EUROCODES
SPREADSHEETS
Structural Design
Carlo Sigmund

TRYOUT - November 2015

User's Guide

to Excel® spreadsheet file
Verification tests
EN 1991-1-4: Eurocode 1

Edited and published by:
Carlo Sigmund

This document is made available only to allow proper validation of the mathematical calculations carried out on spreadsheets. Therefore, this document is not intended to replace or interpret the parts of the standard to which it refers, and which are mentioned herein, nor does it constitute a stand-alone document.

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Eurocodes - Structural Design

The sponsoring editor for this document and the production supervisor was Carlo Sigmund.

Electronic mail: carlo.sigmund@sigmundcarlo.net

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Bridge: Erasmus Bridge
Location: Rotterdam, Netherlands
Length/ main span: 802 m/284 m
Pylon: 139 m
Designer: Architects Ben van Berkel, Freek Loos, UN Studio.

Note: The pages of this document were created electronically using Inkscape 0.48

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Section 1

Eurocode 1
EN 1991-1-4
Section 7 (Page 61 to 65)

1.1 Free-standing walls, parapets, fences and signboards

For free-standing walls and parapets resulting pressure coefficients $c_{p,net}$ should be specified for the zones A, B, C and D as shown in Figure 7.19.

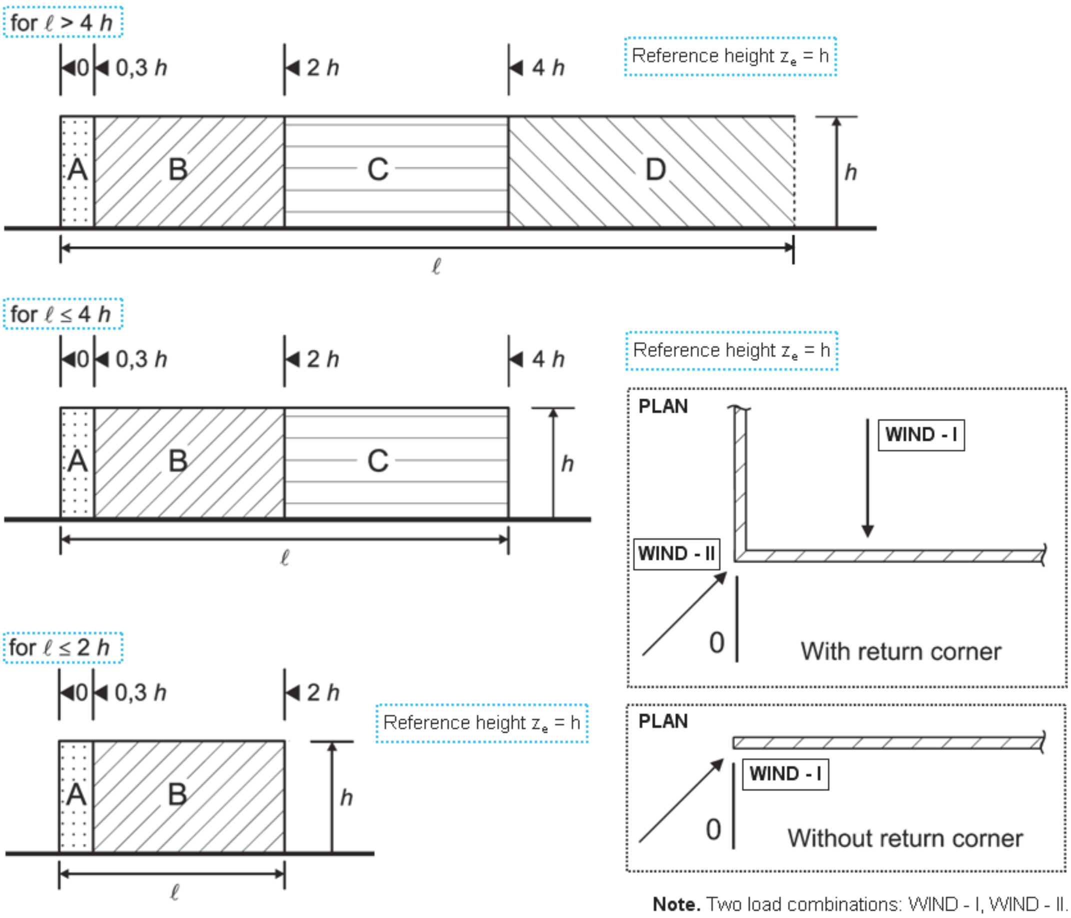

Figure 1.1 From Figure 7.19 [modified] - Key to zones of free-standing walls and parapets.

The values of the resulting pressure coefficients $c_{p,net}$ for free-standing walls and parapets depend on the solidity ratio φ. For solid walls the solidity φ should be taken as 1, and for walls which are 80% solid (i.e. have 20% openings) $\varphi = 0{,}8$. Porous walls and fences with a solidity ratio $\varphi \leq 0{,}8$ should be treated as plane lattices in accordance with 7.11.

Values of the resulting pressure coefficients $c_{p,net}$ for free-standing walls and parapets may be given in the National Annex. Recommended values are given in Table 7.9 for two different solidity ratio. These recommended values correspond to a direction of oblique wind compared to the wall without return corner (see Figure 7.19) and, in the case of the wall with return corner, to the two opposite directions indicated in Figure 7.19 (modified)[1]. The reference area in both cases is the gross area. Linear interpolation may be used for solidity ratio between 0,8 and 1.

Solidity	Zone		A	B	C	D
$\varphi = 1$	with return corners	$l/h \leq 3$	2,3	1,4	1,2	1,2
		$l/h = 5$	2,9	1,8	1,4	1,2
		$l/h \geq 10$	3,4	2,1	1,7	1,2
	with return corners of length ≥ h[a]		2,1	1,8	1,4	1,2
$\varphi = 0{,}8$			1,2	1,2	1,2	1,2

Table 1.1 Recommended pressure coefficients $c_{p,net}$ for free-standing walls and parapets.

(a). Linear interpolation may be used for return corner lengths between 0,0 and h.

The reference height for free standing walls and fences should be taken as $z_e = h$, see Figure 7.19. The reference height for parapets on buildings should be taken as $z_e = (h + h_p)$, see Figure 7.6.

1.2 Shelter factors for walls and fences

If there are other walls or fences upwind that are equal in height or taller than the wall or fence of height, h, under consideration, then an additional shelter factor can be used with the net pressure coefficients for walls and lattice fences. The value of the shelter factor ψ_s depends on the spacing between the walls or fences x, and the solidity φ, of the upwind (sheltering) wall or fence. Values of ψ_s are given in Figure 7.20. The resulting net pressure coefficient on the sheltered wall, $c_{p,net,s}$, is given by:

$$c_{p,\,net,\,s} = \psi_s \cdot c_{p,\,net} \,. \qquad \text{(Eq. 1-1)}$$

(1) See "WIND-I" and "WIND-II".

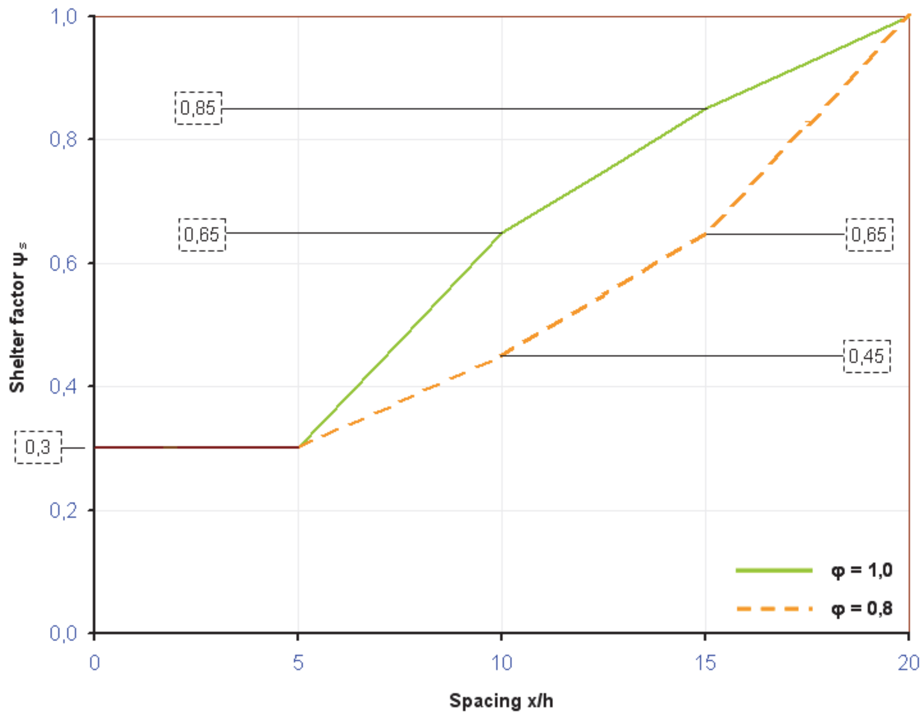

Figure 1.2 From Figure 7.20 - Shelter factor ψ_s for walls and fences for φ-values between 0,8 and 1,0.

The shelter factor should not be applied in the end zones within a distance of h measured from the free end of the wall. In addition, no advantage from shelter should be taken on parts of the downwind wall which extend beyond the projected ends of the upwind wall.

1.3 Signboards

For signboards separated from the ground by a height z_g greater than h/4 (see Figure 7.21) or less than h/4 with $b/h \leq 1$, the force coefficients are given by Expression (7.7):

$$c_f = 1,80 . \qquad \textbf{(Eq. 1-2)}$$

The resultant force normal to the signboard should be taken to act at the height of the centre of the signboard with a horizontal eccentricity “e”. The value of the horizontal eccentricity e may be given in the National Annex. The recommended value is:

$$e = \pm 0,25 \cdot b . \qquad \textbf{(Eq. 1-3)}$$

⚠ Signboards separated from the ground by a height z_g less than h/4 and with $b/h > 1$ should be treated as boundary walls, see 7.4.1. Divergence or stall flutter instabilities should be checked.

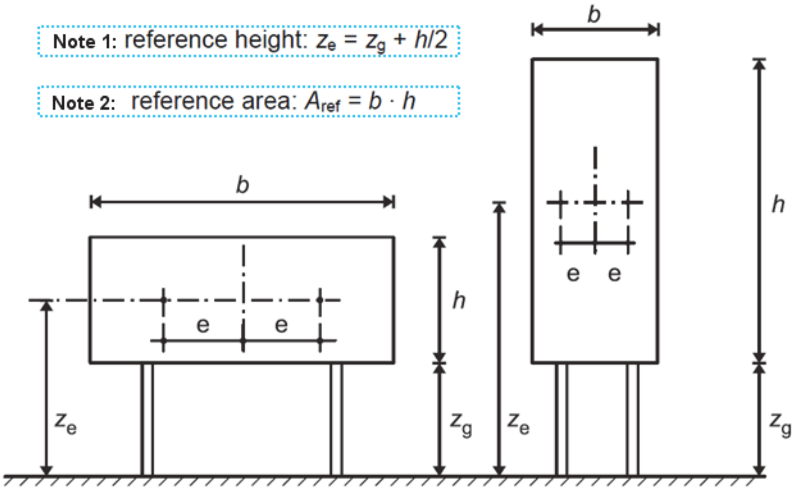

Figure 1.3 From Figure 7.21 - Key for signboards.

