AS/NZS 1170.2:2021

Australian/New Zealand Standard™

Structural design actions

Part 2: Wind actions

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AS/NZS 1170.2:2021

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The following are represented on Committee BD-006:

Australasian Wind Engineering Society
Australian Building Codes Board
Australian Steel Institute
Bureau of Steel Manufacturers of Australia
Cement Concrete & Aggregates Australia — Cement
Concrete Masonry Association of Australia
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Part 2: Wind actions

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Preface

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee, BD-006, General Design Requirements and Loading on Structures, to supersede AS/NZS 1170.2:2011.

The objective of this Standard is to provide wind actions for use in the design of structures subject to wind action. It provides a detailed procedure for the determination of wind actions on structures, varying from those less sensitive to wind action to those for which dynamic response are to be taken into consideration.

The objectives of this revision are to remove ambiguities, and to incorporate recent research and experiences from recent severe wind events in Australia and New Zealand.

This Standard is Part 2 of the *Structural design actions* series, which comprises the following parts:

AS/NZS 1170.0, *Structural design actions, Part 0: General principles*

AS/NZS 1170.1, *Structural design actions, Part 1: Permanent, imposed and other actions*

AS/NZS 1170.2, *Structural design actions, Part 2: Wind actions*

AS/NZS 1170.3, *Structural design actions, Part 3: Snow and ice actions*

AS 1170.4, *Structural design actions, Part 4: Earthquake actions in Australia*

NZS 1170.5, *Structural design actions, Part 5: Earthquake actions — New Zealand*

The wind speeds provided are based on analysis of existing data. The major changes in this edition are as follows:

(a) Definitions and notation have been moved to Clauses 1.4 and 1.5 respectively and new definitions and notation added. Appendices C to G have been re-labelled as Appendices A to E.

(b) Structures covered by and excluded from this Standard have been clarified in Clause 1.1.

(c) The aerodynamic shape factor is now denoted as C_{shp} (in previous editions it was C_{fig}).

(d) A climate change multiplier (M_c) has been included (Equation 2.2 and Clause 3.4), with a current value of 1.05 for cyclonic regions. The uncertainty factors F_C and F_D for cyclonic regions have been removed.

(e) The ground level datum for buildings on sloping or excavated sites has been clarified. Average roof height for buildings with two or more roofs has been clarified.

(f) Windborne debris test speeds when the impacted surface is not vertical or horizontal have been provided (Clause 2.5.8).

(g) New regional boundaries for Australia and New Zealand have been defined with new Regions A0, B1, B2, NZ1, NZ2, NZ3, and NZ4 [Figures 3.1(A) and 3.1(B)].

(h) Interpolation between boundaries, according to distance from the coastline, is allowed in Regions C and D [Table 3.1(A)]. Regional wind speeds for New Zealand have been revised [Table 3.1(B)].

(i) Wind direction multipliers (M_d) have been revised for all regions in Australia and New Zealand. The wind direction multiplier (M_d) has been set to 1.0 for circular or polygonal chimneys, tanks and poles.

(j) Terrain Category 1.5 has been removed. Terrain Category 1 has been re-defined to include all over-water surfaces. The description of Terrain Category 2.5 has been revised (Clause 4.2).

(k) Terrain-height multipliers ($M_{z,cat}$), and turbulence intensities, for Terrain Category 1 have been reduced to reflect observed values of gust factors and turbulence intensities for over-water winds.

(l) Terrain-height multipliers for Region A0 have been revised to reflect measured wind gust profiles measured in convective downdrafts.

(m) The shielding multiplier (M_s) has been set to 1.0 for buildings greater than 25 m in height, and for buildings on steep slopes.

(n) The topographic multiplier (M_t) has been reduced in Region A0.

(o) New lee effect multipliers and zones have been defined for New Zealand.

(p) A new clause (Clause 5.3.4) has been added for an open area/volume factor. This allows some reduction in peak internal pressure for buildings with large internal volumes, and small opening areas.

(q) Values of area reduction factor (K_a) have been included for windward and leeward walls (Clause 5.4.2).

(r) The reference area *a* for local pressure factors has been changed for roofs of large low-rise buildings. A new local pressure case (RC2) has been introduced for the windward end of high-pitched gable roofs (Clause 5.4.4).

(s) Further clarification of the applicability of Section 6 has been given in Clause 6.1. Highly dynamically wind-sensitive structures are excluded.

(t) New methods are provided for the dynamic response factor for the along-wind response of poles or masts with headframes, and for long span horizontal structures.

(u) The equations for the crosswind force spectrum coefficient (C_{fs}) for tall buildings with rectangular cross-sections have been revised (Clause 6.3.2.3). A new more accurate method for the crosswind response of chimneys, poles and masts of circular cross-section has been introduced (Clause 6.3.3).

(v) A new method for the combination of along-wind and crosswind base moments has been introduced (Clause 6.4.1).

(w) Some alternate values of external pressure coefficient ($C_{p,e}$) for saw-tooth roofed buildings have been included (Clause A.2).

(x) The external pressure coefficients for curved roofs have been revised (Table A.3).

(y) New net pressure coefficients ($C_{p,n}$) have been provided for conical canopies (Clause B.3.3), and for arrays of inclined ground-mounted solar panels.

(z) New Notes have been added in Appendix C for determination of wind loads on complex, porous industrial plants, and warnings regarding crosswind response of rectangular sections.

(aa) New informative Clauses have been added to Appendix E for rotational velocities (Clause E.4), peak torsional accelerations (Clause E.5) and combined peak accelerations (Clause E.6).

The design wind actions prescribed in this Standard are the minimum for the general cases described. The Joint Committee has considered exhaustive research and testing information from Australian, New Zealand and overseas sources in the preparation of this Standard.

The terms “normative” and “informative” are used in Standards to define the application of the appendices to which they apply. A “normative” appendix is an integral part of a Standard, whereas an “informative” appendix is only for information and guidance.

Notes to the text contain information and guidance and are not considered to be an integral part of the Standard.

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Section 1 Scope and general

1.1 Scope

This Standard sets out procedures for determining wind speeds and resulting wind actions to be used in the structural design of structures subjected to wind actions other than those caused by tornadoes.

The Standard covers structures within the following criteria:

(a) Buildings and towers less than or equal to 200 m high.

(b) Structures with unsupported roof spans of less than 100 m.

(c) Offshore structures within 30 km from the nearest coastline.

(d) Other structures apart from: offshore structures more than 30 km from the nearest coastline, bridges, windfarm structures and power transmission and distribution structures, including supporting towers and poles.

NOTE 1 This Standard is a stand-alone document for structures within the above criteria. It may be used, in general, for all structures but other information may be necessary.

NOTE 2 If a tall building has a natural frequency less than 1 Hz, Section 6 requires dynamic analysis to be carried out. For other structures, such as lighting poles, dynamic analysis may be required even if the first-mode frequency exceeds 1 Hz (see limits in Clause 6.1).

NOTE 3 For structures excluded by (a) and (b), specialist techniques, including wind-tunnel testing, are required. Further advice, which may include wind-tunnel testing, also should be sought for roofs with unusual geometries or support systems, or the roofs of podiums at the base of tall buildings.

NOTE 4 For structures excluded by (d), wind loads are specified by other Australian or New Zealand Standards (bridges and power transmission and distribution structures), or by international standards (structures more than 30 km offshore, and windfarm structures). These may draw on this Standard for some aspects of wind load determination.

NOTE 5 Structures on any island territory Australia and New Zealand, and offshore structures within 30 km of the shoreline of any of those territories, are covered by this Standard.

NOTE 6 In this document, the words “this Standard” indicates AS/NZS 1170.2, which is Part 2 the AS/NZS 1170 series (see Preface).

1.2 Application

This Standard shall be read in conjunction with AS/NZS 1170.0.

This Standard may be used as a means for demonstrating conformance with the requirements of Part B1 of the National Construction Code (Australia).

NOTE Use methods or information not given in this Standard should be justified by a special study (refer to AS/NZS 1170.0, Appendix A).

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1.3 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this Standard.

NOTE Documents referenced for informative purposes are listed in the Bibliography.

AS 4040.3, *Methods of testing sheet roof and wall cladding, Method 3: Resistance to wind pressures for cyclone regions*

AS/NZS 1170.0, *Structural design actions, Part 0: General principles*

Australian Building Codes Board, National Construction Code (NCC)

1.4 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

1.4.1
aerodynamic shape factor
factor to account for the effects of the geometry of the structure on surface pressure due to wind

1.4.2
aspect ratio
ratio of the average roof height of a building to the smallest horizontal dimension, or the ratio of the largest dimension of a structural member to its crosswind breadth

1.4.3
average recurrence interval
average interval (R) between exceedances of a given wind speed, usually measured in years

Note 1 to entry: For values of R greater than 5 years, this is equal to the reciprocal of the annual probability of exceedance.

1.4.4
awning
roof-like structure, usually of limited extent, projecting from a wall of a building

1.4.5
canopy
roof adjacent to or attached to a building, generally not enclosed by walls

1.4.6
cladding
material that forms the external surface over the framing of a building or structure

1.4.7
design wind speed
wind speed for use in design, adjusted for average recurrence interval, wind direction, geographic position, surrounding environment and height

1.4.8
discharge coefficient
for a ventilator, a non-dimensional quantity relating the rate of airflow through the ventilator to the pressure drop across it

Note 1 to entry: Values for particular ventilators can be obtained from tests carried out by manufacturers or suppliers.

1.4.9
downdraft
vertical air motion originating in a thunderstorm, resulting in severe horizontal winds at ground level

Note 1 to entry: Strong winds of this type are the dominant extreme wind event in inland Australia (Region A0) and may also occur in some coastal regions.

1.4.10
drag
force acting in the direction of the wind stream

Note 1 to entry: See also *lift* (1.4.31).

1.4.11
dynamic response factor
factor to account for the effects of fluctuating forces and resonant response on wind-sensitive structures

1.4.12
eccentricity
distance from the centroid of a surface, to the point of application of the resultant force derived from the net wind pressure

1.4.13
effective surface
wall, roof or internal surface of a building that contributes significantly to load effects on major structural elements

1.4.14
elevated building
building with a clear, unwalled space underneath the first floor, level with a height from ground to underside of the first floor of one-third or more of the total height of the building

1.4.15
enclosed building
building that has a roof and full perimeter walls (nominally sealed) from floor to roof level

1.4.16
escarpment
two-dimensional, steeply sloping face between nominally level lower and upper plains, where the plains have average slopes of not greater than 5 %

1.4.17
first mode shape
deflected shape of a structure at its maximum amplitude under first mode natural vibration

1.4.18
first mode natural frequency
frequency of free oscillation corresponding to the lowest harmonic of vibration of a structure

1.4.19
force coefficient
coefficient that, when multiplied by the incident wind pressure and a reference area, gives the force in a specific direction

1.4.20
free roof
roof (of any type) with no enclosing walls underneath

Note 1 to entry: For example, a freestanding carport.

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1.4.21
freestanding walls
walls that are exposed to the wind on both sides, with no roof attached

Note 1 to entry: Includes fences.

1.4.22
frictional drag
wind force per unit area acting in a direction parallel to the surface in question

1.4.23
gable roof
ridged roof with two sloping surfaces and vertical triangular end walls

1.4.24
hill
isolated three-dimensional topographic feature standing above the surrounding plains having slopes < 5 %

1.4.25
hip roof
roof with four sloping (pitched) surfaces, pyramidal in shape, and with level eaves all round

Note 1 to entry: A hip roof on a rectangular plan has two triangular sloping roofs at the short sides (hip ends) and two trapezoidal sloping roofs at the long sides.

1.4.26
hoardings
freestanding (rectangular) signboards, and the like, supported clear of the ground

1.4.27
immediate supports
supporting members to which cladding is directly fixed

Note 1 to entry: Examples include battens, purlins, girts and studs.

1.4.28
lag distance
horizontal distance downwind, required for the effects of a change in terrain roughness on wind speed to reach the height being investigated

1.4.29
large opening
opening greater than 0.5 % of the area in the external surface of an enclosed building, which directly influences the average internal pressure

1.4.30
lattice towers
three-dimensional frameworks comprising three or more linear boundary members interconnected by linear bracing members joined at common points (nodes), enclosing an open area through which the wind may pass

1.4.31
lift
force acting at 90° to the wind stream

Note 1 to entry: See also *drag* (1.4.10).

1.4.32
mansard roof
roof with two slopes on all four sides, the lower slope steeper than the upper slope

Note 1 to entry: A mansard roof with the upper slopes less than 10° may be assumed to be flat topped.

1.4.33
monoslope roof
planar roof with a constant slope and without a ridge

Note 1 to entry: See also *skillion roof* (1.4.46).

1.4.34
obstructions
natural or man-made objects that generate turbulent wind flow, ranging from single trees to forests and from isolated small structures to closely spaced multi-storey buildings

1.4.35
offshore structures
fixed or floating platforms, jetties, towers or poles

Note 1 to entry: This Standard only applies to offshore structures within 30 km from the nearest coastline of Australian or New Zealand territory.

1.4.36
permeable
surface with an aggregation of small openings, cracks, and the like, which allows air to pass through under the action of a pressure differential

1.4.37
pitched roof
bi-fold, bi-planar roof (two sloping surfaces) meeting at a ridge

1.4.38
pressure
air pressure referenced to ambient air pressure

Note 1 to entry: In this Standard, negative values are less than ambient (suction), positive values exceed ambient. Net pressures act normal to a surface in the direction specified.

1.4.39
pressure coefficient
ratio of the pressure acting at the point on a surface, to the free-stream dynamic pressure of the incident wind

1.4.40
rectangular building
building generally made up of rectangular shapes in plan

Note 1 to entry: See Section 5 for calculation of the aerodynamic shape factor for rectangular buildings.

1.4.41
Reynolds number
Re
ratio of the inertial forces to the viscous forces in the airflow

1.4.42
ridge (topographic feature)
two-dimensional crest or chain of hills with sloping faces on either side of the crest

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1.4.43
roughness length
theoretical quantification of the turbulence-inducing nature of a particular type of terrain on airflow (wind)

1.4.44
Scruton number
Sc
mass-damping parameter

1.4.45
shelter room
space designated to provide shelter to one or more persons

1.4.46
skillion roof
roof on a building with a single roof slope that has a high edge at one side of the building and a low edge at the opposite side

Note 1 to entry: See also *monoslope roof* (1.4.33).

1.4.47
solidity (of cladding)
ratio of the solid area to the total area of the surface

1.4.48
structural elements, major
structural elements with tributary areas that are greater than 10 m^2

1.4.49
structural elements, minor
structural elements with tributary areas that are less than or equal to 10 m^2

1.4.50
terrain
surface roughness condition when considering the size and arrangement of obstructions to the wind

1.4.51
topography
major land surface features, comprising hills, valleys and plains, that strongly influence wind flow patterns

1.4.52
tornado
violently rotating column of air, that is suspended, observable as a funnel cloud attached to the cloud base of a convective cloud

1.4.53
tributary area
area of building surface contributing to the force being considered

1.4.54
tropical cyclone
non-frontal warm-cored low-pressure weather system of synoptic scale that develops over warm waters and has deep organised convection and gale force mean winds or greater extending more than half-way around near the centre and persisting for at least 6 hours

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Note 1 to entry: Wind, rain, wave and storm surge impacts can extend hundreds of kilometres from the centre depending on the storm intensity and scale.

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Note 2 to entry: Refer to the Commonwealth of Australia Bureau of Meteorology for further information.

Note 3 to entry: Winds circulate in a clockwise direction in the southern hemisphere

1.4.55
troughed roof
bi-fold, bi-planar roof with a valley at its lowest point

1.4.56
turbulence intensity
ratio of the standard deviation of the fluctuating component of wind speed to the mean (time averaged) wind speed

1.5 Notation

Unless stated otherwise, the notation used in this Standard has the following meaning with respect to the structure, member or condition to which the Clause applies.

NOTE See Clause 1.7 for units.

A	=	surface area of the element or the tributary area that transmits wind forces to the element, being—
	=	area upon which the pressure acts, which may not always be normal to the wind stream when used in conjunction with the pressure coefficient (C_p);
	=	projected area normal to the wind stream when used in conjunction with a drag force coefficient (C_d); or
	=	areas as defined in applicable clauses (see Appendix C) when used in conjunction with a force coefficient ($C_{F,x}$) or ($C_{F,y}$)
A_a	=	reference area of ancillaries on a tower
a_L	=	constant for determination of the response to vortex shedding of structures with circular cross section (Clause 6.3.3)
A_{ref}	=	reference area of flag
$A_{z,s}$	=	total projected area of the tower section at height z
A_z	=	reference area, at height (z), upon which the pressure (p_z) at that height acts
a	=	dimension used in defining the extent of application of local pressure factors
	=	exponential decay factor
B'	=	background factor for horizontal slender structures
B_s	=	background factor, which is a measure of the slowly varying background component of the fluctuating response, caused by low-frequency wind speed variations
b	=	breadth of a structure or element, usually normal to the wind stream; or
	=	average diameter of a circular section
b_D	=	diagonal breadth of UHF antennas
b_{eff}	=	effective breadth of a headframe

b_{i}	=	average diameter or breadth of a section of a tower member
b_{N}	=	normal breadth of UHF antennas
$b_{0\mathrm{h}}$	=	average breadth of the structure between heights 0 and h
b_{s}	=	average breadth of shielding buildings, normal to the wind stream
b_{sh}	=	average breadth of the structure between heights s and h
b_{t}	=	average breadth of the top third of the structure
b_{z}	=	average breadth of the structure at the section at height (z)
b/w	=	ratio of the average diameter of an ancillary to the average width of a structure
C_{c}	=	aerodynamic excitation parameter (Clause 6.3.3.1)
C_{d}	=	drag force coefficient for a structure or member the direction of the wind stream
C_{da}	=	value of drag force coefficient (C_{d}) on an isolated ancillary on a tower
C_{de}	=	effective drag force coefficient for a tower section with ancillaries
C_{dyn}	=	dynamic response factor
$C_{\mathrm{F,x}}$	=	force coefficient for a structure or member, in the direction of the x-axis
$C_{\mathrm{F,y}}$	=	force coefficient for a structure or member, in the direction of the y-axis
C_{f}	=	frictional drag force coefficient
C_{fs}	=	crosswind force spectrum coefficient generalized for a linear mode shape
$C_{\mathrm{p,b}}$	=	external pressure coefficient for sides of bins, silos and tanks
$C_{\mathrm{p,e}}$	=	external pressure coefficient
$C_{\mathrm{p,i}}$	=	internal pressure coefficient
$C_{\mathrm{p,l}}$	=	net pressure coefficient for the leeward half of a free roof
$C_{\mathrm{p,n}}$	=	net pressure coefficient acting normal to the surface for canopies, freestanding roofs, walls and the like
$C_{\mathrm{p,w}}$	=	net pressure coefficient for the windward half of a free roof
$C_{\mathrm{p1}}(\theta_{\mathrm{b}})$	=	external pressure coefficient on walls of bins, silos or tanks of unit aspect ratio (c/b = 1) as a function of θ_{b}
C_{shp}	=	aerodynamic shape factor
$C_{\mathrm{shp,1}}$	=	aerodynamic shape factor for the first frame in the upwind direction
c	=	exponential decay parameter (Clause C.4.2.3)
	=	net height of a hoarding, flag, bin, silo or tank (not including roof or lid height); or
	=	height between the highest and lowest points on a hyperbolic paraboloid roof
c_1, c_2	=	parameters for crosswind response calculation (Clause 6.3.3.1)

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D	=	downwind roof slope
d	=	depth or distance parallel to the wind stream to which the plan or cross-section of a structure or shape extends (e.g. the outside diameter); or
	=	length of span of curved roof
d_{a}	=	along-wind depth of a porous wall or roof surface
d_{s}	=	length of span of the first pitched roof in a multi-span building
E	=	site elevation above mean sea level
E_{t}	=	spectrum of turbulence in the approaching wind stream
e	=	the base of Napierian logarithms (approximately 2.71828)
e	=	horizontal eccentricity of net pressure (Clause B.2.1)
F	=	force on a building element, in newtons
F_{res}	=	resonant component of the along-wind force (Appendix E)
f	=	frictional force per unit area parallel to a surface, in newtons per square metre
f_{z}	=	the design frictional-distributed force parallel to the surface, calculated in Clause 2.4.2 at height z, in newtons per square metre
g_{R}	=	peak factor for resonant response (10 min period)
g_{c}	=	peak factor cross-wind response of chimneys, masts and poles
g_{v}	=	peak factor for upwind velocity fluctuations
H	=	height of the hill, ridge or escarpment
H_{s}	=	height factor for the resonant response
h	=	average roof height of structure above ground
h_1, h_2	=	component heights of a conical canopy
h_{c}	=	height from ground to the attached canopy, freestanding roof, wall or the like
h_{eff}	=	effective height of a headframe
h_{p}	=	height of parapet above average roof level
h_{r}	=	average height of surface roughness
h_{s}	=	average roof height of shielding buildings
I_{h}	=	turbulence intensity, obtained from Table 6.1 by setting z equal to h
I_{z}	=	turbulence intensity at height z given for various terrain categories in Table 6.1
K	=	factor for maximum tip deflection
K_{a}	=	area reduction factor (Clause 5.4.2); or
	=	aerodynamic damping parameter (Clause 6.3.3.1)

K_{ar}	=	aspect ratio correction factor for individual member forces
K_b	=	factor for breadth/span of curved roofs (Clause A.3)
K_c	=	combination factor
$K_{c,e}$	=	combination factor for external pressures
$K_{c,i}$	=	combination factor for internal pressures
K_i	=	factor to account for the angle of inclination of the axis of members to the wind direction
K_{in}	=	correction factor for interference
K_ℓ	=	local pressure factor
K_m	=	mode shape correction factor for crosswind acceleration
K_p	=	net porosity factor, used for free walls; or
	=	porous cladding reductive factor, used for cladding on buildings
K_r	=	parapet reduction factor
K_{sh}	=	shielding factor for shielded frames in multiple open-framed structures
K_v	=	open area and volume factor for internal pressures
k	=	mode shape power exponent
k_b	=	factor for a circular bin
L_h	=	measure of integral turbulence length scale at height h
L_u	=	horizontal distance upwind from the crest of the hill, ridge or escarpment to a level half the height below the crest
L_1	=	length scale, in metres, to determine the vertical variation of M_h, to be taken as the greater of 0.36 L_u or 0.4 H
L_2	=	length scale, in metres, to determine the horizontal variation of M_h, to be taken as 4 L_1 upwind for all types, and downwind for hills and ridges, or 10 L_1 downwind for escarpments
L	=	leeward wall; or
	=	life of structure
l	=	length of member
l_f	=	flag length
l_s	=	average spacing of shielding buildings
ℓ	=	upwind segment of the roofs of circular, bins, silos and tanks
M_c	=	climate change multiplier (see Clause 3.4); or
	=	crosswind base overturning moment

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M_d = wind direction multiplier (see Clause 3.3)

M_h = hill shape multiplier

M_{lee} = lee (effect) multiplier (taken as 1.0, except in New Zealand lee zones, see Clause 4.4.3)

M_{res} = resonant component of the along-wind base moment (Appendix E)

M_s = shielding multiplier

M_t = topographic multiplier

$M_{z,cat}$ = terrain/height multiplier

m_0 = average mass per unit height

m_f = mass per unit area of flag

m_t = average mass per unit height over the top third of the structure

$m(z)$ = mass per unit height as a function of height z

N = reduced frequency (non-dimensional)

N_g = number of stress exceedances

n = number of spans of a multi-span roof

n_1 = first mode natural frequency of vibration of a structure, in hertz

n_a = first mode natural frequency of vibration of a structure in the along-wind direction, in hertz

n_c = first mode natural frequency of vibration of a structure in the crosswind direction, in hertz

n_s = number of upwind shielding buildings within a 45° sector of radius $20h$ and with $h_s \geq h$

n_θ = natural frequency of twisting (torsional) mode of a tall building (Appendix E)

p = design wind pressure acting normal to a surface, in pascals

= p_e, p_i or p_n where the sign is given by the C_p values used to evaluate C_{shp}

NOTE: Pressures are taken as positive, indicating pressures above ambient and negative, indicating pressures below ambient.

p_e = external wind pressure

p_i = internal wind pressure

p_n = net wind pressure

p_z = design wind pressure, in pascals (normal to the surface), at height z, calculated in Clause 2.4.1

NOTE: The sign convention for pressures leads to forces towards the surface for positive pressures and forces away from the surface for negative pressures.

R = average recurrence interval of the wind speed in years (Clause 3.2); or

	=	furthest point from the centre of rigidity (Appendix E)
R	=	crosswind roof slope
	=	distance from the initiating crest to the leeward edge of the shadow zone (Clause 4.4.3)
Re	=	Reynolds number
r	=	rise of a curved roof;
	=	corner radius of a structural shape; or
	=	aspect ratio of a building (Clause 5.4.4)
	=	radius of a conical canopy
S	=	size reduction factor for tall buildings and free-standing towers
S'	=	effective size reduction factor for towers, poles and masts with headframes
S''	=	size reduction factor for horizontal slender structures
S	=	side wall
Sc	=	Scruton number
St	=	Strouhal number — non-dimensional vortex shedding frequency
s	=	shielding parameter;
	=	height of the level at which action effects are calculated for a structure; or
	=	distance between the underside of a solar panel and the roof surface
	=	equivalent frame spacing
T	=	top roof section
U	=	upwind roof slope
$V_{\mathrm{des},\theta}$	=	building orthogonal design wind speeds (usually, θ = 0°, 90°, 180° and 270°), as given in Clause 2.3
		NOTE: $V_{\mathrm{des},\theta}$ may be expressed as a function of height z, for some applications, e.g. windward walls of tall buildings (>25 m).
$V_{\mathrm{des},\theta}(z)$	=	building orthogonal design wind speeds as a function of height z
V_{n}	=	reduced velocity (non-dimensional)
V_{R}	=	regional gust wind speed, in metres per second, for annual probability of exceedance of $1/R$
$V_{\mathrm{sit},\beta}$	=	wind speeds for a site, varying according to compass direction
W	=	wind actions (refer to AS/NZS 1170.0)
W	=	windward wall
W_{s}	=	wind actions for serviceability limit states (determined using a regional wind speed appropriate to the annual probability of exceedance for serviceability limit states)

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W_u = wind actions for ultimate limit states (determined using a regional wind speed appropriate to the annual probability of exceedance specified for ultimate limit states)

w = width of a tower; or

= shortest horizontal dimension of the building

w_c = width of canopy, awning carport, or similar, from the face of the building

$w_{eq}(z)$ = equivalent static wind force per unit height as a function of height z

x = distance from the windward edge of a canopy or cantilevered roof;

= distance from initiating crest (NZ lee zones — Clause 4.4.3); or

= horizontal distance upwind or downwind of the structure to the crest of the hill, ridge or escarpment

x_i = distance downwind from the start of a new terrain roughness to the position where the developed height of the inner layer equals z (lag distance)

$\ddot{x}_{max}$ = peak acceleration, at the top of a structure in the along-wind direction

$\ddot{y}_{max}$ = peak acceleration, at the top of a structure in the crosswind direction

y_{max} = maximum amplitude of tip deflection in crosswind vibration at the critical wind speed

z = reference height on the structure above the average local ground level, or rotational displacement (Appendix E)

z_0 = aerodynamic roughness length

α = angle of slope of a roof

β = angle of compass wind direction, measured clockwise from North (0°), for determining site wind velocities

ΔC_d = additional drag coefficient due to an ancillary attached to one face or located inside the tower section

Δz = height of the section of the structure upon which the wind pressure acts

δ = solidity ratio of the structure (surface or open frame) which is the ratio of solid area to total area of the structure

δ_e = effective solidity ratio for an open frame

$\varepsilon_{a,m}$ = action effect derived from the mean along-wind response

$\varepsilon_{a,p}$ = action effect derived from the peak along-wind response

$\varepsilon_{c,p}$ = action effect derived from the peak crosswind response

ε_t = combined peak scalar dynamic action effect

ζ = ratio of structural damping to critical damping of a structure

σ = stress level

$\hat{\sigma}_{a(x,y,z)}$	=	combined peak acceleration (see Appendix E)
σ_a	=	standard deviation of acceleration (Appendix E)
σ_{max}	=	maximum stress
θ	=	angle of upwind direction to the orthogonal axes of a structure, in degrees; or
	=	rotational displacement (Appendix E)
$\dot{\theta}$	=	rotational velocity (Appendix E)
θ_a	=	angle of deviation of the wind stream from the line joining the centre of the tower cross-section to the centre of the ancillary, in degrees
θ_b	=	angle from the wind direction to a point on the wall of a circular bin, silo or tank, in degrees
θ_m	=	angle between the wind direction and the longitudinal axis of the member, in degrees
λ	=	spacing ratio for parallel open frames, equal to the frame spacing (centre-to-centre) divided by the projected frame width normal to the wind direction
π	=	the ratio of the circumference of any circle to its diameter (approx. 3.14159)
ρ	=	ratio of the highest component of peak acceleration to the second highest
ρ_{air}	=	density of air, which shall be taken as 1.2 kg/m^3
		NOTE: This value is based on 20 °C and typical ground level atmospheric pressure and variation may be necessary for very high altitudes or cold environments.
$\phi_1 (z)$	=	first mode shape as a function of height z, normalized to unity at $z = h$

1.6 Determination of wind actions

Values of wind actions (W) for use in design shall be established. The values shall be appropriate for the type of structure or structural element, its intended use, design working life and exposure to wind action.

The following wind actions, determined in accordance with this Standard (using the procedures detailed in Section 2 and the values given in the remaining Sections) are deemed to conform to the requirements of this Clause:

(a) W_u determined using a regional wind speed appropriate to the annual probability of exceedance (P) specified for ultimate limit states as given in AS/NZS 1170.0, or the National Construction Code (Australia).

