The Second Generation Eurocodes

Key changes and benefits through design examples

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EN 1991 “Eurocode 1: Actions on structures”

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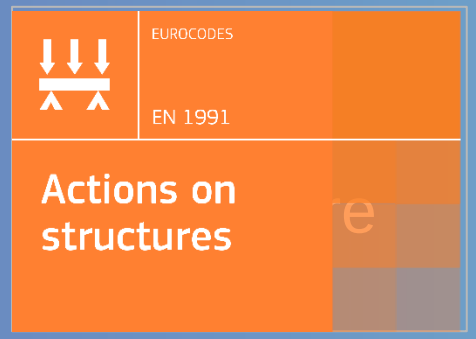
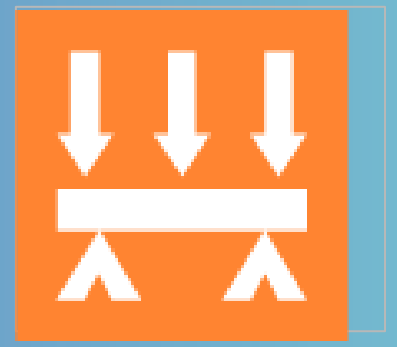
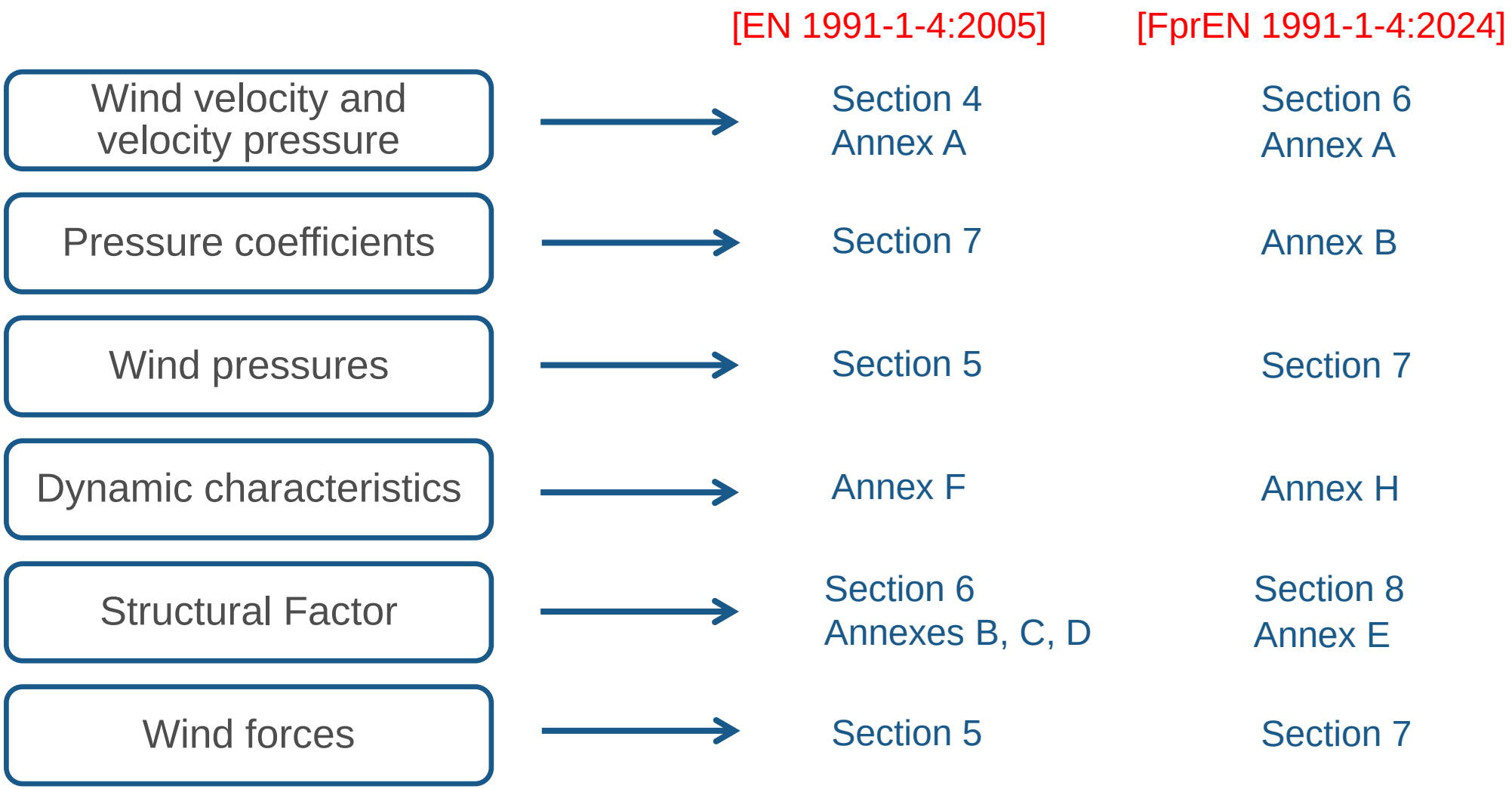
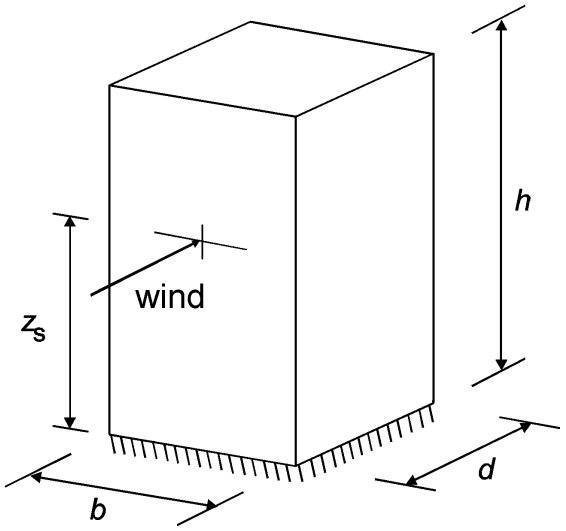




