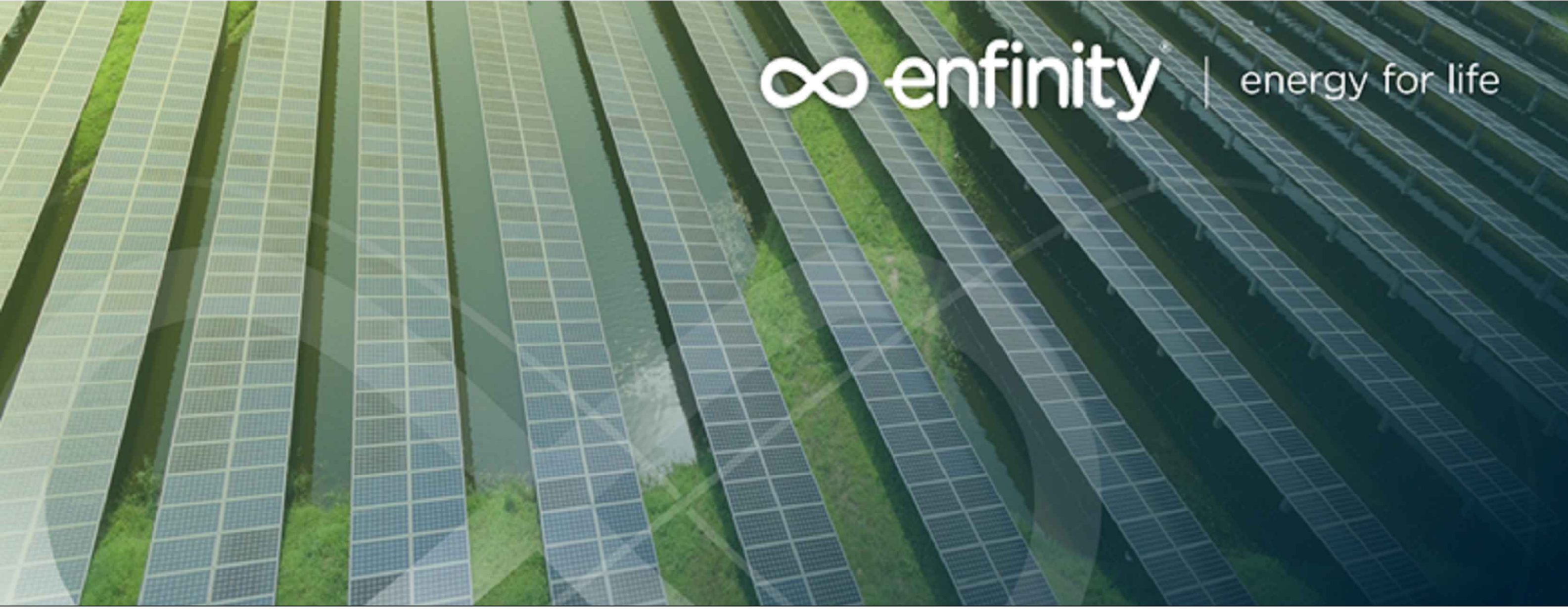

IMPIANTO AGRO-FOTOVOLTAICO "MANIMUZZI" E OPERE CONNESSE

POTENZA IMPIANTO 19.8336 MWp
COMUNI DI COLLEPASSO E CASARANO (LE)

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Titolo Elaborato

RELAZIONE AZIONE DEL VENTO

LIVELLO PROGETTAZIONE	CODICE ELABORATO	FILENAME	RIFERIMENTO	DATA	SCALA
PROGETTO DEFINITIVO	**REL.26**	**---**	**---**	**04/2022**	**---**

Revisioni

REV.	DATA	DESCRIZIONE	ESEGUITO	VERIFICATO	APPROVATO
0.0	**04/2022**	**PRIMA EMISSIONE**	**FAR**	**DEV**	**ENF**

COMUNI DI COLLEPASSO
E CASARANO (LE)
REGIONE PUGLIA

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RELAZIONE AZIONE DEL VENTO

Sommario

1. DESCRIZIONE GENERALE

La struttura meccanica è composta da due telai.

Tre elementi verticali sono fissati nel terreno mediante procedura di speronamento diretto. Sono realizzati in acciaio sezione Ω.

Nella parte superiore di questi, gli elementi di collegamento sono fissi e sostengono le travi principali, e rappresentano degli elementi orizzontali con una sezione tubolare quadrata.