(b) W_s determined using a regional wind speed appropriate to the annual probability of exceedance for the serviceability limit states (see Note 3).

NOTE 1 Information on serviceability conditions and criteria can be found in AS/NZS 1170.0 (see Preface).

NOTE 2 Some design processes require the determination wind pressure (ultimate or serviceability wind pressure). Such pressures should be calculated for the wind speed associated with the annual probability of exceedance (P) appropriate to the limit state being considered.

NOTE 3 For guidance on Item (b), refer to AS/NZS 1170.0.

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1.7 Units

Except where specifically noted, this Standard uses the SI units of kilogram, metre, second, pascal, newton, degree and hertz (kg, m, s, Pa, N, Hz).

Section 2 Calculation of wind actions

2.1 General

The procedure for determining wind actions (W) on structures and elements of structures or buildings shall be as follows:

(a) Determine site wind speeds (see Clause 2.2).

(b) Determine design wind speed from the site wind speeds (see Clause 2.3).

(c) Determine design wind pressures and distributed forces (see Clause 2.4).

(d) Calculate wind actions (see Clause 2.5).

2.2 Site wind speed

The site wind speeds ($V_{\mathrm{sit},\beta}$) defined for the 8 cardinal directions (β) at the reference height (z) above ground (see Figure 2.1) shall be calculated from Equation 2.2:

$$V_{\mathrm{sit},\beta} = V_{\mathrm{R}} M_{\mathrm{c}} M_{\mathrm{d}} \left(M_{\mathrm{z,cat}} M_{\mathrm{s}} M_{\mathrm{t}} \right) \qquad 2.2$$

where

V_{R} = regional gust wind speed, in metres per second, for average recurrence interval of R years, as given in Section 3

M_{c} = climate change multiplier, as given in Section 3

M_{d} = wind directional multipliers for the 8 cardinal directions (β) as given in Section 3

$M_{\mathrm{z,cat}}$ = terrain/height multiplier, as given in Section 4

M_{s} = shielding multiplier, as given in Section 4

M_{t} = topographic multiplier, as given in Section 4

Generally, the wind speed is determined at the average roof height (h). In some cases, this varies according to the structure.

2.3 Design wind speed

The building orthogonal design wind speeds ($V_{\mathrm{des},\theta}$) shall be taken as the maximum cardinal direction site wind speed ($V_{\mathrm{sit},\beta}$) linearly interpolated between cardinal points within a sector ± 45° to the orthogonal direction being considered (see Figures 2.2 and 2.3).

NOTE That is, $V_{\mathrm{des},\theta}$ equals the maximum value of site wind speed ($V_{\mathrm{sit},\beta}$) in the range [$\beta = \theta \pm 45°$] where β is the cardinal direction clockwise from true North and θ is the angle to the building orthogonal axes.

In cases such as walls and hoardings and lattice towers, where an incident angle of 45° is considered, $V_{\mathrm{des},\theta}$ shall be the maximum value of $V_{\mathrm{sit},\beta}$ in a sector ± 22.5° from the 45° direction being considered.

For ultimate limit states design, $V_{\mathrm{des},\theta}$ shall not be less than 30 m/s.

A conservative approach is to design the structure using the wind speed and multipliers for the worst direction. For example, for a building on an escarpment it may be easily checked whether the $V_{\mathrm{R}}\, M_{\mathrm{c}}\, M_{\mathrm{d}}$ ($M_{\mathrm{z,cat}}\, M_{\mathrm{s}}\, M_{\mathrm{t}}$) on the exposed face (towards the escarpment) is the worst case. To simplify design, this value could then be used as the design wind speed for all directions on the building.

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With reference to Figure 2.1, when determining the reference height on a structure, the ground level shall be taken as that of the natural ground (i.e. excluding any excavations, etc.) at the centroid of the footprint of the roof(s). Where there are upper and lower roof(s) on a building, the average roof height shall be taken as that of the upper roof.

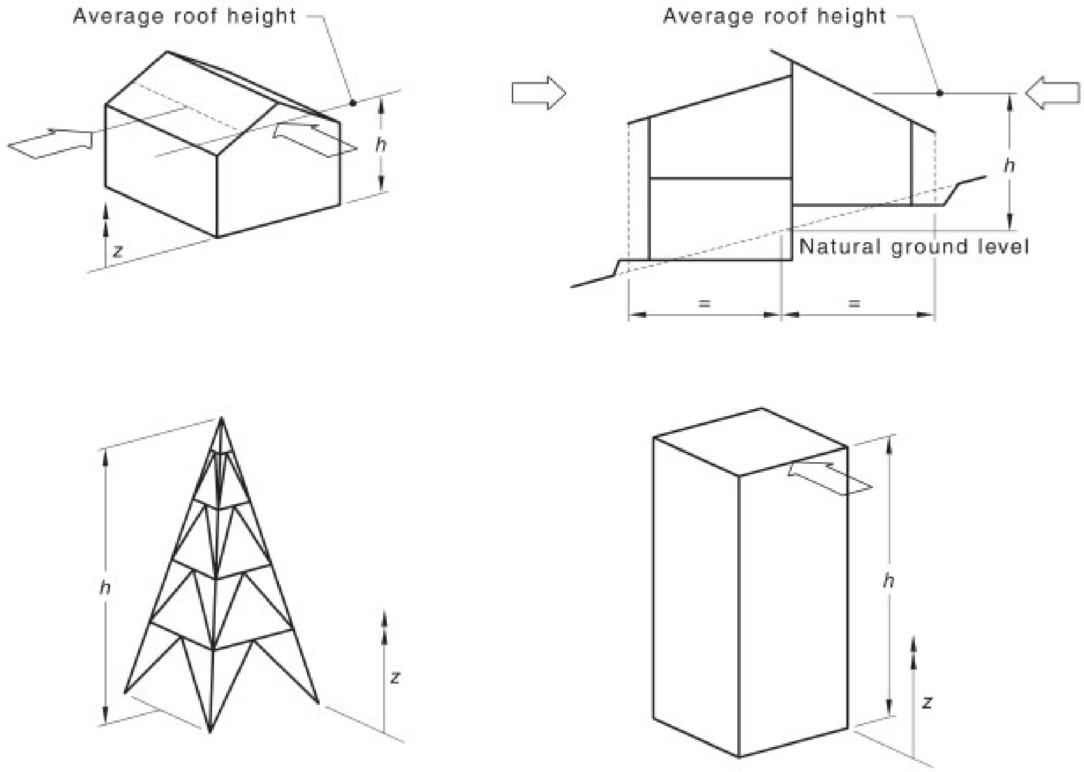


Figure 2.1 — Reference height of structures

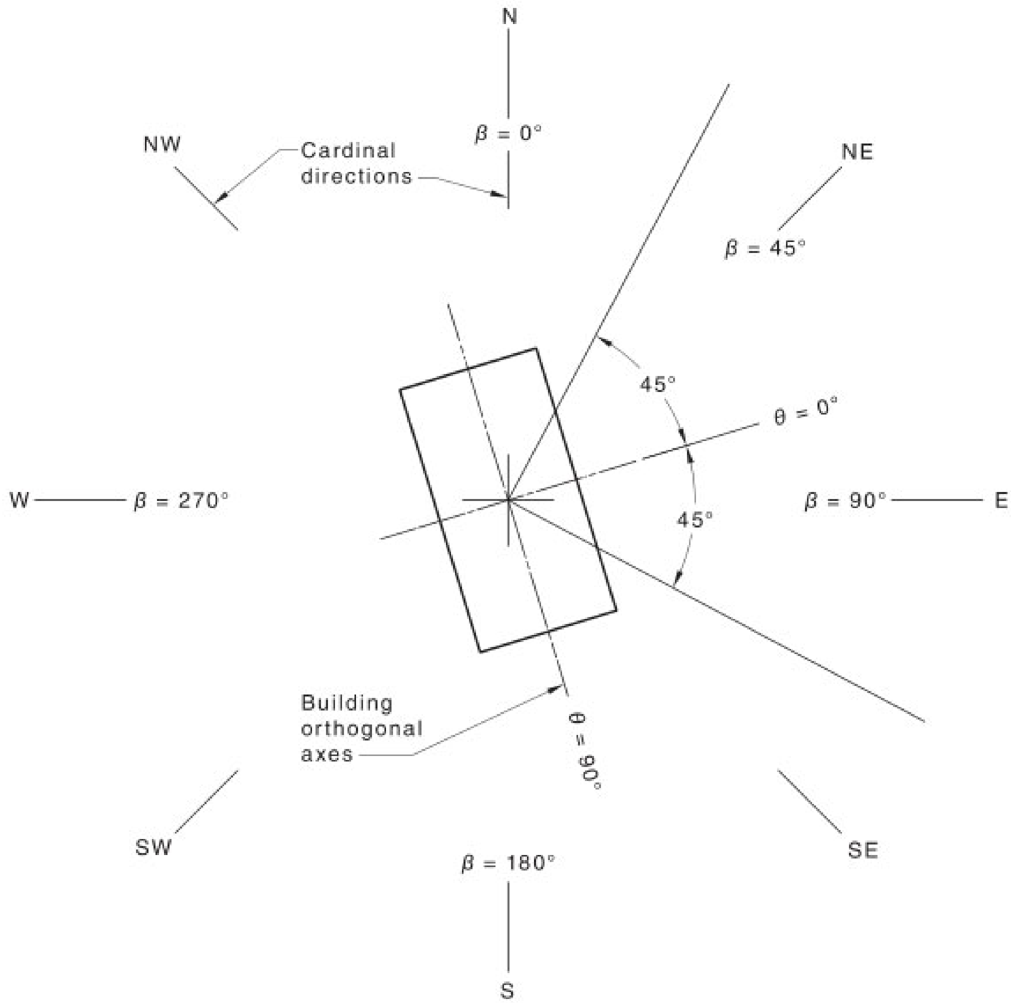
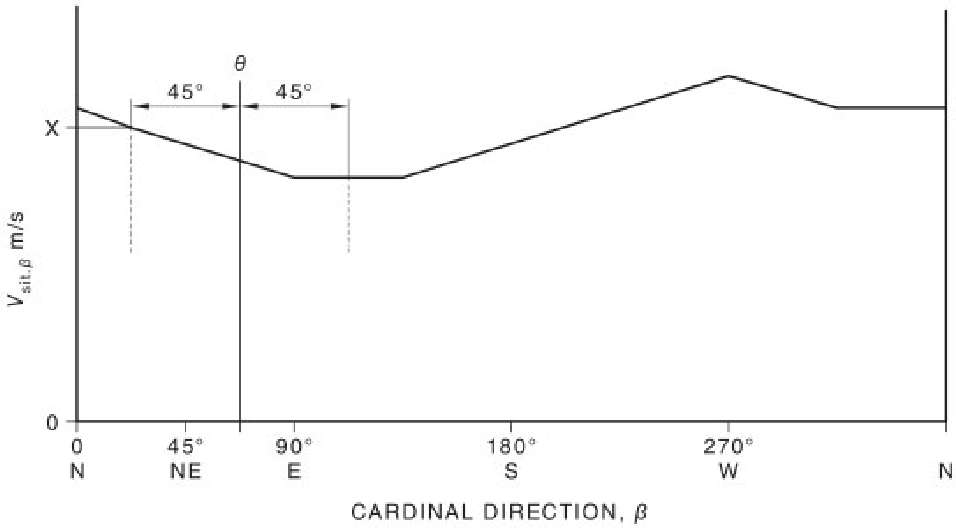


Figure 2.2 — Relationship of wind directions and building orthogonal axes



NOTE The value of $V_{\text{des},\theta}$ is the maximum of $V_{\text{sit},\beta}$ in the range $\theta \pm 45°$, which, in the case shown here, is the wind speed X.

Figure 2.3 — Example of $V_{\text{sit},\beta}$ conversion to $V_{\text{des},\theta}$

2.4 Design wind pressure and distributed forces

2.4.1 Design wind pressures

The design wind pressures (p), in pascals, shall be determined for structures and parts of structures from Equation 2.4(1):

$$p = \left(0.5\rho_{\text{air}}\right)\left[V_{\text{des},\theta}\right]^2 C_{\text{sh}}\ C\ _{\text{yn}} \qquad 2.4(1)$$

where

p = design wind pressure in pascals

= p_e, p_i or p_n where the sign is given by the C_p values used to evaluate C_{shp}

NOTE: Pressures are taken as positive, indicating pressures above ambient and negative, indicating pressures below ambient.

ρ_{air} = density of air, which shall be taken as 1.2 kg/m^3

$V_{\text{des},\theta}$ = building orthogonal design wind speeds (usually, θ = 0°, 90°, 180° and 270°), as given in Clause 2.3

NOTE: For some applications, $V_{\text{des},\theta}$ may be a single value or may be expressed as a function of height (z), e.g. windward walls of tall buildings (>25 m).

C_{shp} = aerodynamic shape factor, as given in Section 5

C_{dyn} = dynamic response factor, as given in Section 6 (the value is 1.0 except where the structure is dynamically wind sensitive [see Section 6])

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2.4.2 Design frictional drag force per unit area

The design wind frictional drag force per unit area (f), in pascals, shall be taken for structures and parts of structures from Equation 2.4(2):

$$f = \left(0.5\rho_{\text{air}}\right)\left[V_{\text{des},\theta}\right]^2 C_{\text{shp}} \tag{2.4(2)}$$

2.5 Wind actions

2.5.1 General

Wind actions (W_u and W_s) for use in AS/NZS 1170.0 shall be determined as given in Clauses 2.5.2 to 2.5.4 and deflections and accelerations of dynamically wind-sensitive structures as given in Clause 2.5.7.

2.5.2 Directions

Wind actions shall be derived by considering wind from no fewer than four orthogonal directions aligned to the structure.

2.5.3 Forces on surfaces or structural elements

2.5.3.1 Forces derived from wind pressure

To determine wind actions, the forces (F) in newtons, on surfaces or structural elements, such as a wall or a roof, shall be the vector sum of the forces calculated from the pressures applicable to the assumed areas (A), using Equation 2.5(1):

$$F = \sum\left(p_z A_z\right) \tag{2.5(1)}$$

where

p_z = design wind pressure in pascals (normal to the surface) at height z, calculated in Clause 2.4.1

NOTE: The sign convention for pressures leads to forces towards the surface for positive pressures and forces away from the surface for negative pressures.

A_z = reference area, in square metres, at height z, upon which the pressure at that height (p_z) acts

For enclosed buildings, internal pressures shall be taken to act simultaneously with external pressures, including the effects of local pressure factors (K_ℓ).

Generally, the most severe combinations of internal and external pressures shall be selected for design, but some reduction in the combined load may be applicable according to Clause 5.4.3.

Where it is required to divide the height of a tall structure into sectors to calculate wind actions (e.g. windward walls of tall buildings [Table 5.2(A)] or for lattice towers [Clause C.4.1]), the sectors shall be of a size to represent reasonably the variation of wind speed with height, as given in Clause 4.2.2.

2.5.3.2 Forces derived from frictional drag

To determine wind actions, the forces (F), in newtons, on a building element, such as a wall or a roof, shall be the vector sum of the forces calculated from distributed frictional drag stresses applicable to the assumed areas, using Equation 2.5(2):

$$F = \sum \left(f_{z} A_{z} \right) \qquad 2.5(2)$$

where

f_z = design frictional drag per unit area parallel to the surface (calculated in Clause 2.4.2) at height z, in pascals

A_z = reference area, in square metres, on which the distributed frictional drag stresses (f_z) act

2.5.3.3 Forces derived from force coefficients

Appendices C and D cover structures for which shape factors are given in the form of force coefficients rather than pressure coefficients. In these cases, to determine wind actions, the forces (F) in newtons shall be calculated from Equation 2.5(3):

$$F = \left(0.5\rho_{\text{air}}\right)\left[V_{\text{des},\theta}\right]^{2} C_{\text{sh}}\ C_{\text{yn}} A_{z} \qquad 2.5(3)$$

where

A_z = as defined in Clause C.4 for lattice towers

= $l \times b$ for members and simple sections in Clause C.2

= A_{ref} as defined in Appendix D for flags and circular shapes

2.5.4 Forces and moments on complete structures

To determine wind actions, the total resultant forces and overturning moments on complete structures shall be taken to be the summation of the effects of the external pressures on all surfaces of the building.

For rectangular enclosed buildings with h > 70 m, torsion shall be applied, based on an eccentricity of 0.2b with respect to the centre of geometry of the building on the along-wind loading.

NOTE For d/b > 1.5, the torsional moments are primarily generated by crosswind forces and specialist advice should be sought.

For dynamic effects, the combination of along-wind and crosswind responses shall be calculated in accordance with Section 6.

2.5.5 Number of stress exceedances produced by wind loading

For structures that may be fatigue sensitive, Figure 2.4 and Equation 2.5(4) show the number of times, N_g, that a stress level, σ, is exceeded under wind loading in a lifetime, L, where L is 20 to 100 years and is expressed as a percentage of the expected maximum stress, $\sigma_{\max}$, in the lifetime, L.

NOTE 1 To assess potential high-cycle fatigue damage in elements a structure subjected to repeated and fluctuating stresses under wind loading, the stress count given in Figure 2.4 and in Equation 2.5(4) may be used, together with stress/cycles to failure relationships, (S-N curves), such as those given for various detail categories in AS 4100. The stress counts in Figure 2.4 include quasi-static stress cycles produced by wind gusting, as well as those produced by resonant vibrations.

NOTE 2 A simplified design approach to steel design, that links the design for fatigue under wind loading to the maximum stress associated with the ultimate load is given by Holmes and Genner (2012). This approach makes use of the cycle count of Figure 2.4.

NOTE 3 The methods in this Clause are not appropriate for assessing the low-cycle fatigue performance cladding elements in Regions C and D, which is covered separately in Clause 2.5.6.

NOTE 4 The methods this Clause are appropriate to wind-induced fluctuating loading from buffeting by turbulence (usually acting in the along-wind direction). They are not suitable to assess fatigue damage produced by crosswind vibrations of slender structures produced by vortex shedding (see Clause 6.3.3). In those cases, potential fatigue damage should be avoided by mitigating the vibrations by various means, such as auxiliary dampers, or aerodynamic devices such as helical strakes.

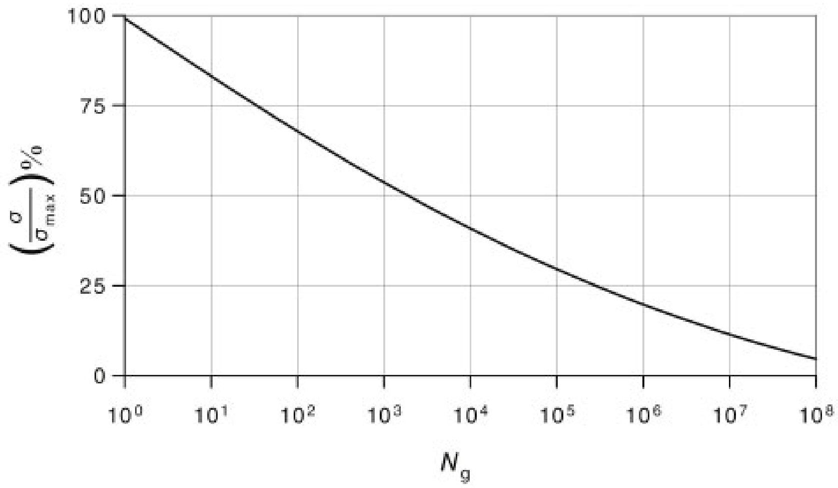

Figure 2.4 — Number of wind load cycles, N_g, for an effect, σ/σ_{max}, during a 20 to 100 year period

The relationship between σ/σ_{max} and N_g is given by Equation 2.5(4), as follows:

$$\frac{\sigma}{\sigma_{max}} = 0.7\left(\log\left(N_g\right)\right)^2 - 17.4\log\left(N_g\right) + 100 \qquad 2.5(4)$$

2.5.6 Performance of cladding elements sensitive to low-cycle fatigue

In Regions C and D, cladding, its connections and immediate supporting members and their fixings shall demonstrate performance under the pressure sequences defined in AS 4040.3 and the National Construction Code (Australia), based on the ultimate limit state wind pressure on external and internal surfaces, as determined in accordance with this Standard.

2.5.7 Deflections of dynamically wind-sensitive structures

Wind actions for dynamically wind-sensitive structures (as defined in Clause 6.1), which may include chimneys, masts and poles of circular cross-section, shall be calculated in accordance with Section 6.

NOTE Information on peak acceleration other wind-sensitive structures is given in Appendix E.

2.5.8 Impact loading from windborne debris

Where windborne debris loading is required for impact resistance testing, the debris impact loading shall be—

(a) a timber test member of 4 kg mass, of a density of at least 600 kg/m^3, with a nominal cross-section of 100 mm × 50 mm impacting end on at:

  (i) 0.4 V_R, normal to wall surfaces;

  (ii) 0.4 V_R × sine of the roof slope, normal to roof surfaces greater than 15° pitch; and

  (iii) 0.1 V_R, normal to roof surfaces less than, or equal to, 15° pitch; and

(b) a spherical steel ball, 8 mm in diameter (approximately 2 g mass) impacting at 0.4 V_R normal to wall surfaces, and roof surfaces greater than 35° pitch; and 0.3 V_R normal to roof surfaces less than, or equal to, 35° pitch,

where V_R is the regional wind speed given in Clause 3.2.

NOTE 1 Examples the use this Clause would be for the evaluation internal pressure (see Clause 5.3.2), or the demonstration of resistance to penetration of the building envelope enclosing a shelter room.

NOTE 2 The two test debris items are representative a large range windborne debris varying masses and sizes that can be generated in severe wind storms.

NOTE 3 The spherical ball missile is representative small missiles, which could penetrate protective screens with large mesh sizes.

NOTE 4 These impact loadings should be applied independently in time and location.

NOTE 5 This Standard does not specify a test method or acceptance criteria. Acceptance criteria may vary according to the purpose of the test. An appropriate test method and acceptance criteria for debris tests are given in Technical Note No. 4 (see Bibliography).

Section 3 Regional wind speeds

3.1 General

This Section shall be used to calculate gust wind speeds appropriate to the region in which a structure is to be constructed, including wind direction effects.

3.2 Regional wind speeds (V_R)

Regional wind speeds (V_R) for all directions based on peak gust wind data shall be as given in Table 3.1(A) or Table 3.1(B) for the regions shown in Figure 3.1(A) and Figure 3.1(B) where R (average recurrence interval) is the average time interval between exceedances of the wind speed listed. For $R \geq 5$ years, it is equal to the reciprocal of the annual probability of exceedance of the wind speed.

The calculated values of V_R have been rounded to the nearest 1 m/s.

In Region C, values of V_R shall be obtained by linear interpolation between the value given for Region C (maximum) and the value given for Region B2 for the same R, according to the distance from the smoothed coastline. In Region D, values of V_R shall be obtained by linear interpolation between the value given for Region D (maximum) and the value given for Region C (maximum) for the same R, according to the distance from the smoothed coastline.

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Table 3.1(A) — Regional wind speeds — Australia

Regional wind speed (m/s)	Region			
	Non-cyclonic		Cyclonic	
	A (0 to 5)	B1, B2	C (maximum)	D (maximum)
V_1	30	26	23	23
V_5	32	28	33	35
V_{10}	34	33	39	43
V_{20}	37	38	45	51
V_{25}	37	39	47	53
V_{50}	39	44	52	60
V_{100}	41	48	56	66
V_{200}	43	52	61	72
V_{250}	43	53	62	74
V_{500}	45	57	66	80
V_{1000}	46	60	70	85
V_{2000}	48	63	73	90
V_{2500}	48	64	74	91
V_{5000}	50	67	78	95
V_{10000}	51	69	81	99
V_R ($R \geq 5$ years)	$67–41R^{-0.1}$	$106–92R^{-0.1}$	$122–104R^{-0.1}$	$156–142R^{-0.1}$

NOTE 1 The peak gust has an equivalent moving average time approximately 0.2 s (Holmes and Ginger, 2012).

NOTE 2 Values for V_1 have not been calculated by the formula for V_R in the Australian regions.

NOTE 3 For ultimate or serviceability limit states, refer to the National Construction Code (Australia) or AS/NZS 1170.0 for information on values of importance level and annual probability of exceedance appropriate for the design of structures. For buildings in townships in cyclonic regions, users should consider overall risk to a community when selecting importance levels.

NOTE 4 For Regions C and D, only the maximum values for the region are tabulated. Lower values V_R may apply in those regions, depending on the distance of the site from the smooth coastline.

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Table 3.1(B) — Regional wind speeds — New Zealand

Regional wind speed (m/s)	Region		
	NZ (1 to 2)	NZ3	NZ4
V_1	31	37	38
V_5	35	42	42
V_{10}	37	44	43
V_{20}	39	46	44
V_{25}	39	46	45
V_{50}	41	48	46
V_{100}	42	50	47
V_{200}	43	51	48
V_{250}	44	51	49
V_{500}	45	53	50
$V_{1\,000}$	46	54	50
$V_{2\,000}$	47	55	51
$V_{2\,500}$	47	55	52
$V_{5\,000}$	48	56	52
$V_{10\,000}$	49	57	53
V_R	$61–30R^{-0.1}$	$71–34R^{-0.1}$	$63–25R^{-0.1}$

NOTE 1 The peak gust has an equivalent moving average time approximately 0.2 s (Holmes and Ginger, 2012).

NOTE 2 For ultimate or serviceability limit states, refer to AS/NZS 1170.0 for information on values importance level and annual probability of exceedance appropriate for the design of structures in New Zealand.

3.3 Wind direction multiplier (M_d)

Except for the following cases, the wind direction multiplier (M_d) for all regions shall be as given in Table 3.2(A) or Table 3.2(B). For the following cases, M_d shall be taken as 1.0:

(a) structures such as chimneys, tanks and poles with circular or polygonal cross-sections; and

(b) cladding and immediate supporting structure (as defined in Clause 5.4.4) on buildings in Regions B2, C and D.

NOTE In regions where the prevailing wind directions vary with wind speed, wind direction multipliers have been calculated for the higher wind gusts (i.e. those associated with ultimate limit states design).

Table 3.2(A) — Wind direction multiplier (M_d) — Australia

Cardinal directions	Region A0	Region A1	Region A2	Region A3	Region A4	Region A5	Region B1	Regions B2, C, D
N	0.90	0.90	0.85	0.90	0.85	0.95	0.75	0.90
NE	0.85	0.85	0.75	0.75	0.75	0.80	0.75	0.90
E	0.85	0.85	0.85	0.75	0.75	0.80	0.85	0.90
SE	0.90	0.80	0.95	0.90	0.80	0.80	0.90	0.90
S	0.90	0.80	0.95	0.90	0.80	0.80	0.95	0.90
SW	0.95	0.95	0.95	0.95	0.90	0.95	0.95	0.90
W	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90
NW	0.95	0.95	0.95	0.95	1.00	0.95	0.90	0.90

NOTE In Region A0 non-synoptic winds are dominant. In Regions A1 and A4, extra-tropical synoptic winds are dominant. Extreme winds in Regions A2, A3, A5 and B1 are caused by a mixture of synoptic (extra-tropical large-scale pressure systems, or tropical cyclones in the case of B1) and non-synoptic (thunderstorm) events. In Regions B2, C, and D, extreme winds from tropical cyclones are dominant.

Table 3.2(B) — Wind direction multiplier (M_d) — New Zealand

Cardinal directions	Region NZ1	Region NZ2	Region NZ3	Region NZ4
N	0.90	0.95	1.00	0.95
NE	0.95	0.90	0.75	0.75
E	0.95	0.80	0.75	0.75
SE	0.95	0.90	0.85	0.75
S	0.90	0.95	0.95	0.85
SW	1.00	1.00	0.95	0.95
W	1.00	1.00	0.90	1.00
NW	0.95	1.00	1.00	1.00

NOTE In all New Zealand regions, extra-tropical synoptic winds are dominant.

3.4 Climate change multiplier (M_c)

The climate change multiplier (M_c) shall be as given in Table 3.3.

Table 3.3 — Climate change multiplier (M_c)

Region	M_c
A (0 to 5)	1.0
B1	1.0
B2	1.05
C	1.05
D	1.05
NZ (1 to 4)	1.0

NOTE The climate change multiplier allows for possible changes in climate affecting extreme winds during the life of structures designed by this Standard. Values of M_c may be adjusted in future amendments, depending on observed or predicted trends.