1.4 Friction coefficients

Friction should be considered for the cases defined in 5.3(3). Friction forces can arise when the wind blows parallel to external surfaces such as walls or roofs. Friction coefficients c_{fr}, for walls and roof surfaces are given in Table 7.10. The

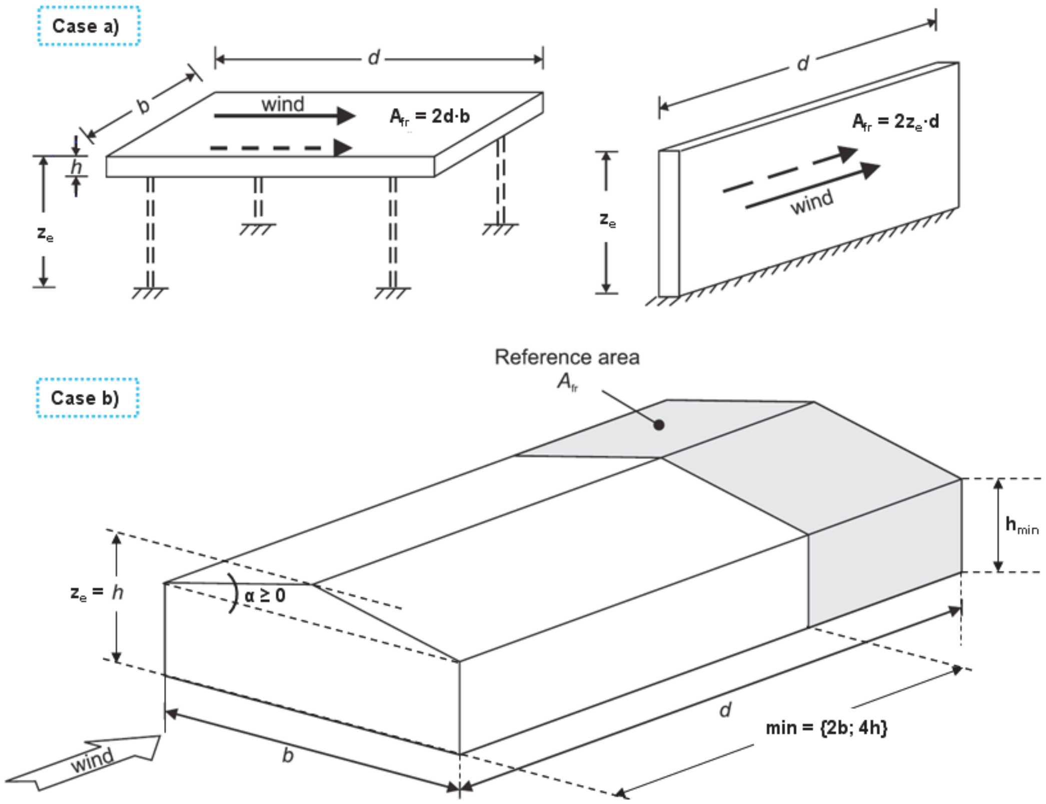

Figure 1.4 From Figure 7.22 [modified]- Reference area for friction.

reference area A_{fr} is given in Figure 7.22. Friction forces should be applied on the part of the external surfaces parallel to the wind, located beyond a distance from the upwind eaves or corners, equal to the smallest value of 2b or 4h.

Surface	Friction coefficient c_{fr}
Smooth (i.e. steel, smooth concrete)	0,01
Rough (i.e. rough concrete, tar-boards)	0,02
very rough (i.e. ripples, ribs, folds)	0,04

Table 1.2 From Table 7.10 - Frictional coefficients c_{fr} for walls, parapets and roof surfaces.

The reference height z_e should be taken equal to the structure height above ground or building height "h", see Figure 7.22.

1.5 Verification tests

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— Splash
— CodeSec7(61to64)
— CodeSec7(64to65).

EXAMPLE 1-A- Free-standing walls and parapets - Sec. 7.4.1 - **test1**

Given: A free standing wall with return corner is given. Height of the free standing wall h = 4,00 m. Length of the free standing wall L = 3,50 m. Solidity ratio $\varphi = 0,85$. According to Table 7.9, find the recommended pressure coefficients $c_{p,net}$.

[*Reference sheet:* CodeSec7(61to64)]-[*Cell-Range: A1:O1-A78:O78*].

Solution: We have: 0,3h = 1,20 m; 2h = 8,00 m; 4h = 16,00 m; L/h = 3,50/4,00 = 0,88 (rounded value). Solidity $0,8 < \varphi < 1$ with return corners and $0 < L < h$: linear interpolation between 0,0 and h. From Table 7.9: $\varphi = 0,8$ with $c_{p,net}$ = 1,2 (zones A, B, C, D), $\varphi = 1$ with return corners of length $\geq$ h with $c_{p,net}$ = 2,1 (zone A); 1,8 (zone B); 1,4 (zone C); 1,2 (zone D).

Case with L $\leq$ 2h applies (see Figure 7.18): only the zones A and B. Linear interpolation between 0,0 and h = 4,00 m with $\varphi = 1$ and L = 3,50 m:

$$\frac{2,1-0}{4-0} = \frac{c_{p,\,net}-0}{3,50-0} \quad \rightarrow \quad c_{p,\,net} = 1,8375 \approx 1,84 \text{ (zone } \mathbf{A} \text{ with } \varphi = 1\text{)}$$

$$\frac{1,8-0}{4-0} = \frac{c_{p,\,net}-0}{3,50-0} \quad \rightarrow \quad c_{p,\,net} = 1,575 \approx 1,58 \text{ (zone } \mathbf{B} \text{ with } \varphi = 1\text{).}$$

For zone A linear interpolation between $\varphi = 0,8$ with $c_{p,net}$ = 1,2 and $\varphi = 1$ with $c_{p,net}$ = 1,84:

$$\frac{1,84-1,2}{1,0-0,8} = \frac{c_{p,\,net}-1,2}{0,85-0,80} \quad\rightarrow\quad c_{p,\,net} = 1,36\,.$$

For zone B linear interp. between $\varphi = 0,8$ with $c_{p,net}$ = 1,2 and $\varphi = 1$ with $c_{p,net}$ = 1,58:

$$\frac{1,58-1,2}{1,0-0,8} = \frac{c_{p,\,net}-1,2}{0,85-0,80} \quad\rightarrow\quad c_{p,\,net} = 1,295 \approx 1,30\,.$$

The reference height for free standing walls should be taken as z_e = h = 4,00 m, see Figure 7.19.

example-end

EXAMPLE 1-B- Shelter factors for walls and fences - Sec. 7.4.2 - **test2**

Given: A wall upwind taller than the wall of height h = 4,00 m considered in the previous example is given. The solidity φ of the upwind sheltering wall is equal to 0,9. The spacing between the walls is x ≤ 40,00 m. Find the resulting pressure coefficient $c_{p,net,s}$ on the sheltered wall.

[*Reference sheet:* CodeSec7(61to64)]-[*Cell-Range: A82:O82-A144:O144*].

Solution: Height of wall under consideration: h = 4,00 m. Therefore: x/h = (40,00)/(4,00) = 10. From Figure 7.20 - "*Shelter factor ψ_s for walls and fences for φ-values between 0,8 and 1,0*":
$\psi_s = 0,65$ for $\varphi = 1$ with x/h = 10; $\psi_s = 0,45$ for $\varphi = 0,8$ with x/h = 10.

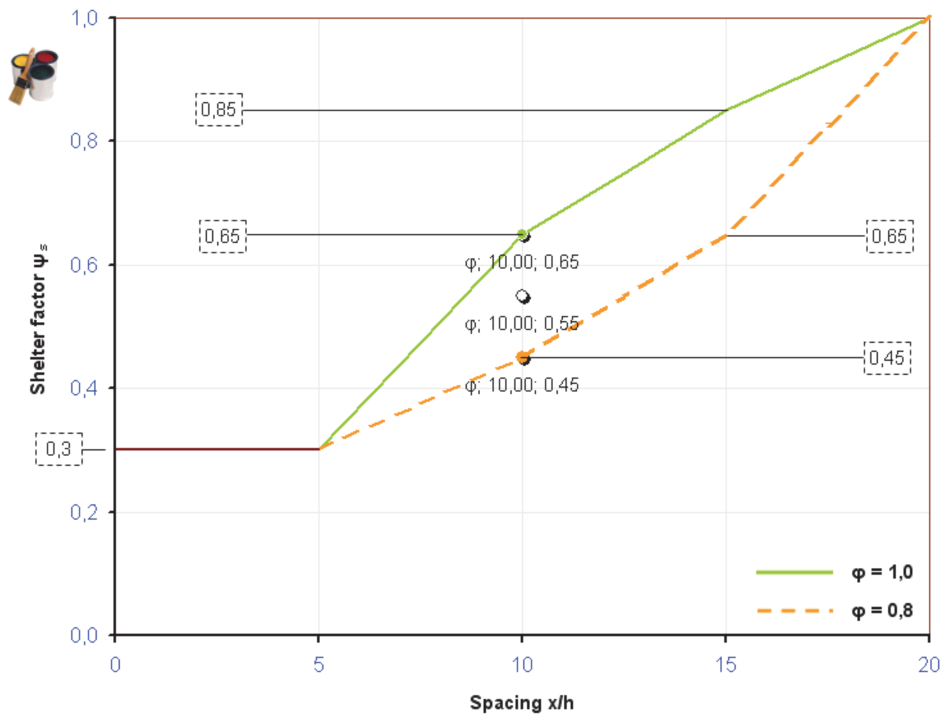

Figure 1.5 From Excel® output.

Linear interpolation (sheltering wall with $\varphi = 0,9$) for $0,8 < \varphi < 1$:
$\psi_s = (0,65 + 0,45)/2 = 0,55$.

From previous example we have (case with $L \leq 2h$ applies): $c_{p,net}$ = 1,36 (zone A); 1,30 (zone B). Therefore the resulting net pressure coefficients are:

$c_{p,net,s} = \psi_s \cdot c_{p,net} = 0,55 \cdot 1,36 = 0,75$ (zone A);

$c_{p,net,s} = \psi_s \cdot c_{p,net} = 0,55 \cdot 1,30 = 0,72$ (zone B).

⚠ The shelter factors should not be applied in the end zones within a distance of h measured from the free end of the wall.

example-end

EXAMPLE 1-C- Signboards - Sec. 7.4.3 - **test3**

Given: A signboard separated from the ground by a height z_g = 2,00 m is given. The dimension of the signboard are h = 10,00 m (height), b = 3,00 (width). The peak velocity pressure at the reference height $z_e = z_g + 0,5h = 7,00$ m is $q_p(z_e) = 1,50$ kN/m². Calculate the shear and bending reaction at the base of the structure.

[*Reference sheet:* CodeSec7(61to64)]-[*Cell-Range: A149:O149-A253:O253*].

Solution: Reference area: $A_{ref} = b \cdot h = (3,00) \cdot (10,00) = 30,00$ m². Case 2 applies with:

$z_g < h/4 \rightarrow 2,00 < (10,00/4) = 2,50$

$b/h \leq 1 \rightarrow 3,00/10,00 = 0,30 \leq 1$.

Therefore, we have $c_f = 1,80$ and $e = \pm 0,25b = \pm 0,25 \cdot (3,00) = \pm 0,75$ m.

Shear and bending reactions acting at the base of the structure

$F_w = c_s \cdot c_d \cdot q_p(z_e) \cdot c_f \cdot A_{ref} = c_s \cdot c_d \cdot 1,50 \cdot 1,80 \cdot 30,00 = c_s \cdot c_d \cdot 81,00$ kN.

$M_{wV} = F_w \cdot e = \pm(c_s \cdot c_d \cdot 81,00) \times 0,75 = \pm c_s \cdot c_d \cdot 60,75$ kNm.

$M_{wH} = F_w \cdot z_e = \pm(c_s \cdot c_d \cdot 81,00) \times 7,00 = \pm c_s \cdot c_d \cdot 567,00$ kNm.

example-end

EXAMPLE 1-D- Friction coefficients - Sec. 7.5 - **test4**

Given: A simple rectangular building with duopitch roof is given. The dimensions of the building are: ridge height h = z_e = 6,00 m, gutter height h_{min} = 2,00 m, width b = 15,00 m (crosswind dimension) and depth d = 30,00 m. Find the frictional force considering a lack of correlation of wind pressures.

[*Reference sheet:* CodeSec7(64to65)]-[*Cell-Range: A1:O1-A128:O128*].

