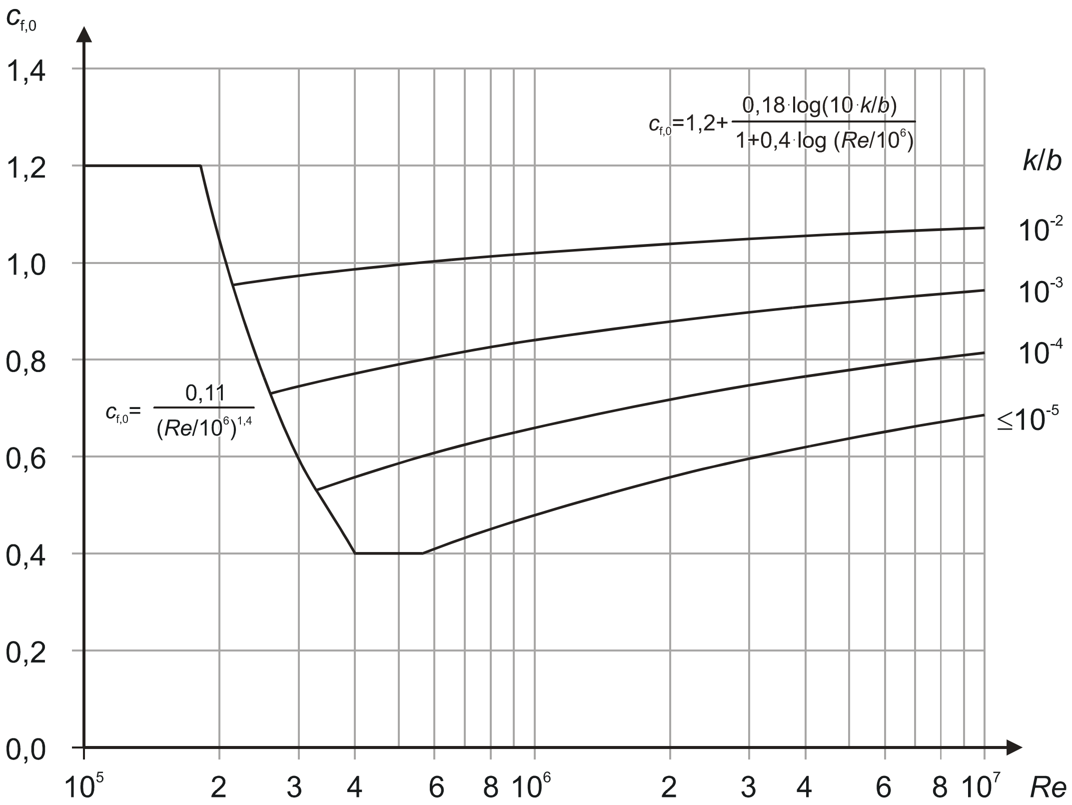


Figure 7.28 — Force coefficient $c_{f,0}$ for circular cylinders without free-end flow and for different equivalent roughness k/b

NOTE 1 Figure 7.28 may also be used for building with $h/d > 5.0$

NOTE 2 Figure 7.28 is based on the Reynolds number with $v = \sqrt{\frac{2 \cdot q_p}{\rho}}$ and q_p given in 4.5

A1 (2) Values of equivalent surface roughness k for new surfaces are given in Table 7.13.

NOTE For aged surfaces the values of the equivalent surface roughness k may be given in the National Annex. A1

(3) For stranded cables $c_{f,0}$ is equal to 1,2 for all values of the Reynolds number Re.

Table 7.13 — Equivalent surface roughness *k*

Type of surface	**Equivalent roughness *k*** mm	**Type of surface**	**Equivalent roughness *k*** mm
glass	0,0015	smooth concrete	0,2
polished metal	0,002	planed wood	0,5
fine paint	0,006	rough concrete	1,0
spray paint	0,02	rough sawn wood	2,0
bright steel	0,05	rust	2,0
cast iron	0,2	brickwork	3,0
galvanised steel	0,2		

(4) The reference area A_{ref} should be obtained by Expression (7.20).

$$A_{ref} = \ell \cdot b \qquad (7.20)$$

where:

ℓ is the length of the structural element being considered.