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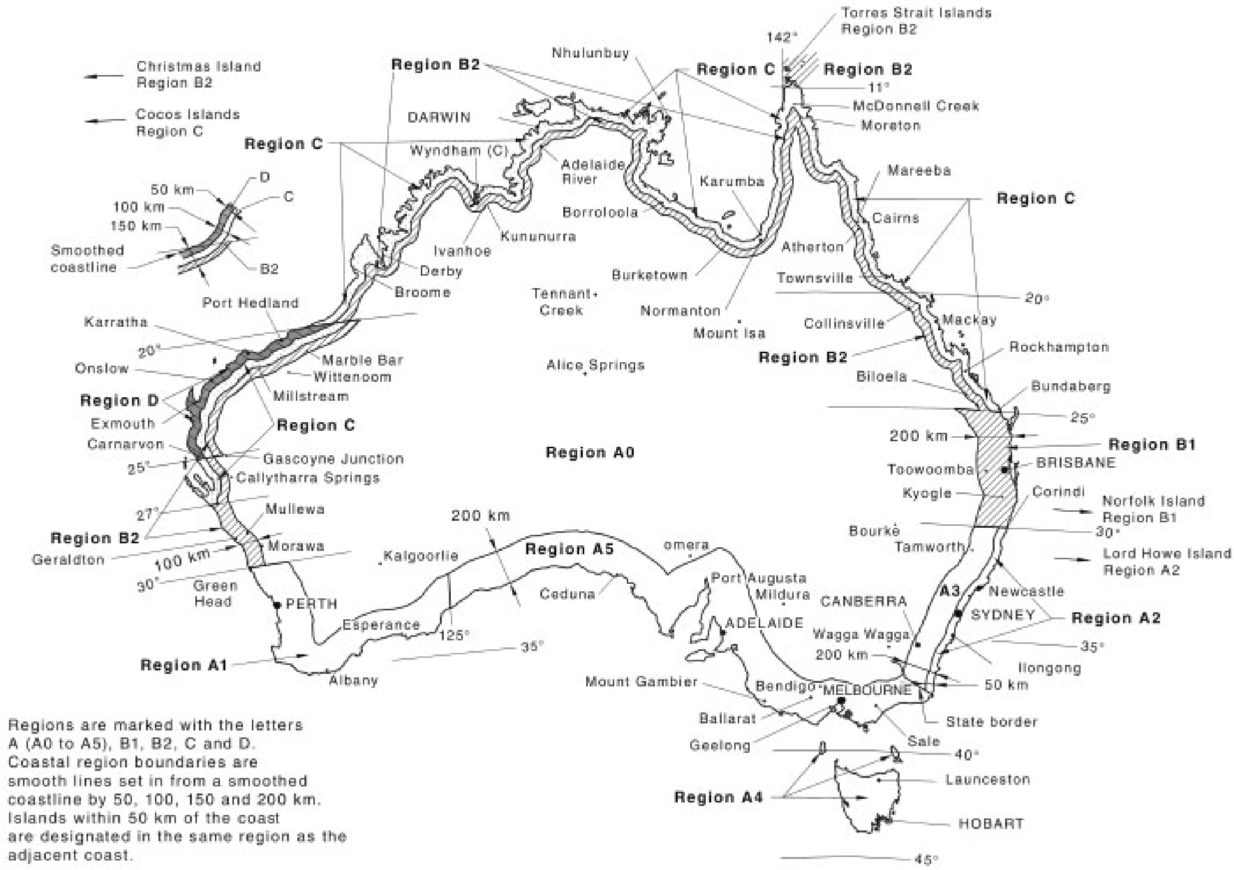

Figure 3.1(A) — Wind regions — Australia

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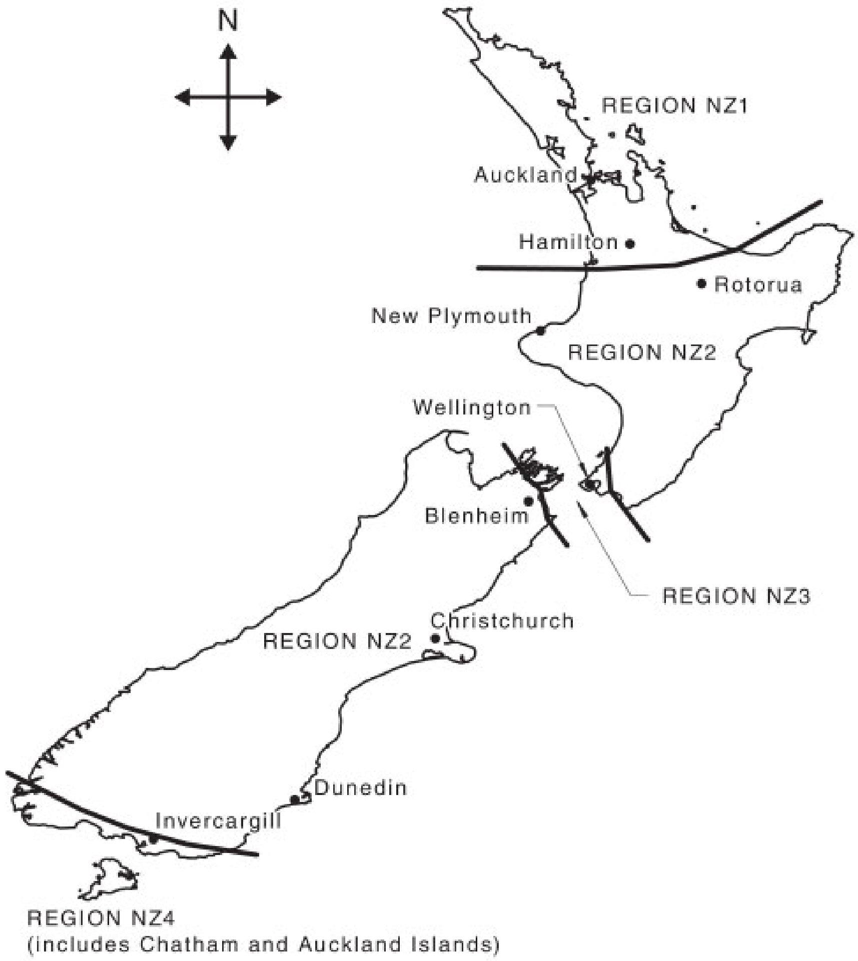


Figure 3.1(B) — Wind regions — New Zealand

Section 4 Site exposure multipliers

4.1 General

This Section shall be used to calculate the exposure multipliers for site conditions related to terrain/height ($M_{z,cat}$), shielding (M_s) and topography (M_t).

The design shall take account of known future changes to terrain roughness when assessing terrain category and to buildings providing shielding when assessing shielding.

4.2 Terrain/height multiplier ($M_{z,cat}$)

4.2.1 Terrain category definitions

Terrain, over which the approach wind flows towards a structure, shall be assessed on the basis of the following category descriptions:

(a) *Terrain Category 1 (TC1)* — Very exposed open terrain with very few or no obstructions, and all water surfaces (e.g. flat, treeless, poorly grassed plains; open ocean, rivers, canals, bays and lakes).

(b) *Terrain Category 2 (TC2)* — Open terrain, including grassland, with well-scattered obstructions having heights generally from 1.5 m to 5 m, with no more than two obstructions per hectare (e.g. farmland and cleared subdivisions with isolated trees and uncut grass).

(c) *Terrain Category 2.5 (TC2.5)* — Terrain with some trees or isolated obstructions, terrain in developing outer urban areas with scattered houses, or large acreage developments with more than two and less than 10 buildings per hectare.

(d) *Terrain Category 3 (TC3)* — Terrain with numerous closely spaced obstructions having heights generally from 3 m to 10 m. The minimum density of obstructions shall be at least the equivalent of 10 house-size obstructions per hectare (e.g. suburban housing, light industrial estates or dense forests).

(e) *Terrain Category 4 (TC4)* — Terrain with numerous large, high (10 m to 30 m tall) and closely-spaced constructions, such as large city centres and well-developed industrial complexes.

Selection of the terrain category shall be made with due regard to the permanence of the obstructions that constitute the surface roughness.

NOTE The aerodynamic roughness length, z_0, in metres, is related to the terrain category number by the following relation: $z_0 = 2 \times 10^{(TC\ \text{number} - 4)}$

4.2.2 Determination of terrain/height multiplier ($M_{z,cat}$)

The variation with height (z) of the effect of terrain roughness on wind speed (terrain and structure height multiplier, $M_{z,cat}$) shall be taken from the values for fully developed profiles given in Table 4.1. For intermediate values of height and terrain category, use linear interpolation.

Table 4.1 — Terrain/height multipliers for gust wind speeds in fully developed terrains — All regions except A0

Height (z) (m)	Terrain/height multiplier ($M_{z,cat}$) Terrain Category 1	Terrain Category 2	Terrain Category 2.5	Terrain Category 3	Terrain Category 4
≤ 3	0.97	0.91	0.87	0.83	0.75
5	1.01	0.91	0.87	0.83	0.75
10	1.08	1.00	0.92	0.83	0.75
15	1.12	1.05	0.97	0.89	0.75
20	1.14	1.08	1.01	0.94	0.75
30	1.18	1.12	1.06	1.00	0.80
40	1.21	1.16	1.10	1.04	0.85
50	1.23	1.18	1.13	1.07	0.90
75	1.27	1.22	1.17	1.12	0.98
100	1.31	1.24	1.20	1.16	1.03
	1.36	1.27	1.24	1.21	1.11
200	1.39	1.29	1.27	1.24	1.16

NOTE 1 In Region A0, use $M_{z,cat\,2}$ for all $z \leq 100$ m in all terrains. For 100 m < $z \leq 200$ m, take $M_{z,cat}$ as 1.24 in all terrains.

NOTE 2 For all other regions, for intermediate terrains use linear interpolation.

NOTE 3 For intermediate values height z, use linear interpolation.

4.2.3 Averaging of terrain categories and terrain-height multipliers

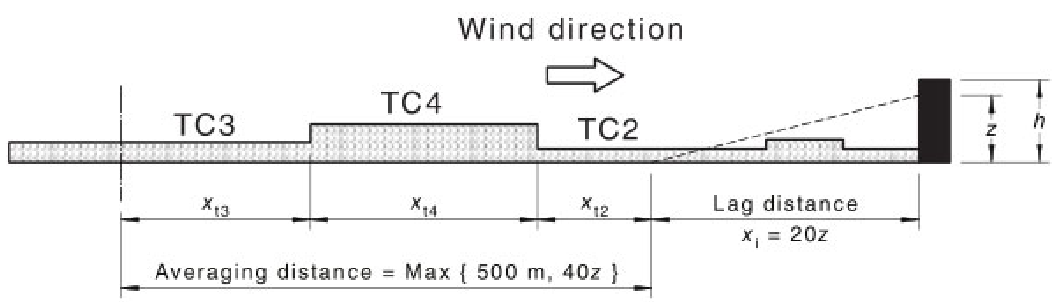
When the upwind terrain varies for any wind direction, an averaging of terrain-height multipliers shall be adopted. The terrain-height multiplier, $M_{z,cat}$, shall be taken as a weighted average over an averaging distance, x_a, depending on the height, z.

NOTE z is equal to the average roof height, h, of a building, when it is less than, or equal to, 25 m.

The averaging distance, x_a, shall be the larger of 500 m or 40z.

Terrain shall be assessed after ignoring the terrain immediately upwind for a lag distance, x_i, where x_i is taken as 20z.

An example of this averaging procedure is given in Figure 4.1.



$$M_{z,cat} = \frac{M_{z,cat2}\,x_{t2} + M_{z,cat4}\,x_{t4} + M_{z,cat3}\,x_{t3}}{x_{t2} + x_{t4} + x_{t3}} \quad \text{for the case illustrated}$$

NOTE The terrain within the lag distance, x_i, is ignored when averaging terrain-height multipliers.

Figure 4.1 — Example of averaging of terrain-height multipliers

4.3 Shielding multiplier (M_S)

4.3.1 General

Shielding may be provided by upwind buildings or other structures. Shielding shall not be provided by trees or vegetation. An upwind building shall not be used to provide shielding on a slope with a gradient that is greater than 0.2, unless its overall height above a common datum, such as mean sea level, exceeds that of the subject building (see Figure 4.2).

The shielding multiplier (M_S) that is appropriate to a particular direction shall be as given in Table 4.2 for structures with $h \leq 25$ m in height (h is defined in Figure 2.1).

The shielding multiplier shall be 1.0 for structures with h greater than 25 m, where the effects of shielding are not applicable for a particular wind direction, or are ignored.

NOTE To accurately determine shielding and interference effects between buildings with h greater than 25 m, wind-tunnel testing is needed. Attention should be given to possible combinations of tall buildings placed together, which can lead to local and overall increases in wind actions.

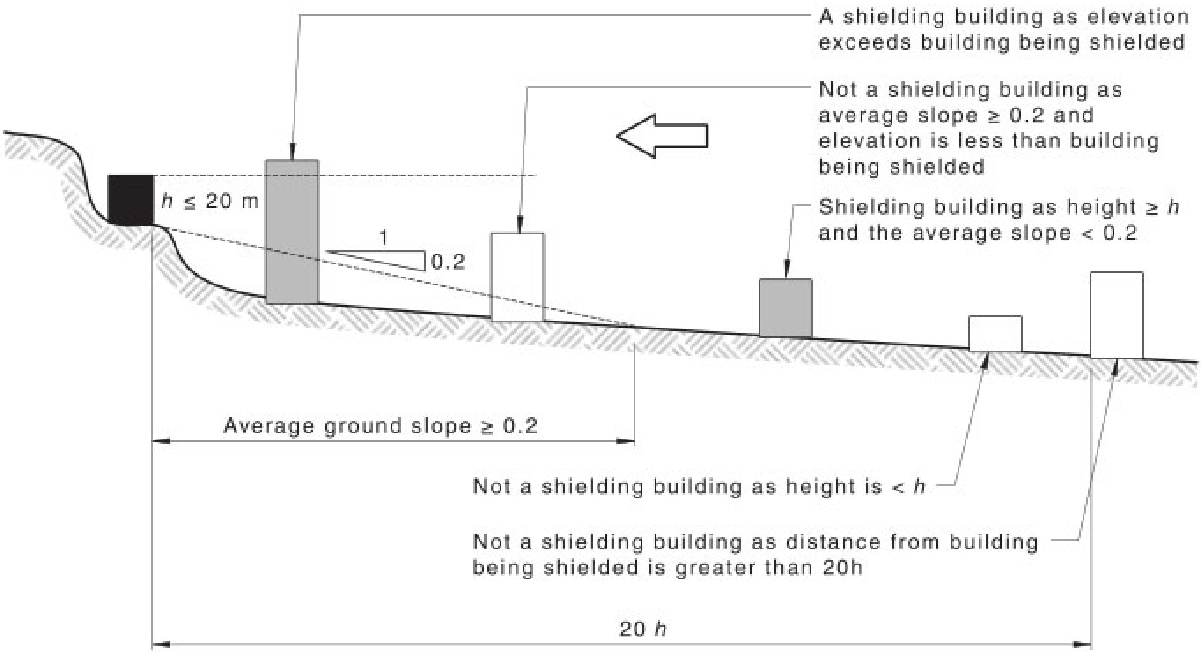


Figure 4.2 — Upwind buildings on a slope

Table 4.2 — Shielding multiplier (M_S) (for $h \leq 25$ m)

Shielding parameter (s)	Shielding multiplier (M_S)
≤ 1.5	0.7
3.0	0.8
6.0	0.9
≥ 12.0	1.0
NOTE For intermediate values	s, use linear interpolation.

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4.3.2 Buildings providing shielding

Only buildings within a 45° sector of radius 20h (symmetrically positioned about the directions being considered) with a height greater than or equal to h shall be used to provide shielding.

Where the average upwind ground gradient between the structure in question and the upwind structure is greater than 0.2, the upwind building shall not be treated as a shielding building (see Figure 4.2).

4.3.3 Shielding parameter (s)

The shielding parameter (s) in Table 4.2 shall be determined from Equation 4.3(1):

$$s = \frac{l_s}{\sqrt{h_s b_s}} \qquad 4.3(1)$$

where

l_s = average spacing of shielding buildings, given by Equation 4.3(2):

$$h\left(\frac{10}{n_s} + 5\right) \qquad 4.3(2)$$

h_s = average roof height of shielding buildings

b_s = average breadth of shielding buildings, normal to the wind stream

h = average roof height, above ground, of the structure being shielded

n_s = number of upwind shielding buildings within a 45° sector of radius 20h and with $h_s \geq h$

4.4 Topographic multiplier (M_t)

4.4.1 General

The topographic multiplier (M_t) shall be taken as follows:

(a) For sites in Regions A4, NZ1, NZ2, NZ3 and NZ4 over 500 m above sea level, use Equation 4.4(1):

$$M_t = M_h M_{lee} (1 + 0.00015E) \qquad 4.4(1)$$

where

M_h = hill shape multiplier

M_{lee} = lee (effect) multiplier (taken as 1.0, except in New Zealand lee zones, see Clause 4.4.3)

E = site elevation above mean sea level, in metres

(b) For sites in Region A0, use Equation 4.4(2):

$$M_t = 0.5 + 0.5M_h \qquad 4.4(2)$$

(c) Elsewhere, the larger value of the following:

(i) $M_t = M_h$

(ii) $M_t = M_{lee}$

4.4.2 Hill-shape multiplier (M_h)

The hill-shape multiplier shall be taken as 1.0 outside of the local topographic zones shown in Figures 4.3 to 4.5, and for H < 10 m. Within the local topographic zones, the hill shape multiplier (M_h) shall be assessed for each cardinal direction considered, taking into account the most adverse topographic cross-section that occurs within the range of directions within 22.5° on either side of the cardinal direction being considered. The values shall be as follows:

(a) For $H/(2L_u) < 0.05$, $M_h = 1.0$

(b) For $0.05 \le H/(2L_u) \le 0.45$ (see Figures 4.3 and 4.4), use Equation 4.4(3):

$$M_h = 1 + \left(\frac{H}{3.5(z + L_1)}\right)\left(1 - \frac{|x|}{L_2}\right) \tag{4.4(3)}$$

(c) For $H/(2L_u) > 0.45$ (see Figure 4.5):

(i) Within the rectangular peak zone (see Figure 4.5), use Equation 4.4(4):

$$M_h = 1 + 0.71\left[1 - \frac{|x|}{L_2}\right] \tag{4.4(4)}$$

(ii) Elsewhere within the local topographic zone (see Figures 4.3 and 4.4), M_h shall be as given in Equation 4.4(3).

where

H = height of the hill, ridge or escarpment

L_u = horizontal distance upwind from the crest of the hill, ridge or escarpment to a level half the height below the crest

x = horizontal distance upwind or downwind of the structure to the crest of the hill, ridge or escarpment

L_1 = length scale, to determine the vertical variation of M_h, to be taken as the greater of 0.36 L_u or 0.4 H

L_2 = length scale, to determine the horizontal variation of M_h, to be taken as 4 L_1 upwind for all types, and downwind for hills and ridges, or 10 L_1 downwind for escarpments

z = reference height on the structure above the average local ground level

NOTE Figures 4.3, 4.4 and 4.5 are cross-sections through the structure's site for a particular wind direction.

For the case where x and z are zero, the value of M_h is given in Table 4.3.

Irrespective of the provisions of this Clause, the influence of any peak may be ignored, provided the crest is distant from the site of the structure by more than 10 times its crest elevation above sea level, and any intervening valley is more than 10 times the distance of the valley floor below the crest.

For escarpments, the average downwind slope, measured from the crest to a distance of the greater of 3.6 L_u or 4 H shall not exceed 0.05.

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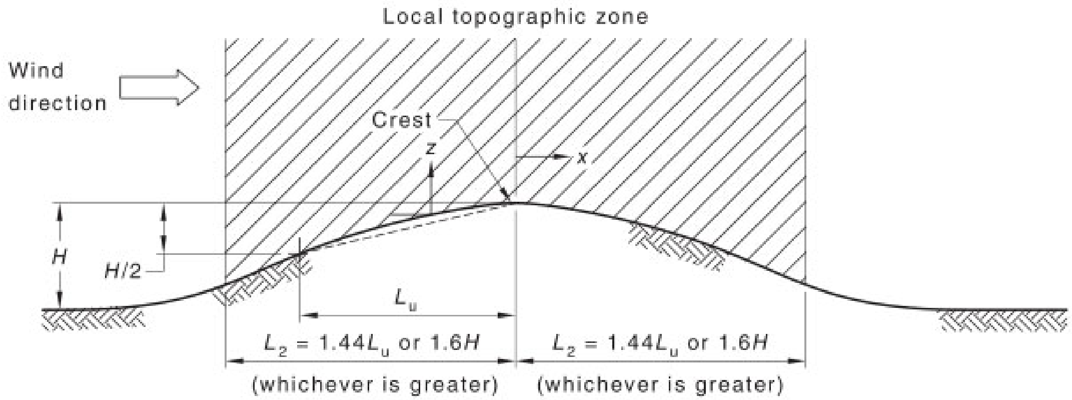

Figure 4.3 — Hills and ridges

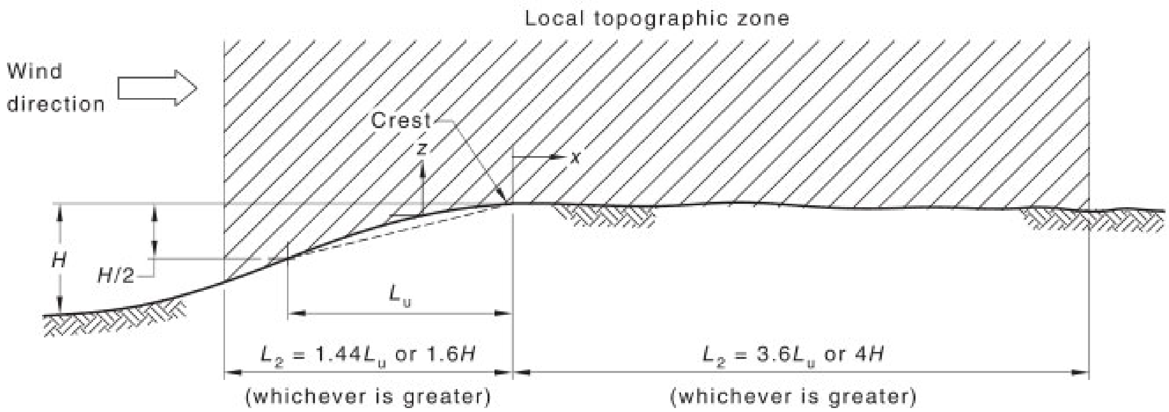

Figure 4.4 — Escarpments

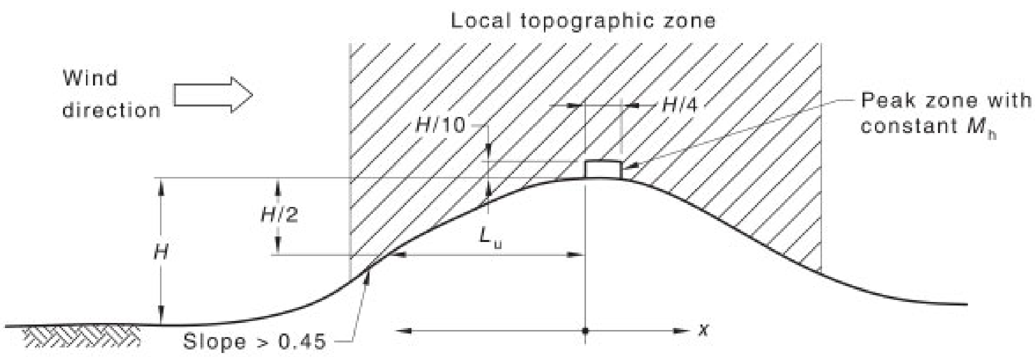

Figure 4.5 — Hills and escarpments having upwind slopes greater than 0.45

Table 4.3 — Hill-shape multiplier at crest $\left(|x|=0\right)$, $z=0$ (for gust wind speeds)

Upwind slope ($H/2L_u$)	M_h
< 0.05	1.0
0.05	1.08
0.10	1.16
0.20	1.32
0.30	1.48
≥ 0.45	1.71

4.4.3 Lee multiplier (M_{lee})

The lee (effect) multiplier (M_{lee}) shall be evaluated for New Zealand sites in the lee zones as shown in Figure 4.6. For all other sites, the lee multiplier shall be 1.0. Within the lee zones, the lee multiplier shall apply only to wind from the cardinal directions nominated in Table 4.4.

Each lee zone shall extend by the distance as specified in Table 4.4, this distance is measured from the leeward crest of the initiating range, downwind in the direction of the wind nominated. The lee zone comprises—

(a) a shadow lee zone, which extends from the crest of the initiating range (the upwind boundary of the lee zone);

(b) an outer lee zone over the remainder of the lee zone; and

(c) lateral transition zones, which extend from the lateral edges of the shadow zone by $x/4$, where x is the distance from the initiating crest along the edge of the shadow zone and by $R/4$ for the lateral edges of the outer zone, where R is the distance from the initiating crest to the leeward edge of the shadow zone. The coordinates of the initiating crests are shown in Table 4.5.

The lee multiplier for shadow zones shall be as specified in Table 4.4. Within the outer lee zone, the lee multiplier shall be determined by linear interpolation with horizontal distance, from the shadow/outer zone boundary (where M_{lee} is from Table 4.4) to the downwind boundary of the outer zone (where M_{lee} = 1.0). Within the lateral transition zone, the lee multiplier shall be determined by linear interpolation along a line parallel to the crest from the value at the point at the lateral edge of the shadow and outer zones to a value of 1.0 at the far edge of the lateral zone.

NOTE No lee zones have been identified in Australia.

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Table 4.4 — New Zealand lee zones direction and extent of shadow and outer zones

Range		Direction	M_{lee}	Shadow (km)	Outer (km)
North Island					
1.	Kaimai	E&SE	1.20	0 to 8	8 to 20
2.	Taranaki	Any, taken to be 90° sector from mountain top downwind to location	1.35	0 to 12	12 to 30
3.	Ruapehu	NW and SE	1.35	0 to 12	12 to 30
4.	Tararua	SE	1.20	0 to 8	8 to 20
5.	Tararua and Orongorongo	NW	1.20	0 to 8	8 to 20
6.	Coastal Wairarapa	NW			
South Island					
7.	West Coast North	E and SE	1.20	0 to 8	8 to 20
8.	West Coast Alps	SE	1.35	0 to 12	12 to 30
9.	Awatere	NW	1.35	0 to 12	(within Inland Kaikoura)
10.	Inland Kaikoura	NW	1.35	0 to 12	(within Southern Alps)
11.	Southern Alps	NW	1.35	0 to 12	12 to 30
12.	Hunter	SW	1.20	0 to 8	8 to 20
13.	Hakataramea	NW	1.20	0 to 8	8 to 20
14.	St Mary's	SW	1.20	0 to 8	8 to 20
15.	Pisa	NW	1.20	0 to 8	8 to 20
16.	Dunstan	NW	1.20	0 to 8	8 to 20
17.	Rock and Pillar	NW	1.20	0 to 8	8 to 20

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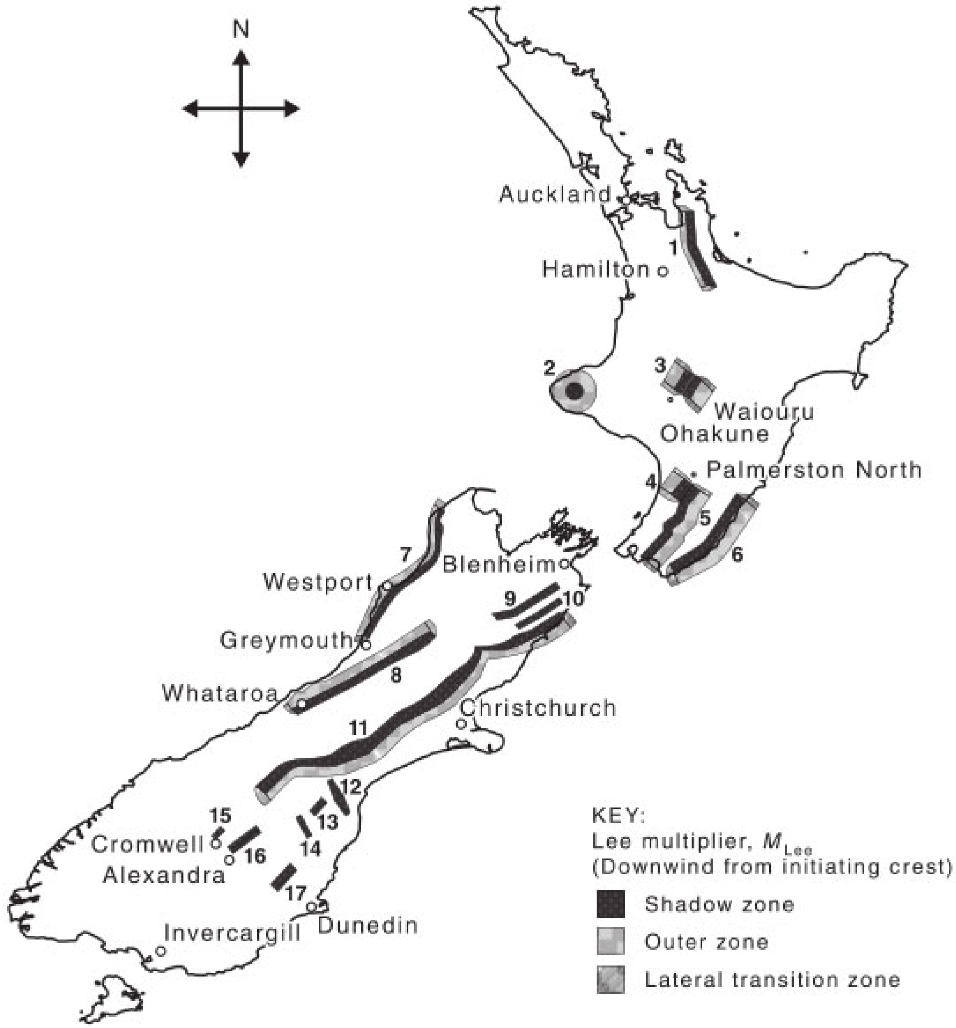


NOTE 1 Some outer and lateral transition zones are not shown.

NOTE 2 For numbers shown, see the first column Table 4.4.