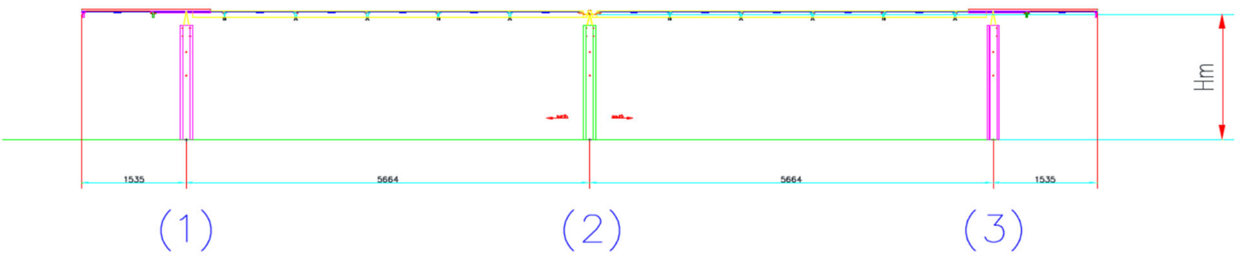
Sulle travi principali, due file di pannelli fotovoltaici in configurazione verticale sono fissate attraverso due diversi tipi di supporto del modulo. Si tratta di traverse secondarie, composte da profilati d'acciaio tubolari rettangolari e sezione Ω.

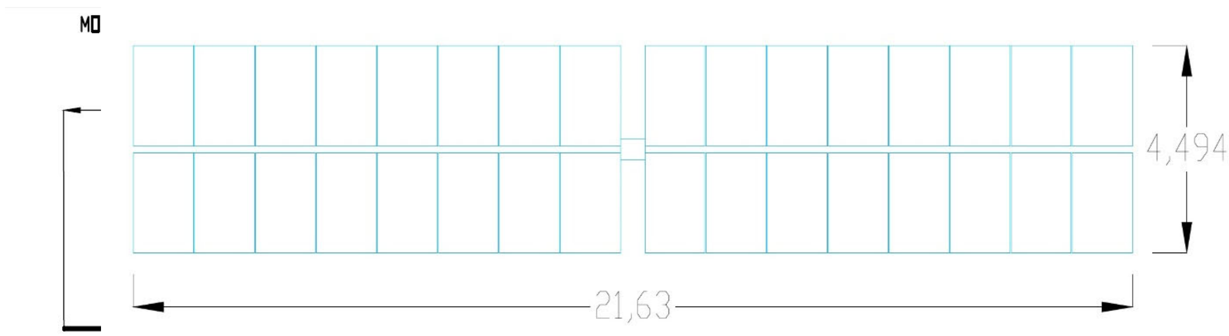
2. SCHEMA GEOMETRICO DEI CALCOLI STRUTTURALI

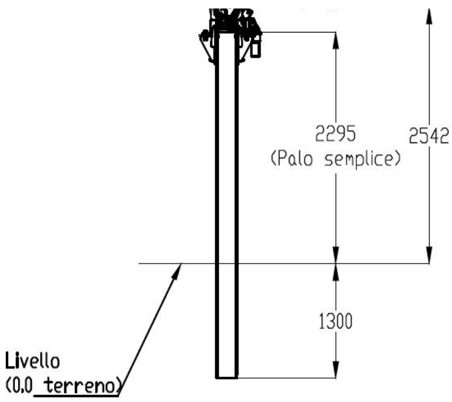
Per il calcolo strutturale abbiamo preso in considerazione tre configurazioni principali:

- MODELLO A: α = 0°;
- MODELLO B: α = 30°;
- MODELLO C: α = 55°;

Queste configurazioni sono quelle che generano il massimo stress nella struttura. Sotto è mostrato un diagramma delle dimensioni geometriche per queste configurazioni.







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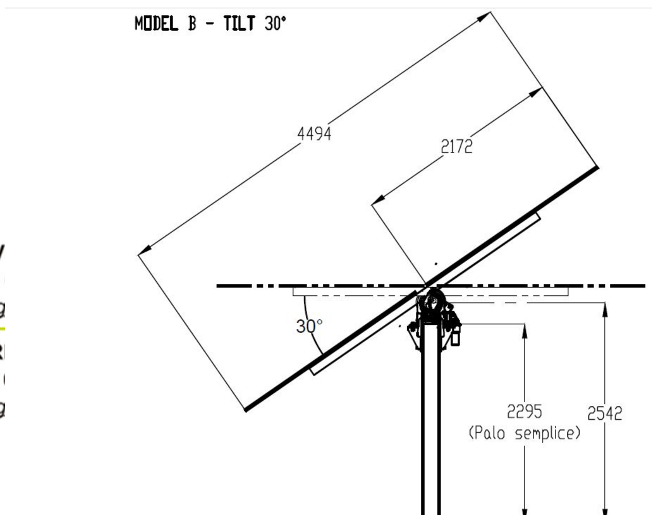
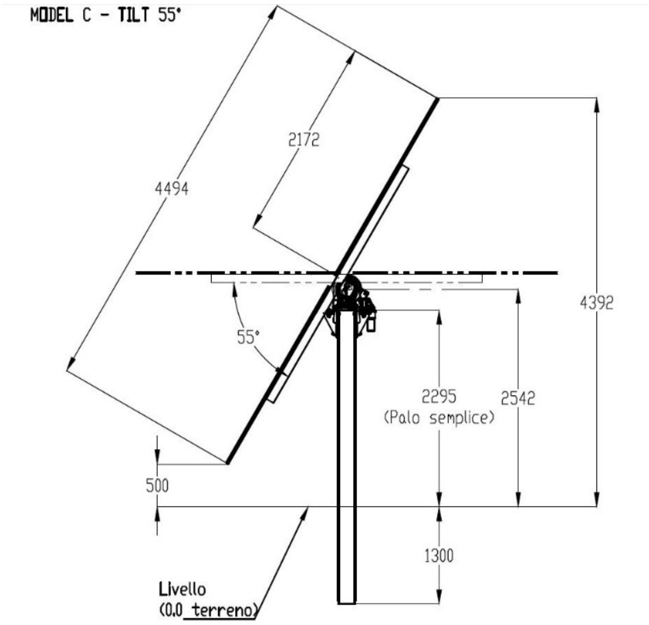