Wind action on medium- and high-rise buildings



Application



b = 40 m

d = 30 m

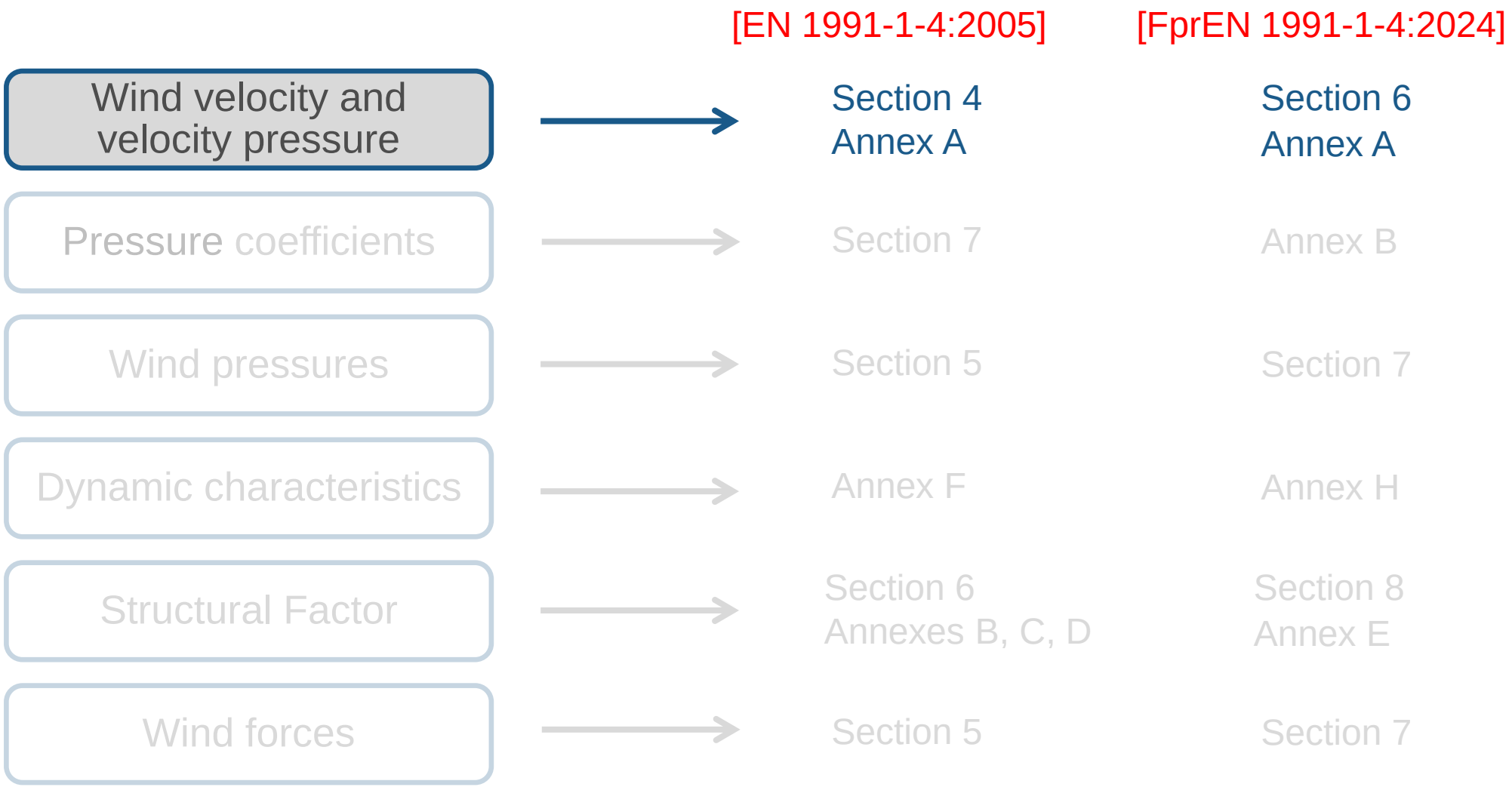
h = 100 m

m = 300 kg/m^3

v_{b0} = 27 m/s

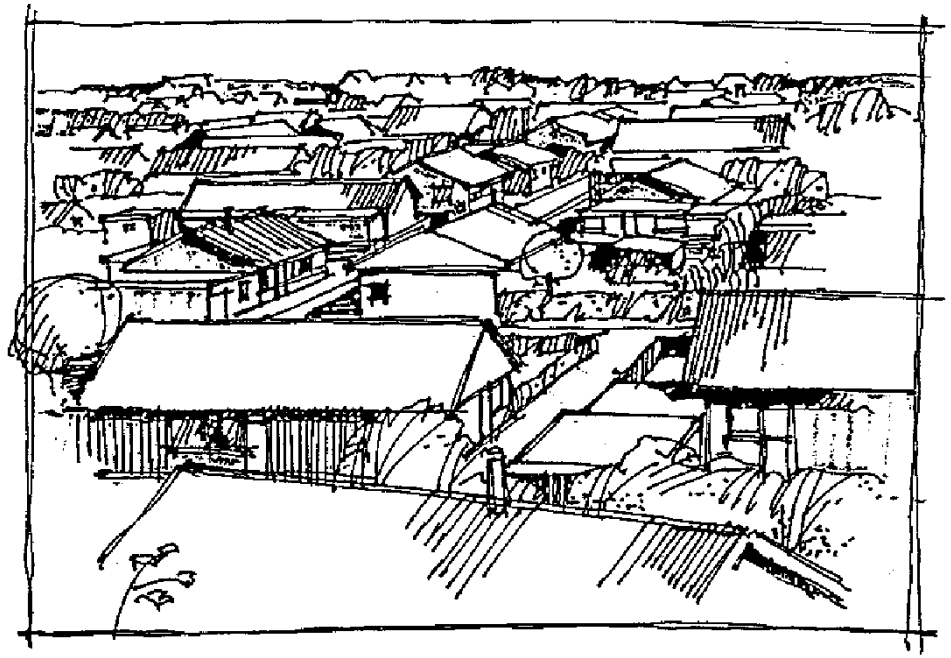
Steel building

Wind action on medium- and high-rise buildings



Application

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 A.1.			