Figure 4.6 — Locations of New Zealand lee zones

Table 4.5 — New Zealand lee zones, coordinates (WGS 84 datum) along initiating crests

Range	Coordinates
South Island	
Southern Alps (NW)	[169.773, −44.321], [170.061, −44.022]
	[170.668, −43.943], [170.797, −43.843]
	[171.401, −43.589], [172.222, −43.029]
	[172.277, −42.869], [172.629, −42.668]
	[172.657, −42.510], [172.764, −42.480]
	[172.948, −42.487], [173.138, −42.451]
	[173.710, −42.198], [173.759, −42.118]
Awatere (NW)	[173.861, −41.687], [173.798, −41.754]
	[173.187, −42.082], [172.954, −42.106]
Inland Kaikoura (NW)	[173.953, −41.827], [173.433, −42.147]
	[173.270, −42.179]
Hunter (SW)	[170.926, −44.670], [170.922, −44.657]
	[170.851, −44.569], [170.801, −44.464]
	[170.769, −44.441], [170.676, −44.301]
St Mary's (SW)	[170.389, −44.859], [170.322, −44.844]
	[170.343, −44.806], [170.302, −44.777]
	[170.291, −44.717]
Hakataramea (NW)	[170.464, −44.616], [170.515, −44.546]
	[170.550, −44.480], [170.561, −44.474]
Pisa (NW)	[169.119, −44.994], [169.141, −44.930]
	[169.189, −44.872], [169.261, −44.827]
Dunstan (NW)	[169.348, −45.064], [169.568, −44.957]
	[169.718, −44.840]
Rock and Pillar (NW)	[169.979, −45.570], [170.009, −45.516]
	[170.173, −45.317], [170.209, −45.248]
West Coast Alps (SE)	[170.241, −43.51], [170.478, −43.434]
	[171.564, −42.785], [171.694, −42.646]
	[172.195, −42.382]
West Coast North (E&SE)	[171.339, −42.390], [171.651, −41.891]
	[172.059, −41.618], [172.227, −41.410]
	[172.213, −40.964], [172.377, −40.910]
	[172.459, −40.792]
North Island	
Tararuas and Orongorongo (NW)	[174.923, −41.423], [175.001, −41.345]
	[175.017, −41.349], [175.266, −41.084]
	[175.267, −40.995], [175.284, −40.956]
	[175.361, −40.873], [175.418, −40.878]
	[175.509, −40.665], [175.691, −40.447]

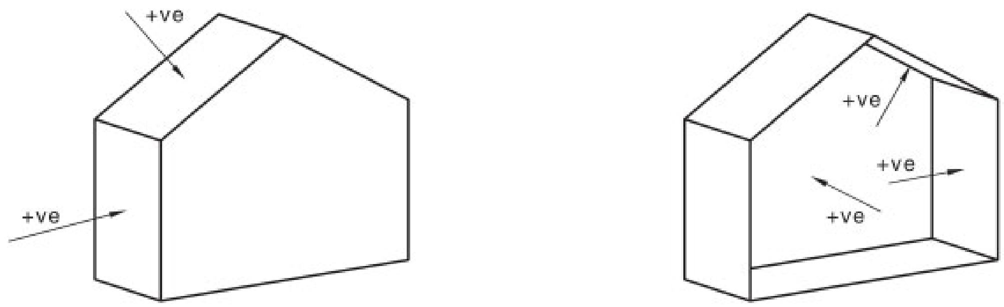
NOTE World Geodetic System 1984 (WGS 84).

Section 5 Aerodynamic shape factor

5.1 General

This Section shall be used to calculate the aerodynamic shape factor (C_{shp}) for structures or parts of structures. Values of C_{shp} shall be used in determining the pressures applied to each surface. For calculating pressures, the sign of C_{shp} indicates the direction of the pressure on the surface or element (see Figure 5.1), positive values indicate pressure acting towards the surface and negative values indicate pressure acting away from the surface (less than ambient pressure, i.e. suction). The wind action effects used for design shall be the sum of values determined for different pressure effects such as the combination of internal and external pressure on enclosed buildings.

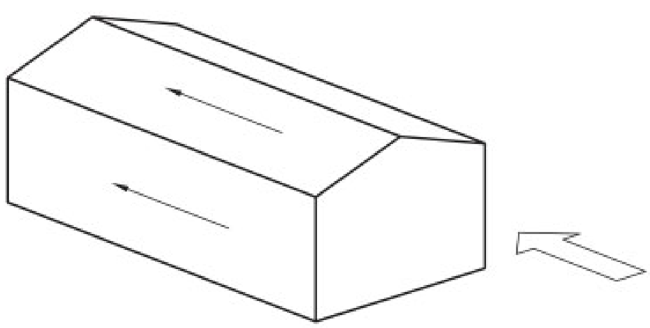
Clauses 5.3, 5.4 and 5.5 provide values for enclosed rectangular buildings. For the purposes of this Standard, rectangular buildings include buildings generally made up of rectangular shapes in plan. Methods for other types of enclosed buildings, exposed members, lattice towers, free walls, free roofs and other structures are given in Appendices A to E.



External pressures Internal pressures

NOTE: C_{shp} is used to give a pressure on one face of the surface under consideration. Positive value of C_{shp} indicates pressure acting towards the surface, negative acting away from the surface.

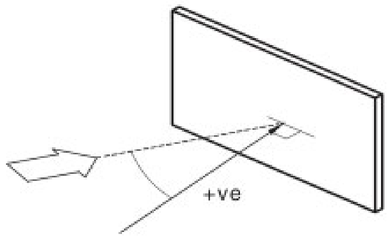
(a) Pressures normal to the surfaces of enclosed buildings



NOTE: C_{shp} is used to give a frictional drag on external surfaces of the structure only. Load per unit area acts parallel to the surface.

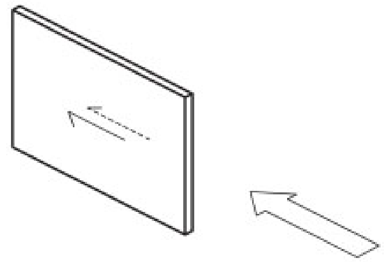
(b) Frictional drag on enclosed buildings

Figure 5.1(A) — Sign conventions for C_{shp}



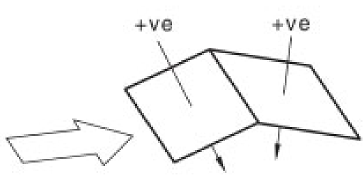
NOTE: C_{shp} is used to give a net pressure normal to the wall derived from face pressures on both upwind and downwind faces. The net pressure always acts normal to the longitudinal axis of the wall.

(c) Pressure normal to the surfaces of walls and hoardings



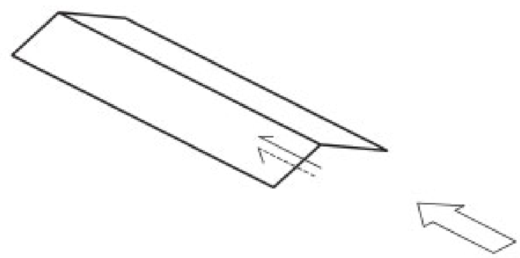
NOTE: C_{shp} is used to give frictional drag on both sides of the wall. Load per unit area acts parallel to both the surfaces of the wall.

(d) Frictional drag on walls and hoardings



NOTE: C_{shp} is used to give net pressure normal to the roof derived from face pressures on both upper and lower surfaces. The net pressure always acts normal to the surface and positive indicates downwards.

(e) Pressure normal to the surfaces freestanding roofs



NOTE: C_{shp} is used to give the total frictional drag forces derived from face frictional forces on both upper and lower surfaces. Load per unit area acts parallel to both the surfaces of the roof.

(f) Frictional drag on freestanding roofs

Figure 5.1(B) — Sign conventions for C_{shp}

5.2 Evaluation of aerodynamic shape factor

The aerodynamic shape factor (C_{shp}) shall be determined for specific surfaces or parts of surfaces as follows:

(a) Enclosed buildings — use Equations 5.2(1), 5.2(2) and 5.2(3):

$$C_{shp} = C_{p,i} K_{c,i} K_{v}\text{, for internal pressures} \quad 5.2(1)$$

$$C_{shp} = C_{p,e} K_{a} K_{c,e} K_{\ell} K_{p}\text{, for external pressures} \quad 5.2(2)$$

$$C_{shp} = C_{f} K_{a} K_{c,e}\text{, for frictional drag forces} \quad 5.2(3)$$

(b) Circular bins, silos and tanks — see Appendix A.

(c) Freestanding walls, hoardings, canopies and roofs — see Appendix B and Equations 5.2(4) and 5.2(5):

$$C_{\text{shp}} = C_{\text{p,n}} K_{\text{a}} K_{\ell} K_{\text{p}} \text{, for pressure normal to surface} \quad 5.2(4)$$

$$C_{\text{shp}} = C_{\text{f}} \text{, for frictional drag forces} \quad 5.2(5)$$

(d) Exposed structural members, frames and lattice towers — see Appendix C.

(e) Flags and circular shapes — see Appendix D.

where

$C_{\text{p,e}}$ = external pressure coefficient

$C_{\text{p,i}}$ = internal pressure coefficient

C_{f} = frictional drag force coefficient

$C_{\text{p,n}}$ = net pressure coefficient acting normal to the surface for canopies, freestanding roofs, walls, and the like

K_{a} = area reduction factor

K_{c} = combination factor

$K_{\text{c,e}}$ = combination factor applied to external pressures

$K_{\text{c,i}}$ = combination factor applied to internal pressures

K_{ℓ} = local pressure factor

K_{v} = open area/internal volume factor for internal pressures

K_{p} = porous cladding reduction factor

5.3 Internal pressure for enclosed rectangular buildings

5.3.1 Internal pressure

5.3.1.1 General

Internal pressure is a function of the external pressures, and the leakage and openings in the external surfaces of the building or an isolated part of a larger building, and for some large buildings, the internal volume. The open area of a surface shall be calculated by adding areas of opening to areas of permeability or leakage on that surface of the building (e.g. vents and gaps in the building envelope).

The height at which the design wind speed is determined for calculation of internal pressures shall be the average roof height (h), as defined in Figure 2.1. However, for the cases of windward wall leakage or openings on a building greater than 25 m in height, the design wind speed at the height of the opening shall be used.

Pressure coefficients for internal pressure ($C_{\text{p,i}}$) shall be determined by either Clause 5.3.1.2 or 5.3.1.3.

NOTE 1 Damage inspections after wind storms, in Regions C and D, have shown that large openings are very likely to occur accidentally due to failure of elements under direct wind pressure, or in the lower levels of a building envelope, by debris impact. Large openings can also occur in Regions A (0 to 5), B (1 to 2) and NZ (1 to 4) under the same circumstances, although openings produced by debris impact are less likely.

NOTE 2 The equivalent free area a ventilator (e.g. ridge or under-eave ventilators) can be determined from the product discharge coefficient and throat area.

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5.3.1.2 Internal pressure coefficients for all cases, except ultimate limit states for parts of buildings below 25 m in Regions C and D

Clause 5.3.1.1 applies to buildings in all regions for serviceability limit states.

For ultimate limit states, it applies to all buildings in Regions A (0 to 5), B (1 to 2) and NZ (1 to 4), and parts of buildings higher than 25 m above ground level in Regions C and D.

Pressure coefficients for internal pressure ($C_{p,i}$) shall be determined from Tables 5.1(A) or 5.1(B). Table 5.1(A) shall be used for the design case where there are no potential openings in any surface with a combined area greater than 0.5 % of the total area of that surface, and the leakage in the walls lead to internal pressures. Table 5.1(B) shall be used for the design case where there are openings in any surface greater than 0.5 % of the total area of that surface, or they can be created accidentally.

5.3.1.3 Internal pressure coefficients for ultimate limit states for parts of buildings below 25 m in Regions C and D

Pressure coefficients for internal pressure ($C_{p,i}$) for parts of a building in Regions C and D below 25 m for ultimate limit states, shall be determined from Table 5.1(B) only.

The ratio of the sum of opening areas on one surface to total open area of other walls and roof surfaces as defined in Table 5.1(B) shall not be taken to be less than two unless —

(a) it can be demonstrated that an opening will not be created in the building envelope as a result of impact loading from the windborne debris defined in Clause 2.5.8; or

(b) a permanently-open roof ventilator, such as a ridge ventilator, has been installed with equivalent total area (see Clause 5.3.1.1 Note 2) of at least that of the largest areas of any potential accidental openings in the walls, considering the combined area of wall openings in each wall surface one at a time; or

(c) permanently-open, wall ventilators have been installed on at least two walls, with equivalent total area (see Clause 5.3.1.1 Note 2) of the ventilators on each wall at least that of the largest of any potential accidental openings in the walls, considering the combined area of wall openings in each wall surface one at a time.

NOTE 1 Low-rise buildings in Regions C and D should be designed for the high internal pressures resulting from large openings, for ultimate limit states. Even in cases where the opening is small or there is no opening, Table 5.1(A) is not intended to be used for low-rise buildings in Regions C and D for ultimate limit states.

NOTE 2 To date, the majority windborne debris in Regions C and D in Australia has not often impacted at heights on buildings above 25 m. This is not the case in other parts of the world and could change in the future with increasing numbers of high-rise buildings.

5.3.2 Openings

5.3.2.1 General

Openings shall be determined according to either Clause 5.3.2.2 (Regions A (0 to 5), B (1 to 2) and NZ (1 to 4), and Regions C, D at heights of 25 m or above) or Clause 5.3.2.3 (Regions C, D below 25 m).

Subject to Clauses 5.3.2.2 and 5.3.2.3, combinations of openings and open area shall be assumed to give internal pressures, which, together with external pressures, give the most adverse wind actions.

NOTE Potential openings include doors or windows that are left open or may fail, vents that are normally open and holes in cladding caused by impacts by windborne debris during a major wind event. Openings can be doors (including balcony doors) or windows that are left open, open under pressure, or open due to the failure of latches or hinges. When determining internal pressures, consideration should be given to scenarios in which large openings may develop. Openings may also be generated by debris impacts, particularly in Regions C and D (see Clause 2.5.8).

5.3.2.2 Openings in buildings in Regions A (0 to 5), B (1 to 2) and NZ (1 to 4), and parts of buildings at heights of 25 m or above in Regions C and D

The full area of doors, including large access doors (e.g. roller doors), and windows that are normally closed, shall be regarded as openings, unless they are demonstrated to be capable of resisting the applied wind pressures.

NOTE 1 When assessing internal pressures, designers should consider the principles robustness, i.e. to avoid situations where the failure of a single component such as a door or window could lead to consequent and disproportionate failure of other elements, or even complete failure of the structure.

NOTE 2 The structural assessment doors that are assumed to remain closed and intact should include elements such as supports, frames, jambs, roller door guides, wind locks, latches and hinges, and fixings, where the resistance of doors relies on those. This assessment of roller doors and their supporting structural elements should also account for any structural resistance to any catenary actions developed by the door under wind load.

5.3.2.3 Openings in buildings for ultimate limit states for parts of buildings below 25 m in Regions C and D

Doors (including large access doors) and windows that are normally closed, and cladding elements, shall be regarded as openings with an area equal to the greater of —

(a) the full area of the element, where it has not been demonstrated that it can resist the applied wind pressures; or

(b) the area of opening that results from debris impact, where the debris impact loading criteria are defined in Clause 2.5.8.

5.3.3 Internal walls and ceilings

Internal walls and ceilings that enclose a space adjacent to an external wall and provide an effective seal between spaces within buildings shall be subject to the pressure derived for the space adjacent to an external wall, determined in accordance with Clauses 5.3.1 and 5.3.2. The known and likely openings in the external wall, in combination with a pressure coefficient of +0.2 or −0.2 on the other side, shall be taken into account to give the largest magnitude pressure difference across the wall or ceiling with a minimum net pressure coefficient of 0.4. Other internal walls that provide an effective seal between spaces within buildings shall be designed for a minimum net pressure coefficient of 0.4. Internal walls and ceilings which do not form a permanent seal shall be designed for a net differential pressure coefficient of 0.3.

NOTE Ceilings may also be subjected to wind-induced pressures, depending on factors such as roof leakage, proximity to rooms with potential large external openings, and the location of manholes.

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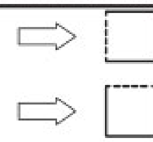
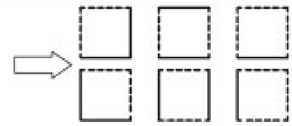
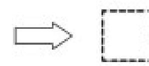
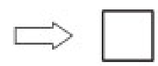
Table 5.1(A) — Internal pressure coefficients ($C_{p,i}$) for buildings — Cases for walls without openings greater than 0.5 % of the wall area and an impermeable roof

Condition	C_{pi}	Examples showing, permeability and wind direction
One wall permeable, other walls impermeable: (a) Windward wall permeable (b) Windward wall impermeable	 $C_{p,e}$ for the windward wall −0.3	
Two or three walls permeable, other walls impermeable: (i) Windward wall permeable (ii) Windward wall impermeable	 −0.1, 0.2 −0.3	
All walls permeable	−0.3 or 0.0, whichever is the more severe for combined actions	
A building effectively sealed and having non-opening windows	−0.2 or 0.0, whichever is the more severe for combined actions	
NOTE Where two values are shown, these are provided as separate load cases.		

In regard to Table 5.1(A), an impermeable surface means a surface having a ratio of total open area to total surface area of less than 0.1 %. A permeable surface means a surface having a ratio of total open area, including leakage, to total surface area between 0.1 % and 0.5 %. Other surfaces with open areas greater than 0.5 % are deemed to have large openings and internal pressures shall be obtained from Table 5.1(B).

Table 5.1(B) — Internal pressure coefficients ($C_{p,i}$) for buildings with openings greater than 0.5 % of the area of the corresponding wall or roof

Ratio of area of openings on one surface to the sum of the total open area (including permeability) of other wall and roof surfaces	Largest opening on windward wall	Largest opening on leeward wall	Largest opening on side wall	Largest opening on roof
0.5 or less	−0.3, 0.0	−0.3, 0.0	−0.3, 0.0	−0.3, 0.0
1	−0.1, 0.2	−0.3, 0.0	−0.3, 0.0	−0.3, 0.0
2	0.7 $K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$
3	0.85 $K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$
6 or more	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$
	t5-1(b)-1			

NOTE 1 $C_{p,e}$ is the relevant external pressure coefficient at the location the largest opening. For example, in Column 2, $C_{p,e}$ means the windward wall pressure coefficient obtained from Table 5.2(A); in Column 3, $C_{p,e}$ means the leeward wall pressure coefficient obtained from Table 5.2(B), in Column 5, $C_{p,e}$ means the roof pressure coefficient for that part the roof containing the opening.

NOTE 2 K_a is the area reduction factor related to the total area of the opening(s), A, on the surface under consideration treating the "tributary area" as the area of the opening. See Clause 5.4.2.

NOTE 3 K_ℓ is the local pressure factor, based on the area and location of the opening on the surface under consideration, treating the "Area, A" as the area of the opening. See Clause 5.4.4.

NOTE 4 Surfaces with openings have a ratio total open area, A, to the total area of that surface related to the internal volume (Vol) under consideration, greater than 0.5 %.

5.3.4 Open area/volume factor, K_v

When the largest opening in a building is on a wall, and the open area is greater than the sum of the total open area on the roof and other wall surfaces by a factor of six or more, then the following Equation 5.3(1) applies:

$$K_v = 1.01 + 0.15\left[\log_{10}\left(100\frac{A^{3/2}}{Vol}\right)\right] \text{ for } 0.09 \le \left(100\frac{A^{3/2}}{Vol}\right) \le 3 \qquad 5.3(1)$$

$$K_v = 0.85, \text{ for } \left(100\frac{A^{3/2}}{Vol}\right) < 0.09$$

$$K_v = 1.085, \text{ for } \left(100\frac{A^{3/2}}{Vol}\right) > 3$$

where A is the open area on the wall and Vol is the internal volume.

For all other cases, K_v shall be taken as 1.0.

NOTE 1 Openings on side walls exposed to relatively small volumes (e.g. partially enclosed balconies on high-rise buildings) may generate significant cavity pressure oscillations.

NOTE 2 Internal volume means the volume the enclosed space exposed to the opening.

5.4 External pressures for enclosed rectangular buildings

5.4.1 External pressure coefficients ($C_{p,e}$)

The external pressure coefficients ($C_{p,e}$) for surfaces of rectangular enclosed buildings shall be as given in Tables 5.2(A), 5.2(B) and 5.2(C) for walls and Tables 5.3(A), 5.3(B) and 5.3(C) for roofs and for some special roofs as given in Appendix A. The parameters (i.e. dimensions) referred to in these Tables are set out in Figure 5.2.

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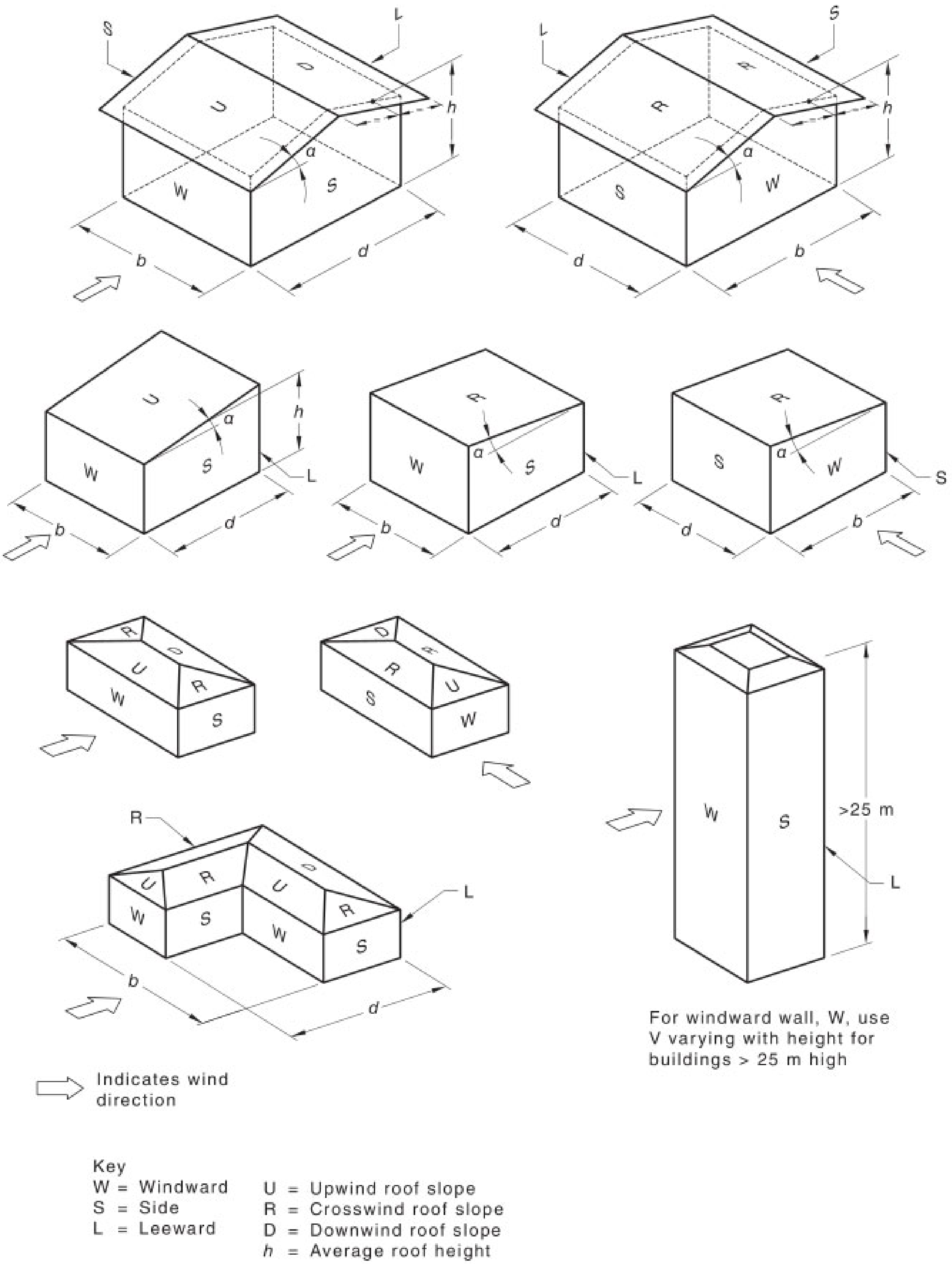

Figure 5.2 — Parameters for rectangular enclosed buildings

For leeward walls, side walls and roofs, wind speed shall be taken as the value at $z = h$. The reference height (h) shall be taken as the average height of the roof.

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Where two values of $C_{p,e}$ are listed, roofs shall be designed for both values. In these cases, roof surfaces may be subjected to either value due to turbulence. Alternative combinations of external and internal pressures (see also Clause 5.3) shall be considered, to obtain the most severe conditions for design.

For roofs, the following alternative load cases should be considered:

(a) When using Table 5.3(A), for the appropriate roof type, slope and edge distance—

 (i) apply the more negative value of $C_{p,e}$ to all pressure zones and surfaces; and

 (ii) apply the less negative (or most positive) value of $C_{p,e}$ to all pressure zones and surfaces.

(b) When using both Tables 5.3(B) and 5.3(C), and for the appropriate parameters—

 (i) apply the more negative value of $C_{p,e}$ from Table 5.3(B) to the upwind slope together with the value from Table 5.3(C) to the downwind slope; and

 (ii) apply the less negative (or positive) value of $C_{p,e}$ from Table 5.3(B) to the upwind slope together with the value from Table 5.3(C) to the downwind slope.

(c) When using Table 5.3(C) only, for steeper crosswind slopes on hip roofs, apply the appropriate $C_{p,e}$ value to both slopes.

For the underside of elevated buildings, $C_{p,e}$ shall be taken as 0.8 and −0.6. For buildings with less elevation above ground than one-third of the height, use linear interpolation between these values and 0.0, according to the ratio of clear unwalled height underneath first floor level to the total building height. For the calculation of underside external pressures, wind speed shall be taken as the value at h.

Under-eaves pressures shall be taken as equal to those applied to the adjacent wall surface below the surface under consideration.

Table 5.2(A) — Walls — External pressure coefficients ($C_{p,e}$) for rectangular enclosed buildings — Windward wall (W)

h	External pressure coefficients ($C_{p,e}$)
> 25.0 m	0.8 (wind speed varies with height)
≤ 25.0 m	For buildings on ground— 0.8, when wind speed varies with height; or 0.7, when wind speed is taken for $z = h$
	For elevated buildings— 0.8 (wind speed taken at h)

Table 5.2(B) — Walls — External pressure coefficients ($C_{p,e}$) for rectangular enclosed buildings — Leeward wall (L)

Wind direction θ degrees (see Figure 2.2)	Roof shape	Roof pitch (α), degrees	d/b	External pressure coefficients ($C_{p,e}$)
0	Hip or gable	< 10	≤ 1	−0.5
			2	−0.3
			≥ 4	−0.2
0	Hip or gable	10	All values	−0.3
0	Hip or gable	15		−0.3
0	Hip or gable	20		−0.4
0	Hip or gable	≥ 25	≤ 0.1	−0.75
			≥ 0.3	−0.5
90	Gable (see Note 3)	All values	≤ 1	−0.5
			2	−0.3
			≥ 4	−0.2

NOTE 1 For intermediate values d/b and α, linear interpolation should be used.

NOTE 2 The design wind speed to be used with these pressure coefficients should be taken at the average roof height ($z = h$).

NOTE 3 For hip roofs use the same values as for $\theta = 0°$.

Table 5.2(C) — Walls — External pressure coefficients ($C_{p,e}$) for rectangular enclosed buildings — Side walls (S)

Horizontal distance from windward edge	External pressure coefficients ($C_{p,e}$)
0 to 1h	−0.65
1h to 2h	−0.5
2h to 3h	−0.3
> 3h	−0.2

NOTE The design wind speed to be used with these pressure coefficients should be taken at the average roof height ($z = h$).

In regard to Tables 5.3(A), 5.3(B) and 5.3(C), for intermediate values of h/d ratios, linear interpolation shall be used. Interpolation shall only be carried out on values of the same sign.

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Table 5.3(A) — Roofs — External pressure coefficients ($C_{p,e}$) for rectangular enclosed buildings — For upwind slope (U), and downwind slope (D) and (R) for roofs with $\alpha < 10°$, and monoslope roofs

Roof type and slope		Horizontal distance from windward edge of roof	External pressure coefficient ($C_{p,e}$)	
Crosswind slopes for gable roofs, and downwind slopes of monoslope roofs (R)	Upwind slope, (U), downwind slope, (D)		$h/d \le 0.5$	$h/d \ge 1.0$
All α	$\alpha < 10°$	0 to $0.5h$	−0.9, −0.4	−1.3, −0.6
		0.5 to $1h$	−0.9, −0.4	−0.7, −0.3
		$1h$ to $2h$	−0.5, 0	(−0.7), (−0.3)
		$2h$ to $3h$	−0.3, 0.1	see Note
		$> 3h$	−0.2, 0.2	

NOTE The values given in parentheses are provided for interpolation purposes.

Table 5.3(B) — Roofs — External pressure coefficients ($C_{p,e}$) for rectangular enclosed buildings — Upwind slope (U) $\alpha \ge 10°$

Upwind slope, (U)	Ratio h/d	External pressure coefficients ($C_{p,e}$)						
		Roof pitch (α) degrees						
		10	15	20	25	30	35	≥ 45
$\alpha \ge 10°$	≤ 0.25	−0.7, −0.3	−0.5, 0.0	−0.3, 0.2	−0.2, 0.3	−0.2, 0.4	0.0, 0.5	0, 0.8 sin α
	0.5	−0.9, −0.4	−0.7, −0.3	−0.4, 0.0	−0.3, 0.2	−0.2, 0.3	−0.2, 0.4	
	≥ 1.0	−1.3, −0.6	−1.0, −0.5	−0.7, −0.3	−0.5, 0.0	−0.3, 0.2	−0.2, 0.3	

Table 5.3(C) — Roofs — External pressure coefficients ($C_{p,e}$) for rectangular enclosed buildings — Downwind slope (D), and (R) for hip roofs, for $\alpha \ge 10°$

Roof type and slope		Ratio h/d	External pressure coefficients ($C_{p,e}$)			
			Roof pitch (α), degrees			
Crosswind slope for hip roofs (R)	Downwind slope (D)		10	15	20	≥ 25
$\alpha \ge 10°$	$\alpha \ge 10°$	≤ 0.25	−0.3	−0.5	−0.6	For $b/d \le 3$; −0.6
		0.5	−0.5	−0.5	−0.6	For $3 < b/d < 8$; $-0.06\,(7 + b/d)$
		≥ 1.0	−0.7	−0.6	−0.6	For $b/d \ge 8$; −0.9

5.4.2 Area reduction factor (K_a) for roofs and walls

For roofs and walls of enclosed buildings, the area reduction factor (K_a) shall be as given in Table 5.4. For all other cases, K_a shall be taken as 1.0. Tributary area (A) is the area contributing to the force being considered. For intermediate values of A, linear interpolation shall be used.