3. QUADRO NORMATIVO

- EUROCODICE 1 – Azioni sulle strutture – Parte 1-4: Azioni in generale – azioni del vento (UNI EN 1991-1-4:2005);
- EUROCODICE 3 – Progettazione delle Strutture in acciaio – Parte 1-1: Regole generali e regole per gli edifici (UNI EN 1993-1-1:2005);
- EUROCODICE 3 – Progettazione delle Strutture in acciaio – Parte 1-8: Progettazione dei collegamenti (UNI EN 1993-1-8:2005);
- D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni;
- Legge 2/2/74 n. 64 e DDMM 3/3/1975 – Norme tecniche per la costruzione in zone sismiche.
- Costruzioni in acciaio: Istruzioni per il calcolo, l’esecuzione, il collaudo e la manutenzione. (C.N.R. 10011/85);
- Istruzioni per la valutazione delle Azioni sulle Costruzioni. (C.N.R. 10012/85);

4. CARICO DEL VENTO

Il carico del vento è determinato, secondo il D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni:

- α = 0°: velocità del vento V = 27 m/s
- α ≠ 0°: velocità del vento V = 15 m/s

La velocità del vento di base è determinata secondo la Tabella 3.3.I del D.M. 17 gennaio 2018 - Norme Tecniche per le Costruzioni.

Il valore è la caratteristica velocità media del vento di 10 minuti, indipendentemente dalla direzione del vento e dal periodo dell'anno, a 10 m sopra il livello del suolo in terreni aperti con bassa vegetazione come erba e ostacoli isolati, con un probabilità di superare la forza progettata non superiore al 2% in 50 anni.

Il sito fotovoltaico si trova in zona 3 (Puglia), come si evince dalla tabella sottostante

Tab. 3.3.I - *Valori dei parametri* $v_{b,0}$, a_0, k_s

Zona	Descrizione	$v_{b,0}$ [m/s]	a_0 [m]	k_s
1	Valle d'Aosta, Piemonte, Lombardia, Trentino Alto Adige, Veneto, Friuli Venezia Giulia (con l'eccezione della provincia di Trieste)	25	1000	0,40
2	Emilia Romagna	25	750	0,45
3	Toscana, Marche, Umbria, Lazio, Abruzzo, Molise, Puglia, Campania, Basilicata, Calabria (esclusa la provincia di Reggio Calabria)	27	500	0,37
4	Sicilia e provincia di Reggio Calabria	28	500	0,36
5	Sardegna (zona a oriente della retta congiungente Capo Teulada con l'Isola di Maddalena)	28	750	0,40
6	Sardegna (zona a occidente della retta congiungente Capo Teulada con l'Isola di Maddalena)	28	500	0,36
7	Liguria	28	1000	0,54
8	Provincia di Trieste	30	1500	0,50
9	Isole (con l'eccezione di Sicilia e Sardegna) e mare aperto	31	500	0,32

Ne consegue che la velocità base del vento Vbo = 27 m/s

La velocità media del vento è determinata, in accordo con la sezione 3.3.1 del D. M. 17 gennaio 2018, second la seguente formula:

Vb = Ca x Vbo

Dove

Vbo = 27 m/s per l’inclinazione del tracker = 0°

Vbo = 15 m/s per l’inclinazione del tracker ≠ 0°

Ca è il coefficiente di altitudine pari a 1

$$c_a = 1 \qquad \text{per } a_s \leq a_0$$

$$c_a = 1 + k_s \left(\frac{a_s}{a_0} - 1 \right) \qquad \text{per } a_0 < a_s \leq 1500 \text{ m}$$

Quindi avremo:

Vb = 28 m/s (α = 0°)

Vb = 15 m/s (α ≠ 0°)

La velocità di riferimento del vento è calcolata, secondo la sezione 3.3.2 del D.M. 17 gennaio 2018, secondo la seguente formula:

Vbr = Cr X Vb

dove Cr è il coefficiente di ritorno, calcolato, rispetto ad un periodo di ritorno Tr di 25 anni, secondo la seguente formula:

$$c_r = 0{,}75\sqrt{1 - 0{,}20 \cdot \ln\left[-\ln\left(1 - \frac{1}{T_R}\right)\right]} = 0{,}75\sqrt{1 - 0{,}20 \cdot \ln\left[-\ln\left(1 - \frac{1}{25}\right)\right]} = 0{,}960$$

Quindi avremo:

Vbr = 0,960 x 27 = 25,92 m/s - (α = 0°)

