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Wind actions on structures

Actions du vent sur les structures

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 4354 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions.*

Annexes A to F of this International Standard are for information only.

Introduction

This International Standard is intended as a model to be used as guidelines for drafting national standards. The data in the annexes are only examples and are not intended to be complete.

Wind actions on structures

1 Scope

This International Standard describes the actions of wind on structures and specifies methods for calculating characteristic values of wind loads for use in designing buildings, towers, chimneys, bridges and other structures, as well as their components and appendages. The loads are suitable for use in conjunction with ISO 2394 and other International Standards concerned with wind loads.

Structures of an unusual nature, size or complexity (e.g. suspension bridges and guyed masts) may require special engineering study; some guidance is given on the limitations of this International Standard in these cases.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2394:—[1)], *General principles on reliability for structures.*

3 Symbols

Symbol	Quantity	Unit
A	area	m^2
A_s	cross-sectional area	m^2
A_s/A	solidity ratio	1
a	decay coefficient	1
a_p	peak acceleration	m/s^2
B	background response factor	1
b	breadth of structure	m
C_{aer}	aerodynamic damping coefficient	1
C_D	drag coefficient (force coefficient in the along-wind direction)	1
C_{dyn}	dynamic response factor	1

1) To be published. (Revision of ISO 2394:1986)

Symbol	Quantity	Unit
C_{exp}	exposure factor	1
$C_{exp, mod}$	modified exposure factor	1
C_f	force coefficient	1
C_{fig}	aerodynamic shape factor	1
$C_{fig, ext}$	external shape factor	1
$C_{fig, int}$	internal shape factor	1
C_p	pressure coefficient (time and spatially averaged)	1
$C_{p, l}$	time-averaged local pressure coefficient	1
C_1, C_2	vortex shedding coefficients	1
$C_{n, \infty}$, $C_{t, \infty}$	force coefficients for infinitely long member	1
D	diameter	m
d	width of building	m
F_h	horizontal deck load	N
F_m	force on member	N
F_{v1} F_{v2}	traffic loads	N
F_v	vertical deck load	N
F_I	force on windward girder	N
F_{II}	force on leeward girder	N
f_0	natural frequency (first mode)	Hz
g_w	statistical peak factor (for the loading effect)	1
H	hill height	m
h	height of structure	m
h_{ref}	reference height	m
h_t	height of truss	m
h_{v1}	height of vehicle above truss	m
h_{v2}	height of truss above deck level	m
I_u	turbulence intensity	1
k_β	reduction factor for sharp-edged members	1
k_{l, z_0}	scale factor of the logarithmic law	1
k_{p, z_0}	scale factor of the power law	1
k_{red}	reduction factor	1
k_x	shielding factor	1
L	turbulent length	m
L_H	half hill length	m
l	length of member	m
l_B	length of bridge	m
l_v	length of vehicle	m
m	mass	kg
m_l	mass per unit length	kg/m
N	return period	year
Q	squared reduced velocity	m/s
q	velocity pressure	Pa
q_x	reduced velocity pressure	Pa

Symbol	Quantity	Unit
q_{hcr}	critical velocity pressure at the top of the structure	Pa
q_{ref}	reference velocity pressure	Pa
$q(N)$	velocity pressure with return period of N	Pa
R	resonant response	1
Re	Reynolds number	1
S, S'	spectral energy factors	1
Sc	Scruton number	1
Sr	Strouhal number	1
T	averaging time	s
v	wind velocity	m/s
v_{hcr}	critical wind velocity at the top of the structure	m/s
v_{peak}	peak wind velocity	m/s
v_{ref}	reference wind velocity	m/s
v_z	velocity at height above ground, z	m/s
W	wind force	N
W_m	mean loading effect	1
W_p	peak loading effect	1
w	wind force per unit area	Pa
w_L	wind force per unit length	N/m
x	distance	m
y_0	maximum amplitude of structure	m
z	height above ground	m
z_0	roughness length of terrain	m
α	roof slope	°
β	index of the power law	1
γ_w	partial safety factor	1
ΔS_z	"speed-up" factor	1
$\bar{\delta}$	mean deflection	m
ζ	damping ratio	1
ζ_{aer}	aerodynamic damping ratio	1
ζ_{str}	structural damping ratio	1
ρ_{air}	mass density of air	kg/m³
ρ_{bldg}	average mass density of the building superstructure envelope	kg/m³
σ_w	root mean square loading effect	1
ν	cycling rate	Hz
ϕ_i	ratio of the dynamic deflection of the structure at point "i" to the maximum amplitude of the structure	1