(5) The reference height z_e is equal to the maximum height above ground of the section being considered.

(6) For cylinders near a plane surface with a distance ratio z_g/b < 1,5 (see Figure 7.29) special advice is necessary.

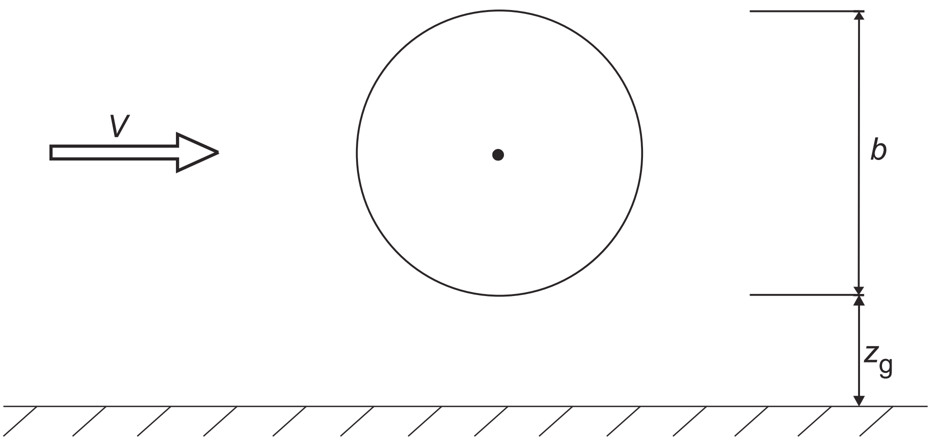


Figure 7.29 — Cylinder near a plane surface

7.9.3 Force coefficients for vertical cylinders in a row arrangement

For vertical circular cylinders in a row arrangement, the force coefficient $c_{f,0}$ depends on the wind direction related to the row axis and the ratio of distance a and the diameter b as defined in Table 7.14. The force coefficient, $c_{f,}$ for each cylinder may be obtained by Expression (7.21):

$$c_f = c_{f,0} \cdot \psi_\lambda \cdot \kappa \tag{7.21}$$

where:

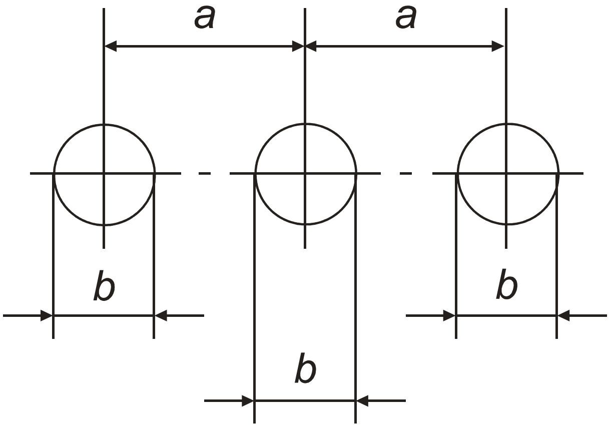
$c_{f,0}$ is the force coefficient of cylinders without free-end flow, (see 7.9.2)

ψ_λ is the end-effect factor (see 7.13)

κ is the factor given in Table 7.14 (for the most unfavourable wind direction)

Table 7.14 — Factor κ for vertical cylinders in a row arrangement

a/b	κ
A1⟩ 2,5 < a/b < 3,5 ⟨A1	1,15
3,5 < a/b < 30	$\kappa = \dfrac{210 - \frac{a}{b}}{180}$
a/b > 30	1,00



a: distance

b: diameter

A1⟩ NOTE For a/b < 2,5 the values of κ may be given in the National Annex ⟨A1

7.10 Spheres

(1) The alongwind force coefficient $c_{f,x}$ of spheres should be determined as a function of the Reynolds number Re (see 7.9.1) and the equivalent roughness k/b (see Table 7.13).