Vbr = 1 x 15 = 15 m/s - (α ≠ 0°)

La pressione cinetica di riferimento è determinata dalla seguente espressione, secondo la sezione 3.3.6 del D.M. 17 gennaio 2018:

$$q_r = \frac{1}{2} \cdot \rho \cdot v_{b,r}^2$$

ρ è la densità dell’aria, calcolata all’altezza di 50 metri sul livello del mare, pari a 1,2 kg/mq

Avremo quindi:

qr = 403 N/mq - (α = 0°)

qr = 135 N/mq - (α ≠ 0°)

Il coefficiente di esposizione dipende dall'altezza della struttura z sopra il terreno e dalla categoria di esposizione del sito in cui si trova la struttura.

$$c_e(z) = k_r^2 c_t \ln(z/z_0)\left[7 + c_t \ln(z/z_0)\right] \quad \text{per } z \geq z_{min}$$
$$c_e(z) = c_e(z_{min}) \quad \text{per } z < z_{min}$$

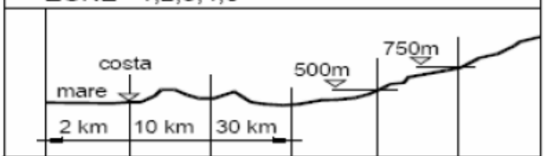
La classe di rugosità dell'intervento può essere considerata la C, un'area a bassa vegetazione come erba e ostacoli isolati.

Tab. 3.3.III - *Classi di rugosità del terreno*

Classe di rugosità del terreno	Descrizione
A	Aree urbane in cui almeno il 15% della superficie sia coperto da edifici la cui altezza media superi i 15 m
B	Aree urbane (non di classe A), suburbane, industriali e boschive
C	Aree con ostacoli diffusi (alberi, case, muri, recinzioni,....); aree con rugosità non riconducibile alle classi A, B, D
D	a) Mare e relativa fascia costiera (entro 2 km dalla costa); b) Lago (con larghezza massima pari ad almeno 1 km) e relativa fascia costiera (entro 1 km dalla costa) c) Aree prive di ostacoli o con al più rari ostacoli isolati (aperta campagna, aeroporti, aree agricole, pascoli, zone paludose o sabbiose, superfici innevate o ghiacciate, ...)

L'assegnazione della classe di rugosità non dipende dalla conformazione orografica e topografica del terreno. Si può assumere che il sito appartenga alla Classe A o B, purché la costruzione si trovi nell'area relativa per non meno di 1 km e comunque per non meno di 20 volte l'altezza della costruzione, per tutti i settori di provenienza del vento ampi almeno 30°. Si deve assumere che il sito appartenga alla Classe D, qualora la costruzione sorga nelle aree indicate con le lettere a) o b), oppure entro un raggio di 1 km da essa vi sia un settore ampio 30°, dove il 90% del terreno sia del tipo indicato con la lettera c). Laddove sussistano dubbi sulla scelta della classe di rugosità, si deve assegnare la classe più sfavorevole (l'azione del vento è in genere minima in Classe A e massima in Classe D).

ZONE 1,2,3,4,5



	2 km	10 km	30 km	500m	750m	
A	- -	IV	IV	V	V	V
B	- -	III	III	IV	IV	IV
C	- -	*	III	III	IV	IV
D	I	II	II	II	III	**

* Categoria II in zona 1,2,3,4
Categoria III in zona 5

** Categoria III in zona 2,3,4,5
Categoria IV in zona 1

I parametri per il calcolo di ce, per il sito con categoria di esposizione III e con un fattore topografico uguale a ct = 1, sono riportati nella tabella seguente:

Tab. 3.3.II - *Parametri per la definizione del coefficiente di esposizione*

Categoria di esposizione del sito	K_r	z_0 [m]	z_{min} [m]
I	0,17	0,01	2
II	0,19	0,05	4
III	0,20	0,10	5
IV	0,22	0,30	8
V	0,23	0,70	12

Pertanto, il valore del coefficiente di esposizione è

$$c_e = k_r^2 c_t \ln\left(\frac{z}{z_0}\right)\left[7 + c_t \ln\left(\frac{z}{z_0}\right)\right] = 0{,}20^2 \ln\left(\frac{5}{0.1}\right)\left[7 + \ln\left(\frac{5}{0.1}\right)\right] = 1{,}708$$

Il coefficiente dinamico Cd è determinato in riferimento al fattore CsCd.

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I fattori strutturali Cs e Cd dovrebbero tenere conto dell'effetto sulle azioni del vento derivante dal verificarsi non simultaneo di picchi di pressione del vento sulla superficie insieme all'effetto delle vibrazioni della struttura dovute alla turbolenza. Il fattore strutturale CsCd può essere separato in un fattore dimensionale (cs) e un fattore dinamico (cd), in base al capitolo 6.3.1.

Il calcolo del fattore strutturale CsCd è stato eseguito mediante l'uso di un foglio Excel, come di seguito descritto.