Solution: Pitch roof angle:

$$\frac{h - h_{min}}{0,5b} = \tan\alpha = \frac{4,00}{7,50} \approx 0,53 \rightarrow \alpha \approx 28° \rightarrow \cos\alpha \approx 0,88 .$$

Substituting the given numerical data we obtain:

$\min\{2b; 4h\} = \min\{2 \cdot (15,00); 4 \cdot (6,00)\} = 24,00\ m$,

$d - \min\{2b; 4h\} = 30,00 - 24,00 = 6,00\ m$,

$A_{fr} = 2[d - \min\{2b; 4h\}] \cdot (h_{min} + 0,5b/\cos\alpha) = 2 \cdot (6,00) \cdot [2,00 + 0,5 \cdot (15,00)/(0,88)]$

$A_{fr} = 126,00\ m^2$.

With a peak velocity pressure (say) $q_p(z_e) = 1,50\ kN/m^2$ and a frictional coefficient $c_{fr} = 0,02$, we get:

$F_{fr} = c_{fr} \cdot q_p(z_e) \cdot A_{fr} = 0,02 \cdot 1,50 \cdot 126,00 = 3,78\ kN$,

$F_{fr}/A_{fr} = c_{fr} \cdot q_p(z_e) = 0,02 \cdot 1,50 = 0,03\ kN/m^2$.

⚠ In the summation of the wind forces acting on building structures, the lack of correlation of wind pressures between the windward and leeward sides may be taken into account. The lack of correlation of wind pressures between the windward and leeward side may be considered as follows. For buildings with $h/d \geq 5$ the resulting force is multiplied by 1. For buildings with $h/d \leq 1$, the resulting force is multiplied by 0,85. For intermediate values of h/d, linear interpolation may be applied.

Building with $h/d = 6,00/30,00 = 0,20 \rightarrow h/d \leq 1$. Therefore, the resulting frictional force should be multiplied by $\xi = 0,85$:

$F_{fr} = 0,85 \cdot (3,78) = 3,21\ kN$;

$F_{fr}/A_{fr} = c_{fr} \cdot q_p(z_e) \cdot \xi = 0,02 \cdot 1,50 \cdot 0,85 = 0,0255\ kN/m^2$.

example-end

EXAMPLE 1-E- Free-standing walls and parapets - Wind actions (Sec. 5.3 - Eq. (5.3)) - **test5**

Given: Using the same data given in the Example 1-A, find the wind forces acting on the free-standing wall. Let us assume the following assumptions:

– peak velocity pressure at the reference height $z_e = h = 4,00\ m$: $q_p(z_e) = 600\ N/m^2$

– structural factor (as defined in Sec. 6): $c_s c_d = 1,0$.

[*Reference sheet:* CodeSec7(61to64)]-[*Cell-Range: A1:O1-A78:O78*].

Solution: From Example 11-V we have:

Case with $L \leq 2h$ (see Figure 7.18).

Linear interpolation from Table 7.9 with solidity ratio equal to $\varphi = 0,85$ [-]:

– Zone **A**: $c_{p,\,net} = 1,36$

– Zone **B**: $c_{p,\,net} = 1,30$.

From Figure 7.19 - "*Key to zones of free-standing walls and parapets*" (case $L \leq 2h$), we get:

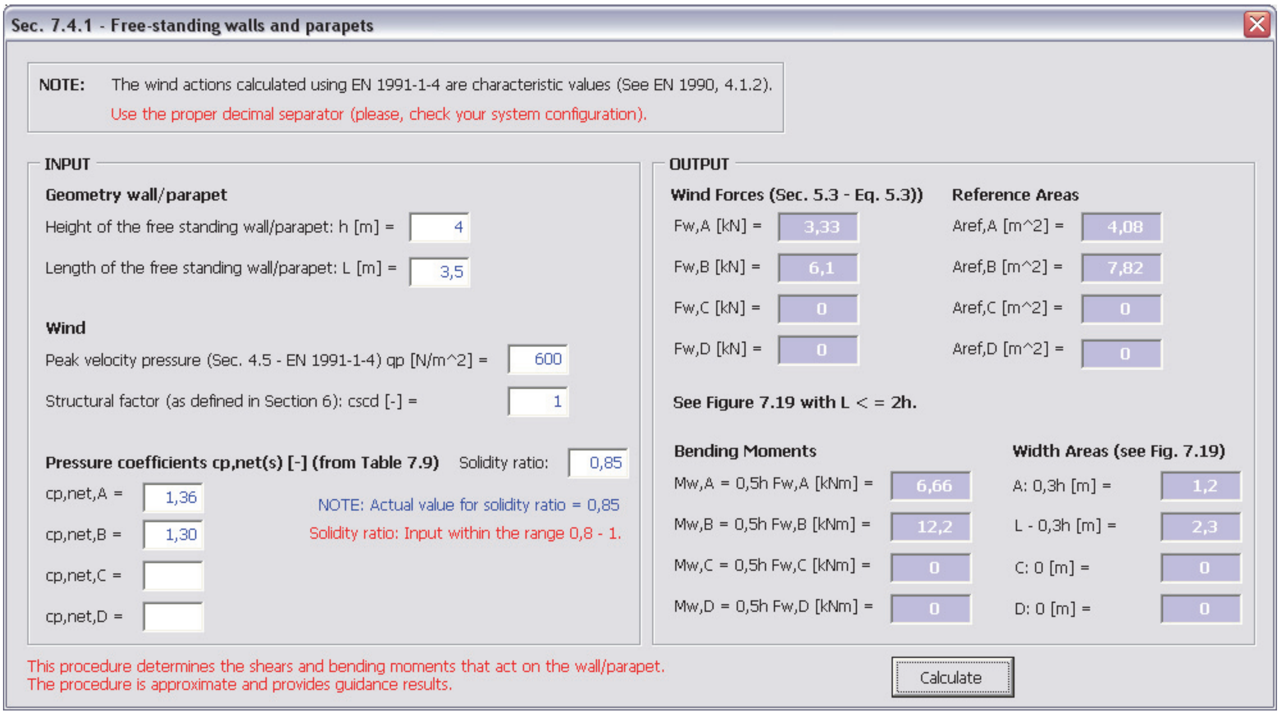

Figure 1.6 PreCalculus Excel® form: procedure for a quick pre-calculation.

Zone A: $0,3h = 0,3 \cdot (4,00) = 1,20 \text{ m}$ with

$A_{ref,\,A} = \varphi \cdot 0,3h^2 = 0,85 \cdot 0,3 \cdot (4,00)^2 = 4,08 \text{ m}^2$ (rounded value),

Zone **B**: $L - 0,3h = 3,50 - 0,3 \cdot (4,00) = 2,30 \text{ m}$ with

$A_{ref,\,B} = \varphi \cdot (L - 0,3 \cdot h) \cdot h = 0,85 \cdot [3,50 - 0,3 \cdot (4,00)] \cdot 4,00 = 7,82 \text{ m}^2$ (rounded value),

Shear and bending reactions acting at the base of the structure

Zone A

$$F_{w,\,A} = c_s c_d \cdot q_p(z_e) \cdot c_{p,\,net} \cdot A_{ref,\,A} = 1,0 \cdot 0,60 \cdot 1,36 \cdot 4,08 = 3,33 \text{ kN}.$$

$$M_{wA} = F_{w,\,A} \cdot 0,5h = (3,33) \times 2,00 = 6,66 \text{ kNm}.$$

Zone B

$$F_{w,\,B} = c_s c_d \cdot q_p(z_e) \cdot c_{p,\,net} \cdot A_{ref,\,B} = 1,0 \cdot 0,60 \cdot 1,30 \cdot 7,82 = 6,10 \text{ kN}.$$

$$M_{wB} = F_w \cdot 0,5h = (6,10) \times 2,00 = 12,20 \text{ kNm}.$$

example-end

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1.6 References [Section 1]

EN 1991-1-4:2005/A1:2010. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, April 2010.

EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, March 2005 (DAV).

Manual for the design of building structures to Eurocode 1 and Basis of Structural Design, April 2010. © 2010 The Institution of Structural Engineers.

Section 2 **Eurocode 1**
EN 1991-1-4
Section 7 (Page 76 to 78)

2.1 Lattice structures and scaffoldings

The force coefficient, c_f, of lattice structures and scaffoldings with parallel chords should be obtained by Expression (7.25):

$$c_f = c_{f,0} \cdot \psi_\lambda \quad \textbf{(Eq. 2-4)}$$

where:

- $c_{f,0}$ is the force coefficient of lattice structures and scaffoldings without end-effects. It is given by Figures 7.33 to 7.35 as a function of solidity ratio ρ (Sec. 7.11 Eq. (2)) and Reynolds number Re
- Re is the Reynolds number using the average member diameter b_i, see Note below
- ψ_λ is the end-effect factor (see Sec. 7.13) as a function of the slenderness of the structure, λ, calculated with "l" and width $b = d$, see Figure 7.32.

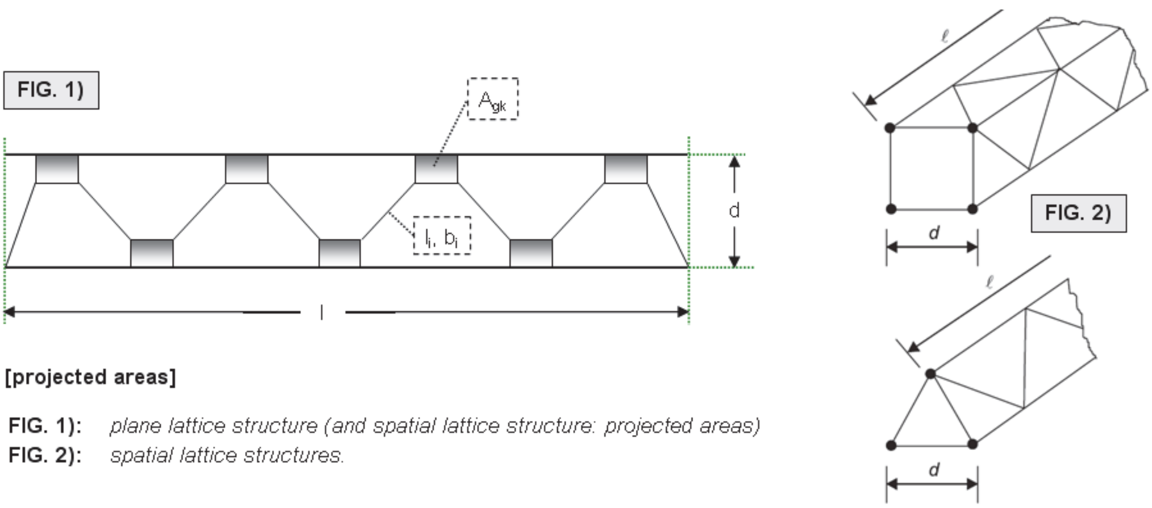

Figure 2.7 From Figure 7.32 - Lattice structure or scaffolding.

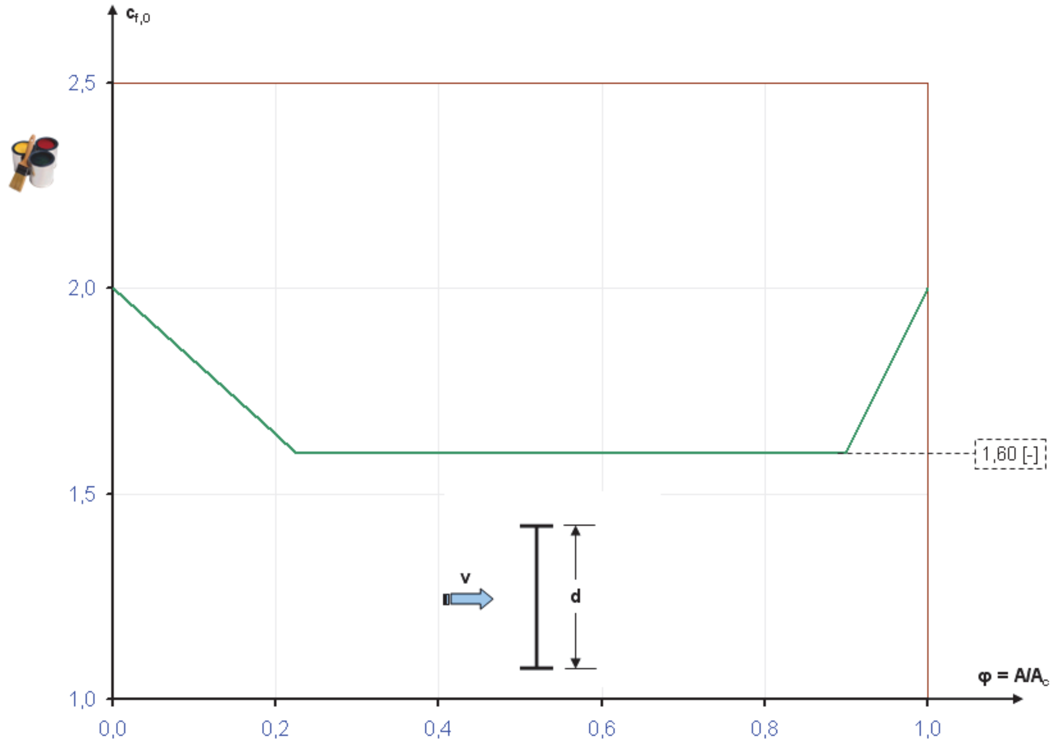

Figure 2.8 From Figure 7.33 - Force coefficient $c_{f,0}$ for a plane lattice structure with angle members as a function of solidity ratio ρ.