4 Wind actions

Wind actions which shall be considered in the design of a structure may produce the following:

a) excessive forces or instability in the structure or its structural members or elements;

b) excessive deflection or distortion of the structure or its elements;

c) repeated dynamic forces causing fatigue or structural elements;

d) aeroelastic instability, in which motion of the structure in wind produces aerodynamic forces augmenting the motion;

e) excessive dynamic movements causing concern or discomfort to occupants or onlookers.

5 Wind force per unit area

For the actions referred to in clause 4 a), b), c) and e), the wind forces per unit area are, in principle, determined from a relationship of the general form:

$$w = q_{ref} \cdot C_{exp} \cdot C_{fig} \cdot C_{dyn} \quad \ldots (1)$$

The wind force per unit area is assumed to act statically in a direction normal to the surface of the structure or element, except where otherwise specified, e.g. with tangential frictional forces. Both internal and external forces shall be considered.

The effects of wind from all directions shall be considered.

For some structures it may be appropriate to represent the wind forces by their resultants. These resultants shall include alongwind (drag), crosswind (lift), torsional and overturning actions. Different magnitudes and distributions of the wind force may be necessary to evaluate the actions described in clause 4 a), b), c) and e).

6 Reference velocity pressure, q_{ref}

Velocity pressure is defined by the expression:

$$q = \frac{1}{2} \rho_{air} v^2 \quad \ldots (2)$$

The reference velocity pressure q_{ref} is normally the specified value of the velocity pressure for the geographical area in which the structure is located. It refers to a standard exposure (i.e. roughness, height and topography), averaging time and annual probability of recurrence (or recurrence interval). In some situations, the reference velocity pressure may be specified as varying with direction.

Analysis procedures and recommended values are given for information in annex B.

In certain cases, critical loading may occur at values of q differing from that specified above. These critical values of q (with reference to a height h) are denoted q_{hcr} and are substituted for q_{ref}. These cases are discussed in annex E.

7 Exposure factor, C_{exp}

The exposure factor accounts for the variability of the velocity pressure at the site of the structure due to

a) the height above ground level,

b) the roughness of the terrain, and

c) the shape and slope of the ground contours in undulating terrain.

The value of the exposure factor may vary with wind direction.

Recommended values of the exposure factor are given for information in annex C.

8 Aerodynamic shape factor, C_{fig}

The aerodynamic shape factor is the ratio of the aerodynamic pressure on the surface of the structure to the velocity pressure. The latter is normally the product of the exposure factor and the reference velocity pressure.

The aerodynamic shape factor normally refers to the mean (time averaged) value of the pressures but, in certain applications (when the mean is very small), it may refer to other statistical measures such as the peak pressure or root mean square pressure. It may refer to a point pressure, a resultant or an average pressure over an area. It is influenced by the geometry and shape of the structure, the exposure, the relative wind direction, the Reynolds number and the averaging time.

Enclosed structures will be subjected to internal pressures determined by the size and distribution of openings and by any pressurization, mechanical or otherwise. Allowance should be made for these by combining the aerodynamic shape factors for the external pressures with those for the internal pressures.

Aerodynamic shape factors may be determined from one of the following sources:

a) annex D;

b) appropriate wind tunnel tests, as described in annex D;

c) other codes or standards, provided that appropriate adjustment is made for any discrepancies in averaging time and exposure from those used in this International Standard, and provided that adequate provision is made for a dynamic response factor.

9 Dynamic response factor, C_{dyn}

The dynamic response factor accounts for the following actions of the wind:

a) fluctuating pressures due to random wind gusts acting for an interval of time shorter than that specified in the averaging time for the reference velocity pressure, and acting over all or part of the surface area of the structure;

b) fluctuating pressures in the wake of the structures (vortex shedding forces), producing resultant forces acting transversely as well as torsionally and longitudinally;

c) fluctuating pressures induced by the motion of the structure due to the wind.

Information on these effects and appropriate values of the dynamic response factor are given for information in annex E.

Resonance may amplify the response to these forces in certain wind-sensitive structures. Such structures are characterized by their lightness, flexibility and low level of structural damping. Indications of the wind-sensitive characteristics of structures are provided in annex E.