Calculation of the structural factor c_s*c_d - for upwind (α=0°)

Geometrical and mechanical characteristics

	III	= Terrain category
zs=	4,450	(m) reference height of the structure
z_0=	0,1	(m)
z_{min}=	5	(m)
V_m=	**26,89**	**(m/s) mean wind velocity**
ρ=	1,2070	(Kg/m³) air density
C_f=	**0,20**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	65	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0,256	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha} \quad \text{for} \quad z \ge z_{min}$$
$$L(z) = L(z_{min}) \quad \text{for} \quad z < z_{min}$$

$L(z)$	38,742	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n\cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8\cdot f_L(z,n)}{(1+10{,}2\cdot f_L(z,n))^{5/3}}$	0,0383	non dimensional power spectral density
T=	**0,21**	**Fundamental period of the structure**
n=	4,76	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n\cdot L(z)}{v_m(z)}$	6,861	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9\cdot\left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0,636	background factor
b=	**14,432**	**(m) length tracker - see fig.6.1**
h=	**4,432**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}}$	3,683	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0,796	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2\cdot\delta}\cdot S_L(z_s,n_{1,x})\cdot R_h(\eta_h)\cdot R_b(\eta_b)$	0,018	Resonance response factor
$\eta_h = \frac{4{,}6\cdot h}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	3,610	
$\eta_b = \frac{4{,}6\cdot b}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	11,756	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0,239	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0,081	

Calculation logarithmic decrement of damping

δ_s=	0,05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f\cdot\rho\cdot b\cdot v_m(z_s)}{2\cdot n_1\cdot m_e}$	0,15	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	0,201	logaritmic decrement of damping

Structural factor cd*cs

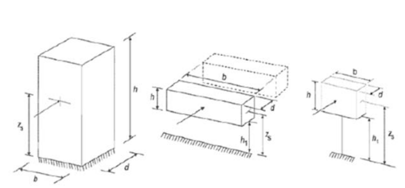
$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0,905**

BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc.

b) parallel oscillator, i.e. horizontal structures such as beams etc.

c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6\cdot h \ge z_{min}$ $\qquad$ $z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad$ $z_s = h_1 + \frac{h}{2} \ge z_{min}$

6.3.1 Structural factor c_sc_d

(1) The detailed procedure for calculating the structural factor c_sc_d is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_sc_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in c_sc_d using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

- the structure corresponds to one of the general shapes shown in Figure 6.1,
- only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

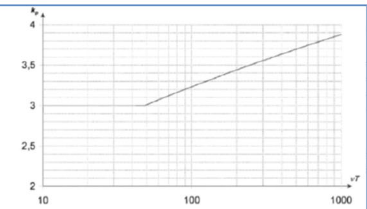


Figure B.2 —Peak factor

$$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

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
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for downwind (α=0°)

Geometrical and mechanical characteristics

	III	= Terrain category
zs=	4,450	(m) reference height of the structure
z_0=	0,1	(m)
z_{min}=	5	(m)
V_m=	**26,89**	**(m/s) mean wind velocity**
ρ=	1,2070	(Kg/m³) air density
C_f=	**0,50**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	65	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0,256	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	38,742	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0,0383	non dimensional power spectral density
T=	**0,21**	**Fundamental period of the structure**
n=	4,76	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	6,861	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0,636	background factor
b=	**14,432**	**(m) length tracker - see fig.6.1**
h=	**4,432**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	3,582	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0,550	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2\cdot\delta} \cdot S_L(z_s, n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$	0,009	Resonance response factor
$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	3,610	
$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	11,756	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0,239	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0,081	

Calculation logarithmic decrement of damping

δ_s=	0,05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$	0,38	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	0,428	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2\cdot k_p \cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0,886**

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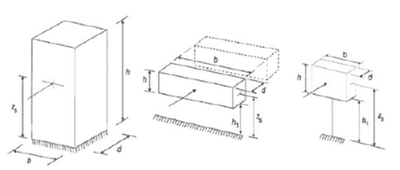
a) vertical structures such as buildings etc.
b) parallel oscillator, i.e. horizontal structures such as beams etc.
c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6 \cdot h \ge z_{min}$ $\qquad$ $z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad$ $z_s = h_1 + \frac{h}{2} \ge z_{min}$

6.3.1 Structural factor $c_s c_d$

(1) The detailed procedure for calculating the structural factor $c_s c_d$ is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1+2\cdot k_p \cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p \cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in $c_s c_d$ using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

– the structure corresponds to one of the general shapes shown in Figure 6.1.