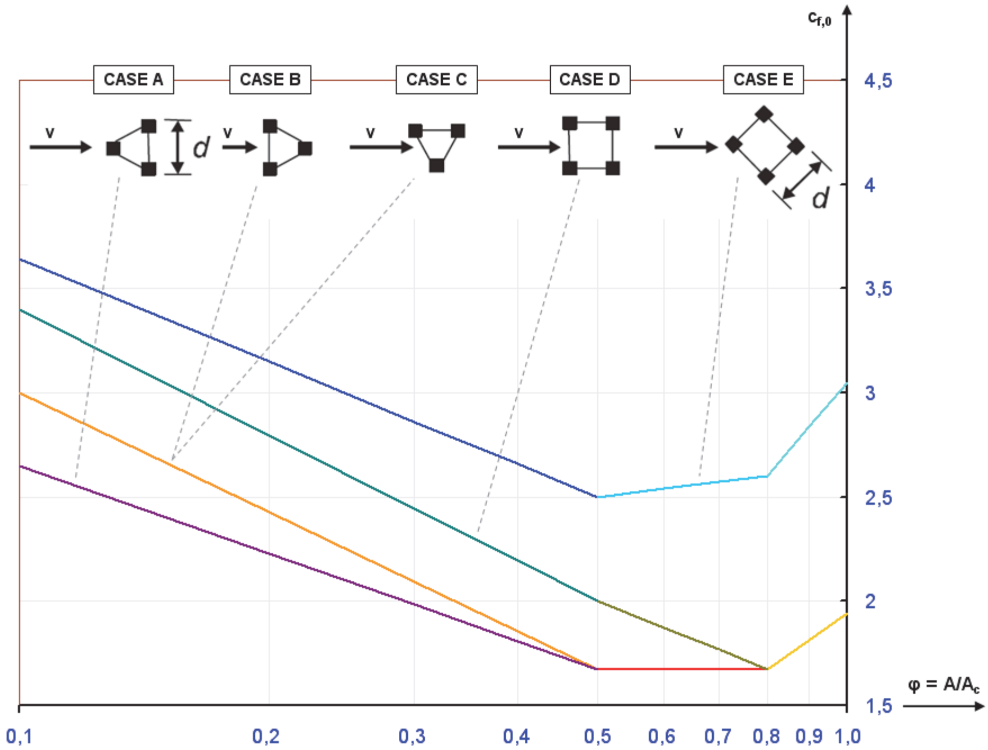

Figure 2.9 From Figure 7.34 - Force coefficient $c_{f,0}$ for a spatial lattice structure with angle members as a function of solidity ratio ρ.

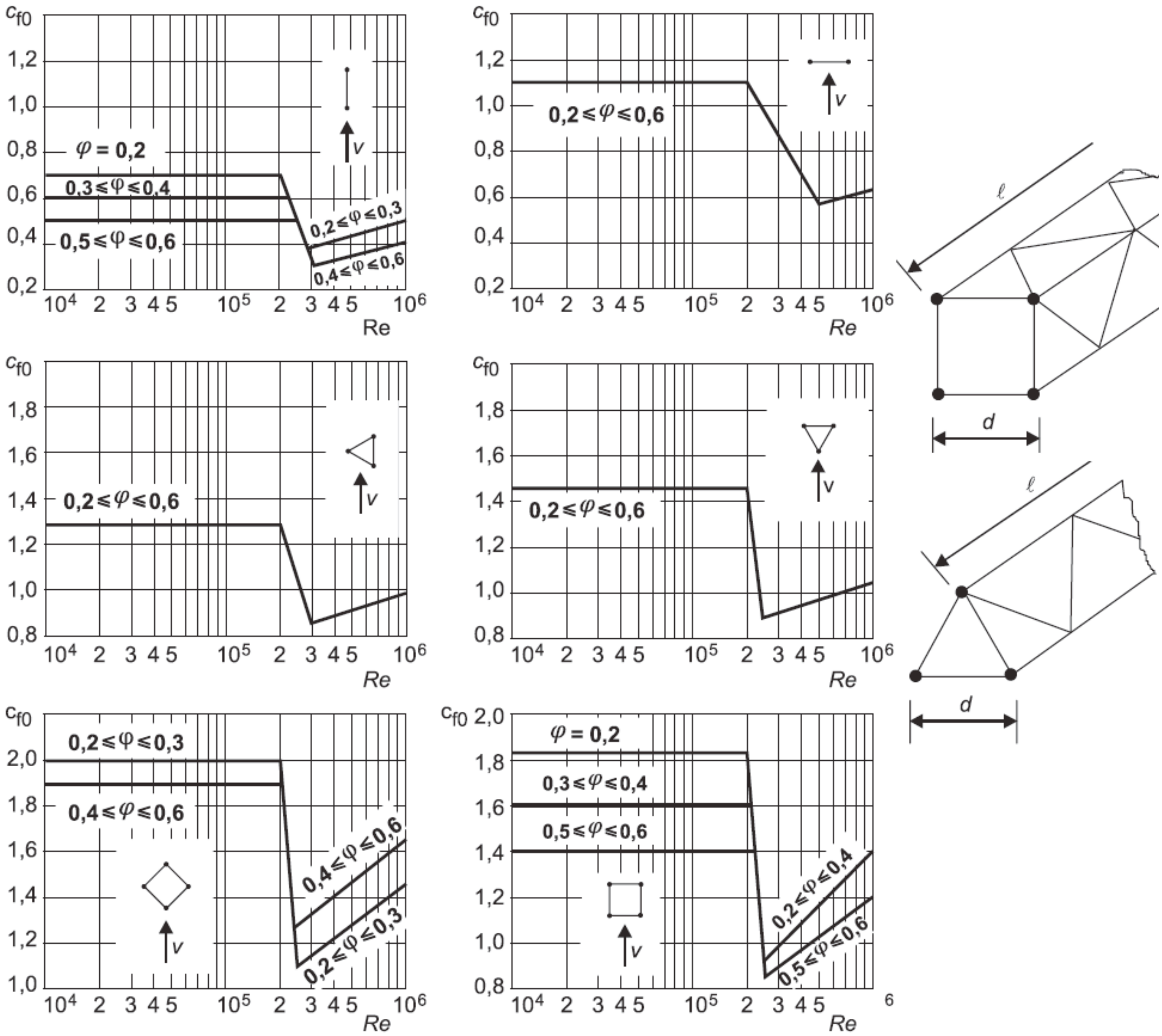

Figure 2.10 From Figure 7.35 - Force coefficient cf,0 for plane and spatial lattice structure with members of circular cross-section.

Note Figure 7.35 is based on the Reynolds number with:

$$v = \sqrt{(2 \cdot q_p)/\rho}$$

and q_p given in EN 1991-1-4 - Sec. 4.5. ρ $[kg/m^3]$ is the density of air.
The National Annex may give a reduction factor for scaffolding without air tightness devices and affected by solid building obstruction. A recommended value is given in prEN 12811.

The solidity ratio, ρ, is defined by Expression (7.26):

$$\rho = A/A_c \qquad \text{(Eq. 2-5)}$$

where:

- A is the sum of the projected area of the members and gusset plates of the face projected normal to the face:

$$A = \sum_i b_i \cdot l_i + \sum_k A_{gk} \qquad \text{(Eq. 2-6)}$$

- A_c is the area enclosed by the boundaries of the face projected normal to the face: $A_c = d \cdot l$
- l is the length of the lattice
- d is the width of the lattice
- b_i, l_i is the width and length of the members "i" (see Figure 7.32), projected normal to the face)
- A_{gk} is the area of the *k-th* gusset plates, projected normal to face.

The reference area A_{ref} should be directly determined by Expression:

$$A_{ref} = A \approx n \cdot (\overline{b_i} \cdot \overline{l_i}) + N \cdot \overline{A}_{gk} \qquad \text{(Eq. 2-7)}$$

where:

- $\overline{b_i}$ is the average width of the members (projected normal to face)
- $\overline{l_i}$ is the average length of the members (projected normal to face)
- n and N are the number of member "i" and of gusset plate (projected normal to face) respectively
- $\overline{A}_{gk}$ is the (average) area of the gusset plates, (projected normal to face).

Important The reference height is equal to the maximum height of the element above ground.

2.2 Verification tests

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— Splash

— CodeSec7(76to78).

EXAMPLE 2-F- Lattice structures and scaffoldings - Sec. 7.11 - Fig. 7.33 and 7.34 - **test1**

Given: Find the wind force F_w acting on a lattice structure using the Expression (5.3) - EN 1991-1-4. Let us assume the following assumptions:

– width of the lattice: $d = 1000$ mm

– length of the lattice: $l = 16000$ mm

– average Area gusset plate (projected normal to the face): $\overline{A}_{gk} = 120000\ mm^2$
– average width of the member "i" (projected normal to the face): $\overline{b_i} = 80\ mm$
– average length of the member "i" (projected normal to the face): $\overline{l_i} = 1300\ mm$
– number of member "i" (projected normal to the face): $n = 48$
– cross section of the elements of the structure: **not circular**
– number of gusset plate (projected normal to the face): $N = 30$
– peak velocity pressure (as defined in Sec. 4.5 - EN 1991-1-4): $q_p(z_e) = 1,50\ kN/m^2$
– air density: $\rho = 1,226\ kg/m^3$
– structural factor (as defined in Section 6): $c_s c_d = 1,1$
– end-effect factor for elements with free-end flow: $\psi_\lambda = 0,90$.
[*Reference sheet:* CodeSec7(76to78)]-[*Cell-Range: A1:O1-A205:O205*].

Solution: Reference area:

$$A_{ref} = \sum_i b_i \cdot l_i + \sum_k A_{gk} \approx n \cdot (\overline{b_i} \cdot \overline{l_i}) + N \cdot \overline{A}_{gk} = 48 \cdot [(80) \cdot (1300)] + 30 \cdot 120000$$

$A = A_{ref} \approx 8,59 \times 10^6\ mm^2 = 8,59\ m^2$ (rounded value).

Solidity ratio with $A_c = d \cdot l = (1000) \cdot (16000) = 1,60 \times 10^7\ mm^2$:

$\rho = A/A_c = (8,59 \times 10^6)/(1,60 \times 10^7) = 0,537 \approx 0,54\ [-]$.

PLANE LATTICE STRUCTURE. From Figure 7.33 - "*Force coefficient $c_{f,0}$ for a plane lattice structure with angle members as a function of solidity ratio ρ*" with $\rho = 0,54\ [-]$ we have $c_{f,0} = 1,60\ [-]$. The force coefficient (Eq. 7.25) is $c_f = c_{f,0} \cdot \psi_\lambda = 1,60 \cdot 0,90 = 1,44\ [-]$. Therefore, assuming $c_s c_d = 1,1$ and $q_p(z_e) = 1,50\ kN/m^2$ (with the reference height z_e equal to the maximum height above ground of the section being considered), the wind force F_w acting on the plane lattice structural element is (Eq. 5.3 - EN 1991-1-4):

$F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} = 1,10 \cdot 1,44 \cdot 1,50 \cdot 8,59 = 20,41\ kN$ (rounded value).