NOTE 1 The values of $c_{f,x}$ may be given in the National Annex. Recommended values based on measurements in low turbulent flow are given in Figure 7.30. Figure 7.30 is based on the Reynolds number with $v = \sqrt{\dfrac{2 \cdot q_p}{\rho}}$ and q_p given in 4.5

NOTE 2 The values in Figure 7.30 are limited to values $z_g > b/2$, where z_g is the distance of the sphere from a plain surface, b is the diameter (see Figure 7.31). For $z_g < b/2$ the force coefficient $c_{f,x}$ is be multiplied by the factor 1,6.

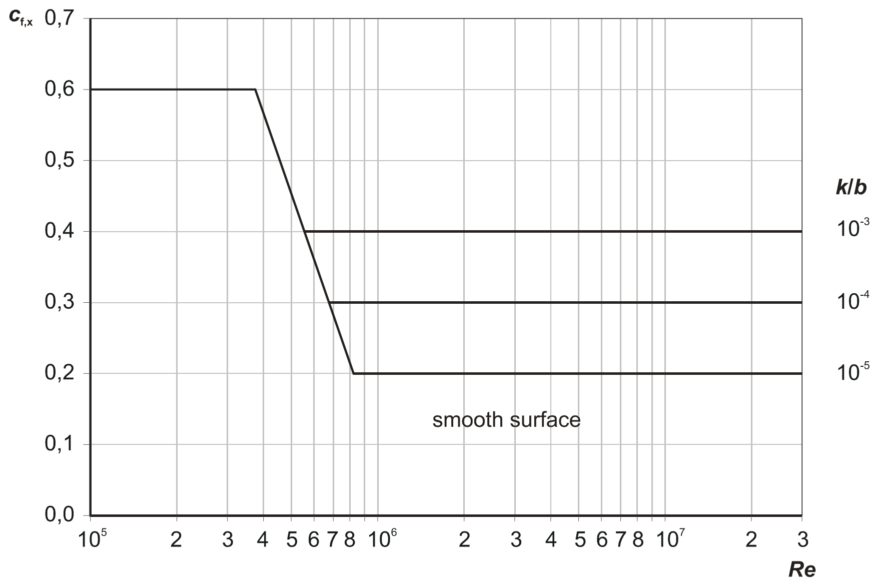


Figure 7.30 — Alongwind force coefficient of a sphere

(2) The vertical force coefficient $c_{f,z}$ of spheres is given by Expression (7.22).

$$c_{f,z} = 0 \quad \text{for} \quad z_g > \frac{b}{2}$$
$$c_{f,z} = +0{,}60 \quad \text{for} \quad z_g < \frac{b}{2} \tag{7.22}$$

(3) In both cases the reference area A_{ref} should be obtained by Expression (7.23).

$$A_{ref} = \pi \cdot \frac{b^2}{4} \tag{7.23}$$

(4) The reference height should be taken as:

$$z_e = z_g + \frac{b}{2} \tag{7.24}$$

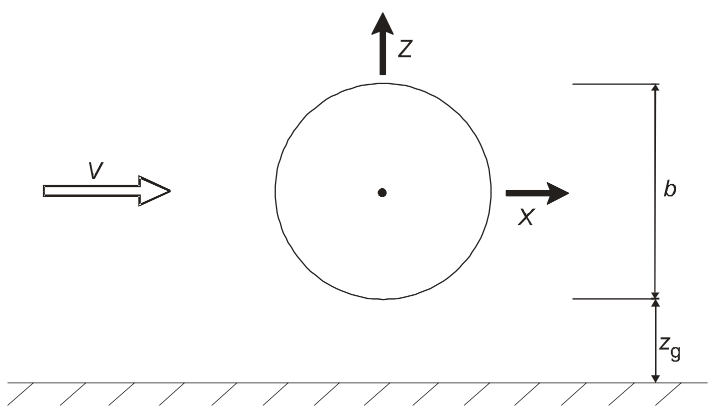


Figure 7.31 — Sphere near a plain surface

7.11 Lattice structures and scaffoldings

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

$$c_f = c_{f,0} \cdot \psi_\lambda \tag{7.25}$$

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 φ (7.11 (2)) and Reynolds number Re.

Re is the Reynolds number using the average member diameter b_i, see Note 1

ψ_λ is the end-effect factor (see 7.13) as a function of the slenderness of the structure, λ, calculated with ℓ and width $b = d$, see Figure 7.32.

NOTE 1 ⟨AC2⟩ Figure 7.35 is based ⟨AC2⟩ on the Reynolds number with $v = \sqrt{\frac{2 \cdot q_p}{\rho}}$ and q_p given in 4.5.

⟨AC2⟩ NOTE 2 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 EN 12811. ⟨AC2⟩

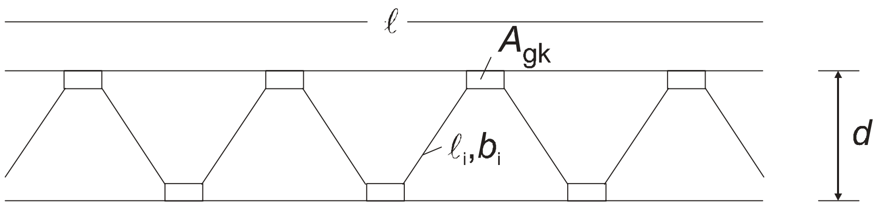


Figure 7.32 — Lattice structure or scaffolding

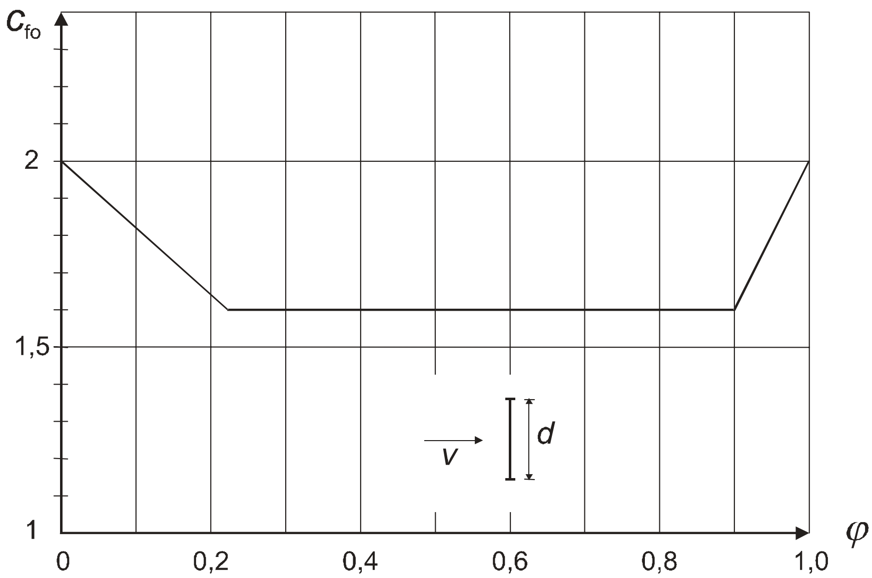


Figure 7.33 — Force coefficient $c_{f,0}$ for a plane lattice structure with angle members as a function of solidity ratio φ