– only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

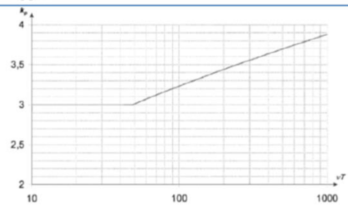


Figure B.2 —Peak factor

$$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

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
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,014
steel stack with two or more liners with external thermal insulation [a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for upwind (α=30°)

Geometrical and mechanical characteristics

	III	= Terrain category
zs=	4,450	(m) reference height of the structure
z_0=	0,1	(m)
z_{min}=	5	(m)
V_m=	**15**	**(m/s) mean wind velocity**
ρ=	1,2070	(Kg/m^3) air density
C_f=	**1,200**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	65	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0,256	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_l}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_l is the turbulence factor. The value of k_l may be given in the National Annex. The recommended value for k_l is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	38,742	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0,0263	non dimensional power spectral density
T=	**0,21**	**Fundamental period of the structure**
n=	4,76	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	12,299	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9\cdot\left(\frac{b+h}{L(z_s)}\right)^{0,63}}$	0,636	background factor
b=	**14,432**	**(m) length tracker - see fig.6.1**
h=	**4,432**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2\cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2\cdot \ln(\nu\cdot T)}}$	3,335	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0,234	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2\cdot\delta}\cdot S_L(z_s,n_{1,x})\cdot R_h(\eta_h)\cdot R_b(\eta_b)$	0,002	Resonance response factor
$\eta_h = \frac{4{,}6\cdot h}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	6,472	
$\eta_b = \frac{4{,}6\cdot b}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	21,075	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0,143	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0,046	

Calculation logarithmic decrement of damping

δ_s=	0,05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f\cdot\rho\cdot b\cdot v_m(z_s)}{2\cdot n_1\cdot m_e}$	0,51	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	0,557	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0,847**

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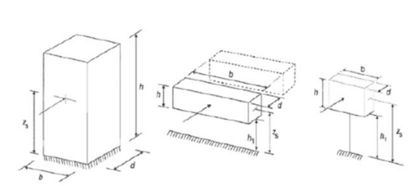
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc. b) parallel oscillator, i.e. horizontal structures such as beams etc. c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6\cdot h \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$

6.3.1 Structural factor c_sc_d

(1) The detailed procedure for calculating the structural factor c_sc_d is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_sc_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in c_sc_d using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

– the structure corresponds to one of the general shapes shown in Figure 6.1,

– only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

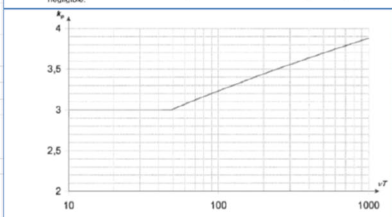


Figure B.2 —Peak factor

$$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

ν is the up-crossing frequency given in (4)

T is the averaging time for the mean wind velocity, T = 600 seconds.

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

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
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for downwind (α=30°)

Geometrical and mechanical characteristics

	III	= Terrain category
zs=	4,450	(m) reference height of the structure
z_0=	0,1	(m)
z_{min}=	5	(m)
V_m=	**15**	**(m/s) mean wind velocity**
ρ=	1,2070	(Kg/m^3) air density
c_f=	**1,800**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	65	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0,256	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_l}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_l is the turbulence factor. The value of k_l may be given in the National Annex. The recommended value for k_l is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	38,742	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0,0263	non dimensional power spectral density
T=	**0,21**	**Fundamental period of the structure**
n=	4,76	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	12,299	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0,63}}$	0,636	background factor
b=	**14,432**	**(m) length tracker - see fig.6.1**
h=	**4,432**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0{,}6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	3,279	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0,194	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_L(z_s,n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$	0,001	Resonance response factor
$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s,n_{1,x})$	6,472	
$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s,n_{1,x})$	21,075	
$R_h = \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2}(1-e^{-2\cdot\eta_h})$	0,143	
$R_b = \frac{1}{\eta_b} - \frac{1}{2 \cdot \eta_b^2}(1-e^{-2\cdot\eta_b})$	0,046	

Calculation logarithmic decrement of damping

δ_s=	0,05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$	0,76	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	0,810	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s)}$	**0,838**

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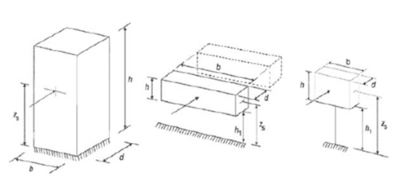
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc. | b) parallel oscillator, i.e. horizontal structures such as beams etc. | c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6 \cdot h \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$

6.3.1 Structural factor c_sc_d

(1) The detailed procedure for calculating the structural factor c_sc_d is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_sc_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7 \cdot I_v(z_s) \cdot \sqrt{B^2}}{1+7 \cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s) \cdot \sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in c_sc_d using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

- the structure corresponds to one of the general shapes shown in Figure 6.1,
- only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

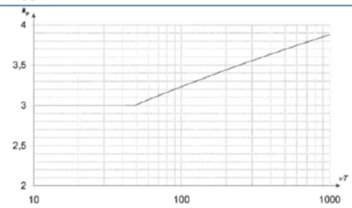


Figure B.2 —Peak factor

$$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0{,}6}{\sqrt{2 \cdot \ln(\nu \cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

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
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for upwind (α=55°)