$F_w/A_{ref} = (20,41)/(8,59) = 2,38\ kN/m^2$, $F_w/l = (20,41)/(16,00) = 1,28\ kN/m$.

SPATIAL LATTICE STRUCTURE. From Figure 7.34 - "*Force coefficient $c_{f,0}$ for a spatial lattice structure with angle members as a function of solidity ratio ρ*", assuming the CASE "A", "B" or "C" (see Figure below) we have $c_{f,0} = 1,68\ [-]$.

The force coefficient (Eq. 7.25) is $c_f = c_{f,0} \cdot \psi_\lambda = 1,68 \cdot 0,90 = 1,51\ [-]$. The wind force F_w acting on the spatial lattice structural element is (Eq. 5.3 - EN 1991-1-4):
(rounded value).

$$F_w = \frac{1,51}{1,44} \cdot (20,41\ kN) = 21,40\ kN \text{ (rounded value) with:}$$

$F_w/A_{ref} = (21,40)/(8,59) = 2,49\ kN/m^2$, $F_w/l = (21,40)/(16,00) = 1,34\ kN/m$.

example-end

EXAMPLE 2-G- Lattice structures: plane/spatial latice structure - circular cross-section - Fig. 7.35 - **test2**

Given: Find the wind force F_w acting on a spatial lattice structure of square section with members of circular cross-section. Let us assume the same geometry assumptions from the previous example.

Note. The influence of neighbouring structures on the wind velocity may influence the Reynolds number value with a variation by ±10%.

[*Reference sheet:* CodeSec7(76to78)]-[*Cell-Range: A207:O207-A421:O421*].

Solution: Peak wind velocity (as defined in Note 2 of Figure 7.27 @ height z_e):

$$v(z_e) = \sqrt{\frac{2 \cdot q_p(z_e)}{\rho}} = \sqrt{\frac{2 \cdot (1500\ \mathrm{N/m^2})}{(1,226\ \mathrm{kg/m^3})}} = 49,5\ \mathrm{m/s}.$$

Reynolds number (as defined in Expression 7.15), using the average member diameter $\overline{b_i} = 80\ \mathrm{mm}$:

$$Re = \frac{\overline{b_i} \cdot v(z_e)}{\nu} = \frac{(0,08\ \mathrm{m}) \cdot (49,5\ \mathrm{m/s})}{(15 \times 10^{-6}\ \mathrm{m^2/s})} = 2,64 \times 10^5\ [-].$$

Solidity ratio with $A_c = d \cdot l = (1000) \cdot (16000) = 1,60 \times 10^7\ \mathrm{mm^2}$:

$\rho = A/A_c = (8,59 \times 10^6)/(1,60 \times 10^7) = 0,537 \approx 0,54\ [-]$. Entering Figure 7.35 with $Re = 2,64 \times 10^5\ [-]$ and $0,5 \le \rho \le 0,6$ we find: $c_{f,0} = 0,87\ [-]$ (see Figure below):

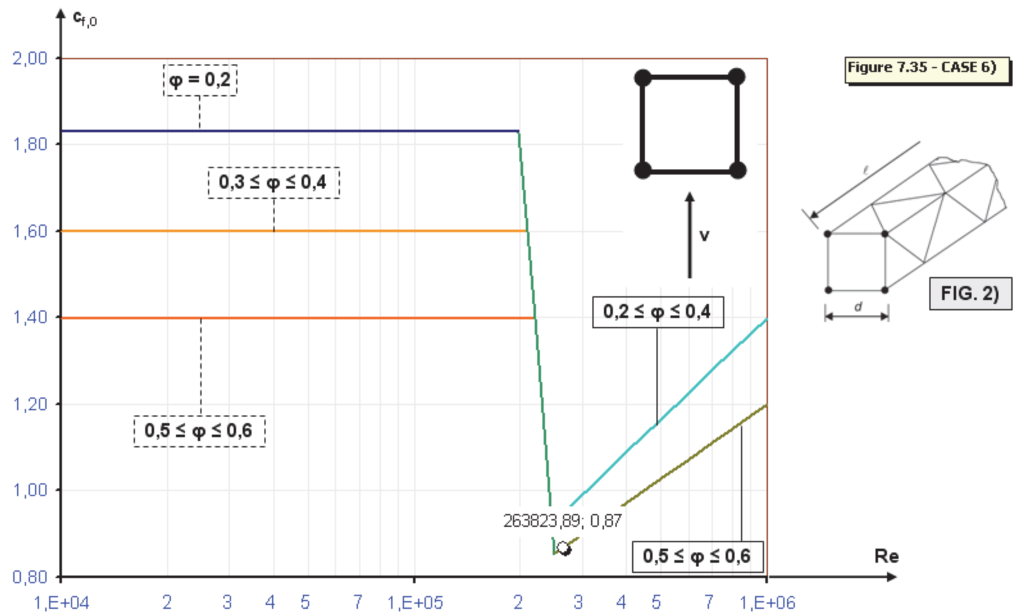

Figure 2.11 From Figure 7.35 - Force coefficient $c_{f,0}$ for plane and spatial lattice structure with members of circular cross-section [with Re from Eq. (7.15) and $0,5 \le \rho \le 0,6$].

Assigning to the Reynolds number a variation of +10% we obtain: $c_{f,0} = 0,89$ [-] (see Figure below):

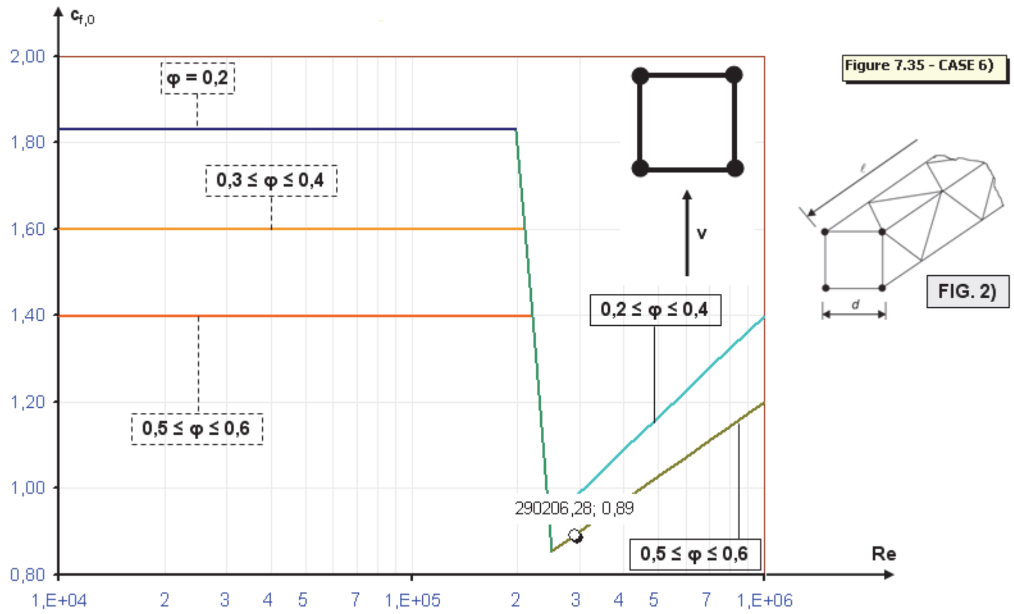

Figure 2.12 From Figure 7.35 - Force coefficient $c_{f,0}$ for plane and spatial lattice structure with members of circular cross-section [for 1,10 x Re with Re from Eq. (7.15) and 0,5 ≤ ρ ≤ 0,6]

Assigning to the Reynolds number a variation of –10% we obtain: $c_{f,0} = 1,07$ [-] (see Figure below):

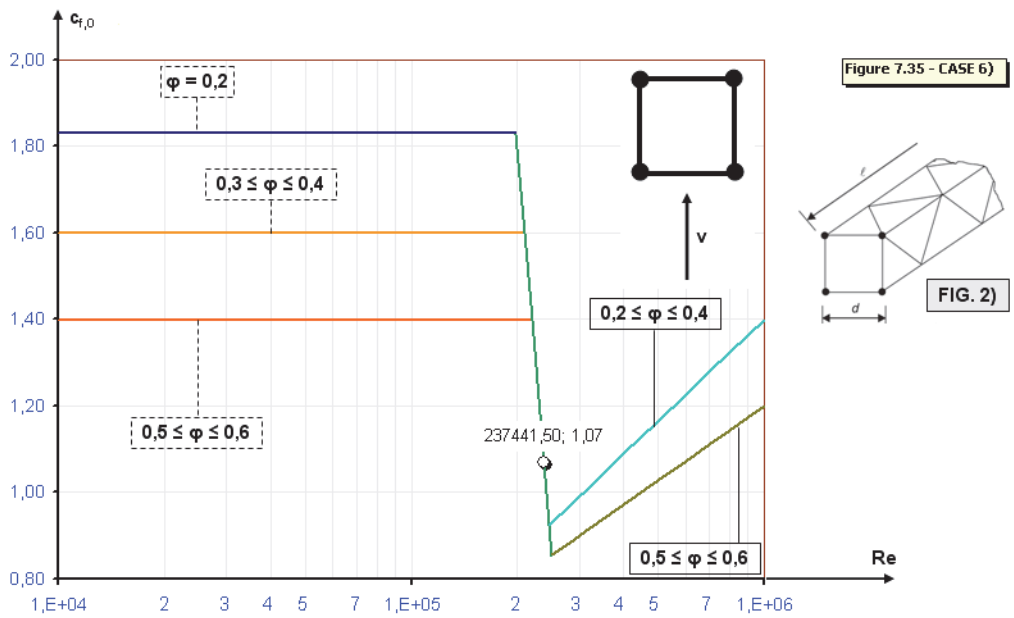

Figure 2.13 From Figure 7.35 - Force coefficient $c_{f,0}$ for plane and spatial lattice structure with members of circular cross-section [for 0,90 x Re with Re from Eq. (7.15) and 0,5 ≤ ρ ≤ 0,6]

The most unfavourable case for the safety is the second: $c_{f,0} = 1,07$ [-] . The force coefficient (Eq. 7.25) is $c_f = c_{f,0} \cdot \psi_\lambda = 1,07 \cdot 0,90 = 0,96$ [-] .

Therefore, assuming $c_s c_d = 1,1$ and $q_p(z_e) = 1,50\ kN/m^2$ (with the reference height z_e equal to the maximum height above ground of the section being considered), the wind force F_w acting on the plane lattice structural element is (Eq. 5.3 - EN 1991-1-4):

$F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} = 1,10 \cdot 0,96 \cdot 1,50 \cdot 8,59 = 13,61\ kN$ (rounded value).

$F_w / A_{ref} = (13,61)/(8,59) = 1,58\ kN/m^2$, $F_w / l = (13,61)/(16,00) = 0,85\ kN/m$.

example-end

2.3 References [Section 2]

EN 1991-1-4:2005/A1:2010. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, April 2010.

EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, March 2005 (DAV).

Guide for the assessment of wind actions and effects on structures. National Research Council of Italy. CNR-DT 207/2008. ROMA – CNR June 11th, 2010.