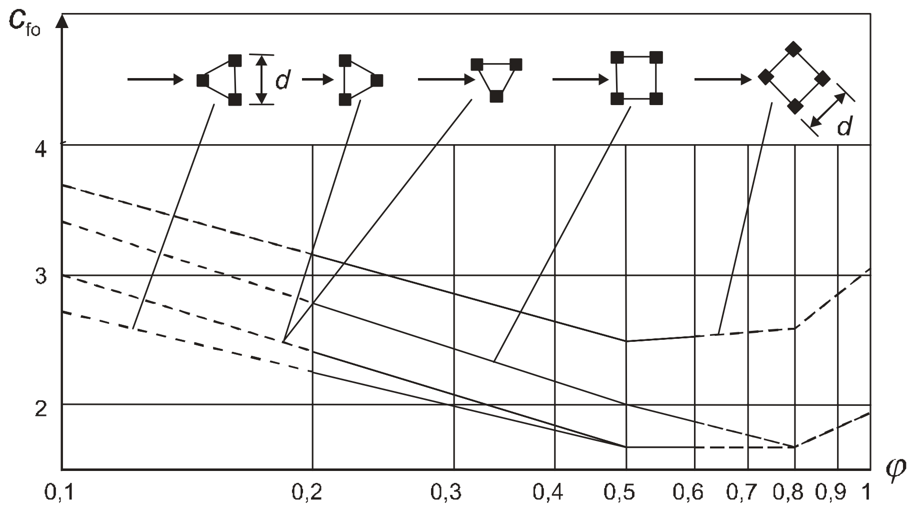


Figure 7.34 —Force coefficient $c_{f,0}$ for a spatial lattice structure with angle members as a function of solidity ratio φ