Application [EN 1991-1-4:2005]

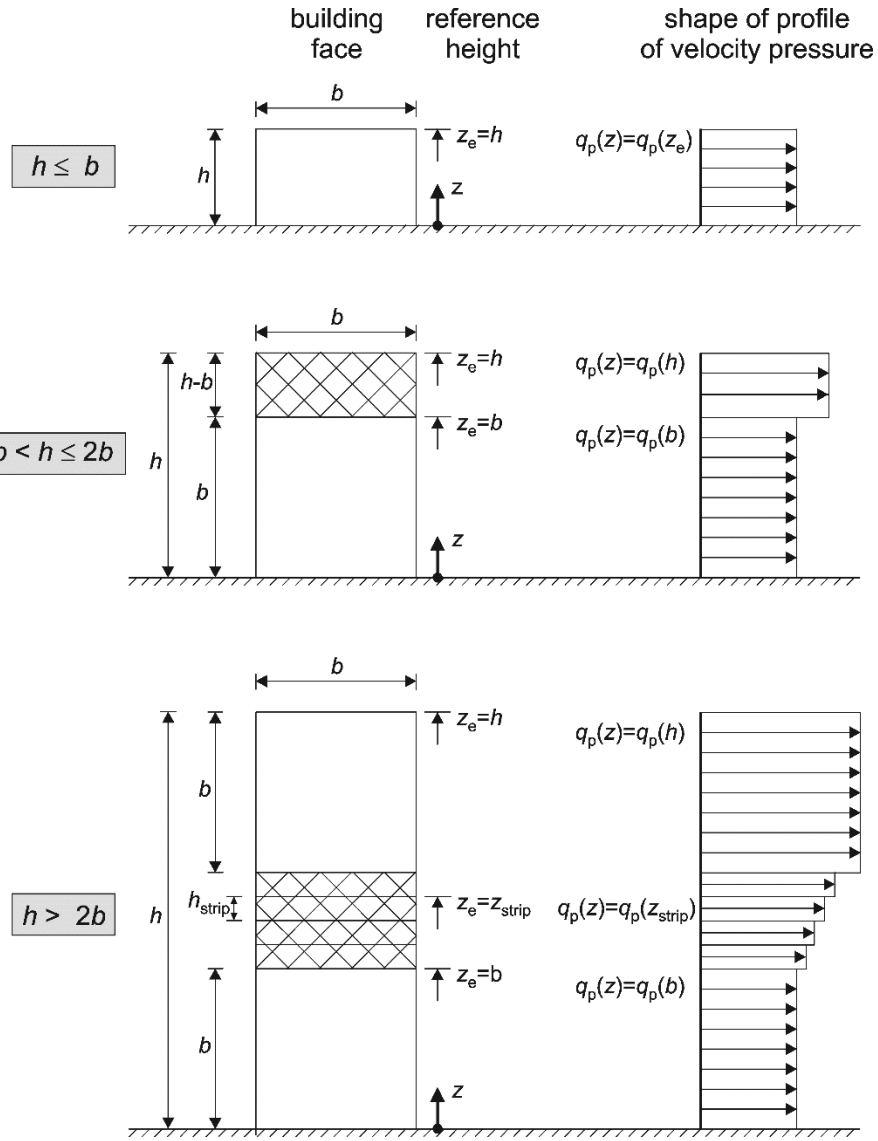
$$c_r(z) = k_r \cdot \ln\left(\frac{z}{z_0}\right)$$

roughness factor

$z_e = 40$ m $\quad c_r(40) = 1{,}054$

$z_e = 60$ m $\quad c_r(60) = 1{,}141$

$z_e = 100$ m $\quad c_r(100) = 1{,}251$



Application [FprEN 1991-1-4:2024]