Section 3 Eurocode 1 EN 1991-1-4 Section 8 (Page 82 to 90)

3.1 Wind actions on bridges

3.1.1 General

This section only applies to bridges of constant depth and with cross-sections as shown in Figure 8.1 consisting of a single deck with one or more spans. Wind actions for other types of bridges (e.g. arch bridges, bridges with suspension cables or cable stayed, roofed bridges, moving bridges and bridges

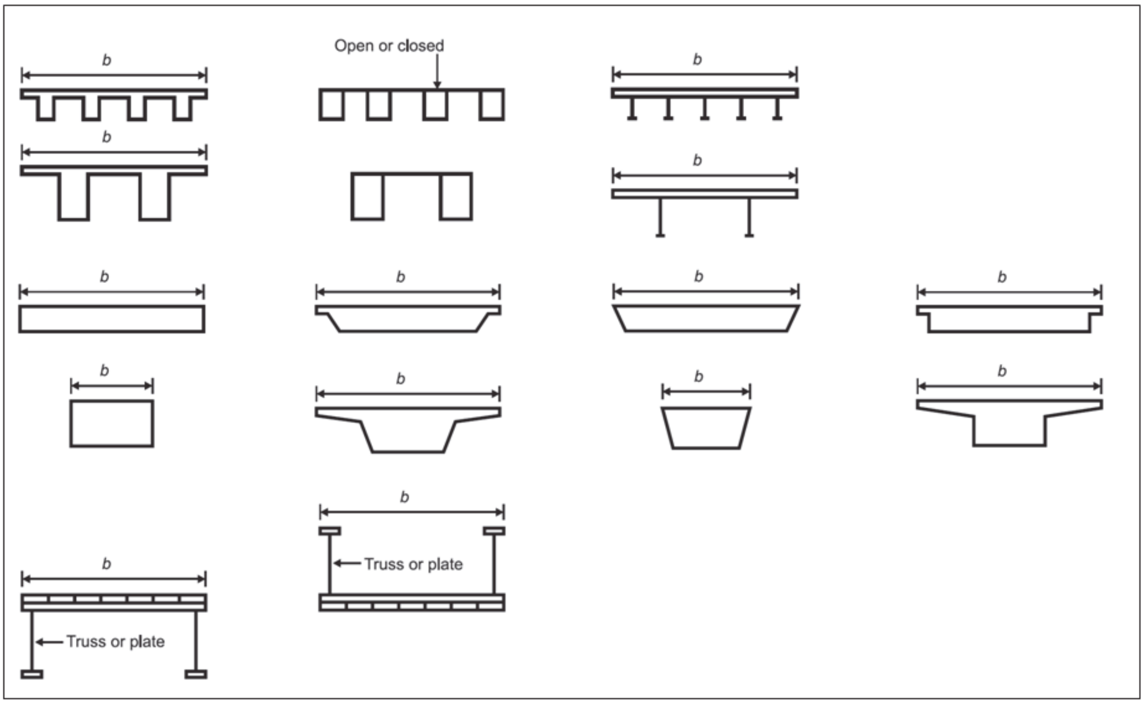

Figure 3.14 From Figure 8.1 - Cross-sections of normal construction decks.

with multiple or significantly curved decks) may be defined in the National Annex. The angle of the wind direction to the deck axis in the vertical and horizontal planes may be defined in the National Annex.

The wind forces exerted on various parts of a bridge (deck and piers) due to wind blowing in the same direction should be considered as simultaneous if they are unfavourable. Wind actions on bridges produce forces in the x, y and z directions as shown in Figure 8.2, where:

— x-direction is the direction parallel to the deck width, perpendicular to the span

— y-direction is the direction along the span

— z-direction is the direction perpendicular to the deck.

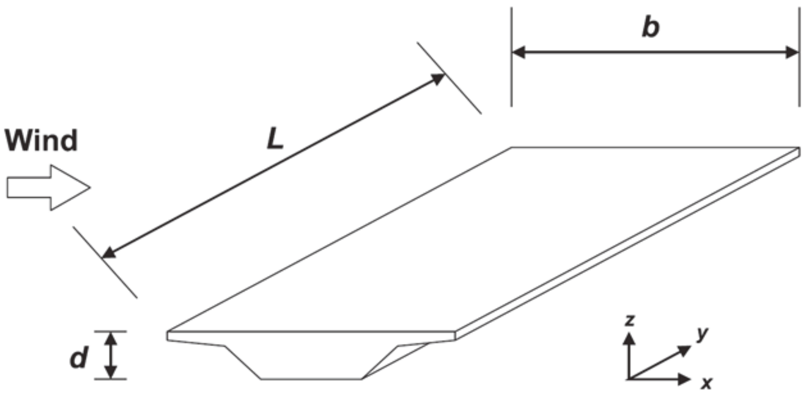

Figure 3.15 From Figure 8.2 - DIrections of wind actions on bridges.

The forces produced in the x- and y-directions are due to wind blowing in different directions and normally are not simultaneous. The forces produced in the z-direction can result from the wind blowing in a wide range of directions; if they are unfavourable and significant, they should be taken into account as simultaneous with the forces produced in any other direction.

Note The notation used for bridges differs from that in 1.7. The following notations (see Figure 8.2 above) are used for bridges:

– L length in y-direction

– b width in x-direction

– d depth in z-direction.

The values to be given to "L", "b" and "d" in various cases are, where relevant, more precisely defined in various clauses. When Sections 5 to 7 are referred to, the notations for "b" and "d" need to be readjusted.

3.1.2 Choice of the response calculation procedure

For normal road and railway bridge decks of less than L = 40 m span a dynamic response procedure is generally not needed. For the purpose of this categorization, normal bridges may be considered to include bridges constructed in steel, concrete, aluminium or timber, including composite construction, and whose shape of cross sections is generally covered by Figure 8.1. If a dynamic response procedure is not needed, $c_s c_d$ may be taken equal to 1,0. The National Annex may give criteria and procedures.

3.2 Force coefficients

3.2.1 Force coefficients in x-direction (general method)

Force coefficients for parapets and gantries on bridges should be determined were relevant. The National Annex may give force coefficients for parapets and gantries on bridges. It is recommended to use Section 7.4. Force coefficients for wind actions on bridge decks in the x-direction are given by:

$$c_{f,x} = c_{fx,0} \qquad \textbf{(Eq. 3-8)}$$

where $c_{fx,0}$ is the force coefficient without free-end flow (see 7.13).

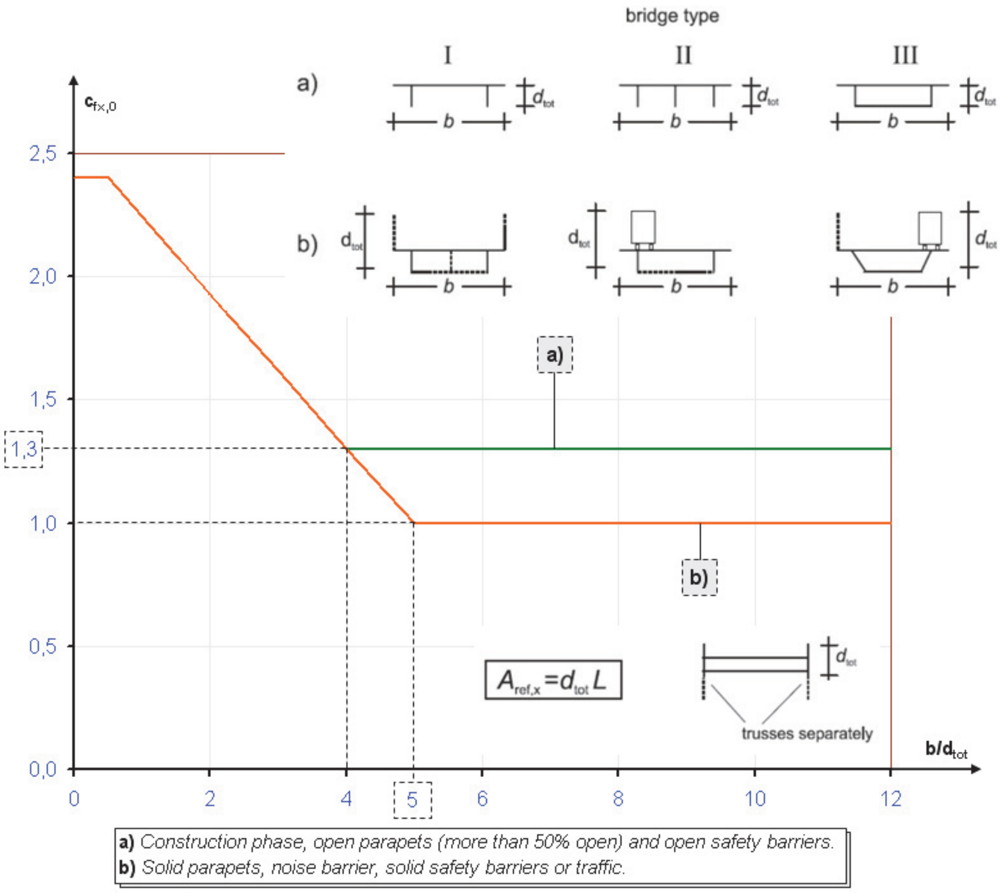

Figure 3.16 From Figure 8.3 - Force coefficient for bridges, $c_{fx,0}$.

A bridge has usually no free-end flow because the flow is deviated only along two sides (over and under the bridge deck). For normal bridges $c_{fx,0}$ may be taken equal to 1,3. Alternatively, $c_{fx,0}$ may be taken from Figure 8.3 where some typical cases for determining $A_{ref,x}$ (as defined in 8.3.1(4)) and d_{tot} are shown.

Where the windward face is inclined to the vertical (see Figure 8.4), the drag coefficient $c_{fx,0}$ may be reduced by 0,5% per degree of inclination, α_1 from the vertical, limited to a maximum reduction of 30%.

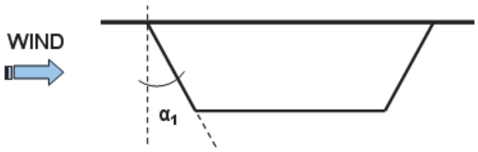

Figure 3.17 From Figure 8.4 - Bridge with inclined windward face.

Note This reduction is not applicable to F_w, defined in 8.3.2, unless otherwise specified in the National Annex.

Where a bridge deck is sloped transversely, $c_{fx,0}$ should be increased by 3% per degree of inclination, but not more than 25%.

Reference areas $A_{ref,x}$ for load combinations without traffic load should be based on the relevant value of d_{tot} as defined in Figure 8.5 and Table 8.1.

However, the total reference area $A_{ref,x}$ should not exceed that obtained from considering an equivalent plain (web) beam of the same overall depth, including all projecting parts.

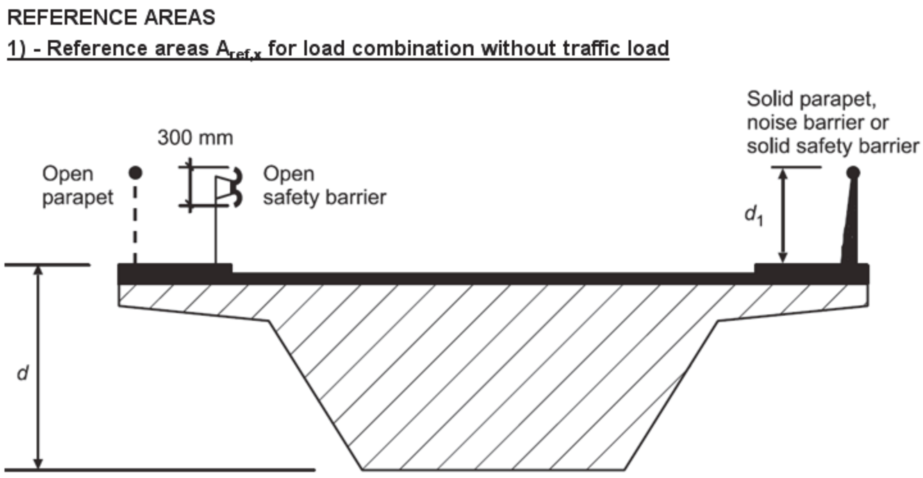

Figure 3.18 From Figure 8.5 - Depth d_{tot} to be used for $A_{ref,x}$.

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

Table 3.3 From Table 8.1 - Depth d_{tot} to be used for $A_{ref,x}$.

Instead of the areas for load combinations without traffic load, the reference areas $A_{ref,x}$ for load combinations with traffic load should be taken into account where they are larger:

— for road bridges, a height of 2 m from the level of the carriageway, on the most unfavourable length, independently of the location of the vertical traffic loads

— for railway bridges, a height of 4 m from the top of the rails, on the total length of the bridge.

Note The reference height, z_e, may be taken as the distance from the lowest ground level to the centre of the bridge deck structure, disregarding other parts (e.g. parapets) of the reference areas.

Wind pressure effects from passing vehicles are outside the scope of this Part. For wind effects induced by passing trains see EN 1991-2.