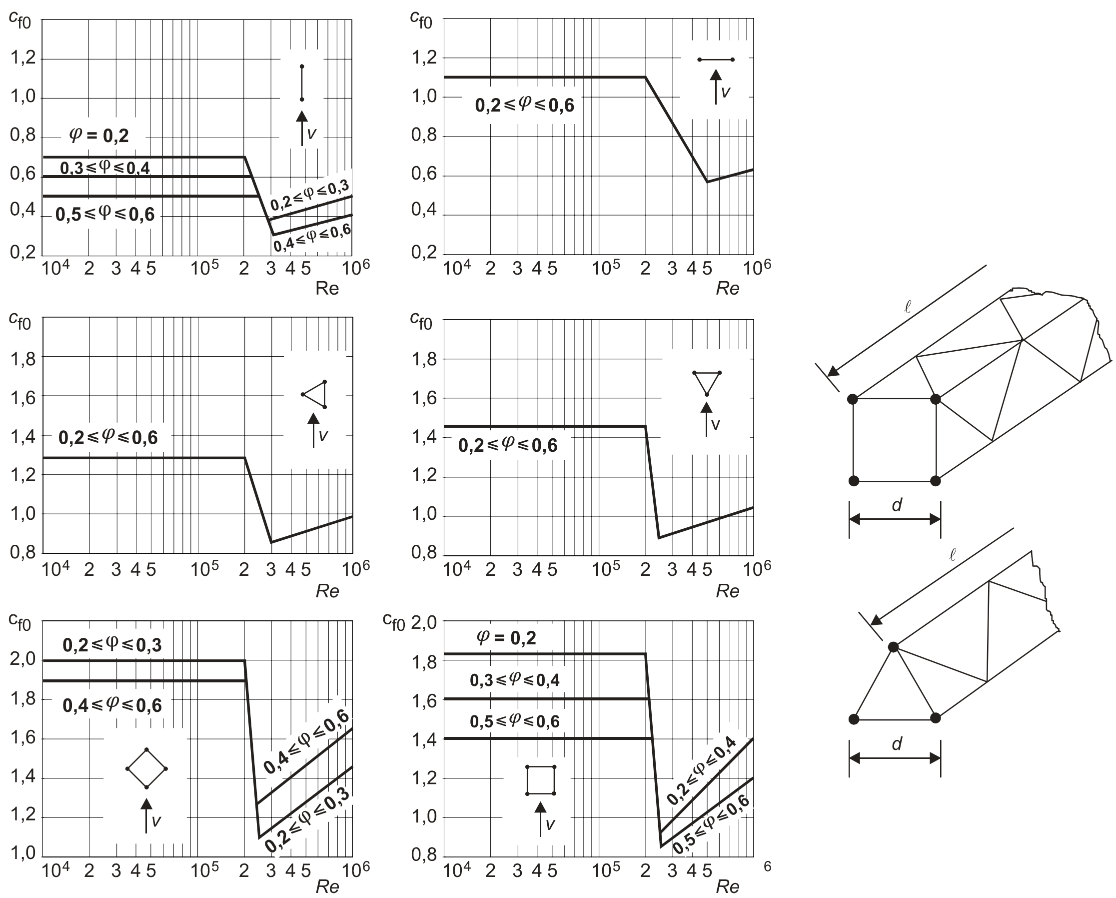


Figure 7.35 — Force coefficient $c_{f,0}$ for plane and spatial lattice structure with members of circular cross-section

(2) The solidity ratio, φ, is defined by Expression (7.26).

$$\varphi = \frac{A}{A_c} \tag{7.26}$$

where:

A is the sum of the projected area of the members and gusset plates of the face projected normal to the face: $A = \sum_i b_i \cdot \ell_i + \sum_k A_{gk}$

A_c is the the area enclosed by the boundaries of the face projected normal to the face = $d\ \ell$

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 individual member i (see Figure 7.32), projected normal to the face

A_{gk} is the area of the gusset plate k

(3) The reference area A_{ref} should be determined by Expression (7.27)

$$A_{ref} = A \tag{7.27}$$

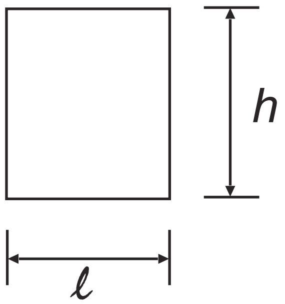
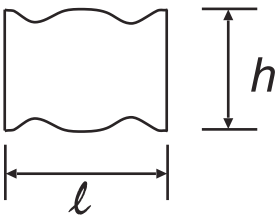
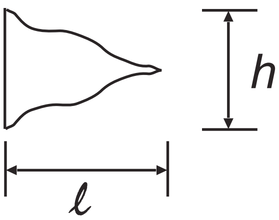
(4) The reference height z_e is equal to the maximum height of the element above ground.

7.12 Flags

(1) Force coefficients c_f and reference areas A_{ref} for flags are given in Table 7.15.

(2) The reference height z_e is equal to the height of the flag above ground.

Table 7.15 — Force coefficients c_f for flags

Flags	A_{ref}	c_f
Fixed Flags  Force normal to the plane	$h \cdot \ell$	1,8
Free Flags a) 	$h \cdot \ell$	$0{,}02 + 0{,}7 \cdot \frac{m_f}{\rho \cdot h} \cdot \left(\frac{A_{ref}}{h^2}\right)^{-1{,}25}$
b)  Force in the plane	$0{,}5 \cdot h \cdot \ell$	

where:

m_f is the mass per unit area of the flag
[AC2⟩ ρ is the air density (see 4.5 (1) NOTE 2) ⟨AC2]
z_e is the height of the flag above ground

NOTE The equation for free flags includes dynamic forces from the flag flutter effect

7.13 Effective slenderness λ and end-effect factor ψ_λ

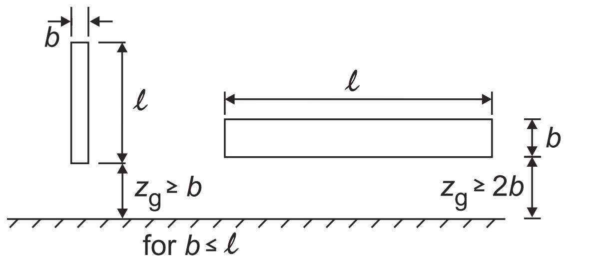
(1) Where relevant, the end-effect factor ψ_λ should be determined as a function of slenderness ratio λ.