The same strips are used as for the EN 1991-1-4:2005 calculations

A different choice would reduce the resultant actions

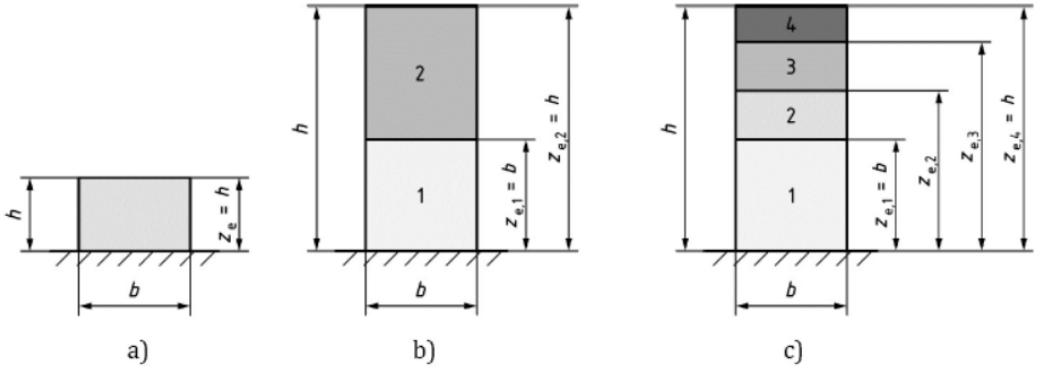


Figure B.3 — Reference height for zone D (windward wall) of buildings

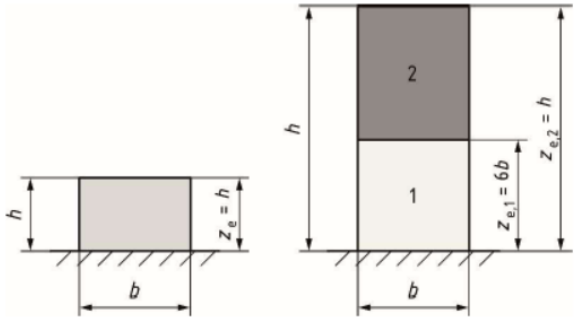


Figure B.4 — Reference height for zone A, B, C (side wall) and zone E (leeward wall) of buildings

Application

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

$v_m(40)$ = 28,4 m/s

$v_m(60)$ = 30,8 m/s

$v_m(100)$ = 33,8 m/s

mean wind velocity

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

$I_v(40)$ = 0,20

$I_v(60)$ = 0,19

$I_v(100)$ = 0,17

turbulence intensity

Application

peak velocity pressure

[EN 1991-1-4:2005]

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

$q_p(40)$ = 1230 Pa

$q_p(60)$ = 1377 Pa

$q_p(100)$ = 1573 Pa

[FprEN 1991-1-4:2024]

$$c_e(z) = \frac{q_p(z)}{q_b} = c_r^2(z) \cdot c_o^2(z) \cdot [1 + g_u \cdot I_u(z)]^2$$

$$q_p(z) = \frac{1}{2} \cdot \rho \cdot v_p^2(z) = c_e(z) \cdot q_b$$

$q_p(40)$ = 1284Pa

$q_p(60)$ = 1421 Pa

$q_p(100)$ = 1603 Pa

Wind action on medium- and high-rise buildings

	[EN 1991-1-4:2005]	[FprEN 1991-1-4:2024]
Wind velocity and velocity pressure	Section 4 Annex A	Section 6 Annex A
Pressure coefficients	**Section 7**	**Annex B**
Wind pressures	Section 5	Section 7
Dynamic characteristics	Annex F	Annex H
Structural Factor	Section 6 Annexes B, C, D	Section 8 Annex E
Wind forces	Section 5	Section 7

Application [EN 1991-1-4:2005]

Zone	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤ 0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

h/d = 3,33

$c_{pe,10}$ = 0,8

$c_{pe,10}$ = -0,617

external pressure coefficient (loaded area 10 m² or more)

Application [FprEN 1991-1-4:2024]

