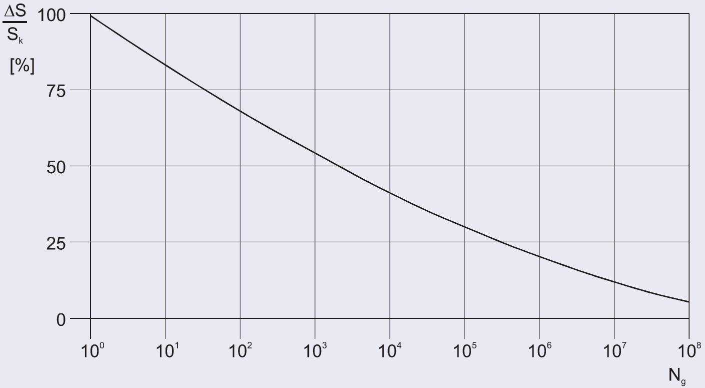
Number of loads for dynamic response

- Number of times N_g that some wind action ΔS is reached or exceeded during a period of 50 years
- Expressed as a % of S_k, where S_k is the effect due to a 50 years return period of wind action
- given by:

$$\frac{\Delta S}{S_k} = 0.7 \cdot [\log(N_g)]^2 - 17.4 \cdot \log(N_g) + 100$$

Annex B (informative): Procedure 1 for $c_s c_d$

Number of loads for dynamic response



Annex B (informative): Procedure 1 for $c_s c_d$

Displacements and accelerations - serviceabillity assesments

- The maximum along-wind displacement is determined from the equivalent static wind force
- The standard deviation $\sigma_{a,x}$ of the characteristic along-wind acceleration of the structural at point at height z:
- given by:

$$\sigma_{a,x}(z) = \frac{c_f \cdot \rho \cdot b \cdot I_v(z_e) \cdot v_m^2(z_e)}{m_{1,x}} \cdot R \cdot K_x \cdot \Phi_{1,x}(z)$$

Annex B (informative): Procedure 1 for $c_s c_d$

where

- c_f ... the force coefficient
- ρ ... air density
- b ... width of the structure
- $I_v(z_e)$ ... turbulence intensity at height z_e
- $v_m(z_e)$ ... the mean wind velocity at height z_e
- R ... the square root of the resonant response factor R^2

Annex B (informative): Procedure 1 for $c_s c_d$

and

- K_x ... non-dimensional coefficient given by

$$K_x = \frac{\int_0^h v_m^2(z) \cdot \Phi_{1,x}(z) \cdot dz}{v_m^2(z_e) \cdot \int_0^h \Phi_{1,x}^2(z) \cdot dz}$$

- $m_{1,x}$ ... the along-wind fundamental modal mass
- $n_{1,x}$ ... fundamental along-wind frequency, in Hz
- $\Phi_{1,x}(z)$ ... fundamental along-wind modal shape
- h ... height of the structure

Annex B (informative): Procedure 1 for $c_s c_d$

Non-dimensional coefficient K_x

- If the orography factor is $c_o(z) = 1$
- If the fundamental modal shape may be assumed as:

$$\Phi_{1,x}(z) = (\frac{z}{h})^{\zeta}$$

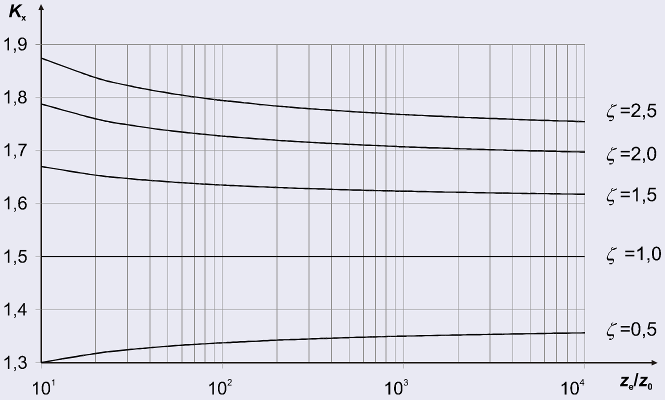
then the coefficient K_x is given by

$$K_x = \frac{(2\zeta + 1) \cdot [(\zeta + 1) \cdot (\ln(\frac{z_e}{z_0}) + 0.5) - 1]}{(\zeta + 1)^2 \cdot \ln(\frac{z_e}{z_0})}$$

where z_0 is the roughness length

Annex B (informative): Procedure 1 for $c_s c_d$

Non-dimensional coefficient K_x



Annex C (informative)

Procedure 2 for determining structural factor $c_s c_d$

- Wind turbulence (turbulent length scale L)
- Structural factor $c_s c_d$
- Number of loads for dynamic response
- Service displacement and accelerations for serviceability assesments
- Somewhat different expressions for B^2, R^2 and $\sigma_{a,x}$
- Overall results should be similar to results obtained from Procedure 1

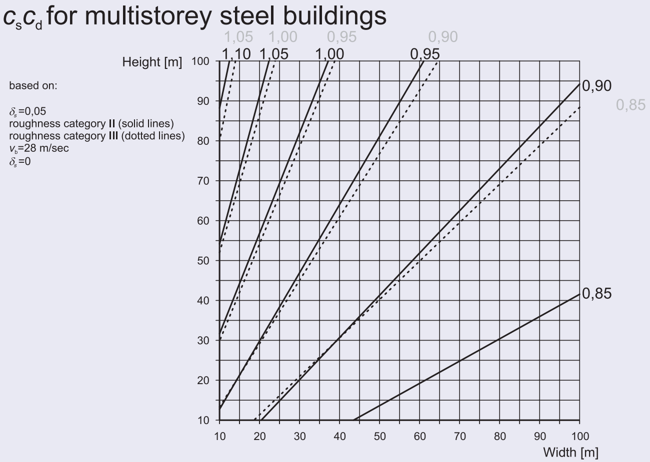
Annex D (informative): $c_s c_d$ for different structures