10 Criterion for aeroelastic instability

For structures affected by wind actions specified in clause 4 d) that cause aeroelastic instability, it must be shown that the performance of the structure, without further application of the load factor, is acceptable up to a wind velocity somewhat higher than v_{ref}. Unless alterative rational procedures are available, this wind velocity shall be taken as $\sqrt{\gamma_w} \cdot v_{ref}$, where γ_w is the normal partial safety factor and v_{ref} is the reference design wind velocity (corresponding to q_{ref} as defined in clause 6). A discussion of this problem is given in annex E.

11 Methods of analysis

Two methods or levels of design analysis are recommended in this International Standard which are referred to as the simplified method and the detailed method. In addition, for certain wind-sensitive structures, special supplementary studies are recommended.

The simplified method for estimating wind loading is described fully in annex A. It provides simplified values of the exposure factor C_{exp}, aerodynamic shape factor C_{fig} and dynamic response factor C_{dyn}, consistent with those in annexes C, D and E. The method is intended for the design of cladding of most normal structures. It can also be used for the design of the main structural system of structures meeting all the criteria given in annex A.

For the detailed method of estimating wind loading, the appropriate values of the exposure factor, shape factor and dynamic response factor are given in annexes C, D and E. This method is principally of assistance in assessing the dynamic response of the structure, the influence of unusual exposure, and the characteristics of more complex aerodynamic shapes.

Structures sensitive to wind include those that are particularly flexible, slender, tall or of light weight. Unusual geometry may also give rise to an unexpectedly large response to wind. In these instances, supplementary studies by an expert in the field are recommended and these may include wind-tunnel tests. These tests may be used to establish details of the overall structural loads and the distribution of external local pressures. Details of suitable testing procedures are given in annex D.

Alternative methods of analysis to those recommended in this International Standard may be permitted provided it can be demonstrated that the level of safety achieved is generally equivalent to that achieved in this International Standard. Guidance on the level of safety is given in annex F.

Annex A
(informative)

Simplified method of analysis

A.1 Criteria

This simplified method is intended for the design of the cladding of most normal structures. It can also be used for the design of the main structural system of structures which meet all of the following criteria.

a) The structure is less than 15 m in height above ground.

b) The structure is not unusually exposed for any wind direction; i.e. it is not situated near a hillcrest nor headland.

c) The structure is relatively rigid. For habitable buildings, the deflections under wind loading, calculated by the simplified method, should be less than 1/500 of the height of the structure or of the relevant span. For industrial structures (e.g. chimneys), higher deflections may be acceptable depending on the serviceability requirements.

A.2 General relationship

The general relationship for determining the wind loading is given by equation (1) (see clause 5):

$$w = q_{\mathrm{ref}}\ C_{\mathrm{exp}}\ C_{\mathrm{fig}}\ C_{\mathrm{dyn}}$$

The values of the factors to be used are given below.

A.3 Reference velocity pressure, q_{ref}

This is defined in annex B, for a given region.

A.4 Exposure factor, C_{exp}

This is determined from table A.1 for each height range in question.

On coastal or particularly exposed, flat, open sites, the values of C_{exp} given in table A.1 should be increased by a factor. This factor will normally be in a range from 1,2 to 1,4. If detailed information is not available, the value 1,3 is recommended.

Table A.1 — Exposure factor, C_{exp} — Simplified method

Applicability	Range of height of structure, h m	C_{exp}
Structural design	$0 < h \leqslant 5$ $5 < h \leqslant 10$ $10 < h \leqslant 15$	0,9 1 1,1
Cladding design	$0 < h \leqslant 20$ $20 < h \leqslant 25$ $25 < h \leqslant 35$ $35 < h \leqslant 45$ $45 < h \leqslant 55$ $55 < h \leqslant 65$ $65 < h \leqslant 80$ $80 < h \leqslant 100$	1,2 1,3 1,4 1,5 1,6 1,7 1,8 1,9

A.5 Combined aerodynamic shape factor and dynamic response factor, $C_{fig}C_{dyn}$

The combined wind loading on external and internal surfaces should be based on the *combined* factor as follows:

$$(C_{fig}C_{dyn})_{com} = (C_{fig}C_{dyn})_{ext} - (C_{fig}C_{dyn})_{int} \qquad \text{. . . (A.1)}$$