Table 5.4 — Area reduction factor (K_a)

Tributary area (A), m^2	Roofs and side walls (K_a)	Windward walls (K_a) $h < 25$ m	Leeward walls (K_a) $h < 25$ m
≤ 10	1.0	1.0	1.0
25	0.9	0.95	1.0
≥ 100	0.8	0.9	0.95

5.4.3 Action combination factor (K_c)

Where wind pressures acting on a combination of surfaces of an enclosed building (e.g. windward wall, roof, side wall, leeward wall, internal surface) contribute simultaneously to a structural action effect (e.g. member axial force or bending moment) on a structural, or cladding element, combination factors ($K_{c,e}$ and $K_{c,i}$), less than 1.0, may be applied to the external and internal surfaces when calculating the combined actions.

A surface shall be either a windward wall, a side wall, a leeward wall, a roof (the upwind and downwind roof are treated together as a single surface), or the internal surfaces of the building treated as a single surface. An internal surface shall not be treated as an effective surface if $|C_{pi}| < 0.4$

Where pressures on two contributing surfaces act together in combination to produce a structural action effect, $K_{c,e}$ and $K_{c,i}$ may be taken as 0.9. Where three (or more) contributing surfaces act in combination, $K_{c,e}$ and $K_{c,i}$ may be taken as 0.8.

Examples of appropriate combination factors ($K_{c,e}$ and $K_{c,i}$) are given in Table 5.5.

The product K_a. $K_{c,e}$ shall not be less than 0.8.

NOTE Action combination factors less than 1.0 account for the non-simultaneous action peak pressures on effective surfaces.

Table 5.5 — Examples of action combination factors $K_{c,e}$ and $K_{c,i}$ for action effects on structural elements from wind pressure on effective surfaces

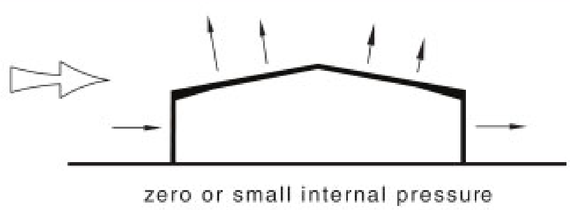
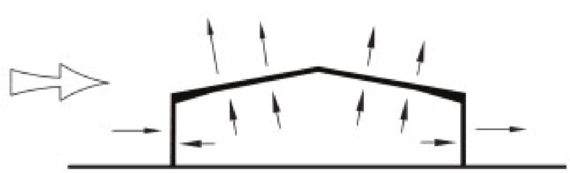
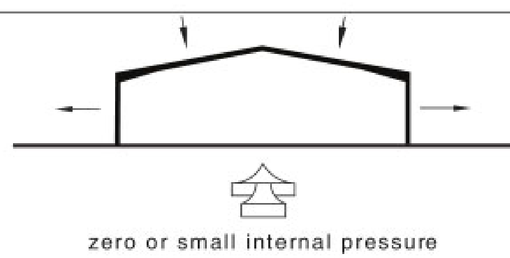
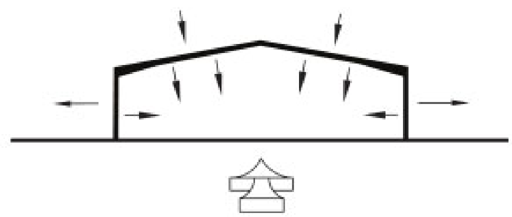
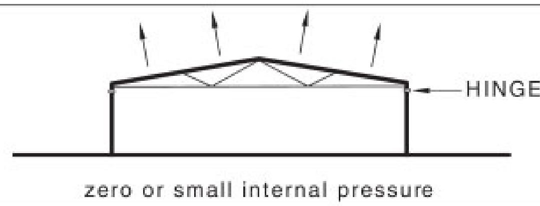
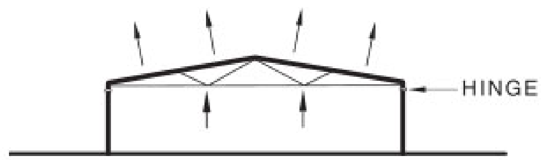
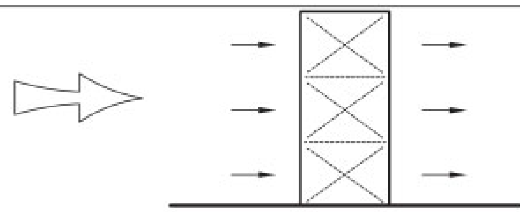
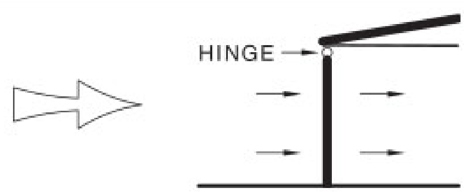
Design case	Example diagram	External $K_{c,e}$	Internal $K_{c,i}$
(a) *3 effective surfaces* Pressures from windward and leeward walls in combination with roof pressures		0.8	1.0 (not an effective surface)
(b) *4 effective surfaces* Pressures from windward and leeward walls in combination with roof pressures and internal pressures		0.8	0.8
(c) *3 effective surfaces* Pressures from side walls in combination with roof pressures		0.8	1.0 (not an effective surface)

Table 5.5 *(continued)*

Design case	Example diagram	External $K_{c,e}$	Internal $K_{c,i}$
(d) *4 effective surfaces* Pressures from side walls in combination with roof pressures and internal pressures		0.8	0.8
(e) *1 effective surface* Roof pressures acting alone		1.0	1.0 (not an effective surface)
(f) *2 effective surfaces* Roof pressures in combination with internal pressures		0.9	0.9
(g) *2 effective surfaces* Lateral pressure on windward and leeward walls		0.9	1.0 (not an effective surface)
(h) *2 effective surfaces* Lateral pressure on external and internal surfaces		0.9	0.9

5.4.4 Local pressure factor (K_ℓ) for cladding

The local pressure factor (K_ℓ) shall be taken as 1.0 in all cases except when determining the wind actions applied to cladding, their fixings, the members that directly support the cladding, and the immediate fixings of these members. In these cases, K_ℓ shall be taken either as 1.0 or the value from Table 5.6 for the area and locations indicated, whichever gives the most adverse effect when combined with the external and internal pressures. If any area of cladding is covered by more than one case in Table 5.6, the largest value of K_ℓ obtained for any case shall be used.

Where the cladding or the supporting member extends beyond the distance a given in Table 5.6, a value of $K_\ell = 1.0$ shall apply to wind force contributions imposed beyond that distance.

Design cases for negative pressures in Table 5.6 are alternative cases and shall not be applied simultaneously.

For walls, the value of dimension a is the minimum of $0.2b$ or $0.2d$ or the height (h) as shown in Figure 5.3. For roofs, the value of a is the minimum of $0.2b$ or $0.2d$, if (h/b) or $(h/d) \geq 0.2$; or $2h$ if both (h/b) and $(h/d) < 0.2$. The side ratio of any local pressure factor area shall not exceed 4.

Where interaction is possible, external pressures shall be taken to act simultaneously with internal pressures given in Clause 5.3 and with the under-eaves pressures given in Clause 5.4.1. The resultant actions shall be added.

For rectangular buildings, the negative limit on the product $K_\ell \, C_{p,e}$ shall be −3.0 in all cases. The RC1 case only applies to flat or near-flat roofs (slope less than 10°). The RC2 case only applies to roof pitches greater than, or equal to, 10°.

For flat or near-flat roofs (slope less than 10°) with parapets, values of K_ℓ for areas RA1, RA2 and RC1 in the lee of the parapet may be modified by multiplying the values from Table 5.6 by the parapet reduction factor (K_r), given in Table 5.7. For intermediate values in Table 5.7, linear interpolation shall be used.

Table 5.6 — Local pressure factor (K_ℓ)

Design case	Figure 5.3 reference case	Building aspect ratio (r)	Area (A)	Proximity to edge	$K\ell$
Positive pressures					
Windward wall	WA1	All	$A \leq 0.25a^2$	Anywhere	1.5
All other areas	—	All	—	—	1.0
Negative pressures					
Upwind corners of roofs with pitch < 10°	RC1	All	$A \leq 0.25a^2$	< a from two edges	3.0
AND					
Downwind corners of roofs with pitch ≥ 10°	RC2			< a from both roof edge and ridge	3.0
Upwind roof edges	RA1	All	$A \leq a^2$	< a	1.5
	RA2	All	$A \leq 0.25a^2$	< 0.5a	2.0
Downwind side of hips and ridges of roofs with pitch ≥ 10°	RA3	All	$A \leq a^2$	< a	1.5
	RA4	All	$A \leq 0.25a^2$	< 0.5a	2.0
Side walls near windward wall edges	SA1	≤ 1	$A \leq a^2$	< a	1.5
	SA2		$A \leq 0.25a^2$	< 0.5a	2.0
	SA3	> 1	$A \leq 0.25a^2$	> a	1.5
	SA4		$A \leq a^2$	< a	2.0
	SA5		$A \leq 0.25a^2$	< 0.5a	3.0
All other areas	—	All	—	—	1.0

NOTE 1 Figure reference numbers and dimension a are defined in Figure 5.3.

NOTE 2 The building aspect ratio (r) is defined as the average roof height (h) divided by the smaller of b or d.

Table 5.7 — Reduction factor (K_r) due to parapets

H	h_p	K_r
≤ 25 m	≤ 0.07 h	1.0
	0.1 h	0.8
	≥ 0.2 h	0.5

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Table 5.7 *(continued)*

H	h_p	K_r
> 25 m	≤ 0.02 w	1.0
	0.03 w	0.8
	≥ 0.05 w	0.5

NOTE h_p is the height of parapet above average roof level, and w is the shortest horizontal dimension of the building.

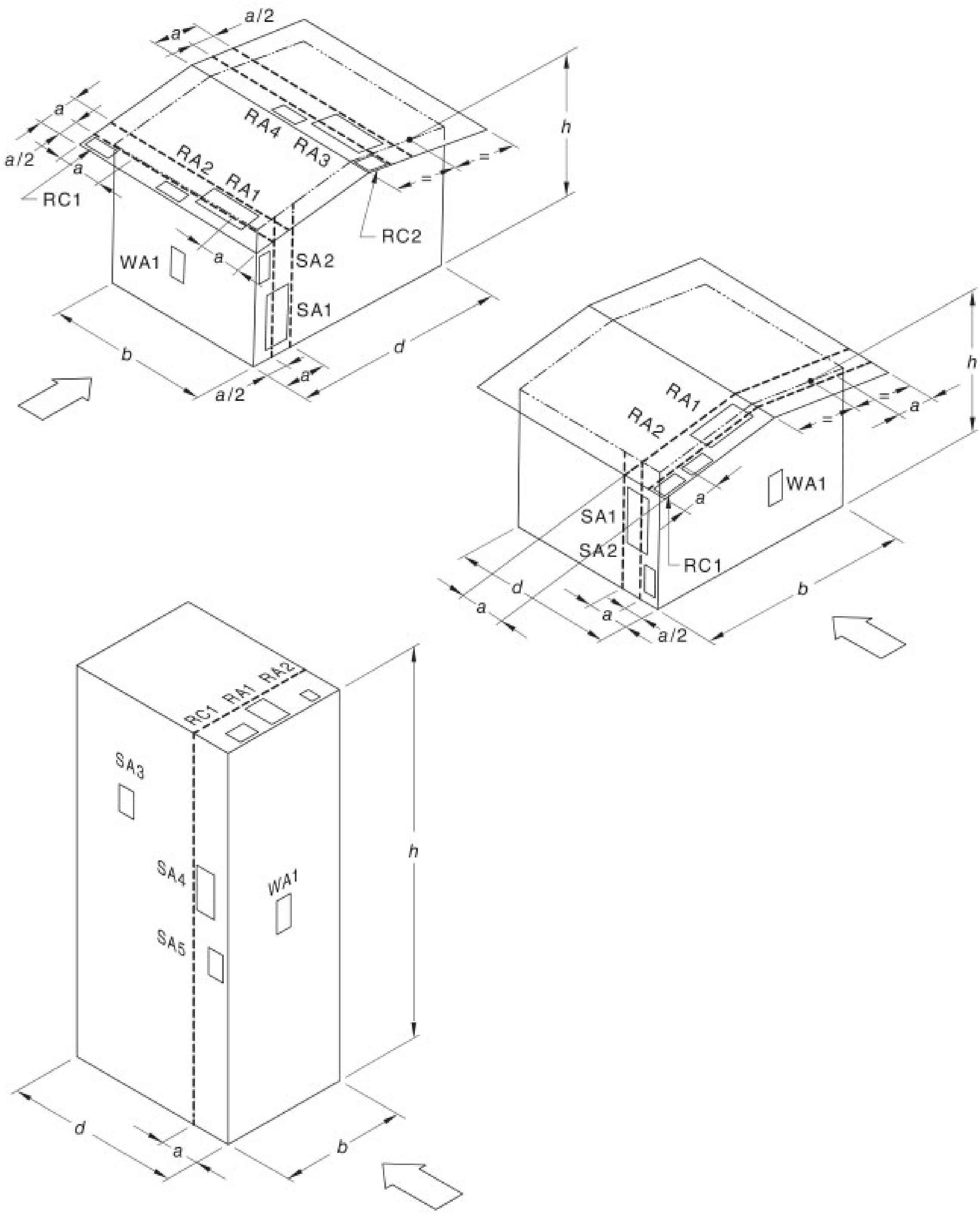

Figure 5.3 — Local pressure factors (K_ℓ)

5.4.5 Permeable cladding reduction factor (K_p) for roofs and side walls

The permeable cladding reduction factor (K_p) shall be taken as 1.0 except that where an external surface consists of permeable cladding and the open area ratio is greater than 0.1 % and less than 1 %, the values given in Table 5.8 may be used for negative pressure. The open-area ratio is the ratio of the open area of the surface to the total area of the surface. Figure 5.4 shows dimension d_a.

Table 5.8 — Permeable cladding reduction factor (K_p)

Horizontal distance from windward edge (see Note)	K_p
0 to $0.2d_a$	0.9
$0.2d_a$ to $0.4d_a$	0.8
$0.4d_a$ to $0.8d_a$	0.7
$0.8d_a$ to $1.0d_a$	0.8
NOTE d_a is the along-wind depth of the surface, in metres.	

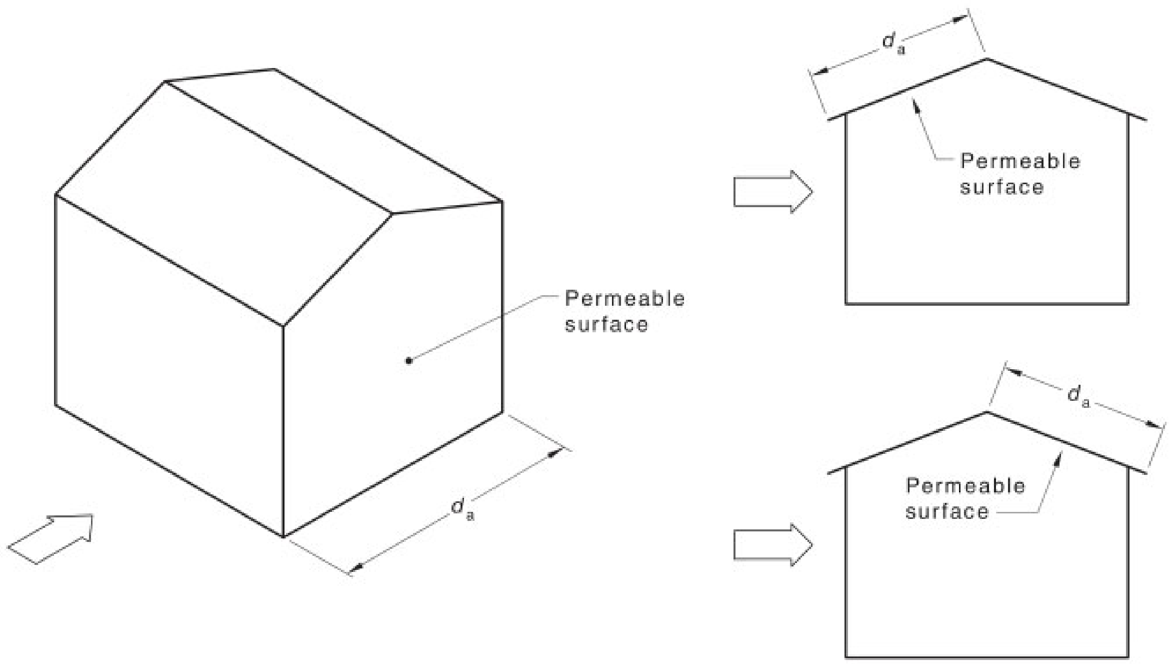

Figure 5.4 — Notation for permeable surfaces

5.5 Frictional drag forces for enclosed buildings

The frictional drag (f) shall be calculated for roofs and side walls of enclosed buildings, in addition to pressures normal to the surface, only where the ratio d/h or d/b is greater than 4. The aerodynamic shape factor (C_{shp}) equals the frictional drag coefficient (C_f) in the direction of the wind as given in Table 5.9.

The effect shall be calculated on the basis of areas as follows:

(a) For $h \leq b$, area = $(b + 2h)(d - 4h)$.

(b) For $h > b$, area = $(b + 2h)(d - 4b)$.

Table 5.9 — Frictional drag coefficient (C_f) for $d/h > 4$ or $d/b > 4$

Distance, x, from windward edge	Surface description	C_f
$x \geq$ the lesser 4h and 4b	Surfaces with ribs across the wind direction	0.04
	Surfaces with corrugations across the wind direction	0.02
	Smooth surfaces without corrugations or ribs or with corrugations or ribs parallel to the wind direction	0.01
$x <$ the lesser of 4h and 4b	All surfaces	0

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Section 6 Dynamic response factor

6.1 Introduction

This Section covers those structures subject to dynamic excitation by wind, defined in Clauses 6.2 and 6.3.

This Standard does not provide dynamic response factors for the following:

(a) Structures with a first mode natural frequency less than 0.2 Hz, heights greater than 200 m, or whenever significant coupling is evident in the first three modes of vibration.

(b) Buildings and horizontal structures that have two fundamental modes of sway within 10 % of each other and are both less than 0.4 Hz.

(c) Buildings with a height to minimum overall width ratio of greater than 6.

(d) Linked or connected buildings where the connection extends above (h/5), and the first-mode natural frequency is less than 0.5 Hz.

(e) Cases that involve excitation resulting from aerodynamic interference from other structures.

(f) Roofs supported on two or more sides with natural frequencies less than 0.8 Hz.

(g) Cantilevered roofs with a first mode natural frequency of less than 0.5 Hz.

(h) Facade elements, such as sunshades.

6.2 Structures for which C_{dyn} = 1.0

A dynamic response factor (C_{dyn}) shall be taken to equal 1.0 for the following cases:

(a) Buildings and free-standing towers, where the natural frequency of the first mode of vibration is greater than 1 Hz.

(b) Poles and chimneys with height to average diameter aspect ratio less than 5.

(c) Ground-mounted solar panels with natural frequencies greater than 5 Hz.

6.3 Other structures

The following requirements apply:

(a) For buildings and free-standing towers, with first mode natural frequencies in the range 0.2 to 1 Hz, C_{dyn} shall be as defined in Clause 6.2 for along-wind response and Clause 6.3 for crosswind response.

(b) For cantilevered roofs with a first mode natural frequency between 0.5 Hz and 1 Hz, C_{dyn} shall be as defined in Clause B.5.

(c) The dynamic response of poles, masts and chimneys of circular cross-section with height to average diameter aspect ratio greater than 5 shall be determined from Clauses 6.2.2 and 6.3.3.

(d) The dynamic response factor for horizontal slender structures with a first mode natural frequency between 1 Hz and 0.5 Hz, C_{dyn} shall be as defined in Clause 6.2.3.

NOTE 1 Appendix E provides information on calculating accelerations for serviceability in tall wind-sensitive structures.

NOTE 2 Special studies such as wind-tunnel testing should be undertaken for dynamically-sensitive structures not covered by this Standard.

NOTE 3 Wind-tunnel tests should also be considered for tall buildings when the crosswind response determined from Clause 6.3 exceeds the along-wind response determined from Clause 6.2 for the same axis direction.

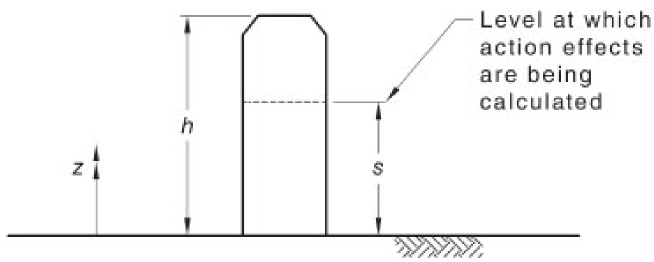
NOTE 4 For structures with high frequencies, designers should also consider the possibility fatigue failure (see Clause 2.5.5).

6.4 Along-wind response

6.4.1 Dynamic response factor (C_{dyn}) for tall buildings and free-standing towers

For calculation of action effects (bending moments, shear forces, member forces) at a height s on the structure (see Figure 6.1), the wind pressures on the structure at a height z shall be multiplied by a dynamic response factor (C_{dyn}). This factor is dependent on both z and s and $s < z < h$. For the calculation of base bending moments, deflections and acceleration at the top of the structure, a single value of C_{dyn} shall be used with s taken as zero. For the calculation of C_{dyn}, the value of $V_{des,\theta}$ is calculated at the reference height (h).

NOTE Information on peak along-wind acceleration for serviceability is given in Clause E.2.



NOTE $s < z < h$

Figure 6.1 — Notation for heights

The dynamic response factor (C_{dyn}) shall be calculated from Equation 6.2(1):

$$C_{dyn} = \frac{1 + 2I_h \sqrt{g_v{}^2 B_S + \dfrac{H_s g_R{}^2 S E_t}{\zeta}}}{(1 + 2g_v I_h)} \tag{6.2(1)}$$

where

s	=	height of the level at which action effects are calculated for a structure
h	=	average roof height of a structure above the ground, or height to the top of a tower
I_h	=	turbulence intensity, obtained from Table 6.1 by setting $z = h$
g_v	=	peak factor for the upwind velocity fluctuations, which shall be taken as 3.4
B_s	=	background factor, which is a measure of the slowly varying background component of the fluctuating response, caused by low-frequency wind speed variations, given by Equation 6.2(2):

$$B_S = \frac{1}{1 + \dfrac{\sqrt{0.26(h-s)^2 + 0.46 b_{sh}{}^2}}{L_h}} \tag{6.2(2)}$$

where b_{sh} is the average breadth of the structure between heights s and h

L_h = a measure of the integral turbulence length scale at height h in metres, given by Equation 6.2(3):

$$= 85(h/10)^{0.25} \tag{6.2(3)}$$

H_s = height factor for the resonant response which equals $1 + (s/h)^2$

g_R = peak factor for resonant response (10 min period) given by Equation 6.2(4):

$$= \sqrt{1.2 + 2\log_e(600n_a)} \tag{6.2(4)}$$

S = size reduction factor given by Equation 6.2(5), where n_a is first mode natural frequency of vibration of a structure in the along-wind direction in hertz and b_{0h} is the average breadth of the structure between heights 0 and h:

$$\frac{1}{\left[1 + \frac{3.5 n_a h (1 + g_v I_h)}{V_{des,\theta}}\right]\left[1 + \frac{4 n_a b_{0h} (1 + g_v I_h)}{V_{des,\theta}}\right]} \tag{6.2(5)}$$

E_t = $(\pi/4)$ times the spectrum of turbulence in the approaching wind stream, given by Equation 6.2(6):

$$\frac{\pi N}{\left(1 + 70.8N^2\right)^{5/6}} \tag{6.2(6)}$$

where

N = reduced frequency (non-dimensional)

$$= n_a L_h \left[1 + (g_v I_h)\right] / V_{des,\theta}$$

n_a = first mode natural frequency of vibration of a structure in the along-wind direction in Hertz

$V_{des,\theta}$ = building design wind speed determined at the building height, h (see Clause 2.3)

ζ = ratio of structural damping to critical damping of a structure

NOTE 1 For structural damping in structures for ultimate limit states, values ζ should be—

(a) for steel structures: 0.015 to 0.02 of critical; and

(b) for reinforced-concrete structures: 0.02 to 0.03 of critical.

NOTE 2 For structural damping in tall buildings for serviceability limit states (for deflections), values ζ should be—

(a) for steel structures: 0.01 to 0.012 of critical; and

(b) for reinforced-concrete structures: 0.01 of critical to 0.015 of critical.

NOTE 3 For structural damping in tall buildings for serviceability limit states (for annual peak accelerations), values ζ should be—

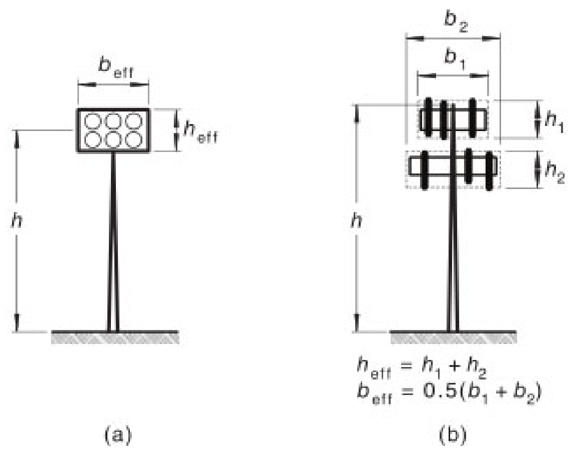
(a) for steel structures: 0.005 to 0.01 of critical; and

(b) for reinforced-concrete structures: 0.008 to 0.012 of critical.

NOTE 4 Note that the above ranges are intended to accommodate various tip deflection to height ratios. Users should seek other sources for advice on possible values structural damping as a function the type construction, building dimensions and amplitude of vibration.

6.4.2 Dynamic response factor for towers, poles and masts with head frames (C_{dyn})

This Clause is applicable when headframes have effective projected area that is greater than the total projected area of the supporting tower, pole or mast. For the supporting tower, pole or mast with a projected area greater than the headframe, see Clause 6.2.1.



Key

h_{eff} = the sum of the heights of the headframes/ancillaries

h = height of the pole/tower/mast supporting the headframe(s)

b_{eff} = the average width of headframes/ancillaries considered in h_{eff}

Figure 6.2 — Dimensions of a pole or mast with headframe

The dynamic response factor, C_{dyn}, for the along-wind response of towers, poles or masts with large headframes, such as lighting towers, shall be calculated from Equation 6.2(7):

$$C_{dyn} = \frac{1 + 2I_h\sqrt{g_v{}^2 + \frac{g_R{}^2 S' E_t}{\zeta}}}{1 + 2g_v I_h} \tag{6.2(7)}$$

where S' is the effective size reduction factor given by Equation 6.2(8):

$$S' = \frac{1}{\left[1 + \frac{3.5n_a h_{eff}\left(1 + g_v I_h\right)}{V_{des,\theta}}\right]\left[1 + \frac{4n_a b_{eff}\left(1 + g_v I_h\right)}{V_{des,\theta}}\right]} \tag{6.2(8)}$$

where h_{eff} and b_{eff} are the vertical and horizontal dimensions of the headframe (see Figure 6.2).

All other terms in Equations 6.2(7) and 6.2(8) are defined in Clause 6.2.1.

6.4.3 Dynamic response factor for horizontal slender structures (C_{dyn})

The dynamic response factor, C_{dyn}, for the along-wind response of slender horizontal structures, such as elevated pipelines or gantries, shall be calculated from Equation 6.2(9):

$$C_{dyn} = \frac{1 + 2I_h \sqrt{{g_v}^2 B' + \frac{{g_R}^2 S'' E_t}{\zeta}}}{1 + 2g_v I_h} \qquad 6.2(9)$$

where B' = 1.0 in Regions A0, A2, A3, A5 and B1

$$B' = \frac{1}{1 + \frac{0.68b}{L_h}} \text{ elsewhere} \qquad 6.2(10)$$

$$S'' = \frac{1}{1 + \frac{4n_a b\left(1 + g_v I_h\right)}{V_{des,\theta}}} \qquad 6.2(11)$$

All other terms in Equations 6.2(9), 6.2(10) and 6.2(11) are defined in Clause 6.2.1.