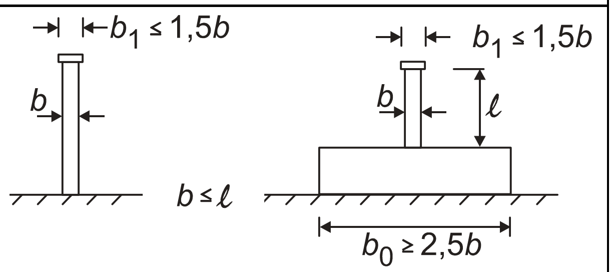
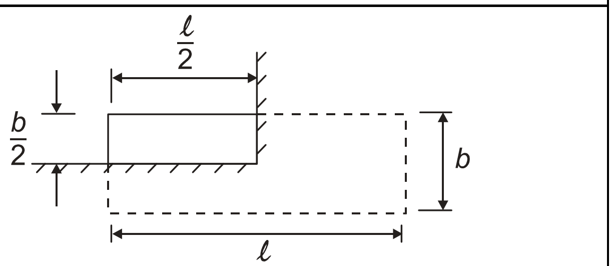
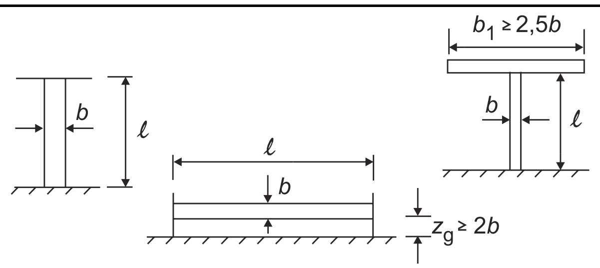
NOTE The force coefficients, $c_{f,0}$, given in 7.6 to 7.12 are based on measurements on structures without free-end flow away from the ground. The end-effect factor takes into account the reduced resistance of the structure due to the wind flow around the end (end-effect). Figure 7.36 and Table 7.16 are based on measurements in low turbulent flow. Values, taking the effect of turbulence into account may be specified in the National Annex.

(2) The effective slenderness λ should be defined depending on the dimensions of the structure and its position.

NOTE The National Annex may give values for λ and ψ_λ . Recommended values for λ are given in Table 7.16 and indicative values for ψ_λ are given in Figure 7.36 for different solidity ratio φ.

Table 7.16 — Recommended values of λ for cylinders, polygonal sections, rectangular sections, sharp edged structural sections and lattice structures

<table>
<tr><th>No.</th><th>Position of the structure,
wind normal to the plane of the page</th><th>Effective slenderness λ</th></tr>
<tr><td>1</td><td>
</td><td rowspan="3">For polygonal, rectangular and sharp edged sections and lattice structures:
for $\ell \geq 50$ m, $\lambda = 1{,}4\ \ell/b$ or $\lambda = 70$, whichever is smaller
for $\ell < 15$ m, $\lambda = 2\ \ell/b$ or $\lambda = 70$, whichever is smaller
For circular cylinders:
for $\ell \geq 50$, $\lambda = 0{,}7\ \ell/b$ or $\lambda = 70$, whichever is smaller
for $\ell < 15$ m, $\lambda = \ell/b$ or $\lambda = 70$, whichever is smaller

For intermediate values of ℓ, linear interpolation should be used</td></tr>
<tr><td>2</td><td>
</td></tr>
<tr><td>3</td><td></td></tr>
<tr><td>4</td><td>
</td><td>for $\ell \geq 50$ m, $\lambda = 0{,}7\ \ell/b$ or $\lambda = 70$, whichever is larger
for $\ell < 15$ m, $\lambda = \ell/b$ or $\lambda = 70$, whichever is larger
For intermediate values of ℓ, linear interpolation should be used</td></tr>
</table>