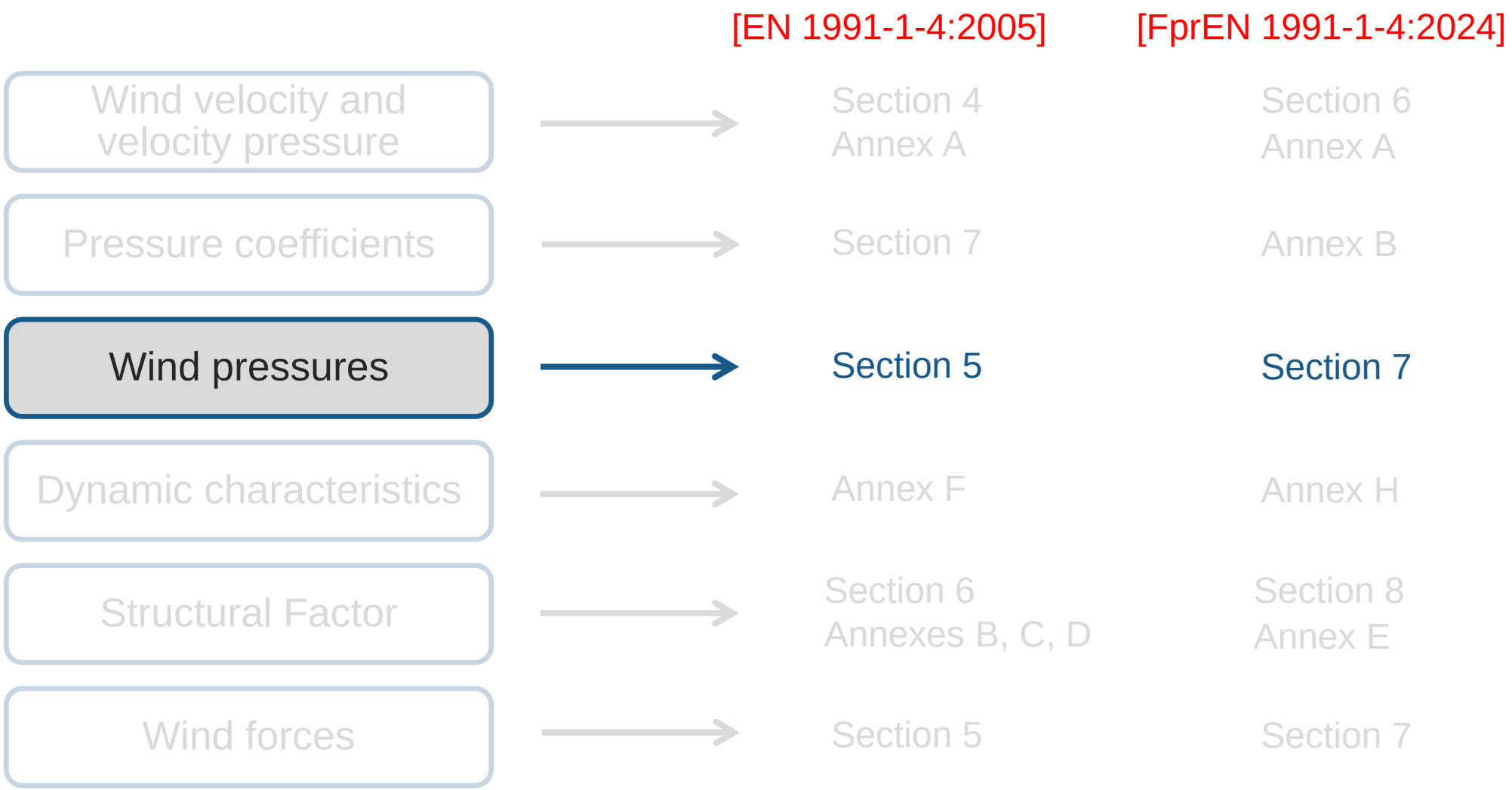
h/d = 3,33

h/d	Zones A, B, C	Zone D	Zone E
	c_{peg}	c_{peg}	c_{peg}
5	−0,9	0,8	−0,7
$1 \le h/d \le 5$	−0,9	0,8	$-0,5 - 0,05\cdot(h/d-1)$
1	−0,9	0,8	−0,5
$0,5 \le h/d \le 1$	−0,9	$0,7 + 0,1\cdot h/d$	$-0,3 - 0,2\cdot h/d$
0,5	−0,9	0,75	−0,4
$0 \le h/d \le 0,5$	$-0,5 - 0,8\cdot h/d$	$0,7 + 0,1\cdot h/d$	$-0,3 - 0,2\cdot h/d$
0	−0,5	0,7	−0,3

c_{peg} = 0,8 c_{peg} = -0,617

global pressure coefficient

Wind action on medium- and high-rise buildings



Application

[EN 1991-1-4:2005]

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

Zone D: windward

$w_e(40)$ = 984 Pa

$w_e(60)$ = 1102 Pa

$w_e(100)$ = 1258 Pa

Zone E: leeward

$w_e(40)$ = - 970 Pa

$w_e(60)$ = - 970 Pa

$w_e(100)$ = - 970 Pa

[FprEN 1991-1-4:2024]

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

Zone D: windward

$p_e(40)$ = 1027 Pa

$p_e(60)$ = 1137 Pa

$p_e(100)$ = 1283 Pa

Zone E: leeward

$p_e(40)$ = - 989 Pa

$p_e(60)$ = - 989 Pa

$p_e(100)$ = - 989 Pa

Wind action on medium- and high-rise buildings

	[EN 1991-1-4:2005]	[FprEN 1991-1-4:2024]
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Wind forces	Section 5	Section 7

Application

$$n_1 = \frac{46}{h}\ [\text{Hz}]$$

n_1 = 0,46 Hz

fundamental frequency (along wind vibration)

$$\Phi_1(z) = \left(\frac{z}{h}\right)^{\zeta}$$

ζ_1 = 1,5

mode shape

$$m_e = \frac{\int_0^{\ell} m(s) \cdot \Phi_1^2(s)\, \mathrm{ds}}{\int_0^{\ell} \Phi_1^2(s)\, \mathrm{ds}}$$

m_e = 360.000 kg/m

effective mass

Application

$$\delta = \delta_s + \delta_a + \delta_d$$

Structural type	structural damping, δ_s
reinforced concrete buildings	0,10
steel buildings	0,05
mixed structures concrete + steel	0,08
reinforced concrete towers and chimneys	0.03

$z_s = 0{,}6h = 60$ m

$$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$$

$\delta_s = 0.05$

$\delta_a = 0.0066$ → $\delta = 0.0566$

logarithmic decrement of damping

Wind action on medium- and high-rise buildings

	[EN 1991-1-4:2005]	[FprEN 1991-1-4:2024]
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Application [EN 1991-1-4:2005]

$$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$$

L_t = 300 m

z_t = 200 m

$L(z_s)$ = 144 m — *turbulent length scale*

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

$c_r(z_s)$ = 1,141 — *roughness factor*

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

$v_m(z_s)$ = 30,8 m/s — *mean wind velocity*

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

$I_v(z_s)$ = 0,19 — *turbulence intensity*

Application [EN 1991-1-4:2005 – Procedure 1]

$$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$$

$f_L(z_s,n) = 2{,}15$ *non dimensional frequency*

$$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$$

$S_L(z_s,n) = 0{,}079$ *non dimensional power spectral density function*

$$B^2 = \frac{1}{1+0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$$

$B^2 = 0{,}531$ *background response factor*

Application [EN 1991-1-4:2005 – Procedure 1]

$$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s, n_{1,x})$$

η_h = 6,867

$$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s, n_{1,x})$$

η_b = 2,747

non dimensional parameter

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

R_h = 0,135

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

R_b = 0,298

aerodynamic admittance

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

R^2 = 0,277

resonant response factor

Application [EN 1991-1-4:2005 – Procedure 2]

$$B^2 = \frac{1}{1+\frac{3}{2}\cdot\sqrt{\left(\frac{b}{L(z_s)}\right)^2+\left(\frac{h}{L(z_s)}\right)^2+\left(\frac{b}{L(z_s)}\cdot\frac{h}{L(z_s)}\right)^2}}$$

$B^2 = 0{,}463$

(0,531)

background response factor

$$\phi_y = \frac{c_y \cdot b \cdot n}{v_m(z_s)}$$

$\phi_y = 17{,}17$

$$\phi_z = \frac{c_z \cdot h \cdot n}{v_m(z_s)}$$

$\phi_z = 6{,}87$

non dimensional parameter

$$K_s(n) = \frac{1}{1+\sqrt{(G_y\cdot\phi_y)^2+(G_z\cdot\phi_z)^2+\left(\frac{2}{\pi}\cdot G_y\cdot\phi_y\cdot G_z\cdot\phi_z\right)^2}}$$