$c_s c_d$ values for different types of structures

- $c_s c_d$ for multistorey steel buildings
- $c_s c_d$ for multistorey concrete buildings
- $c_s c_d$ for steel chimneys without liners
- $c_s c_d$ for concrete chimneys without liners
- $c_s c_d$ for steel chimneys with liners

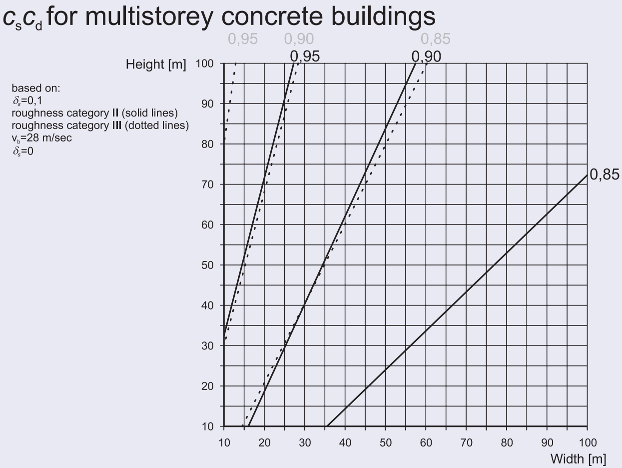
Annex D (informative): $c_s c_d$ for different structures

$c_s c_d$ values for multistorey steel buildings



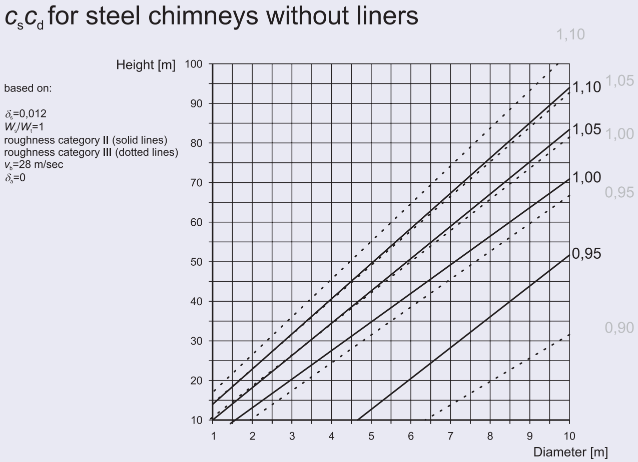
Annex D (informative): $c_s c_d$ for different structures

$c_s c_d$ values for multistorey concrete buildings



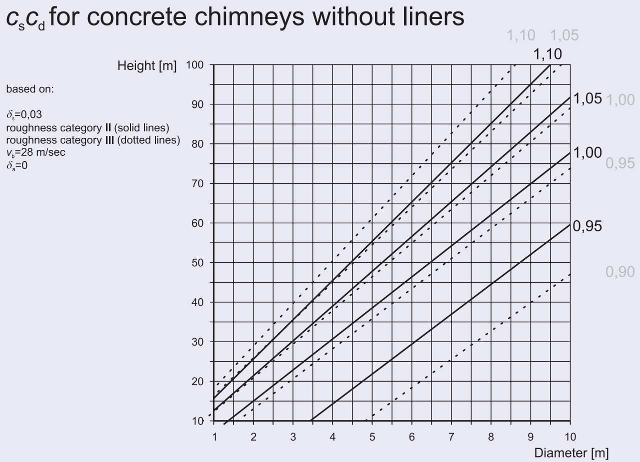
Annex D (informative): $c_s c_d$ for different structures

$c_s c_d$ values for steel chimneys without liners



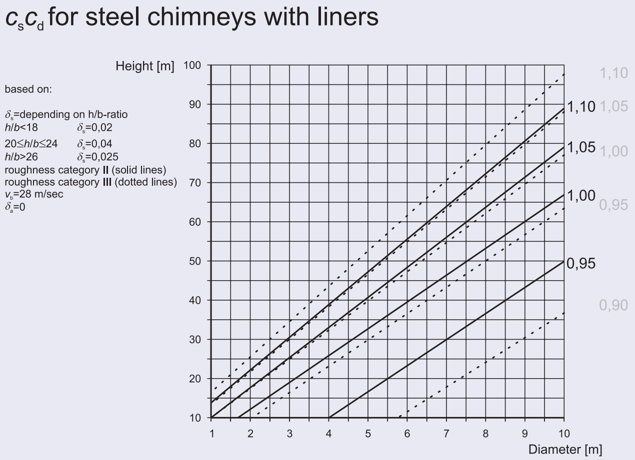
Annex D (informative): $c_s c_d$ for different structures

$c_s c_d$ values for concrete chimneys without liners



Annex D (informative): $c_s c_d$ for different structures

$c_s c_d$ values for steel chimneys with liners



Annex E (informative)

Vortex shedding and aeroelastic instabilities

- Vortex shedding
- Galloping
- Divergence and flutter