A.5.1 Walls and roofs

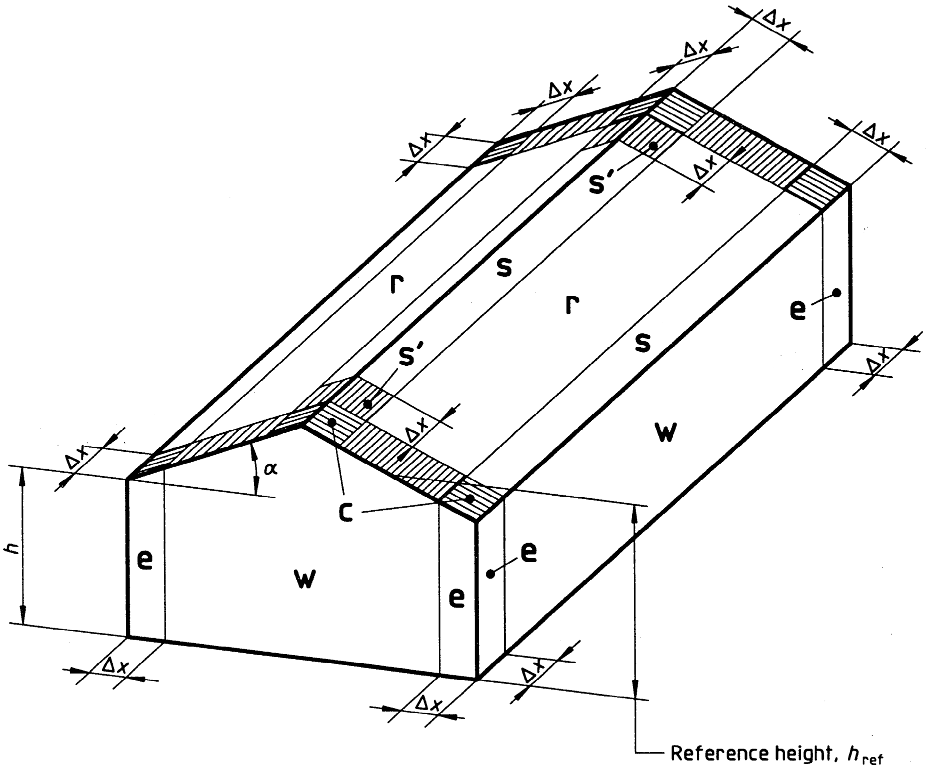
The products of the internal aerodynamic shape factor and dynamic response factor, $(C_{fig}C_{dyn})_{int}$, are given in table A.2.

Table A.2 — Internal pressures — Shape factors and dynamic response factors

Type of structure	$C_{fig, int}$	$C_{dyn, int}$	$(C_{fig}C_{dyn})_{int}$
Buildings with large openings (e.g. sheds with an open side; industrial buildings with shipping doors or ventilators having a high probability of being open; large glass windows exposed to damage from debris)	− 0,7	2	− 1,4
Buildings with openings less than 1 % of total wall area, not uniformly distributed (e.g. most enclosed buildings with windows and doorways)	− 0,7	1	− 0,7
Buildings without large openings, and only small openings of less than 0,1 % of total area (e.g most tall buildings which are normally sealed and ventilated mechanically; exceptionally, low buildings such as windowless warehouses with door systems designed to withstand the wind)	0 − 0,3	1 1	0 − 0,3

For low buildings with flat or gable roofs, the product of the external aerodynamic shape factor and the dynamic response factor, $(C_{fig}C_{dyn})_{ext}$, is presented in figures A.1, A.2 and A.3.

The cladding, fastenings, secondary structural elements (girts and purlins) and individual roof or wall panels should be designed using factors given in figure A.2 for walls and figure A.3 for roofs. Reductions for larger tributary areas may be made.