$K_s = 0{,}0593$

size reduction function

Application [EN 1991-1-4:2005 – Procedure 2]

$$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_L(z_s, n_{1,x}) \cdot K_s(n_{1,x})$$

R^2 = 0,408

(0,277)

resonant response factor

Application [EN 1991-1-4:2005]

	[Procedure 1]	[Procedure 2]	
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2 + R^2}}$	$\nu = 0{,}27$	$\nu = 0{,}34$	*up-crossing frequency*
$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	$k_p = 3{,}38$	$k_p = 3{,}45$	*peak factor*
$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s)}$	$c_s c_d = 0{,}924$	$c_s c_d = 0{,}955$	*structural factor*

Application [FprEN 1991-1-4:2024]

$$L_{\mathrm{u}}^{x}(z) = L_{\mathrm{t}} \cdot \left(\frac{z}{z_{\mathrm{t}}}\right)^{\alpha}$$

L_t = 300 m

z_t = 300 m
(200 m)

$L(z_s)$ = 112 m
(144 m)

turbulent length scale

$$f_{\mathrm{u}}(z,n) = \frac{n \cdot L_{\mathrm{u}}^{x}(z)}{v_{\mathrm{m}}(z)}$$

$f_u(z_s,n)$ = 1,68
(2,15)

non dimensional frequency

$$S_{\mathrm{N,u}}(z,n) = \frac{n \cdot S_{\mathrm{u}}(z,n)}{\sigma_{\mathrm{u}}^{2}} = \frac{6{,}8 \cdot f_{\mathrm{u}}(z,n)}{(1 + 10{,}2 \cdot f_{\mathrm{u}}(z,n))^{5/3}}$$

$S_{N,u}(z_s,n)$ = 0,091
(0,079)

non dimensional power spectral density function

Application [FprEN 1991-1-4:2024]

$$\phi_{B,\mathrm{C}} = 3{,}0 \cdot b / L_{\mathrm{u}}^{x}(z_{\mathrm{s}})$$

$$\phi_{B,\mathrm{L}} = 3{,}0 \cdot l / L_{\mathrm{u}}^{x}(z_{\mathrm{s}})$$

$\phi_{B,C}$ = 1,067

$\phi_{B,L}$ = 2,668

non-dimensional background size parameters

$$\chi^2(\phi) = \chi_{\mathrm{U}}^2(\phi) = \frac{2}{\phi^2} \cdot \left(\phi - 1 + e^{-\phi}\right)$$

χ^2_U = 0,722

χ^2_U = 0,488

background admittance function

$$B^2 = \chi_{\mathrm{U}}^2\left(\phi_{B,\mathrm{C}}\right) \cdot \chi_{\mathrm{U}}^2\left(\phi_{B,\mathrm{L}}\right)$$

B^2 = 0,351

(0,531)

background response factor

Application [FprEN 1991-1-4:2024]

$$\phi_{R,\mathrm{C}} = 8{,}6 \cdot \frac{b \cdot n}{v_{\mathrm{m}}(z_{\mathrm{s}})}$$

$$\phi_{R,\mathrm{L}} = 8{,}6 \cdot \frac{l \cdot n}{v_{\mathrm{m}}(z_{\mathrm{s}})}$$

$\phi_{R,C}$ = 5,136
(1,067)

$\phi_{R,L}$ = 12,84
(2,668)

non-dimensional resonant size parameters

$$\chi^2(\phi) = \chi^2_{\mathrm{U}}(\phi) = \frac{2}{\phi^2} \cdot \left(\phi - 1 + e^{-\phi}\right)$$

χ^2_U = 0,314
(0,298)

χ^2_U = 0,144
(0,135)

resonant admittance function

$$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_{\mathrm{N,u}}(z_{\mathrm{s}}, n_{1,\mathrm{x}}) \cdot \chi^2_{\mathrm{U}}(\phi_{R,\mathrm{C}}) \cdot \chi^2_{\mathrm{U}}(\phi_{R,\mathrm{L}})$$

R^2 = 0,359
(0,277)

resonant response factor

Application [FprEN 1991-1-4:2024]