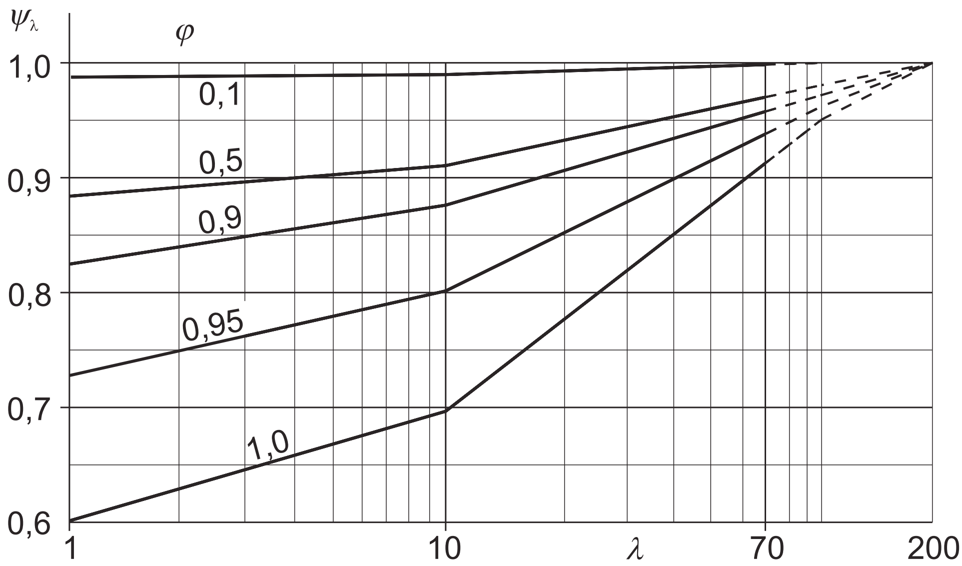


Figure 7.36 — Indicative values of the end-effect factor ψ_λ as a function of solidity ratio φ versus slenderness λ

(3) The solidity ratio φ (see Figure 7.37) is given by Expression (7.28).

$$\varphi = \frac{A}{A_c} \tag{7.28}$$

where:

A is the sum of the projected areas of the members

A_c is the overall envelope area $A_c = \ell \cdot b$

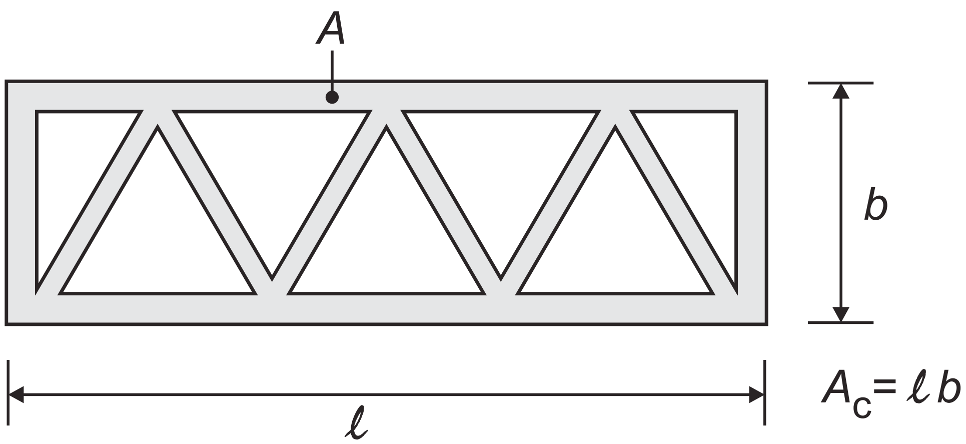


Figure 7.37 — Definition of solidity ratio φ