1,41

	III	= Terrain category
zs=	4,450	(m) reference height of the structure
z_0=	0,1	(m)
z_{min}=	5	(m)
V_m=	**15**	**(m/s) mean wind velocity**
ρ=	1,2070	(Kg/m³) air density
C_f=	**1,410**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	65	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0,256	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_0(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_0 is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	38,742	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0,0263	non dimensional power spectral density
T=	**0,21**	**Fundamental period of the structure**
n=	4,76	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	12,299	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0,636	background factor
b=	**14,432**	**(m) length tracker - see fig.6.1**
h=	**4,432**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0{,}6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	3,313	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0,217	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_L(z_s,n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$	0,001	Resonance response factor
$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s,n_{1,x})$	6,472	
$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s,n_{1,x})$	21,075	
$R_h = \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2}(1-e^{-2\cdot\eta_h})$	0,143	
$R_b = \frac{1}{\eta_b} - \frac{1}{2 \cdot \eta_b^2}(1-e^{-2\cdot\eta_b})$	0,046	

Calculation logarithmic decrement of damping

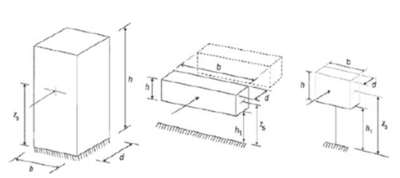
δ_s=	0,05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$	0,60	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	0,645	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s)}$	**0,843**

BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc. — b) parallel oscillator, i.e. horizontal structures such as beams etc. — c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6 \cdot h \ge z_{min}$ — $z_s = h_1 + \frac{h}{2} \ge z_{min}$ — $z_s = h_1 + \frac{h}{2} \ge z_{min}$

6.3.1 Structural factor $c_s c_d$

(1) The detailed procedure for calculating the structural factor $c_s c_d$ is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7 \cdot I_v(z_s) \cdot \sqrt{B^2}}{1+7 \cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s) \cdot \sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in $c_s c_d$ using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

– the structure corresponds to one of the general shapes shown in Figure 6.1,

– only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

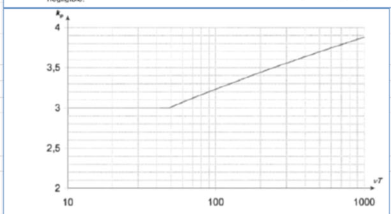


Figure B.2 —Peak factor

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$ or k_p= 3 whichever is larger

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

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
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for downwind (α=55°)

Geometrical and mechanical characteristics

	III	= *Terrain category*
zs=	4,450	*(m) reference height of the structure*
z_0=	0,1	*(m)*
z_{min}=	5	*(m)*
V_m=	**15**	**(m/s) mean wind velocity**
ρ=	1,2070	(Kg/m³) air density
C_f=	**1,755**	**force coefficient for the structure (Section 7)**
c_0=	1	*orography factor*
Massa del 1° modo	65	*(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.*
Iv=	0,256	*turbulence intensity*

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha} \quad \text{for} \quad z \ge z_{min}$$
$$L(z) = L(z_{min}) \quad \text{for} \quad z < z_{min}$$

	38,742	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0,0263	non dimensional power spectral density
T=	**0,21**	**Fundamental period of the structure**
n=	4,76	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	12,299	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1 + 0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0,636	background factor
b=	**14,432**	**(m) length tracker - see fig.6.1**
h=	**4,432**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	3,282	
T=	600	*(sec) is the averaging time for the mean wind velocity*
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2 + R^2}}$	0,196	*is the up-crossing frequency*
$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_L(z_s, n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$	0,001	Resonence response factor
$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	6,472	
$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	21,075	
$R_h = \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2}(1 - e^{-2\cdot\eta_h})$	0,143	
$R_b = \frac{1}{\eta_b} - \frac{1}{2 \cdot \eta_b^2}(1 - e^{-2\cdot\eta_b})$	0,046	

Calculation logarithmic decrement of damping

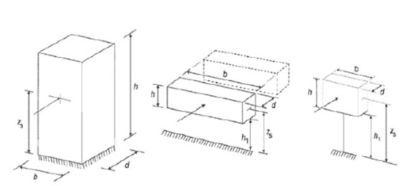
δ_s=	0,05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$	0,74	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	0,791	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s)}$	**0,839**

BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc. b) parallel oscillator, i.e. horizontal structures such as beams etc. c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6 \cdot h \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$

6.3.1 Structural factor $c_s c_d$

(1) The detailed procedure for calculating the structural factor $c_s c_d$ is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1 + 7 \cdot I_v(z_s) \cdot \sqrt{B^2}}{1 + 7 \cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s) \cdot \sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in $c_s c_d$ using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

– the structure corresponds to one of the general shapes shown in Figure 6.1,

– only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

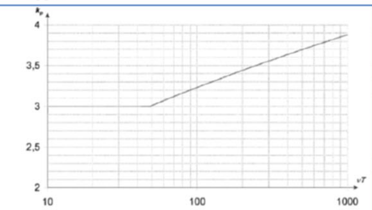


Figure B.2 —Peak factor

$$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

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
unlined welded steel stacks without external thermal insulation		0.012
unlined welded steel stack with external thermal insulation		0.020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Il coefficiente di pressione Cp dipende dalla tipologia e dalla geometria della costruzione e dal suo orientamento rispetto alla direzione del vento.

Il coefficiente d’attrito cf dipende dalla scabrezza della superficie sulla quale il vento esercita l’azione tangente.