3.2.2 Force in x-direction. Simplified Method

The wind force in the x-direction may be obtained using Expression (8.2 [*modified*]):

$$F_w = c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x} \qquad \text{(Eq. 3-9)}$$

where:

- ρ is the density of air (see Sec. 4.5)
- v_b is the basic wind speed (see Sec. 4.2(2))
- C is the wind load factor $C = c_e \cdot c_{f,x}$ where $c_e = c_e(z_e)$ is the exposure factor given in Sec. 4.5 and $c_{f,x}$ is given in Sec. 8.3.1(1)
- $A_{ref,x}$ is the reference area given in Sec. 8.3.1
- $c_s c_d$ is the structural factor (as defined in Sec. 6).[2]

(2) For the purpose of this categorization, normal bridges may be considered to include bridges constructed in steel, concrete, aluminium or timber, including composite construction, and whose shape of cross sections is generally covered by Figure 8.1. If a dynamic response procedure is not needed (L > 40 m), $c_s c_d$ may be taken equal to 1,0. For normal road and railway bridge decks of less than L = 40 m span a dynamic response procedure is generally not needed.

Note C-values may be defined in the National Annex. Recommended values are given in Table 8.2.

b/d_{tot} [(a)]	$z_e \leq 20$ m	$z_e = 50$ m
≤ 0,5	6,7	8,3
≥ 4,0	3,6	4,5

Table 3.4 From Table 8.2 - Recommended values of the force factor C for bridges[(b)].

(a). For intermediate values of d/b_{tot} and of z_e linear interpolation may be used.
(b). This table is based on the following assumptions:
– terrain category II according to Table 4.1
– force coefficient $c_{f,x}$ according to Sec. 8.3.1(1)
– $c_0 = 1,0$
– $k_1 = 1,0$.

3.2.3 Wind forces on bridge decks in z-direction

Force coefficients $c_{f,z}$ should be defined for wind action on the bridge decks in the z-direction, both upwards and downwards (lift force coefficients). $c_{f,z}$ should not be used to calculate vertical vibrations of the bridge deck.

The National Annex may give values for $c_{f,z}$. In the absence of wind tunnel tests the recommended value may be taken equal to ±0,9. This value takes globally into account the influence of a possible transverse slope of the deck, of the slope of terrain and of fluctuations of the angle of the wind direction with the deck due to turbulence.

As an alternative $c_{f,z}$ may be taken from Figure 8.6. In using it:

— the depth d_{tot} may be limited to the depth of the deck structure, disregarding the traffic and any bridge equipment

— for flat, horizontal terrain the angle α of the wind with the horizontal may be taken as ± 5° due to turbulence. This is also valid for hilly terrain when the bridge deck is at least 30 m above ground.

The reference area $A_{ref,z}$ is equal to the plan area (see Figure 8.2):

$$A_{ref,z} = b \cdot L \qquad \text{(Eq. 3-10)}$$

No end-effect factor should be taken into account. The reference height z_e is the same as for $c_{f,x}$ (see Sec. 8.3.1(6)). Therefore, according to Eq. 3-9 we have:

$$F_{w,z} = c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot (c_e \cdot c_{f,z}) \cdot A_{ref,z} \qquad \text{(Eq. 3-11)}$$

If not otherwise specified the eccentricity of the force in the x-direction may be set to e = b/4.

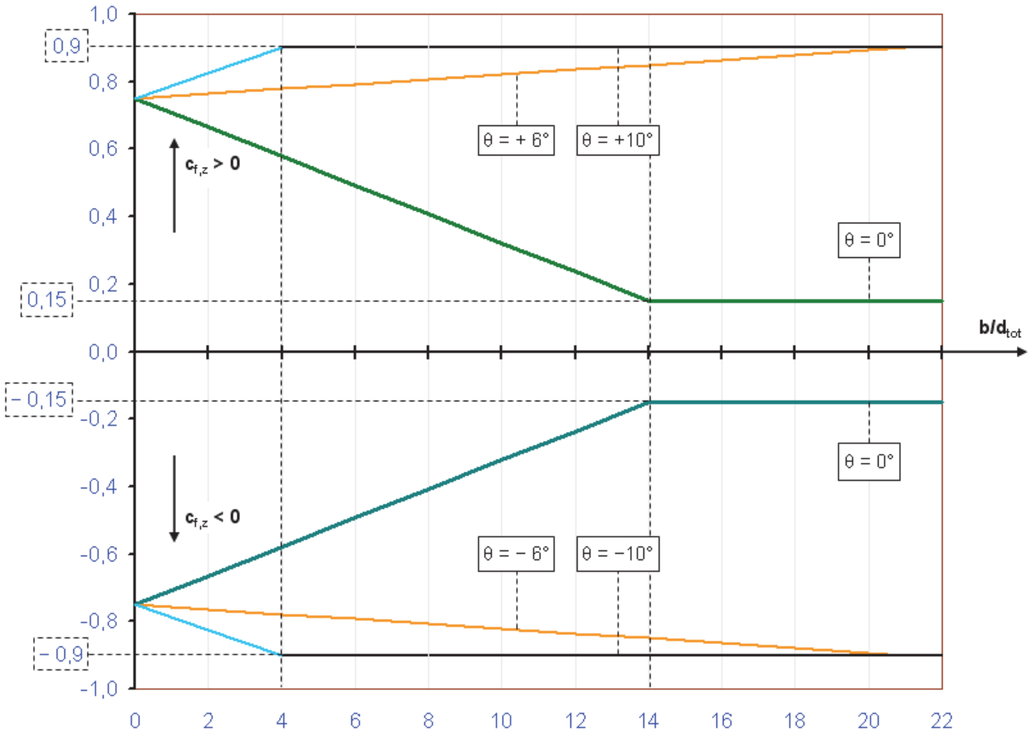

Figure 3.19 From Figure 8.6 - Force coefficient $c_{f,z}$ for bridges with transversal slope and wind inclination.

3.2.4 Wind forces on bridge decks in y-direction

1) If necessary, the longitudinal wind forces in y-direction should be taken into account.

Note The National Annex may give the values. The recommended values are:
– for plated bridges, 25% of the wind forces in x-direction,
– for truss bridges, 50% of the wind forces in x-direction.

3.3 Verification tests

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— Splash
— CodeSec8.

EXAMPLE 3-H- Force coefficients in x-direction (general method) - Sec. 8.3.1 - **test1**

Given: Find the force coefficients $c_{f,x}$ for wind actions on bridge deck in the x-direction according to Figure 8.3. Consider the two cases: **case a)** construction phase, open parapets (more than 50% open) and open safety barriers; **case b)** solid parapets, noise barrier, solid safety barriers or traffic.

Let us assume the following assumptions (see Figure 8.2 - "*Directions of the wind actions on bridges*"):

– bridge span (considered): $L = 30,00$ m

– width of the deck of the bridge: $b = 13,00$ m

– depth of the deck of the bridge: $d = 2,10$ m

– max height of vehicles/trains along the entire bridge span: $\Delta d_{tot} = 4$ m.

[*Reference sheet:* CodeSec8]-[*Cell-Range: A1:O1-A128:O128*].

Solution: From Figure 8.3 - "*Force coefficient for bridges, $c_{fx,0}$*" we have:

Case a): $d_{tot} = d = 2,10$ m, $b/d_{tot} = (13,00)/(2,10) = 6,19$ [-] (rounded value). According to Figure 8.3 we get: $c_{fx,0} = 1,30$ [-] (see figure below).

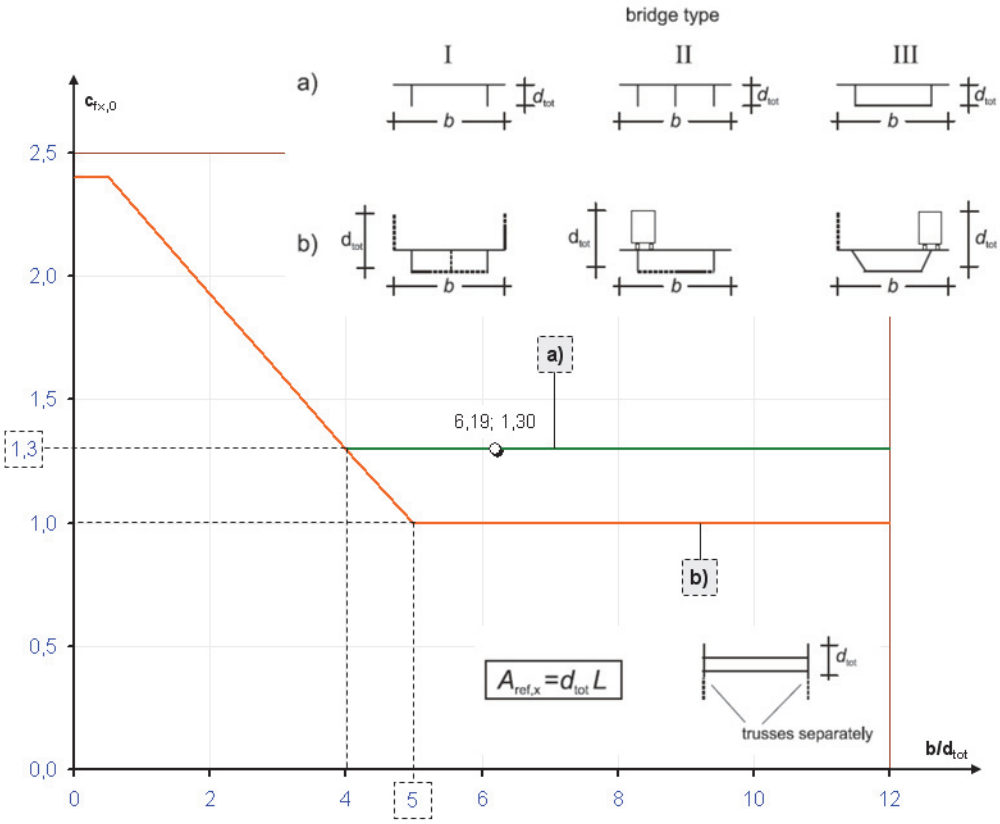


Figure 3.20 Excel® output: **case a)**.

Case b): $d_{tot} = d + \Delta d_{tot} = 2,10 + 4 = 6,10$ m, $b/d_{tot} = (13,00)/(6,10) = 2,13$ [-] (rounded value). According to Figure 8.3 we get: $c_{fx,0} = 1,89$ [-] (see figure below). The straight line with constant slope (< 0) has the equation:

$$\frac{1,3-2,4}{4-0,5} = \frac{c_{fx,0}-2,4}{b/d_{tot}-0,5} \rightarrow \frac{1,3-2,4}{4-0,5} = \frac{c_{fx,0}-2,4}{2,13-0,5} \rightarrow c_{fx,0} = 1,89\ [-].$$

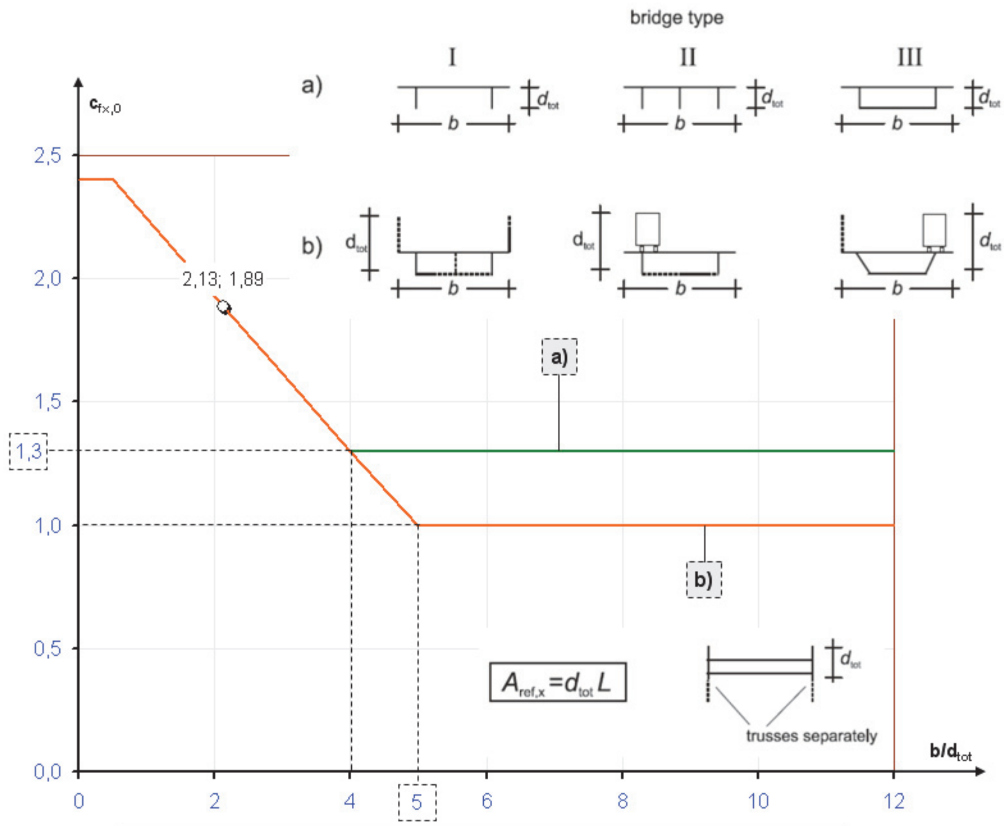


Figure 3.21 Excel output: **case b)**.