10 ° < a < 45 °

Figure A.1 — Surfaces of walls and roofs

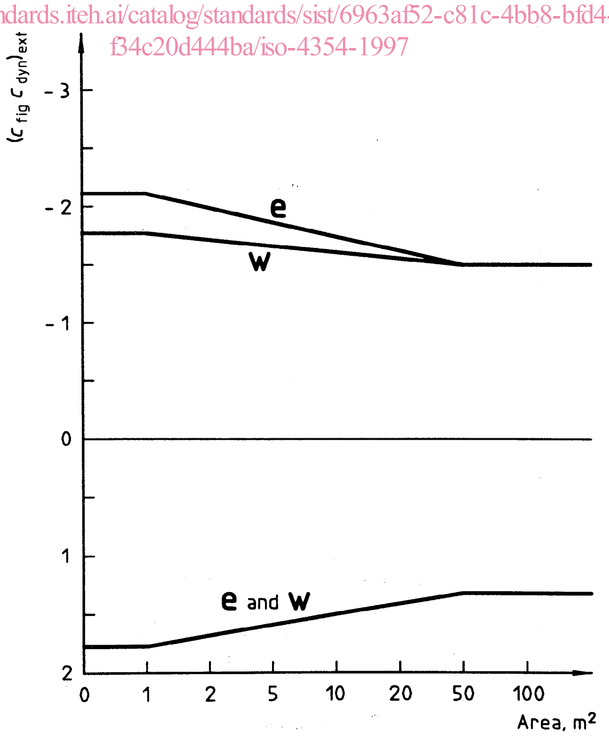
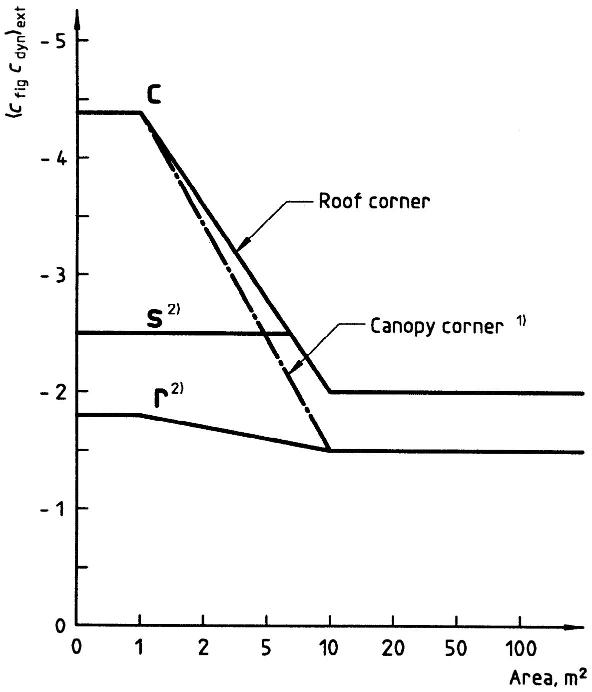
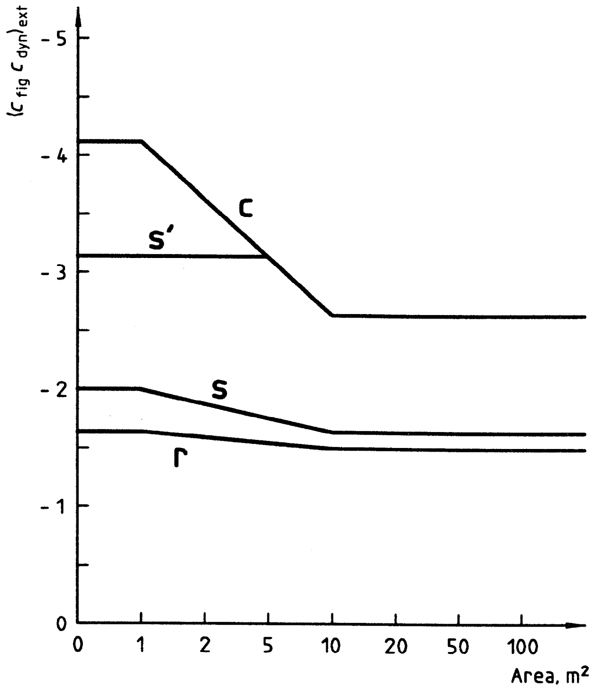