Table 6.1 — Turbulence intensity (I_z)

Height (z) m	Terrain Category 1	Terrain Category 2	Terrain Category 2.5	Terrain Category 3	Terrain Category 4
≤ 5	0.128	0.196	0.234	0.271	0.342
10	0.117	0.183	0.211	0.239	0.342
15	0.112	0.176	0.201	0.225	0.342
20	0.109	0.171	0.193	0.215	0.342
30	0.104	0.162	0.183	0.203	0.305
40	0.101	0.156	0.178	0.195	0.285
50	0.099	0.151	0.170	0.188	0.270
75	0.095	0.140	0.158	0.176	0.248
100	0.092	0.131	0.149	0.166	0.233
	0.089	0.117	0.134	0.150	0.210
200	0.087	0.107	0.123	0.139	0.196

6.5 Crosswind response

6.5.1 General

Clause 6.3.2 gives methods for determining equivalent static forces and base overturning moments and C_{shp} C_{dyn} for tall enclosed buildings and towers of rectangular cross-section, and Clause 6.3.3 gives deflections and equivalent static forces for chimneys, masts and poles of circular cross-section. Calculation of crosswind response is not required for porous lattice towers.

NOTE 1 Information on peak crosswind acceleration for serviceability is given in Appendix E.

NOTE 2 UHF antennas with the cross-sections shown in Figure C.3 may have potential for significant crosswind response.

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6.5.2 Crosswind response of tall enclosed buildings and towers of rectangular cross-section

6.5.2.1 Equivalent static crosswind force

The equivalent static crosswind force per unit height (w_{eq}) as a function of z (evaluated using force equals mass times acceleration) in newtons per metre shall be calculated from Equation 6.3(1):

$$w_{\mathrm{eq}}\left(z\right) = 0.5\rho_{\mathrm{air}}\left[V_{\mathrm{des},\theta}\right]^2 dC_{\mathrm{shp}}C_{\mathrm{dyn}} \qquad 6.3(1)$$

where $V_{\mathrm{des},\theta}$ is evaluated at $z = h$, and d is the horizontal depth of the structure parallel to the wind stream and Equation 6.3(2) applies:

$$\left(C_{\mathrm{sh}}\ C\ _{\mathrm{yn}}\right) = 1.5g_{\mathrm{R}}\left(\frac{b}{d}\right)\frac{K_{\mathrm{m}}}{\left(1 + g_{\mathrm{v}}I_{\mathrm{h}}\right)^2}\left(\frac{z}{h}\right)^k\sqrt{\frac{\pi C_{\mathrm{fs}}}{\zeta}} \qquad 6.3(2)$$

where

g_{R} = peak factor for crosswind response, given by:

$$\sqrt{1.2+2\log_{\mathrm{e}}\left(600n_{\mathrm{c}}\right)}$$

K_{m} = mode shape correction factor for crosswind acceleration, given by:

$0.76 + 0.24k$

where

K = mode shape power exponent for the fundamental mode

C_{fs} = crosswind force spectrum coefficient generalized for a linear mode shape given in Clause 6.3.2.3

NOTE Values the exponent k should be taken as:

(a) 1.5 for uniform cantilever.

(b) 0.5 for a slender framed structure (moment resisting).

(c) 1.0 for a building with central core and moment-resisting façade.

(d) 2.3 for a tower decreasing in stiffness with height, or with a large mass at the top.

(e) Value obtained from fitting $\phi_1(z) = (z/h)^k$ to the computed modal shape of the structure, where $\phi_1(z)$ equals the fundamental mode shape as a function of height z, normalized to unity at $z = h$.

6.5.2.2 Crosswind base overturning moment

The crosswind base overturning moment (M_{c}), (which can be derived by the integration from 0 to h of $w_{\mathrm{eq}}(z)\ z\ dz$) shall be calculated from Equation 6.3(3):

$$M_{\mathrm{c}} = 0.5g_{\mathrm{R}}b\left[\frac{0.5\rho_{\mathrm{air}}\left[V_{\mathrm{des},\theta}\right]^2}{\left(1 + g_{\mathrm{v}}I_{\mathrm{h}}\right)^2}\right]h^2\left(\frac{3}{k+2}\right)K_{\mathrm{m}}\sqrt{\frac{\pi C_{\mathrm{fs}}}{\zeta}} \qquad 6.3(3)$$

where the value $\left(\frac{3}{k+2}\right)K_{\mathrm{m}}$ is the mode shape correction factor for crosswind base overturning moment.

6.5.2.3 Crosswind force spectrum coefficient (C_{fs})

The reduced velocity (V_n) shall be calculated as follows using $V_{des,\theta}$ calculated at $z = h$, from Equation 6.3(4):

$$V_n = \frac{V_{des,\theta}}{n_c b\left(1 + g_v I_h\right)} \qquad 6.3(4)$$

For cases where the value of V_n is greater than 8, the following method shall only be used for preliminary design.

NOTE Wind tunnel testing should be undertaken to confirm the response tall buildings prior to finalising the design for cases where the value of V_n is greater than 8.

Values of the crosswind force spectrum coefficient generalized for a linear mode shape (C_{fs}) shall be calculated from the reduced velocity (V_n) as follows (see Figures 6.3 to 6.6):

(a) For a 3:1:1 square section ($h{:}b{:}d$), where V_n is in the range 2 to 16:

(i) For turbulence intensity of 0.12 at $2h/3$, use Equation 6.3(5):

$$\log_{10} C_{fs} = 0.000353 V_n^{\,4} - 0.0134 V_n^{\,3} + 0.15 V_n^{\,2} - 0.345 V_n - 3.109 \qquad 6.3(5)$$

(ii) For turbulence intensity of 0.2 at $2h/3$, use Equation 6.3(6):

$$\log_{10} C_{fs} = 0.00008 V_n^{\,4} - 0.0028 V_n^{\,3} + 0.0199 V_n^{\,2} + 0.13 V_n - 2.985 \qquad 6.3(6)$$

(b) For a 6:1:1 square section ($h{:}b{:}d$), where V_n is in the range 2 to 16, use Equation 6.3(7):

$$\log_{10} C_{fs} = 0.00037 V_n^{\,4} - 0.0145 V_n^{\,3} + 0.17 V_n^{\,2} - 0.49 V_n - 2.5 \qquad 6.3(7)$$

(c) For a 6:2:1 rectangular section ($h{:}b{:}d$), where V_n is in the range 2 to 16, use Equation 6.3(8):

$$\log_{10} C_{fs} = \frac{-0.00045 V_n^{\,4} + 0.065 V_n^{\,2} - 3.05}{0.00015 V_n^{\,4} - 0.018 V_n^{\,2} + 1} \qquad 6.3(8)$$

(d) For a 6:1:2 rectangular section ($h{:}b{:}d$), where V_n is in the range 2 to 16, use Equation 6.3(9):

$$\log_{10} C_{fs} = -0.0087.V_n^{2} + 0.2419 V_n - 3.1458 \qquad 6.3(9)$$

For intermediate values of $h{:}b$, $b{:}d$, or turbulence intensity, linear interpolation of $\log_{10} C_{fs}$ shall be used. Extrapolation shall not be used.

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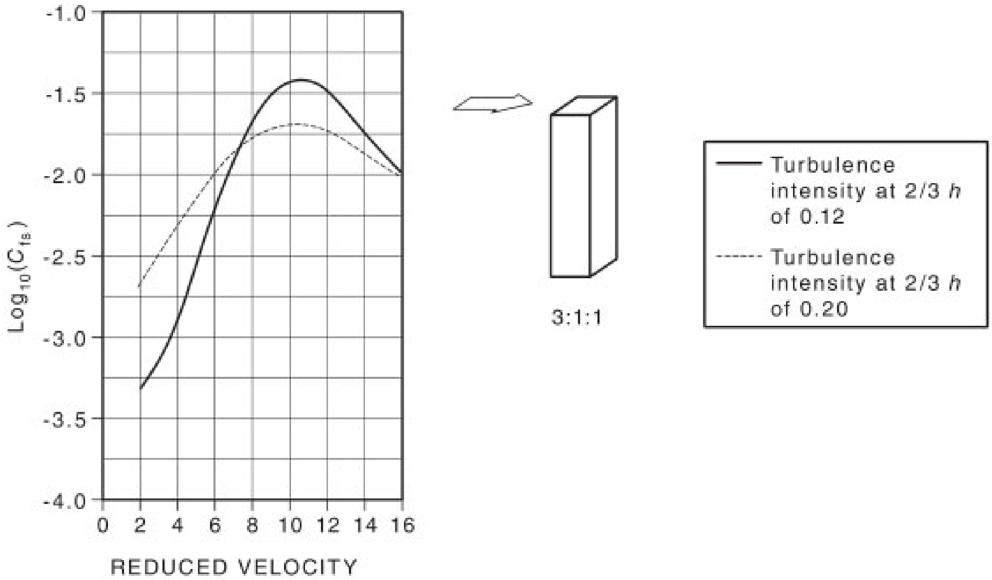

Figure 6.3 — Crosswind force spectrum coefficient for a 3:1:1 square section

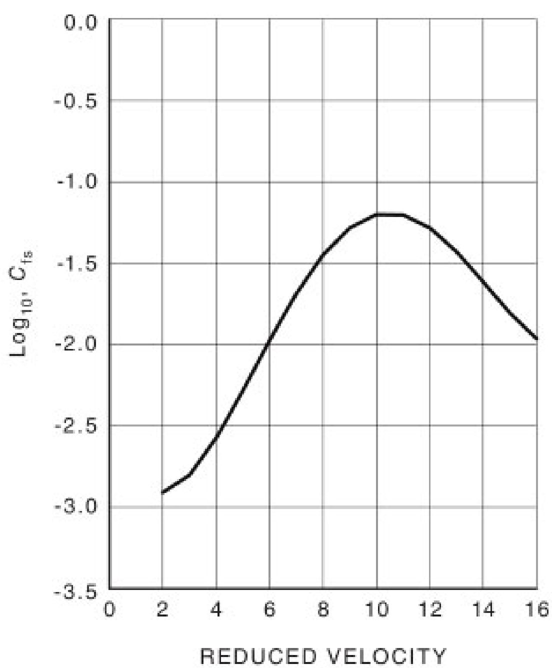

Figure 6.4 — Crosswind force spectrum coefficient for a 6:1:1 square section

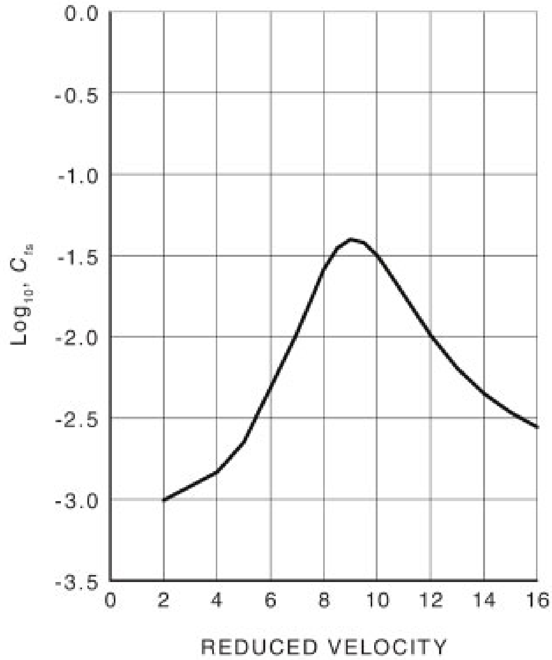

Figure 6.5 — Crosswind force spectrum coefficient for a 6:2:1 rectangular section

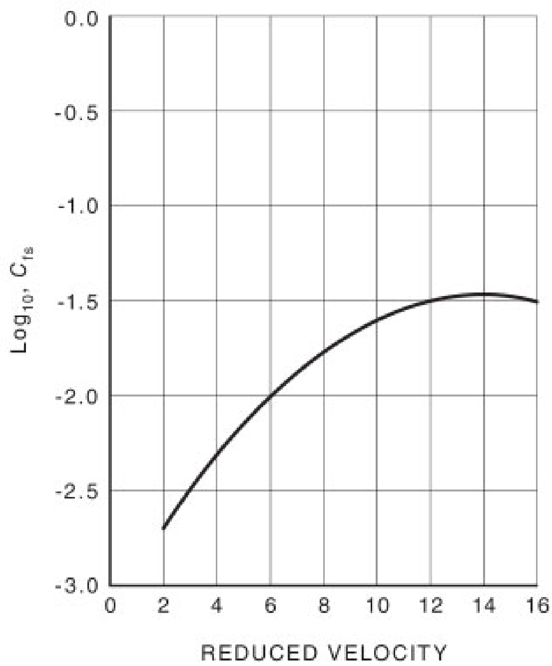

Figure 6.6 — Crosswind force spectrum coefficient for a 6:1:2 rectangular section

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6.5.3 Crosswind response of cantilevered chimneys, masts and poles of circular cross-section

6.5.3.1 Crosswind tip deflection

The maximum amplitude of tip deflection (y_{max}) in crosswind vibration at the critical wind speed due to vortex shedding for chimneys, masts or poles of circular cross-section (without ladders, strakes or other appendages near the top) shall be calculated from Equations 6.3(10) and 6.3(11):

$$y_{max} = g_c \sigma_{y,max} \tag{6.3(10)}$$

$$\left(\frac{\sigma_{y,max}}{b_t}\right)^2 = c_1 + \sqrt{c_1^2 + c_2} \tag{6.3(11)}$$

where

b_t = average breadth of the top third of the structure

g_c = $\sqrt{2}\left(1+1.2\arctan(0.75(Sc/(4\pi K_a))^4)\right)$

c_1 = $\dfrac{a_L^2}{2}\left(1-\dfrac{Sc}{4\pi K_a}\right)$

c_2 = $\dfrac{a_L^2}{K_a}\dfrac{\rho_{air} b_t^2}{m_t}\dfrac{C_c^2}{St^4}\dfrac{b_t}{h}$

St = Strouhal number, taken as 0.20 for a circular cross-section

Sc = Scruton number given by:

= $4\pi m_t \zeta / \left(\rho_{air} b_t^2\right)$

where

m_t = average mass per unit height over the top third of the structure

ζ = ratio of structural damping to critical damping of a structure

NOTE For structural damping, values ζ should be:

(a) for unlined welded steel poles and stacks: 0.002 of critical; and

(b) for reinforced concrete towers and chimneys: 0.005 of critical.

Equation 6.3(11) requires three aerodynamic constants (a_L, K_a and C_c) and for circular cross-sections these shall be calculated from Table 6.2.

Table 6.2 — Constants for determination of the response to vortex shedding

Constants	$Re \le 10^5$	$Re = 5 \times 10^5$	$Re \ge 10^6$
a_L	0.4	0.4	0.4
$K_{a,max}$	2	0.5	1
C_c	0.02	0.005	0.01

NOTE 1 For circular cylinders the constants C_c and $K_{a,max}$ are assumed to vary linearly with the logarithm of the Reynolds number for $1 \times 10^5 < Re < 5 \times 10^5$ and for $5 \times 10^5 < Re < 1 \times 10^6$.

NOTE 2 K_a decreases with increasing turbulence, using $K_a = K_{a,max}$ provides larger estimates of displacements or $K_a (I_h) = K_{a,max} \times \max(1 - 3 \times I_h, 0.25)$.

NOTE 3 $Re = \dfrac{bV_{des,\theta}}{15 \times 10^{-6}\left(1 + g_v I_h\right)}$

6.5.3.2 Equivalent static crosswind force

The equivalent static wind force per unit height (w_{eq}) for chimneys, masts or poles of circular cross-section (without ladders, strakes or other appendages near the top), as a function of height z, $w_{eq}(z)$, shall be calculated from Equation 6.3(12):

$$w_{eq}(z) = m(z)(2\pi n_1)^2 y_{max} \phi_1(z) \qquad 6.3(12)$$

where

$m(z)$ = mass per unit height as a function of height (z)

n_1 = first mode natural frequency of vibration of a structure, in hertz

$\phi_1(z)$ = first mode shape as a function of height (z), normalized to unity at $z = h$, which shall be taken as $(z/h)^2$

NOTE Equation 6.3(12) may be written as:

$$w_{eq}(z) = 0.5\rho_{air}\left[V_{crit}\right]^2 b_t C_{sh}\ C_{yn}$$

where

V_{crit} = critical wind speed for vortex shedding, which is approximately $5n_1 \times b_t$ for circular sections

$C_{shp} \times C_{dyn}$ = the product of effective aerodynamic shape factor and dynamic response factor

6.6 Combination of along-wind and crosswind response

6.6.1 Combination of base moments

The load combinations presented in Tables 6.3(A) and 6.3(B) shall be applied to each of the four directional sectors.

Table 6.3(A) — Load combinations for equivalent static loads for buildings < 70 m

Load cases	Peak load combinations
1 and 2	1.0(along-wind) ± 0.8(crosswind)
3 and 4	0.8(along-wind) ± 1.0(crosswind)

Table 6.3(B) — Load combinations for equivalent static loads for buildings > 70 m

Load cases	Peak load combinations
1 to 4	1.0(along-wind ± 0.15B offset) ± 0.8(crosswind)
5 to 8	0.8(along-wind ± 0.15B offset) ± 1.0(crosswind)
9 to 12	0.8(along-wind ± 0.2B offset) ± 0.8(crosswind)

NOTE This Section provides the equivalent static overall load on a tall building or similar structures. This method assumes that the along-wind and crosswind responses in each of the combinations below are determined for the same design wind event from the same directional sector. This method also assumes that the responses from the three components are random and independent (for example no significant coupling in the response of two or more components in the same mode of vibration). However, this is not the case when the crosswind response of structures with circular cross-sections is calculated using Clause 6.3.3. The peak crosswind response, as calculated using Clause 6.3.3 occurs at a critical wind speed for vortex-induced vibrations, which is generally much lower than the design wind speed for which the maximum along-wind response occurs.

6.6.2 Combination of load effects

The total combined peak scalar dynamic action effect (ε_t), such as an axial load in a column, shall be calculated from Equation 6.4(1):

$$\varepsilon_t = \varepsilon_{a,m} + \sqrt{\left(\varepsilon_{a,p} - \varepsilon_{a,m}\right)^2 + \varepsilon_{c,p}{}^2} \qquad 6.4(1)$$

where

$\varepsilon_{a,m}$ = action effect derived from the mean along-wind response, given as follows, where the values of g_v, I_h and C_{dyn} are defined in Clause 6.2.1:

$\varepsilon_{a,p} / [\, C_{dyn} (1 + 2g_v I_h)]$

$\varepsilon_{a,p}$ = action effect derived from the peak along-wind response

$\varepsilon_{c,p}$ = action effect derived from the peak crosswind response

NOTE 1 The factor $[C_{dyn} (1 + 2g_v I_h)]$ is a gust factor (G).

NOTE 2 Maximum action effects derived from the crosswind response chimneys, masts and poles circular cross-section (Clause 6.3.3), which occur at the critical wind speed for vortex shedding, should not be combined with action effects for along-wind response calculated at a different wind speed.

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Appendix A
(normative)

Additional pressure coefficients for enclosed buildings

A.1 Additional pressure coefficients

The external pressure coefficients ($C_{p,e}$) given in this Appendix shall be used to calculate the aerodynamic shape factor for pressures on enclosed buildings for the shapes shown, in accordance with Clauses 5.2 and 5.4, including local pressure factors (Clause 5.4.2), action combination factors (Clause 5.4.3) and area reduction factors (Clause 5.4.4).

A.2 Multi-span buildings ($\alpha < 60°$)

External pressure coefficients ($C_{p,e}$) for the multi-span buildings shown in Figures A.1 and A.2 for wind directions $\theta = 0°$ and $\theta = 180°$ shall be obtained from Table A.1 or Table A.2.

Where two values are listed for pressure coefficients in Tables A.1 and A.2, the roof shall be designed for both values.

All pressure coefficients shall be used with the value of wind speed applying at average roof height (h).

External pressure coefficients for wind directions of $\theta = 90°$ and $\theta = 270°$ shall be obtained from Table 5.3(A). However, [−0.05(n − 1)] shall be added to the roof pressure coefficients in the region 0 to 1h from the leading edge, where n is the total number of spans. For this calculation, take n = 4, if n is greater than 4.

Table A.1 — External pressure coefficients ($C_{p,e}$) for multi-span buildings — Pitched roofs

Surface reference (see Figure A.1)				
A	*B*	*C*	*M*	*Y*
+0.7, +0.2	Use Table 5.3(A), 5.3(B) or 5.3(C) for same (h/d_s) and α, as appropriate		−0.3 and ± 0.2 for α < 10° −0.5 and ± 0.3 for α ≥ 10°	+0.1, −0.2

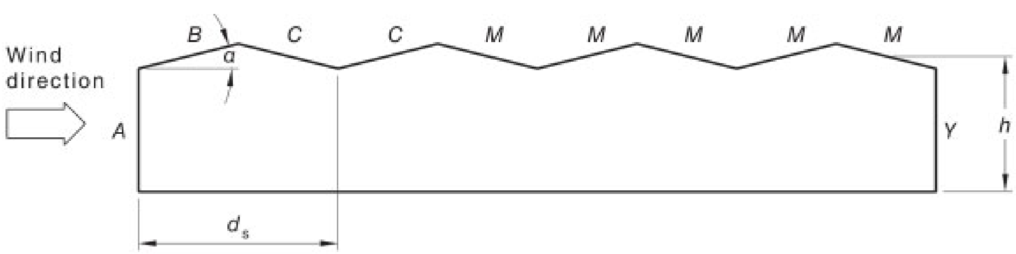

Figure A.1 — External pressure coefficients ($C_{p,e}$) for multi-span buildings — Pitched roofs

Table A.2 — External pressure coefficients ($C_{p,e}$) for multi-span buildings — Saw-tooth roofs

Wind direction (θ) degrees	Surface reference (see Figure A.2)								
	A	***B***	***C***	***D***	***M***	***N***	***W***	***X***	***Y***
0	+0.7, −0.1	−0.9, −0.4	−0.9, −0.4	−0.5, +0.2	−0.5, +0.5	−0.5, +0.3	−0.3, +0.5	−0.4, −0.2	−0.2, +0.1
	±0.2	±0.2	−0.3, +0.2	±0.2	−0.4, 0.0	−0.4, 0.0	−0.7, −0.3	−0.3, +0.1	+0.7, −0.1

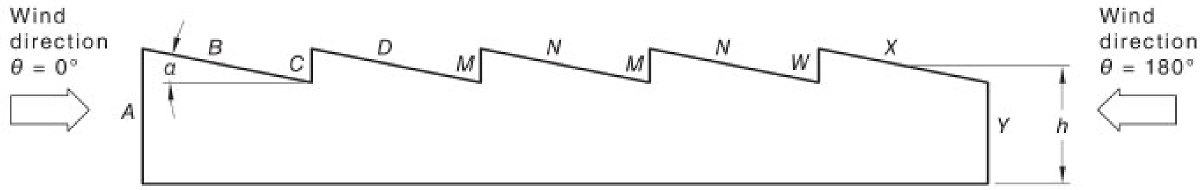

Figure A.2 — External pressure coefficients ($C_{p,e}$) for multi-span buildings — Saw-tooth roofs

A.3 Buildings with curved roofs

For external pressure coefficients ($C_{p,e}$) of curved, arched or domed roofs with profiles approximating a circular arc, wind directions normal to the axis of the roof shall be obtained from Table A.3.

When two values are listed, the roof shall be designed for both values. In these cases, roof surfaces may be subjected to either positive or negative values due to turbulence. Alternative combinations of external and internal pressures (see Clause 2.5) shall be considered, to obtain the most severe conditions for design.

All pressure coefficients shall be used with the value of wind speed applying at average roof height (h).

External pressure coefficients ($C_{p,e}$) for wind directions parallel to the axis (ridge) of arched roofs shall be obtained from Table 5.3(A).

NOTE External pressure coefficients on any vertical walls supporting the arched roof should be taken from Clause 5.4. Clause A.5.2.1 may be used for shape factors for walls of domed buildings of circular cross-section.

The zero values provided for the windward quarter are alternative values for action effects, such as bending, which are sensitive to pressure distribution. (Turbulence and fluctuations in pressure will produce a range of values occurring at different times during a wind event.)

For arched roofs, the effect of breadth-to-span ratio shall be taken into account by multiplying all the coefficients in Table A.3 by a factor K_b equal to $(b/d)^{0.25}$, where b = breadth normal to the wind and d = span (see Figure A.3). If $(b/d)^{0.25}$ is less than 1.0, K_b shall be taken as 1.0.

Limiting values of $C_{p,e}$ $(b/d)^{0.25}$ are +0.8 and −1.7.

Table A.3 provides external pressure coefficients for circular arc roofs with no substantial interference to the airflow over the roof. Where a ridge ventilator of a height at least 5 % of the total height of the roof is present, the external pressure coefficient on the central half of the roof (T) shall be modified by adding +0.3; that is, the value of a negative coefficient (suction) is reduced by 0.3. Such reductions shall not be made for the wind direction along the axis of the roof, for which the ridge ventilator has little effect on the airflow and resulting external pressures.

All combinations of external pressure coefficients on U, T and D shall be checked, the additional asymmetric loading case with the windward half of the roof receiving the most positive pressure, and the leeward half the most negative pressure by subdividing the central half (T) into two equal sections. For r/d < 0.1, Table 5.3(A) shall be applied.

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Table A.3 — External pressure coefficients ($C_{p,e}$) — Curved roofs

	Rise to span ratio (r/d)	Windward quarter (U)	Central half (T)	Leeward quarter (D)
Roof springs from ground	$0.1 \le r/d \le 0.3$	$+1.6(r/d)$, $-0.6 + (r/d)$	$+0.2$, $-0.7 - 1.67(r/d)$	$+0.3-(r/d)$, -0.6
	$0.3 < r/d \le 0.5$	$+1.6(r/d)$, $-0.6+(r/d)$	$+0.2$, -1.2	$+0.3-(r/d)$, -0.6
	$0.5 < r/d \le 0.6$	$+0.8$, -0.1	$+0.2$, -1.2	$+0.3-(r/d)$, -0.6
Roof springs from walls	$0.1 \le r/d \le 0.2$	$-0.2+2(r/d)$, -1.3	$+0.2$, $-0.7 - 1.67(r/d)$	$+0.3-(r/d)$, -0.6
	$0.2 < r/d \le 0.3$	$-0.2+2(r/d)$, $-3.3+10(r/d)$	$+0.2$, $-0.7 - 1.67(r/d)$	$+0.3-(r/d)$, -0.6
	$0.3 < r/d \le 0.5$	$-0.2+2(r/d)$, $-0.6+(r/d)$	$+0.2$, -1.2	$+0.3-(r/d)$, -0.6
	$0.5 < r/d \le 0.6$	$+0.8$, -0.1	$+0.2$, -1.2	$+0.3-(r/d)$, -0.6

NOTE 1 h is the average roof height, d is the span, and r is the rise of the arch, see Figure A.3.

NOTE 2 All values in the table should be multiplied by $(b/d)^{0.25}$ up to limiting values +0.8, −1.7.

NOTE 3 For $r/d < 0.1$, see Table 5.3(A).

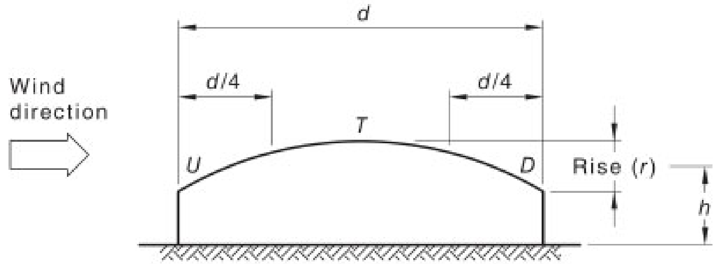

Figure A.3 — External pressure coefficients ($C_{p,e}$) — Curved roofs

A.4 Mansard roofs

The external pressure coefficients ($C_{p,e}$) for a flat-topped mansard roof (see Figure A.4) for the wind direction $\theta = 0°$ shall be determined as follows:

(a) *For upwind slope* (U) — using values for upwind slope given in Clause 5.4.1.

(b) *For downwind slope* (D) — using values for downwind slope given in Clause 5.4.1, using the same roof pitch α as for the upwind slope.

(c) *For flat top* (T) — using the same values as determined for downwind slope.

The external pressure coefficients ($C_{p,e}$) for the wind direction $\theta = 90°$ shall be determined from Clause 5.4.1 assuming R for gable roofs.

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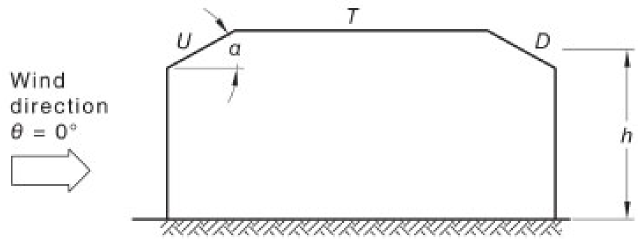

Figure A.4 — External pressure coefficients ($C_{p,e}$) for mansard roofs

A.5 Circular bins, silos and tanks

A.5.1 General

Grouped circular bins, silos and tanks with spacing between walls greater than two diameters shall be treated as isolated silos. Closely spaced groups with spacing less than 0.1 diameters shall be treated as a single structure for wind actions and pressure determined using Tables 5.2(A) to (C) and 5.3(A) to (C). For intermediate spacings, linear interpolation shall be used.