$g_B = 3{,}5$ — *peak factor for the background response*

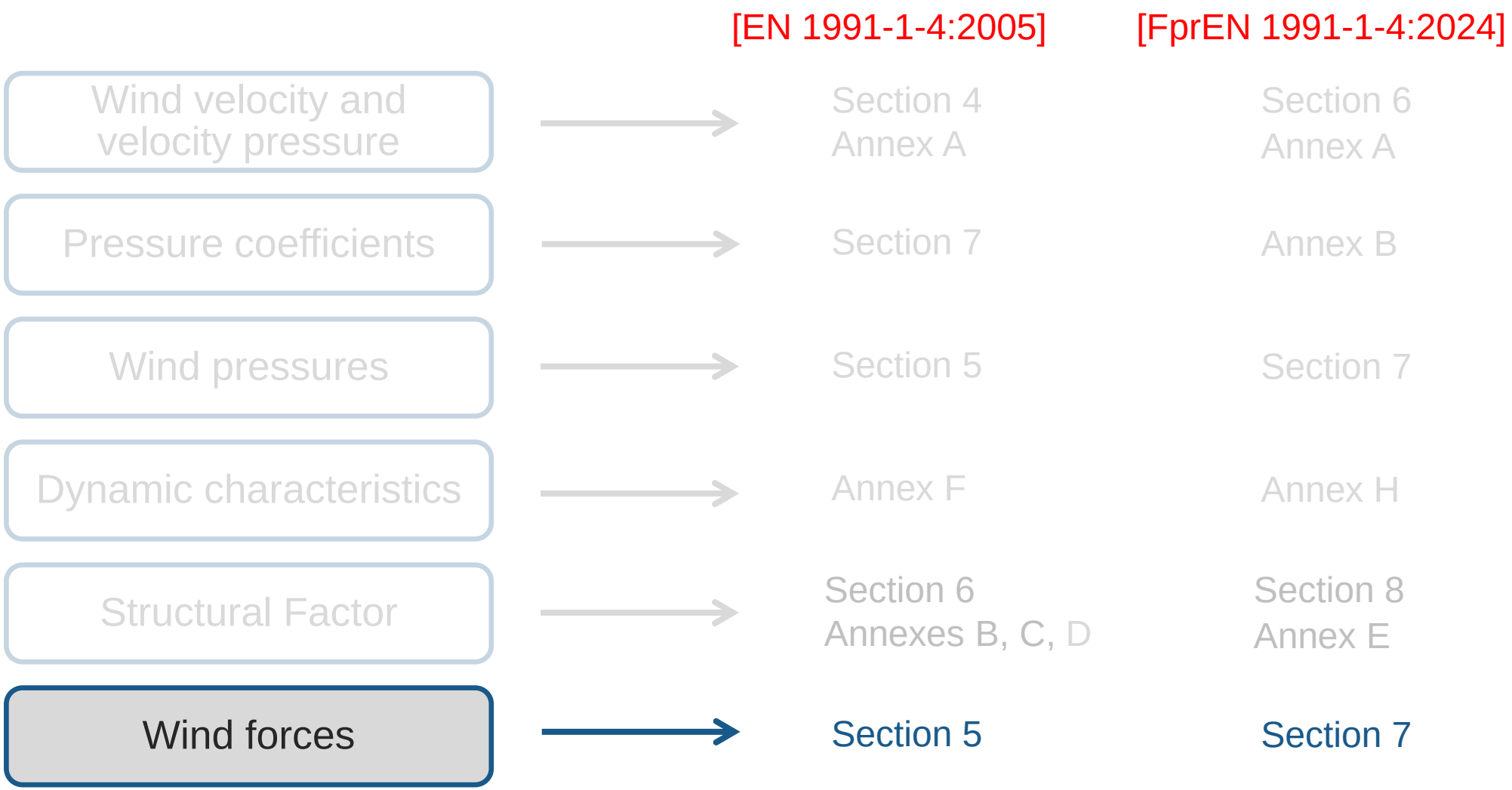
$$g_R = \max\begin{cases}\sqrt{2 \cdot \ln(n_x \cdot t)} + \dfrac{0{,}5772}{\sqrt{2 \cdot \ln(n_x \cdot t)}} \\ g_R = 2{,}8\end{cases}$$

$g_R = 3{,}52$ — *peak factor for the resonant response*

$$c_{sd} = \frac{1 + 2 \cdot I_u(z_s) \cdot \sqrt{(g_B \cdot B)^2 + (g_R \cdot R)^2}}{1 + 2\, g_B \cdot I_u(z_s)}$$

$c_{sd} = 0{,}913$ (0,924) — *structural factor*

Wind action on medium- and high-rise buildings



Application

[EN 1991-1-4:2005]

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

[Procedure 1]

F_W = 7,72 MN

M_W = 398 MNm

[Procedure 2]

F_W = 7,97 MN

M_W = 411 MNm

[FprEN 1991-1-4:2024]

$$F_{w,se} = \sum_{all\ elements}^{vector\ sum} c_{sd}(F_{pe} + F_{pnet} + F_{fr} + F_{cf}) + F_{pi}$$