Figure A.2 — Values of $(C_{fig}C_{dyn})_{ext}$ for low buildings — Walls

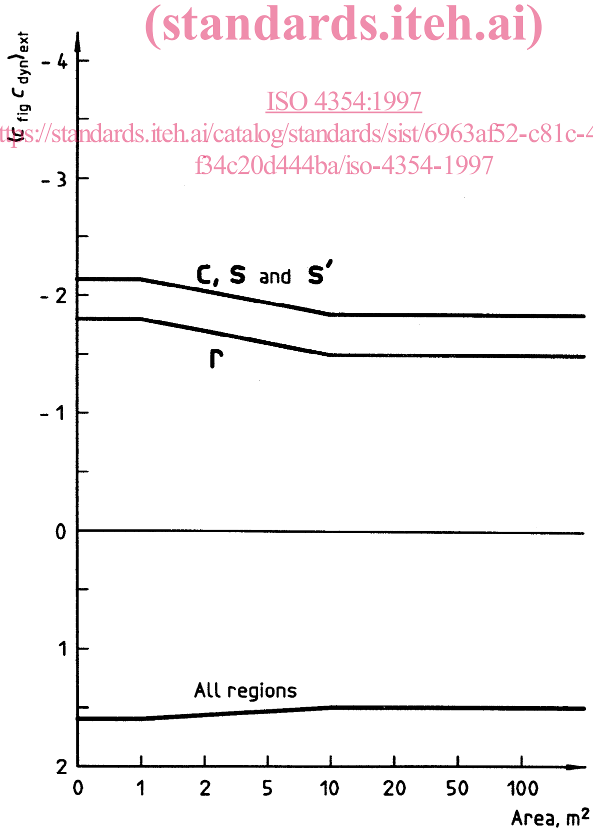


1) Canopy coefficients include contributions from both upper and lower surfaces.
2) s and r are applicable to both roofs and canopies.

a) 0° < α ≤ 10°



b) 0° < α ≤ 30°



c) 30° < α ≤ 45°

Figure A.3 — Values of $(C_{fig}C_{dyn})_{ext}$ for low buildings — Roofs

For estimation for the loads for the design of the foundations and footings, excluding anchorages, 70 % of the values of $(C_{fig}C_{dyn})_{ext}$ may be used.

The abscissa areas in figures A.2 and A.3 are the design tributary area within the specified zone.

The reference height h_{ref} for pressures is the mid-height of the roof or 6 m, whichever is the larger.

Dx is 10 % of the smallest horizontal dimension or 40 % of height h, whichever is the smaller. Also, where $Dx \geqslant 1$ m, $Dx \geqslant 4$ % of the smallest horizontal dimension.

A.5.2 Frames

Figure A.4 shows the wind directions to be considered on the surfaces of framed low buildings.

Factors given in tables A.3 and A.4 for the frame loading may be used only if more than one roof or wall surface participates in the action, and only for estimating loading on rigid frames, total roof uplift, sliding shear or overturning. The design should consider wind acting from any direction.

For estimation of the loads for the design of the foundations and footings, excluding anchorages, 70 % of the values of $(C_{fig}C_{dyn})$ may be used.

The building should be designed for all wind directions. Each corner should be considered in turn as the windward corner shown in figure A.4. For all roof slopes, load case A and load case B1 (see tables A.3 and A.4) are required as two separate loading conditions to generate the wind actions. If the roof slope is 20° or more, a third loading condition B2 is also required (see table A.4).

The value of Dy is 6 m or 2 Dx, whichever is the greater.

Table A.3 — Values of $(C_{fig}C_{dyn})_{ext}$ for load case A: Winds generally perpendicular to ridge

Roof slope a	Building surface							
	1	2	3	4	1E	2E	3E	4E
0° to 5°	0,75	- 1,3	- 0,7	- 0,55	1,15	- 2	- 1	- 0,8
20°	1	- 1,3	- 0,9	- 0,8	1,5	- 2	- 1,3	- 1,2
30° to 45°	1,05	0,4	- 0,8	- 0,7	1,3	0,5	- 1	- 0,9
90°	1,05	1,05	- 0,7	- 0,7	1,3	1,3	- 0,9	- 0,9

Table A.4 — Values of $(C_{fig}C_{dyn})_{ext}$ for load cases B1 and B2: Winds generally parallel to ridge

Load case	Roof slope a	Building surface											
		1	2	3	4	5	6	1E	2E	3E	4E	5E	6E
B1	< 20°	0	- 1,3	- 0,7	0	0,75	- 0,55	0	- 2	- 1	0	- 1,15	- 0,6
B2	⩾ 20°	- 0,65	- 1,3	- 0,7	- 0,85	0	0	- 0,9	- 2	- 1	- 0,9	0	0