Entrambi questi coefficienti, definiti coefficienti aerodinamici, possono essere ricavati da dati suffragati da opportuna documentazione o da prove sperimentali in galleria del vento.

La condizione $\phi=1$ è sostanzialmente diversa da quella prevista per gli edifici in quanto l’eventuale ostruzione può essere offerta anche da elementi che non delimitano completamente e permanentemente lo spazio al di sotto della tettoia.

A valle della massima ostruzione si adotta $\phi=0$.

Le azioni aerodinamiche esercitate dal vento sulle tettoie dipendono fortemente dal grado di bloccaggio in quanto la presenza di un’ostruzione, anche soltanto sul lato sottovento, impedisce il passaggio dell’aria al di sotto della tettoia.

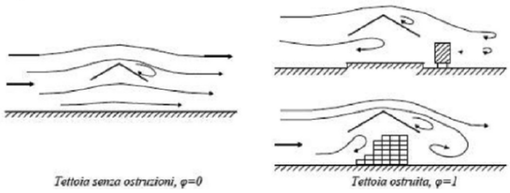


Figura C3.3.20 - *Differenze nel flusso dell’aria per tettoie con $\phi=0$ e $\phi=1$*

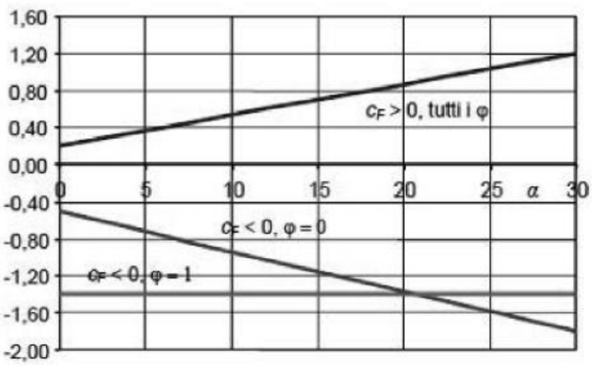


Figura C3.3.21 - *Coefficienti di pressione complessiva per tettoie a semplice falda*

Tabella C3.3.XV - *Coefficienti di forza per tettoie a semplice falda (α in °).*

Valori positivi	Tutti i valori di φ	$c_F = +0,2 + \alpha/30$
Valori negativi	φ = 0	$c_F = -0,5 - 1,3 \cdot \alpha/30$
	φ = 1	$c_F = -1,4$

Model A, α=0°

- $c_{pn,+0°} = 0{,}2 + \alpha/30 = +0{,}20$ *upwind*
- $c_{pn,-0°} = -0{,}5 - 1{,}3 \cdot \alpha/30 = -0{,}50$ *downwind*

Model B, α=30°

- $c_{pn,+30°} = 0{,}2 + \alpha/30 = +1{,}20$ *upwind*
- $c_{pn,-30°} = -0{,}5 - 1{,}3 \cdot \alpha/30 = -1{,}80$ *downwind*

Il calcolo della pressione del vento è determinato secondo la Sezione 3.3.4 del D.M. 17 gennaio 2018 - Norme Tecniche per le Costruzioni, basato sulla seguente espressione:

$$P_{w,\alpha} = q_{r,\alpha} \cdot c_e \cdot c_d \cdot c_{pn,\alpha}$$

Pertanto, le condizioni di carico sono:

Model A, α=0°

- $P_{w,+0°} = q_{r,+0°} \cdot c_e \cdot c_s c_d \cdot c_{pn,+0°} = 436 \cdot 1{,}708 \cdot 0{,}905 \cdot 0{,}20 = 135\ N/m^2$ .. (upwind);
- $P_{w,-0°} = q_{r,-0°} \cdot c_e \cdot c_s c_d \cdot c_{pn,-0°} = -436 \cdot 1{,}708 \cdot 0{,}886 \cdot 0{,}5 = -330\ N/m^2$ (downwind);

Model B, α=30°

- $P_{w,+30°} = q_{r,+30°} \cdot c_e \cdot c_s c_d \cdot c_{pn,+30°} = 136 \cdot 1 \cdot 0{,}847 \cdot 1{,}20 = 138\ N/m^2$..... (upwind);
- $P_{w,-30°} = q_{r,-30°} \cdot c_e \cdot c_s c_d \cdot c_{pn,-30°} = -136 \cdot 1 \cdot 0{,}838 \cdot 1{,}8 = -205\ N/m^2$. (downwind);

Model C, α=55°

- $P_{w,+55°} = q_{r,+55°} \cdot c_e \cdot c_s c_d \cdot c_{pn,+55°} = 136 \cdot 1 \cdot 0{,}843 \cdot 1{,}410 = 161\ N/m^2$... (upwind);
- $P_{w,-55°} = q_{r,-55°} \cdot c_e \cdot c_s c_d \cdot c_{pn,-55°} = -136 \cdot 1 \cdot 0{,}839 \cdot 1{,}755 = -200\ N/m^2$ (downwind);

I tecnici:

Arch. Gianluca Francavilla

Ing. Piero Farenti