F_W = 7,81 MN *base shear*

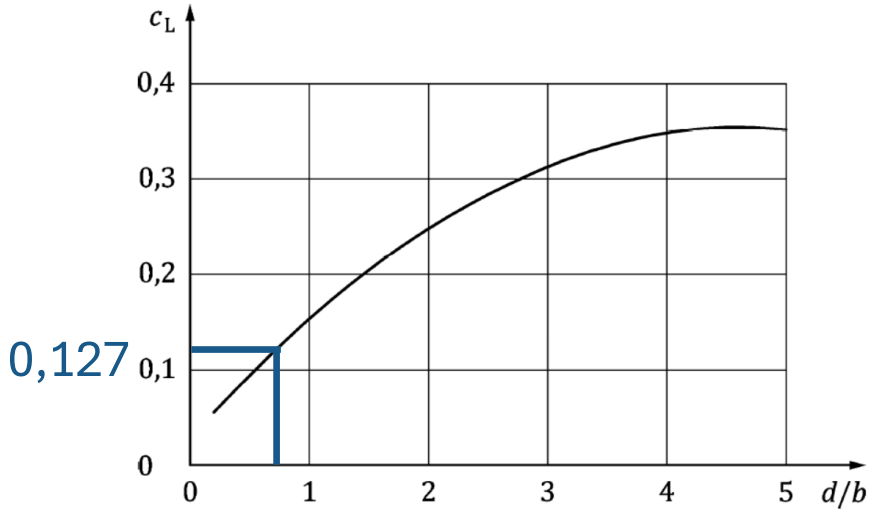
M_W = 402 MN *base moment*

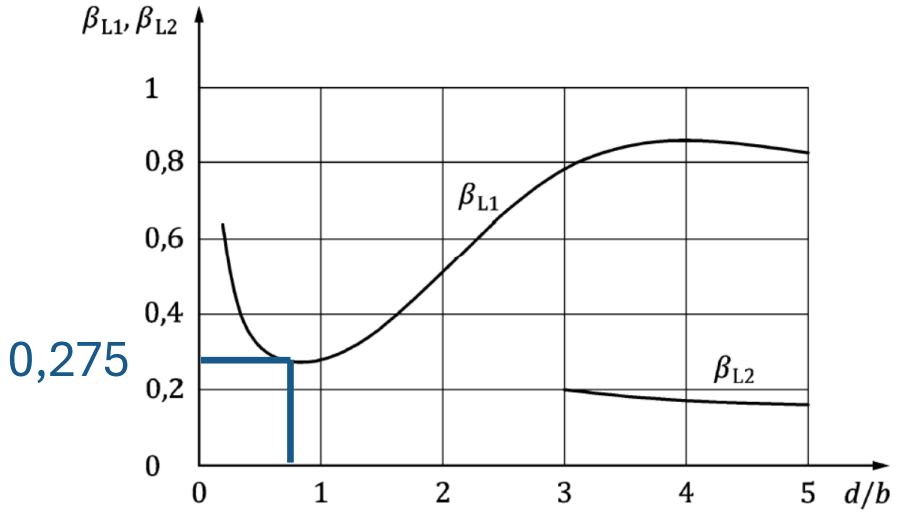
Acrosswind action [FprEN 1991-1-4:2024]

Wind velocity and velocity pressure → Annex F

$$c_L = -0{,}015 \cdot \left(\frac{d}{b}\right)^2 + 0{,}14 \cdot \frac{d}{b} + 0{,}03$$

$$\beta_{L1} = \frac{\left(\frac{d}{b}\right)^4 + 2{,}3 \cdot \left(\frac{d}{b}\right)^2}{\left[2{,}4 \cdot \left(\frac{d}{b}\right)^4 - 9{,}2 \cdot \left(\frac{d}{b}\right)^3 + 18 \cdot \left(\frac{d}{b}\right)^2 + 9{,}5 \cdot \left(\frac{d}{b}\right) - 0{,}15\right]} + \frac{0{,}12}{\left(\frac{d}{b}\right)}$$

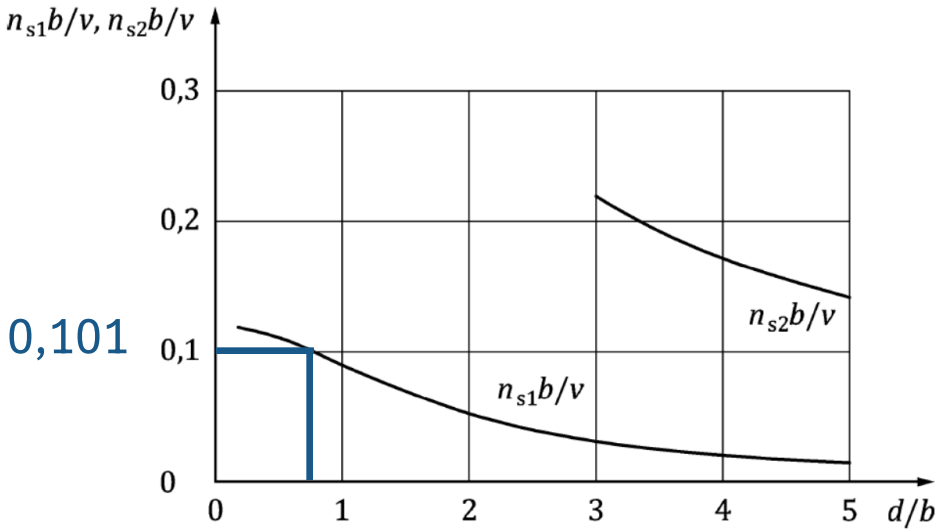




Acrosswind action [FprEN 1991-1-4:2024]

$$n_{s1} = \frac{0{,}12}{\left\{1 + 0{,}38 \cdot \left(\frac{d}{b}\right)^2\right\}^{0{,}89}} \frac{v_{\mathrm{m}}(h)}{b}$$

$$S_{\mathrm{L}} = \sum_{j=1}^{m} \frac{4k_{Lj} \cdot \left(1 + 0{,}6 \cdot \beta_{\mathrm{Lj}}\right) \cdot \beta_{\mathrm{Lj}}}{\pi} \frac{\left(\frac{n_{\mathrm{L}}}{n_{\mathrm{sj}}}\right)^2}{\left[1 - \left(\frac{n_{\mathrm{L}}}{n_{\mathrm{sj}}}\right)^2\right]^2 + 4 \cdot \beta_{Lj}^2 \cdot \left(\frac{n_{\mathrm{L}}}{n_{\mathrm{sj}}}\right)^2}$$



0,101

S_L = 0,0150

Acrosswind action [FprEN 1991-1-4:2024]

$$R_{\mathrm{L}}^2 = \frac{\pi^2 \cdot S_{\mathrm{L}}}{2 \cdot \delta_{\mathrm{L}}}$$

R^2_L = 1,482 *resonant response factor*

$$c_{\mathrm{dL}} = k_{\mathrm{L}} \cdot \sqrt{1 + R_{\mathrm{L}}^2}$$

c_{dL} = 5,55 *acrosswind dynamic factor*

$$f_{\mathrm{L}}(z) = 3 \cdot q_{\mathrm{m}}(h) \cdot c_{\mathbf{L}} \cdot b \cdot \left(\frac{z}{h}\right) \cdot c_{\mathrm{dL}}$$

F_W = 6,8 MN *base shear*

M_W = 451 MNm *base moment*

Summary

- New set of global pressure coefficients for buildings
- Quadratic peak velocity pressures
- Turbulent length scale scaled to 300 m
- One procedure for the structural factor
- New formula for the background factor
- New formula for the resonant factor
- New procedure for acrosswind actions

Thank you!

F. Ricciardelli

Convenor of CEN/TC 250/SC 1/WG 1/TG 2(Wind)