For normal bridges $c_{fx,0}$ may be taken equal to 1,3. Alternatively, $c_{fx,0}$ may be taken from Figure 8.3 (see input above).

example-end

EXAMPLE 3-I- Force in x-direction - Simplified Method - Sec. 8.3.2 and 8.3.4 - **test2**

Given: Find the wind forces acting on the deck of a plated bridge in the x,y-directions for both cases **a)** and **b)** (see Figure 8.3 - "*Force coefficient for bridges, $c_{fx,0}$*"). Using the numerical data given in the previous example, assume the following additional assumptions:

– reference height (distance from the lowest ground level to the centre of the bridge deck structure): $z_e = 35$ m

– exposure factor given in Sec. 4.5 (@ height z_e): $c_e = c_e(z_e) = 3,73$ [-]

– basic wind speed (see Sec. 4.2(2)): $v_b = 25$ m/s

– density of air: $\rho = 1,25$ kg/m³

– structural factor (as defined in Section 6): $c_s c_d = 1,00$ [-]

– type of traffic load: "*railway bridge*"

– the bridge deck is sloped transversely. Transverse slope of the deck: $\alpha_2 = 2°$

– road restraint system (see Table 8.1): *"open parapet and open safety barrier"*.

[*Reference sheet:* CodeSec8]-[*Cell-Range: A138:O138-A350:O350*].

Solution: From Sec. 8.3.1(2) for $\alpha_2 = 2°$ we get: $(2°) \cdot [(3/100)/\mathrm{deg}] \rightarrow 6/100 = 0,06$ (6%). Increasing factor for the force coefficient $c_{fx,0}$: $IF = 1,06$ [-]. From previous example: $c_{fx,0} = 1,30$ [-]. Actual value used for calculations (increase factor applied):

$c_{fx,0} = IF \cdot 1,30\ [-] = 1,06 \cdot 1,30 = 1,38\ [-]$ (rounded value).

Case a): Construction phase (see Figure 8.3)

From Table 8.1 - *"Depth d_{tot} to be used for $A_{ref,x}$"* with *"open parapet and open safety barrier"* we obtain:

$d_{tot} = d + 0,6\ m = (2,10 + 0,60) = 2,70\ m$ (for road restraint system: <u>on one side</u>) and

$d_{tot} = d + 1,2\ m = (2,10 + 1,20) = 3,30\ m$ (for road restraint system: <u>on both side</u>)

with:

$b/d_{tot} = (13,00)/(2,70) = 4,81\ [-]$ (for road restraint system: <u>on one side</u>)

$b/d_{tot} = (13,00)/(3,30) = 3,94\ [-]$ (for road restraint system: <u>on both side</u>).

Road restraint system <u>on one side</u>: $A_{ref,x} = d_{tot} \cdot L = (2,70) \cdot (30,00) = 81,00\ m^2$

Road restraint system <u>on both side</u>: $A_{ref,x} = d_{tot} \cdot L = (3,30) \cdot (30,00) = 99,00\ m^2$.

From Table 8.2 - *"Recommended values of the force factor C for bridges"*, linear interpolation with $20\ m < z_e < 50\ m$ and $b/d_{tot} = 4,81\ [-]$, $b/d_{tot} = 3,94\ [-]$. Thus, linear interpolation between $z_e \le 20\ m$ and $z_e = 50\ m$ for $b/d_{tot} \ge 4,0$:

$$\frac{4,50 - 3,60}{50 - 20} = \frac{C - 3,60}{z_e - 20} \rightarrow \frac{4,50 - 3,60}{50 - 20} = \frac{C - 3,60}{35 - 20} \rightarrow C = 4,05\ [-].$$

Linear interpolation for $b/d_{tot} = 3,94\ [-]$ (within the range $(0,5; 4,0)$) with:

$$\frac{8,30 - 6,70}{50 - 20} = \frac{C - 6,70}{z_e - 20} \rightarrow \frac{8,30 - 6,70}{50 - 20} = \frac{C - 6,70}{35 - 20} \rightarrow C = 7,50\ [-]. \text{ Thus:}$$

$$\frac{4,05 - 7,50}{4,0 - 0,5} = \frac{C - 6,70}{b/d_{tot} - 0,5} \rightarrow \frac{4,05 - 7,50}{4,0 - 0,5} = \frac{C - 6,70}{3,94 - 0,5} \rightarrow C = 4,11\ [-].$$

Case (a): Road restraint system <u>on one side</u> without traffic loads with $C = 4,05\ [-]$.

Case (b): Road restraint system <u>on both side</u> without traffic loads with $C = 4,11\ [-]$.

Instead, using the exposure factor: $C = c_e(z_e) \cdot c_{f,x} = 3,73 \cdot 1,38 = 5,15\ [-]$

WIND FORCES IN THE X-DIRECTION (see Figure 8.2)

Case (a) with $C = 5,15\ [-]$, $A_{ref,x} = 81,00\ m^2$:

$$F_w = c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x} = 1 \cdot 0,5 \cdot (1,25) \cdot (25,00)^2 \cdot (5,15) \cdot 81,00 \times 10^{-3} = 162,95\ kN$$

$F_w/L = (162,95)/(30,00) = (5,43)\ kN/m$ (rounded values).

Case (b) with $C = 5,15$ [-], $A_{ref,x} = 99,00$ m²:

$$F_w = c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x} = 1 \cdot 0,5 \cdot (1,25) \cdot (25,00)^2 \cdot (5,15) \cdot 99,00 \times 10^{-3} = 199,16 \text{ kN}$$

$F_w/L = (199,16)/(30,00) = (6,64)$ kN/m (rounded values).

WIND FORCES IN THE Y-DIRECTION (see Figure 8.2)

Case (a) with $C = 5,15$ [-], $A_{ref,x} = 81,00$ m² for plated bridge (Fact = 0,25):

$$F_{w,y} = 0,25 \cdot \left(c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x}\right) = 0,25 \cdot (162,95 \text{ kN}) = 40,74 \text{ kN}$$

$F_{w,y}/L = (40,74)/(30,00) = (1,36)$ kN/m (rounded values).

Case (b) with $C = 5,15$ [-], $A_{ref,x} = 99,00$ m²:

$$F_w = c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x} = 1 \cdot 0,5 \cdot (1,25) \cdot (25,00)^2 \cdot (5,15) \cdot 99,00 \times 10^{-3} = 199,16 \text{ kN}$$

$F_w/L = (199,16)/(30,00) = (6,64)$ kN/m (rounded values).

Note Wind forces in the y-direction for the **Case (C)** ("*bridge carrying lanes of traffic*") are calculated using the same algorithm in the spreadsheet. The calculation is then omitted.

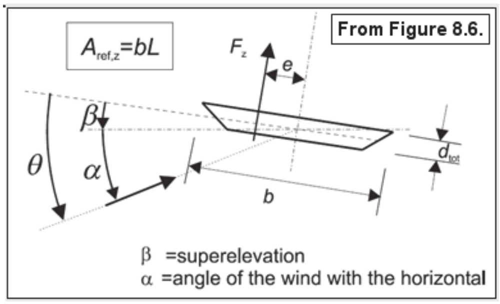
EXAMPLE 3-J- Force in z-direction - Simplified Method - Sec. 8.3.3 - **test2b**

Given: Referring to the data in the previous example, calculate the wind forces on the bridge deck in z-direction. The force coefficients $c_{f,z}$ may be taken from Figure 8.6. In using it, assume the following assumptions:

– $d_{tot} = 2,10$ m (limited to the depth of the deck structure, disregarding the traffic and any bridge equipment)

– hilly terrain

– bridge superelevation: $\beta = 3°$ (see Figure below):



– wind load factor C calculated from exposure factor @z_e: $c_e(z_e) = 3,73$ [-]

– eccentricity of the force in the x-direction set to $e = b/4 = (13,00)/4 = 3,25$ m.

[*Reference sheet:* CodeSec8]-[*Cell-Range: A357:O357-A454:O454*].

Solution: For flat, horizontal terrain the angle α of the wind with the horizontal may be taken as ±5° due to turbulence. This is also valid for hilly terrain when the bridge deck is at least 30 m above ground. Therefore (see Figure 8.6 - "*Force coefficient $c_{f,z}$ for bridges with transversal slope and wind inclination*"), we get:

$\theta = \alpha + \beta = \pm(5° + 3°) = \pm 8°$ with: $b/d_{tot} = (13,00)/(2,10) = 6,19\ [-]$.

From Figure 8.6, linear interpolation between the two straight lines with constant slope (= 0 for $\theta = 10°$ and < 0 for $\theta = 6°$):

$$\frac{0,90 - 0,75}{21 - 0} = \frac{c_{f,z} - 0,75}{b/d_{tot} - 0} \rightarrow \frac{0,90 - 0,75}{21 - 0} = \frac{c_{f,z} - 0,75}{6,19} \rightarrow c_{f,z} = 0,79\ [-]\ (\text{for } \theta = 6°),$$

Thus:

$$\frac{0,90 - 0,79}{10° - 6°} = \frac{c_{f,z} - 0,79}{\theta - 6°} \rightarrow \frac{0,90 - 0,79}{10° - 6°} = \frac{c_{f,z} - 0,79}{8° - 6°} \rightarrow c_{f,z} = 0,85\ [-]\ (\text{for } c_{f,z} > 0)$$

$c_{f,z} = -0,85\ [-]$ for $c_{f,z} < 0$.

WIND FORCES IN THE Z-DIRECTION (see Figure 8.2)

With $C = c_e(z_e) \cdot c_{f,z} = (3,73) \cdot (\pm 0,85) = \pm 3,17\ [-]$,

$A_{ref,z} = b \cdot L = (13,00) \cdot (30,00) = 390\ m^2$:

$$F_{w,z} = c_s c_d \cdot \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot A_{ref,x} = 1 \cdot 0,5 \cdot (1,25) \cdot (25,00)^2 \cdot (\pm 3,17) \cdot 390 \times 10^{-3} = \pm 482,93\ kN$$

$F_{w,z}/L = (\pm 482,93\ kN)/(30,00) = \pm 16,10\ kN/m$

TORQUE:

$M_{w,z} = F_{w,z} \cdot e = F_{w,z} \cdot b/4 = (\pm 482,93\ kN) \cdot (13,00\ m)/4 = \pm 1569,52\ kNm$

$T_{w,z} = M_{w,z}/L = (\pm 1569,52\ kNm)/(30,00\ m) = \pm 52,32\ kNm/m$.

example-end

3.4 References [Section 3]

EN 1991-1-4:2005/A1:2010. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, April 2010.

EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, March 2005 (DAV).

Guide for the assessment of wind actions and effects on structures. National Research Council of Italy. CNR-DT 207/2008. ROMA – CNR June 11th, 2010.