A.5.2 Isolated circular bins, silos and tanks

A.5.2.1 Walls

The aerodynamic shape factor (C_{shp}) for calculating external pressures on the walls of bins, silos and tanks of circular cross-section shall be equal to the external pressure coefficients ($C_{p,b}$) as a function of the angle θ_b (see Figure A.5), given by Equation A.5(1) for shapes in the ranges indicated:

$$C_{p,b}(\theta_b) = k_b C_{p1}(\theta_b) \qquad \text{A.5(1)}$$

where

the cylinder is standing on the ground or supported by columns of a height not greater than the height of the cylinder (c)

c/b is in the range 0.25 to 4.0 inclusive

θ_b = angle from the wind direction to a point on the wall of a circular bin, silo or tank, in degrees

k_b = factor (or function) for a circular bin, given by Equations A.5(2) and A.5(3):

= 1.0 for $C_{p1} \geq -0.15$; or

$$= 0.55\left[C_{p1}(\theta_b) + 0.15\right]\log_{10}(c/b) \quad \text{for } C_{p1} < -0.15 \qquad \text{A.5(2)}$$

$$C_{p1}(\theta_b) = -0.5 + 0.4\cos\theta_b + 0.8\cos 2\theta_b + 0.3\cos 3\theta_b - 0.1\cos 4\theta_b - 0.05\cos 5\theta_b \qquad \text{A.5(3)}$$

For calculating the overall drag force on the wall section of circular bins, silos and tanks (both elevated and on ground) C_{shp} shall be taken as 0.63 (based on an elevation area $b \times c$). This drag force coefficient arises from an integration of the along-wind component of the normal pressures given by Equations A.5(2) and A.5(3).

External pressure coefficients for the underside of elevated bins, silos and tanks shall be calculated as for elevated enclosed rectangular buildings (see Clause 5.4.1).

Figure A.6 is a graphical presentation of the external pressure coefficient (C_{p1}) for circular bins, silos and tanks of unit aspect ratio (i.e. c/b = 1.0) at individual locations around the perimeter, and θ_b degrees from the incident wind direction as calculated from Equation A.5(1).

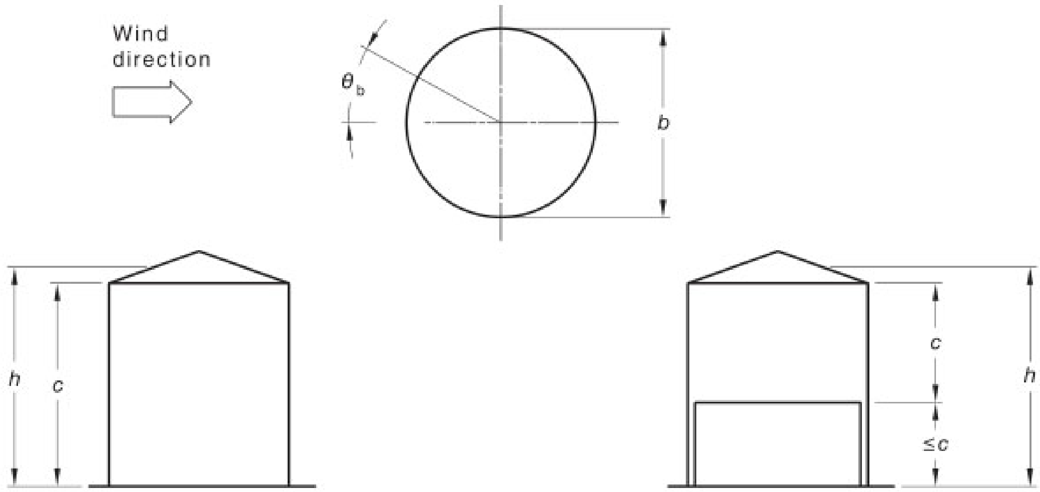

Figure A.5 — External pressure coefficients ($C_{p,b}$) on walls of circular bins, silos and tanks (0.25 ≤ c/b ≤ 4.0)

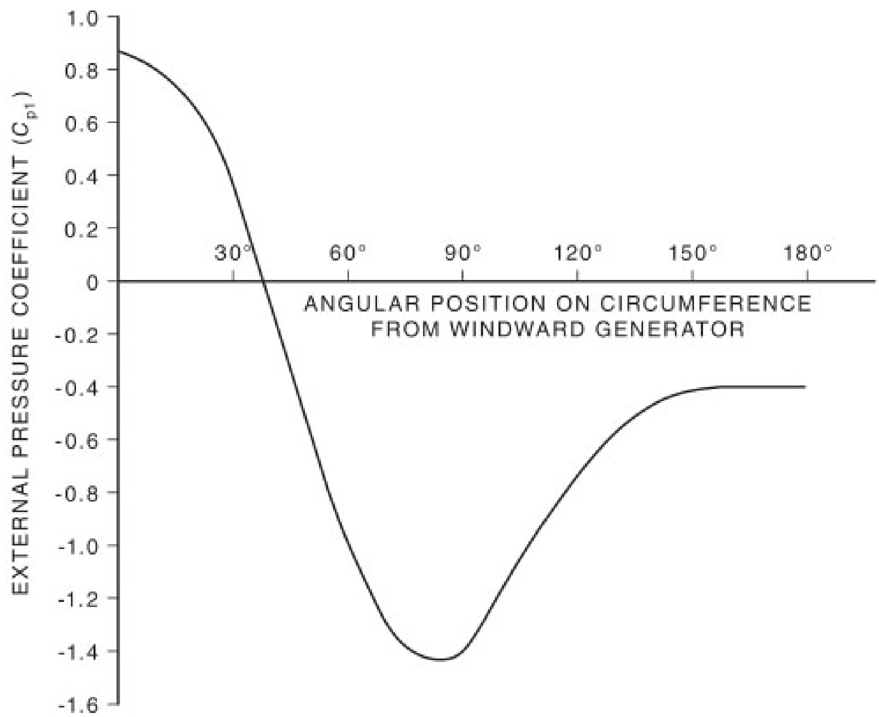

Figure A.6 — Plot of external pressure coefficients (C_{p1}) on walls of circular bins, silos and tanks (c/b = 1.0)

A.5.2.2 Roofs and lids

The aerodynamic shape factor (C_{shp}) for calculating external pressures on the roofs or lids of bins, silos or tanks of circular cross-section, as shown in Figure A.7, shall be as follows in Equation A.5(4):

$$C_{shp} = C_{p,e} K_a K_\ell \qquad \text{A.5(4)}$$

where $C_{p,e}$ is given in Table A.4 for Zones A and B as shown in Figure A.7. K_a is given in Clause 5.4.2 and K_ℓ is given in Clause 5.4.4.

The local pressure factor (K_ℓ) is applicable to the windward edges of roofs with slope less than or equal to 30°, and to the region near the cone apex for roofs with slope greater than 15°. The applicable areas are shown in Figure A.7.

Table A.4 — External pressure coefficients ($C_{p,e}$) for roofs of circular bins, silos and tanks

Zone A	Zone B
−0.8	−0.5

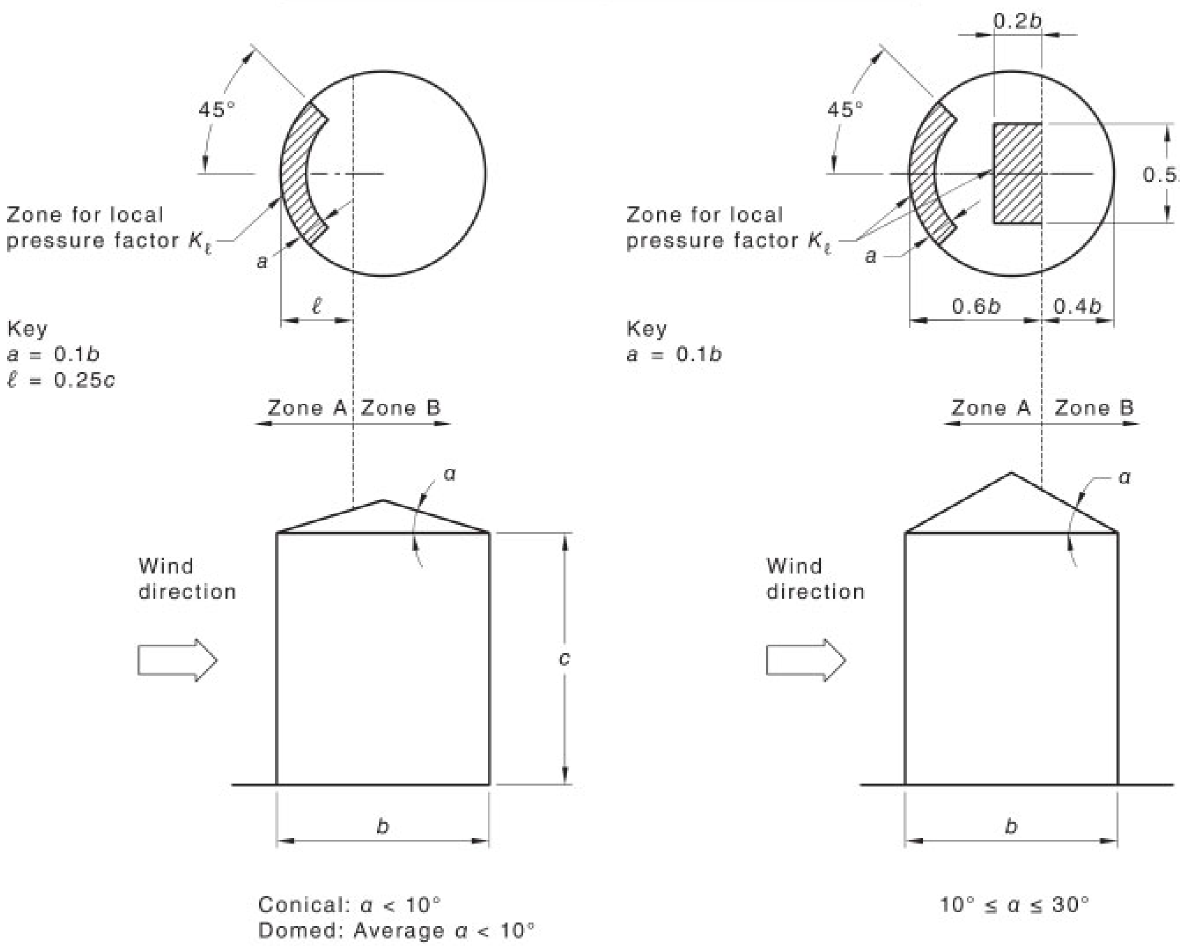

Figure A.7 — External pressure coefficients ($C_{p,e}$) for roofs of circular bins, silos and tanks ($0.25 < c/b < 4.0$)

A.5.2.3 Internal pressures in bins, silos and tanks

Internal pressures within bins, silos and tanks with vented roofs shall be determined as an area-weighted average of the external pressures at the position of the vents and openings, determined according to Clause A.5.2.2.

For open-top bins, silos or tanks, the internal pressure shall be determined from Equation A.5(5):

$$C_{shp} = C_{p,i}$$

$$= -0.9 - 0.35\log_{10}(c/b) \qquad \text{A.5(5)}$$

Appendix B
(normative)

Freestanding walls, hoardings, canopies and solar panels

B.1 General

B.1.1 Application

This Appendix shall be used to calculate aerodynamic shape factors (C_{shp}) for the following structures and structural elements:

(a) Free roofs, including hyperbolic paraboloid roofs, and conical canopies.

(b) Canopies, awnings and carports (adjacent to enclosed buildings).

(c) Cantilevered roofs.

(d) Hoardings and freestanding walls.

(e) Solar panels mounted on ground, or on enclosed buildings with inclined roofs.

To calculate forces on the structure, use the area of the structure (one side only) as the reference area for normal pressures, and use the area of all the affected sides as the reference area for frictional pressure.

B.1.2 Area reduction factor (K_a)

For the design of freestanding roofs and canopies, the area reduction factor (K_a) shall be as defined in Clause 5.4.2. For all other cases in this Appendix, K_a = 1.0.

B.1.3 Local net pressure factor (K_ℓ)

For the design of cladding elements and elements that offer immediate support to the cladding in free roofs and canopies, the values of local net pressure factor (K_ℓ) given in Table B.1 shall be used. For other elements in free roofs and canopies and for all other cases in this Appendix, K_ℓ = 1.0. If an area of cladding is covered by more than one case in Table B.1, the largest value of K_ℓ shall be used. The largest aspect ratio of any local pressure factor area on the roof shall not exceed 4.

Table B.1 — Local net pressure factors (K_ℓ) for open structures

Case	Description	Local net pressure factor (K_ℓ)
1	Pressures on an area between 0 and $1.0a^2$ within a distance $1.0a$ from an upwind roof edge, or downwind of a ridge with a pitch of 10° or more	1.5
2	Pressures on an area of $0.25a^2$ or less, within a distance $0.5a$ from an upwind roof edge, or downwind of a ridge with a pitch of 10° or more	2.0
3	Upward net pressures on an area $0.25a^2$ or less, within a distance $0.5a$ from an upwind corner of a free roof with a pitch of less than 10°	3.0
NOTE Where a is 20 % of the shortest horizontal plan dimension of the free roof or canopy.		

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B.1.4 Net porosity factor (K_p)

For freestanding hoardings and walls, the net porosity factor (K_p) shall be as calculated in Equation B.1. For all other cases in this Appendix, K_p = 1.0.

$$K_p = 1 - (1 - \delta)^2 \tag{B.1}$$

where

δ = solidity ratio of the structure (surface or open frame), which is the ratio of solid area to total area of the structure

B.2 Freestanding hoardings and walls

B.2.1 Aerodynamic shape factor for normal net pressure on freestanding hoardings and walls

The aerodynamic shape factor (C_{shp}) for calculating net pressure across freestanding rectangular hoardings or walls (see Figure B.1) shall be as follows:

$$C_{shp} = C_{p,n} K_p \tag{B.2}$$

where

$C_{p,n}$ = net pressure coefficient acting normal to the surface, obtained from Table B.2 using the dimensions defined in Figure B.1

K_p = net porosity factor, as given in Clause B.1.4

NOTE 1 The factors K_a and K_ℓ do not appear in this Equation as they are taken as 1.0.

NOTE 2 Height for calculation $V_{des,\theta}$ is the top of the hoarding or wall, i.e. height (h) (see Figure B.1).

Pressures derived from Equation B.2 shall be applied to the total area (gross) of the hoarding or wall (e.g. $b \times c$).

The resultant of the pressure shall be taken to act at half the height of the hoarding, ($h - c/2$), or wall, ($c/2$), with a horizontal eccentricity (e).

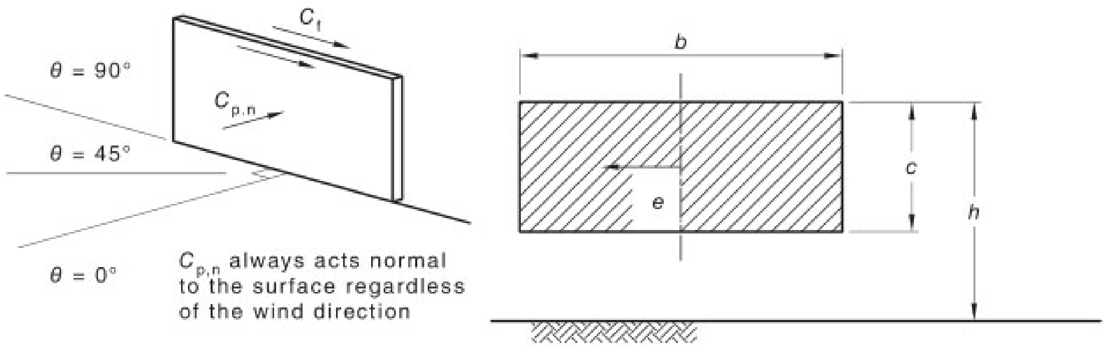

Figure B.1 — Freestanding hoardings and walls

Table B.2(A) — Net pressure coefficients ($C_{p,n}$) — Hoardings and freestanding walls — Wind normal to hoarding or wall, θ = 0°

b/c	c/h	$C_{p,n}$	e
0.5 to 5	0.2 to 1	$1.3 + 0.5[0.3 + \log_{10}(b/c)](0.8 - c/h)$	0
> 5		$1.7 - 0.5\ c/h$	0
all	< 0.2	$1.4 + 0.3\log_{10}(b/c)$	0

Table B.2(B) — Net pressure coefficients ($C_{p,n}$) — Hoardings and freestanding walls — Wind at 45° to hoarding or wall, θ = 45°

b/c	c/h	$C_{p,n}$	e
0.5 to 5 inclusive	0.2 to 1	$1.3 + 0.5[0.3 + \log_{10}(b/c)](0.8 - c/h)$	$0.2b$
	< 0.2	$1.4 + 0.3\log_{10}(b/c)$	$0.2b$

Table B.2(C) — Net pressure coefficients ($C_{p,n}$) — Hoardings and freestanding walls — Wind at 45° to hoarding or wall, θ = 45°

b/c	c/h	Distance from windward free end	$C_{p,n}$
> 5	≤ 0.7	0 to $2c$	3.0
		$2c$ to $4c$	1.5
		> $4c$	0.75
	> 0.7	0 to $2h$	2.4
		$2h$ to $4h$	1.2
		> $4h$	0.6

In regard to Table B.2(C), where a return wall or hoarding forms a corner extending more than $1c$, the $C_{p,n}$ on 0 to $2c$ for a hoarding shall be 2.2, and 0 to $2h$ for a wall $C_{p,n}$ shall be 1.8.

Table B.2(D) — Net pressure coefficients ($C_{p,n}$) — Hoardings and freestanding walls — Wind parallel to hoarding or wall, θ = 90°

b/c	c/h	Distance from windward free end	$C_{p,n}$ (see Note)
All	≤ 0.7	0 to $2c$	±1.2
		$2c$ to $4c$	±0.6
		> $4c$	±0.3
	> 0.7	0 to $2h$	±1.0
		$2h$ to $4h$	±0.25
		> $4h$	±0.25
NOTE Take values $C_{p,n}$ of the same sign.			

B.2.2 Aerodynamic shape factor for frictional drag

The aerodynamic shape factor (C_{shp}) for calculating frictional drag effects on freestanding hoardings and walls, where the wind is parallel to the hoarding or wall, shall be equal to C_f, which shall be determined as given in Table B3. The frictional drag on both surfaces shall be calculated and summed and added to the force on any exposed members calculated in accordance with Appendix C.

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Table B.3 — Frictional drag coefficient (C_f)

Surface description	C_f
Surfaces with ribs across the wind direction	0.04
Surfaces with corrugations across the wind direction	0.02
Smooth surfaces without corrugations or ribs, or with corrugations or ribs parallel to the wind direction	0.01

B.3 Free roofs and canopies

B.3.1 Aerodynamic shape factor for net pressure on free roofs

The aerodynamic shape factor (C_{shp}) for net pressures normal to free roofs of monoslope, pitched or troughed configuration shall be calculated from Equation B.3(1):

$$C_{shp} = C_{p,n} K_a K_\ell \qquad \text{B.3(1)}$$

where

$C_{p,n}$ = net pressure coefficient acting normal to the surface, obtained for the windward half of a free roof ($C_{p,w}$) or net pressure coefficient for the leeward half of a free roof ($C_{p,\ell}$), as given in Tables B.4 to B.7 for roofs within the geometrical limits given (positive indicates net downward pressure)

K_a = area reduction factor, as given in Clause B.1.2

K_ℓ = local pressure factor, as given in Clause B.1.3

NOTE The factor K_p does not appear in this Equation as it is taken as 1.0.

For free roofs of low pitch with fascia panels, the fascia panel shall be treated as the wall of an elevated building, and the $C_{p,e}$ found from Clause 5.4.

In Tables B.4, B.5, B.6 and B.7, "empty under" implies that any goods or materials stored under the roof block less than 50 % of the cross-section exposed to the wind. "Blocked under" implies that goods or materials stored under the roof block more than 75 % of the cross-section exposed to the wind.

To obtain intermediate values of blockage and roof slopes other than those shown, use linear interpolation. Interpolation shall be carried out only between values of the same sign. Where no value of the same sign is given, for interpolation purposes 0.0 shall be assumed.

Where alternative pressure coefficient values are listed in Tables B.4(A), B.4(B), B.5 and B.6, for the appropriate roof slope, blockage and wind direction, all combinations of values $C_{p,w}$ and $C_{p,\ell}$ shall be taken into account.

For θ = 90°, with 0.25 ≤ h/d ≤ 1 the roof pitch is effectively zero, and Table B.4(A) with α = 0° shall be used to determine $C_{p,n}$.

Table B.4(A) — Net pressure coefficients ($C_{p,n}$) for monoslope free roofs — 0.25 ≤ h/d ≤ 1 (see Figure B.2)

Roof pitch (α) degrees	θ = 0 degrees				θ = 180 degrees			
	$C_{p,w}$		$C_{p,\ell}$		$C_{p,w}$		$C_{p,\ell}$	
	Empty under	Blocked under	Empty under	Blocked under	Empty under	Blocked under	Empty under	Blocked under
0	−0.3, 0.4	−1.0, 0.4	−0.4, 0.0	−0.8, 0.4	−0.3, 0.4	−1.0, 0.4	−0.4, 0.0	−0.8, 0.4
15	−1.0	−1.5	−0.6, 0.0	−1.0, 0.2	0.8	0.8	0.4	−0.2
30	−2.2	−2.7	−1.1, −0.2	−1.3, 0.0	1.6	1.6	0.8	0.0

Table B.4(B) — Net pressure coefficients ($C_{p,n}$) for monoslope free roofs — 0.05 ≤ h/d < 0.25 (see Figure B.2)

Conditions	h/d	Horizontal distance (x) from windward edge	Net pressure coefficients ($C_{p,n}$)
For $\alpha \leq 5°$, or For all α with $\theta = 90°$	$0.05 \leq h/d < 0.25$	$x \leq 1h$	Values given for $C_{p,w}$ in Table B.4(A), for $\alpha = 0°$
		$1h < x \leq 2h$	Values given for $C_{p,\ell}$ in Table B.4(A), for $\alpha = 0°$
		$x > 2h$	−0.2, 0.2 for empty under −0.4, 0.2 for blocked under

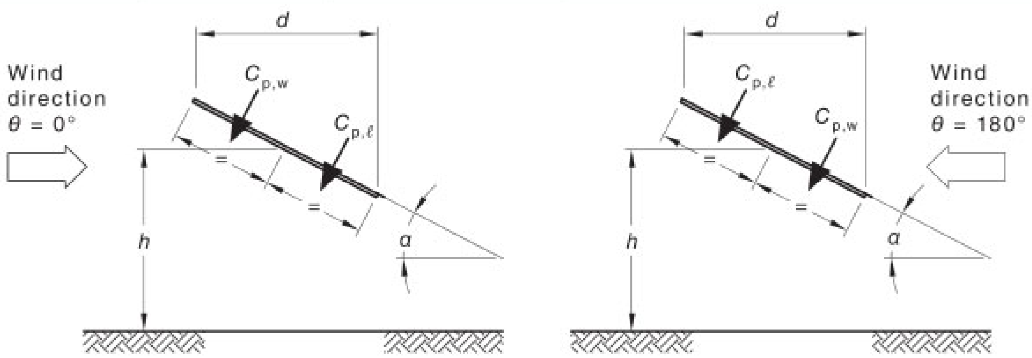

Figure B.2 — Monoslope free roofs

Table B.5 — Net pressure coefficients ($C_{p,n}$) for pitched free roofs — 0.25 ≤ h/d ≤ 1 (see Figure B.3)

Roof pitch (α) degrees	θ = 0°			
	$C_{p,w}$		$C_{p,\ell}$	
	Empty under	Blocked under	Empty under	Blocked under
≤ 15	−0.3, 0.4	−1.2	−0.4, 0.0	−0.9
22.5	−0.3, 0.6	−0.9	−0.6, 0.0	−1.1
30	−0.3, 0.8	−0.5	−0.7, 0.0	−1.3

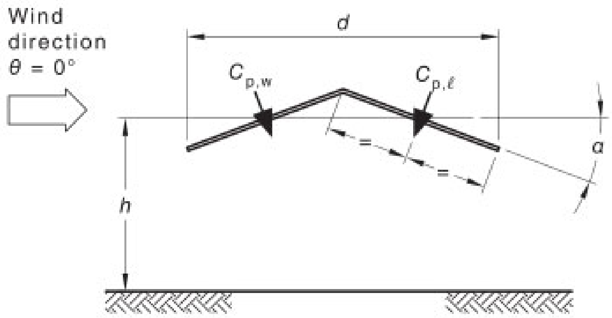

Figure B.3 — Pitched free roofs

Table B.6 — Net pressure coefficients ($C_{p,n}$) for troughed free roofs — 0.25 ≤ h/d ≤ 1 (see Figure B.4)

Roof pitch (α) degrees	θ = 0°			
	$C_{p,w}$		$C_{p,\ell}$	
	Empty under	Blocked under	Empty under	Blocked under
7.5	−0.6, 0.4	−0.7	0.3	−0.3
15	−0.6, 0.4	−0.8	0.5	−0.2
22.5	−0.7, 0.3	−1.0	0.7	−0.2

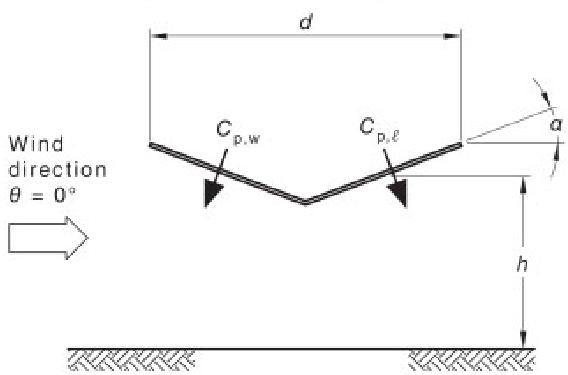

Figure B.4 — Troughed free roofs

Table B.7 — Net pressure coefficients ($C_{p,n}$) for hypar free roofs — Empty under (see Figure B.5)

Conditions	θ, degrees	$C_{p,w}$	$C_{p,\ell}$
Empty under, 0.25 < h/d < 0.5, 0.1 < c/d < 0.3, and 0.75 < b/d < 1.25	0	+0.45	+0.25
		−0.45	−0.25
	90	+0.45	+0.25
		−0.45	−0.25
NOTE: $C_{p,n}$ is defined as positive downwards, and only combinations values of the same sign need to be considered.			

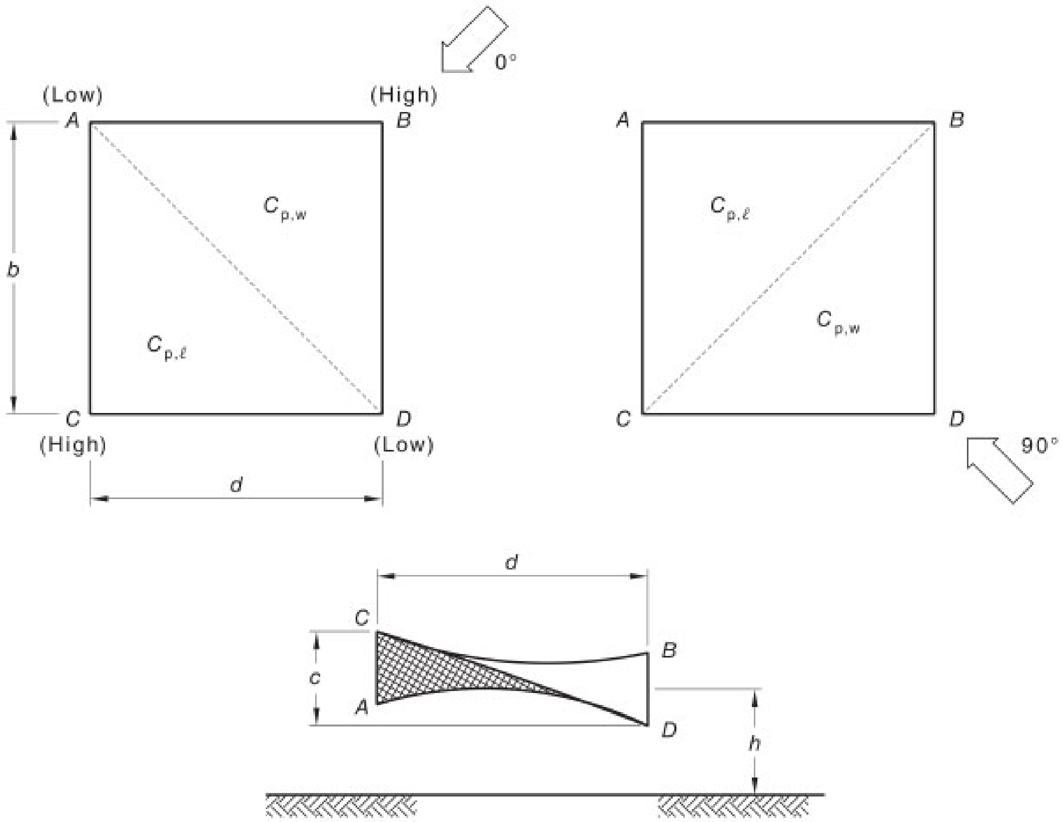

Figure B.5 — Hyperbolic paraboloid (hypar) roofs

B.3.2 Aerodynamic shape factor for frictional drag and drag on exposed members for free roofs

The aerodynamic shape factor (C_{shp}) for calculating frictional drag on free roofs of monoslope, pitched or troughed configuration shall be equal to C_f calculated as given in Table B.3. For free roofs, the frictional drag on both upper and lower surfaces shall be calculated and added to the drag on any exposed members calculated in accordance with Appendix C (see Clause 2.5).

Calculation of frictional drag pressure is not required for wind directions of 0° or 180°, as shown in Figures B.2, B.3 and B.4, for free roofs with pitches of 10° or more.

B.3.3 Aerodynamic shape factor for net pressure on conical canopies

The aerodynamic shape factor (C_{shp}) for net pressures normal to conical canopies shall be calculated from Equation B.3(2):

$$C_{shp} = C_{p,n} K_a K_\ell \quad \text{B.3(2)}$$

where

$C_{p,n}$ = net pressure coefficient acting normal to the surface, obtained for segments of a cover as given in Table B.8 within the geometrical limits given (positive indicates net inwards pressure)

K_a = area reduction factor, as given in Clause B.1.2

K_ℓ = local pressure factor, as given in Clause B.1.3

In Table B.8, "Empty under", "Partially blocked under" and "Blocked under" mean that any goods or materials stored under the cover block less than 20 %, 20 % to 60 % and more than 60 % respectively of the total volume under the cover.

Table B.8 — Net pressure coefficients ($C_{p,n}$) for conical canopies — $1.0 \leq h_1/h_2 \leq 5.0$ — $0.5 \leq h_1/r \leq 2$ (see Figure B.6)

Segment	Empty under	Partially blocked under	Blocked under
A1	0.60	0.50	0.40
A2	0.10	−0.10	−0.15
B1	−0.10	−0.20	−0.25
B2	−0.60	−0.90	−0.80
C1	−0.45	−0.40	−0.35
C2	−0.80	−0.95	−0.85
D1	−0.45	−0.30	−0.25
D2	−0.75	−0.85	−0.75

Net pressure coefficients shall be combined with design wind speeds at the average roof height, $h = h_2 + (h_1/2)$.

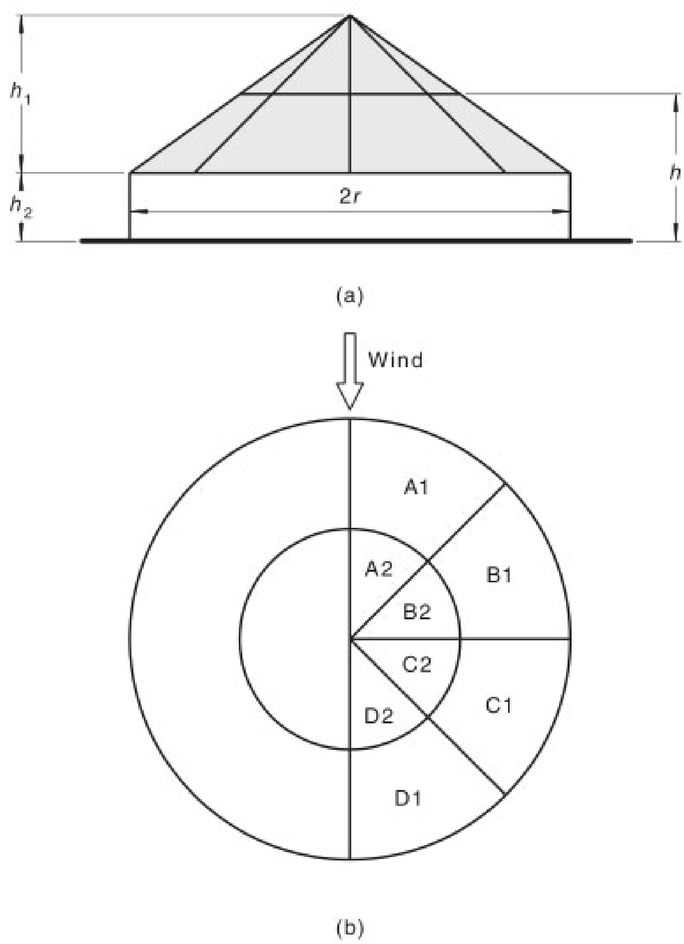

Figure B.6 — Conical canopies

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B.4 Attached canopies, awnings and carports (roofs)

B.4.1 Aerodynamic shape factor for net pressure on attached canopies

The aerodynamic shape factor (C_{shp}) for net pressures normal to the roof on canopies, awnings or carports adjacent to enclosed buildings and with a roof slope of 10° or less shall be calculated from Equation B.4:

$$C_{shp} = C_{p,n} K_a K_\ell \qquad \text{B.4}$$

where

$C_{p,n}$ = net pressure coefficient acting normal to the surface, as given in Tables B.9 and B.10

K_a = area reduction factor, as given in Clause B.1.2

K_ℓ = local pressure factor, as given in Clause B.1.3

NOTE 1 The values given for $C_{p,n}$ assume that any goods and materials stored under the canopy do not represent more than a 75 % blockage.

NOTE 2 The factor K_p does not appear in this Equation as it is taken as 1.0.

Where indicated, attached canopies, awnings or carports shall be designed for both downward (positive) and upward (negative) net wind pressures.

For wind directions normal to the attached wall (θ = 0 degrees) for canopies and awnings, $C_{p,n}$ shall be taken from Table B.9 or Table B.10 with reference to Figure B.7. All pressure coefficients shall be used with the value of wind speed applying at average roof height (h) and h_c is the average height of the canopy above ground.

For wind directions parallel to the wall of the attached building (θ = 90° or 270°), the canopy or awning shall be considered aerodynamically as a free roof and the net pressure coefficients ($C_{p,n}$) shall be obtained in accordance with Table B.4(A) or Table B.4(B) or, where the canopy is partially enclosed, from Table B.10.

In regard to Table B.9, for intermediate values of h_c/h, linear interpolation shall be used.

Table B.9 — Net pressure coefficients ($C_{p,n}$) for canopies and awnings attached to buildings for θ = 0° [see Figure B.7(a)]

Design case	h_c/h	Net pressure coefficients ($C_{p,n}$)
$h_c/h < 0.5$	0.1	1.2, −0.2
	0.2	0.7, −0.2
	0.5	0.4, −0.2
$h_c/h \geq 0.5$	0.5	0.5, −0.3
	0.75	0.4, [−0.3 − 0.2(h_c/w_c)] or −1.5 (see Note)
	1.0	0.2, [−0.3 − 0.6(h_c/w_c)] or −1.5 (see Note)
NOTE Whichever negative value has the lower magnitude.		

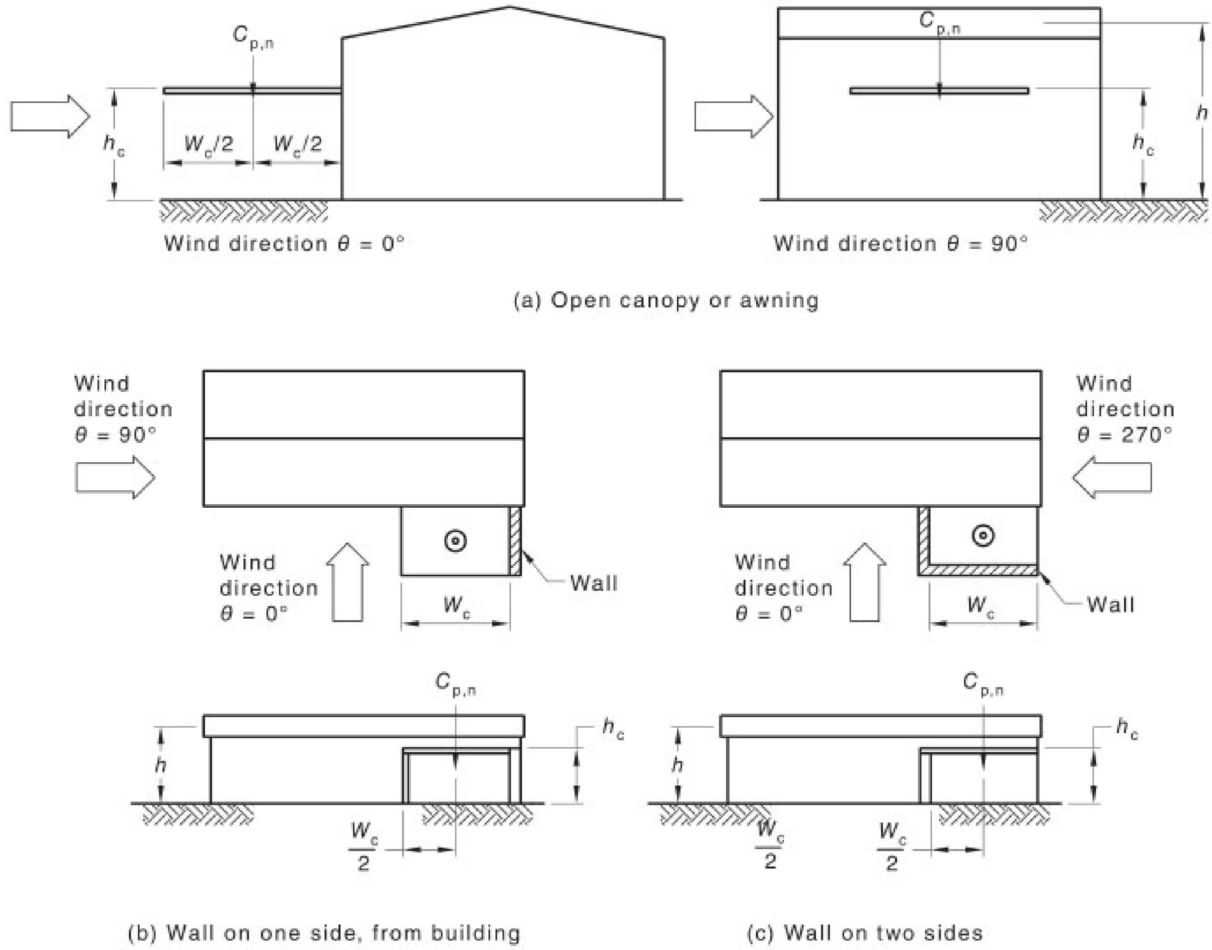

Figure B.7 — Net pressure coefficients ($C_{p,n}$) for canopies, awnings and carports attached to buildings

Table B.10 — Net pressure coefficients ($C_{p,n}$) for partially enclosed carports [see Figures B.7(b) and B.7(c)]

Conditions	Partially enclosed	Wind direction (θ), degrees	Net pressure coefficients ($C_{p,n}$)
$h_c/w_c \leq 0.5$ and $h_c/h < 0.8$	Wall on one side attached to building, see Figure B.7(b)	0	−0.7
		90	−1.0
	Wall on two sides, see Figure B.7(c)	0	−0.6
		270	−1.2

B.4.2 Aerodynamic shape factor for frictional drag and drag on exposed members of attached canopies

The aerodynamic shape factor (C_{shp}) for calculating frictional drag effects on attached canopies, awnings or carport roofs, where the wind is parallel to the attached wall, shall be equal to C_f as given in Table B.3. For canopies, the frictional drag on both upper and lower surfaces shall be calculated and added to the drag on any exposed members calculated in accordance with Appendix C (see Clause 2.5).

B.5 Cantilevered roofs

For an isolated cantilever roof with no interference from upstream structures within six roof heights, the aerodynamic shape factors ($C_{shp,1}$, $C_{shp,2}$) for structural loading of main supporting members is given in Table B.11, with reference to Figure B.8.

Table B.11 — Aerodynamic shape factor for isolated cantilever roofs with roof pitch of −7° < α < 7° and where θ = 0°

Load direction	Bay position	Height/span $h/d \leq 1.4$		Height/span $h/d > 1.4$	
		$C_{shp,1}$	$C_{shp,2}$	$C_{shp,1}$	$C_{shp,2}$
Upward loading (−)	Internal	−1.8	−1.1	−1.4	−1.4
	End	−1.3	−1.0	−1.9	−1.1
Downward loading (+)	Internal	0.25	0.15	0.20	−0.15
	End	0.55	0.65	0.20	0.0

Use Table B.4(B) for θ = 90° for blocked under and α = 0°.

Use Table B.4(A) for θ = 180° for blocked under and α = 0°.

NOTE 1 For cladding loads on roofing elements, Clause B.3 should be used, assuming blocked under.

NOTE 2 Wind tunnel testing or similar studies should be carried out if there is a similar height grandstand roof within six roof heights of the cantilevered roof in question.

Dynamic response shall be taken into account by determining the dynamic response factor (C_{dyn}) as follows:

(a) Use Equation B.5 for cases where cantilevered beams are greater than 15 m long:

$$\left(\frac{V_{des,\theta}}{1+g_v I_h}\right)\left(\frac{1}{n_1 d}\right) > 0.4 \text{ and } n_1 < 1\,\text{Hz}$$

$$C_{dyn} = \left(1.0 + 0.5\left[\left(\frac{V_{des,\theta}}{1+g_v I_h}\right)\left(\frac{1}{n_1 d}\right) - 0.4\right]\right) \quad \text{B.5}$$

where

n_1 = first mode frequency of vibration of the cantilevered roof in the vertical bending mode

(b) For all other cases, C_{dyn} = 1.0.

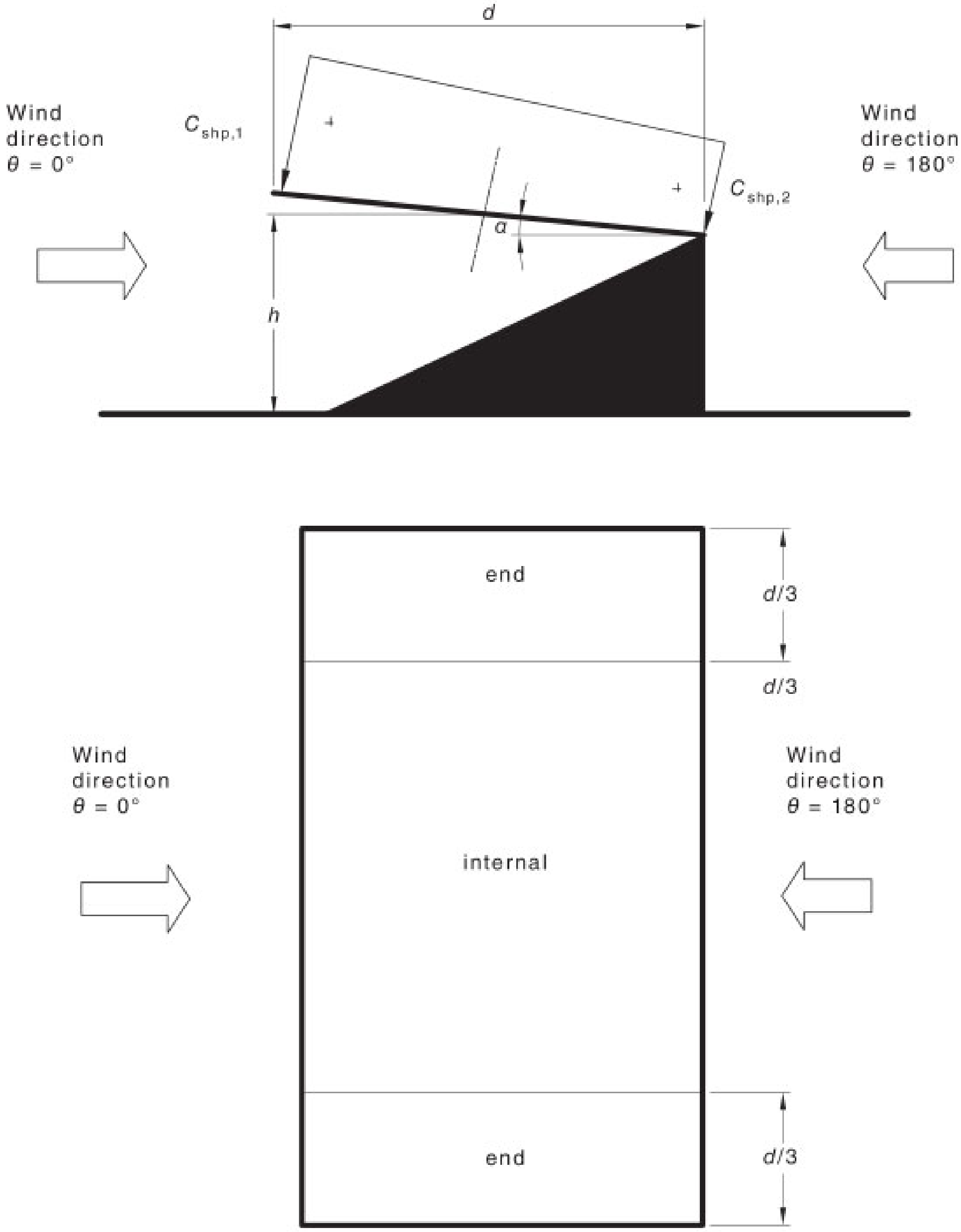

Figure B.8 — Cantilevered roof

B.6 Solar panels

B.6.1 Panels mounted parallel to inclined roofs

The use of this Clause (B.6) shall be limited to the calculation of wind loads on solar panels with the following restrictions:

(a) Panels attached to enclosed buildings with aspect ratios $h/b \leq 0.5$ and $h/d \leq 0.5$.

(b) Panels be attached parallel to the roof plane.

(c) Panels with a gap of between 50 mm and 300 mm between the underside of the panel and the roof(s) (no pitched frames).

(d) Panels with a minimum distance between panel and roof edge of $2s$ where s is the gap between the underside of the panel and the roof surface, as shown in Figure B.9 (roof edge includes ridges with pitch ≥ 10°).

The aerodynamic shape factor (C_{shp}) for calculating net pressures for solar panels satisfying the above conditions, as shown in Figure B.9, is given in Table B.12. The aerodynamic shape factor (C_{shp}) contains local pressure and area reduction effects for calculating net loads on individual panels installed as part of an array of panels in the areas of the roof identified in Figure B.10.

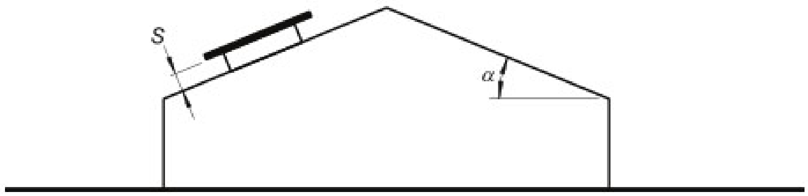

Figure B.9 — Panel mounted parallel to roof plane

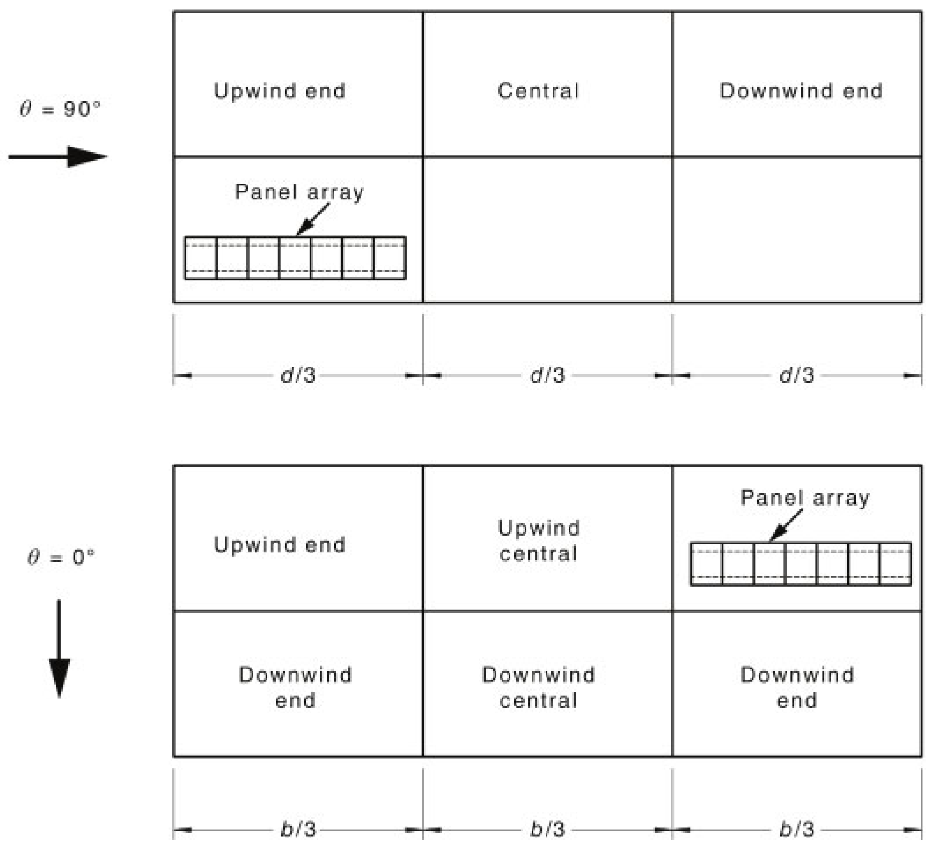

Figure B.10 — Roof zones for panel array

Table B.12 — Aerodynamic shape factor (C_{shp}) for calculating net pressures acting normal to panels mounted parallel to a roof surface with a gap of s = 50 to 300 mm

Wind direction	Array position	Aerodynamic shape factor (C_{shp})			
		$\alpha < 5°$	$5° \le \alpha < 10°$	$10° \le \alpha < 20°$	$20° \le \alpha \le 30°$
$\theta = 0°$	Upwind end	−1.7, +0.4	−1.1, +0.8	−1.1, +0.6	−1.0, +0.6
	Upwind central	−1.4, +0.5	−0.8, +0.5	−0.7, +0.3	−0.8, +0.3
	Downwind end	−1.3, +0.5	−1.1, +0.5	−1.4, +0.4	−1.3, +0.5
	Downwind central	−1.4, +0.5	−0.8, +0.4	−1.0, +0.4	−1.1, +0.4
			$5° \le \alpha \le 30°$		
$\theta = 90°$	Upwind end	−1.7, +0.4	−1.7, +0.4		
	Central	−1.4, +0.5	−1.2, +0.5		
	Downwind end	−1.3, +0.5	−1.1, +0.5		

NOTE 1 Positive C_{shp} corresponds to a net downwards pressure.

NOTE 2 The installation a panel may result in changes to the external pressure on the roof below the panel.

The aerodynamic shape factor (C_{shp}) contains local pressure and area reduction effects for calculating net loads on individual panels installed as part of an array of panels in the areas of the roof identified in Figure B.9.

Aerodynamic shape factors for the top of the roof beneath the panels shall be taken as:

(a) +0.6 when C_{shp} in Table B.12 is negative;

(b) −0.6 when C_{shp} in Table B.12 is positive.

NOTE 1 Wind loads on roof-mounted solar panels and wind loads on roof beneath panels may be considered to act simultaneously.

NOTE 2 Wind loads on inclined solar panels on flat or near flat roofs are not currently covered by this Standard.

B.6.2 Panels mounted on ground

The use of this Section shall be limited to the calculation of wind loads on solar panel arrays with the following restrictions as shown in Figure B.11:

(a) Panels attached to a ground mounted frame with aspect ratios $2 \le d/h \le 5$ and $b/d \ge 2$.

(b) Panels attached to the frame at an inclination to ground, $\alpha \le 30°$.

(c) Panel arrays with a spacing of $3.5 \le s/h \le 10$.

(d) Panels with a minimum gap between the underside of the panel and the ground surface $c/h \ge 0.2$.

NOTE Tracking, ground-mounted, solar panel arrays have occasionally experienced severe vibrations due to aeroelastic forces (flutter). These effects are not covered in this Standard; specialist advice should be sought.

The aerodynamic shape factor (C_{shp}) for net pressures normal for solar panels, satisfying the above conditions, shall be calculated from Equation B.6:

$$C_{shp} = C_{p,n} K_a K_\ell \qquad \text{B.6}$$

where

$C_{p,n}$ = net pressure coefficient acting normal to the surface, obtained for the windward half of a panel array ($C_{p,w}$) or net pressure coefficient for the leeward half of a panel array ($C_{p,\ell}$), as given in Tables B.13 and B.14 (positive indicates net downward pressure). For $\theta = 90°$, the array pitch is effectively zero, and Tables B.13 and B.14 with $\alpha = 0°$ shall be used to determine $C_{p,n}$.

K_a = area reduction factor, as given in Clause B.1.2

K_ℓ = local pressure factor, as given in Clause B.1.3

NOTE 1 The factor K_p does not appear in this Equation as it is taken as 1.0.

NOTE 2 Areas A1, A2, A3, B1, B2, B3 apply to the upwind row panels. Areas C1, C2, C3, D1, D2, D3 apply to all shielded downwind panels.

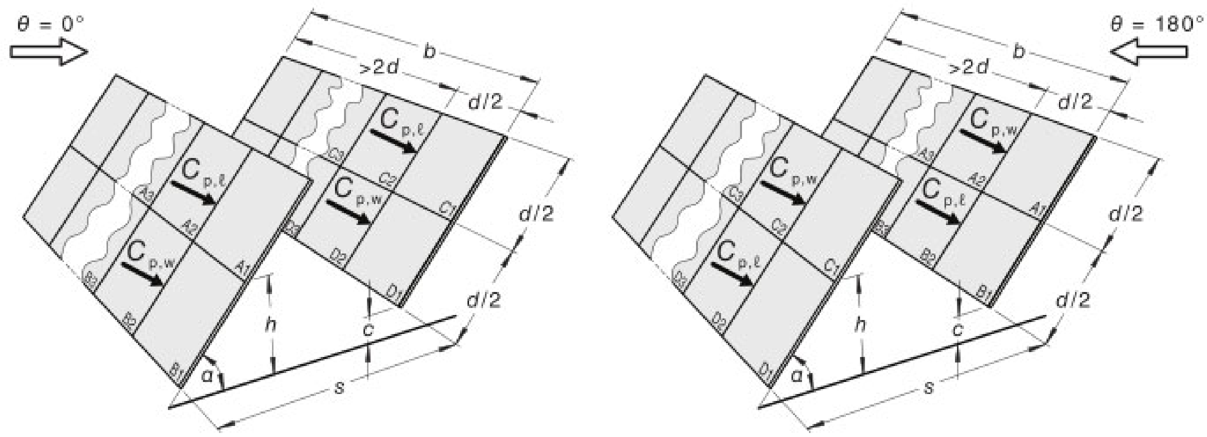

Figure B.11 — Solar panel arrays

Table B.13 — Net pressure coefficients ($C_{p,n}$) for solar panel array — $\theta = 0°$ (see Figure B.11)

Panel pitch (α) degrees	θ = 0 degrees							
	$C_{p,w}$		$C_{p,l}$		$C_{p,w}$		$C_{p,l}$	
	B1	B2, B3	A1	A2, A3	D1	D2, D3	C1	C2, C3
0	0.45	0.45	0.25	0.10	0.40	0.25	0.25	0.10
15	1.20	1.20	0.80	0.45	1.40	0.80	0.90	0.40
20	1.30	1.20	0.80	0.45	1.50	0.75	0.90	0.45
25	1.45	1.35	0.95	0.60	1.60	0.85	1.00	0.55
30	1.50	1.25	0.95	0.70	1.70	0.85	1.10	0.65

Table B.14 — Net pressure coefficients ($C_{p,n}$) for solar panel array — $\theta = 180°$ (see Figure B.11)

Panel pitch (α) degrees	θ = 180 degrees							
	$C_{p,w}$		$C_{p,l}$		$C_{p,w}$		$C_{p,l}$	
	A1	A2, A3	B1	B2, B3	C1	C2, C3	D1	D2, D3
0	−0.50	−0.55	−0.35	−0.20	−0.50	−0.35	−0.35	−0.15
15	−1.20	−1.40	−0.60	−0.85	−1.40	−1.45	−0.70	−0.65
20	−1.40	−1.45	−0.75	−0.90	−1.40	−1.40	−0.70	−0.70
25	−1.50	−1.45	−0.75	−0.95	−1.50	−1.35	−0.75	−0.80
30	−1.60	−1.50	−0.80	−0.95	−1.55	−1.30	−0.90	−0.85

Appendix C
(normative)

Aerodynamic shape factors for exposed structural members, frames and lattice towers

C.1 General

This Appendix shall be used to calculate aerodynamic shape factors (C_{shp}) for structures and components consisting of exposed members, such as lattice frames, trusses and towers.

All pressure coefficients shall be used with the value of wind speed applying at the height of the component being considered.

C.2 Aerodynamic shape factors for individual members and frames

C.2.1 Simple shapes and individual members

The aerodynamic shape factor (C_{shp}) for individual exposed structural members, with an aspect ratio (l/b) greater than 8, shall be calculated as follows:

(a) For wind axes, use Equation C.2(1):

$$C_{shp} = K_{ar} K_i C_d \tag{C.2(1)}$$

(b) For body axes, use Equations C.2(2) and C.2(3):

$$C_{shp} = K_{ar} K_i C_{F,x} \text{ along member's } x\text{-axis (major axis)} \tag{C.2(2)}$$

$$C_{shp} = K_{ar} K_i C_{F,y} \text{ along member's } y\text{-axis (minor axis)} \tag{C.2(3)}$$

where

l = length of member

b = breadth of element, normal to the wind stream

K_{ar} = aspect ratio correction factor for individual member forces, as given in Table C.1

K_i = factor to account for the angle of inclination of the axis of members to the wind direction, determined as follows:

= 1.0, when the wind is normal to the member

= $\sin^2 \theta_m$ for rounded cylindrical shapes

= $\sin \theta_m$ for sharp-edged prisms, (sharp-edged prisms are those with b/r greater than 16)

θ_m = angle between the wind direction and the longitudinal axis of the member, in degrees

r = corner radius of a structural shape

C_d = drag force coefficient for a structure or member in the direction of the wind stream, as given in Clause C.3

$C_{F,x}$ and $C_{F,y}$ = force coefficients for a structure or member, in the direction of the x- and y-axes respectively, as given in Clause C.3

Table C.1 — Aspect ratio correction factors (K_{ar})

Aspect ratio, l/b (see Note)	Correction factor K_{ar}
≤ 8	0.7
14	0.8
30	0.9
40 or more	1.0
NOTE For intermediate values l/b, use linear interpolation.	

C.2.2 Single open frame

The aerodynamic shape factor (C_{shp}) for a structure of open frame type, comprising a number of members where the members are sharp-edged rectangular or structural sections, lying in a single plane normal to the wind direction (see Figure C.1), shall be taken from Equation C.2(4):

(a) For $0.2 < \delta_e < 0.8$ and $1/3 < (l/b) < 3$ (where l/b is the aspect ratio of the whole frame).

$$C_{shp} = 1.2 + 0.26(1 - \delta_e) \quad \text{C.2(4)}$$

The reference area, A_{ref}, to be used in Equation C.2(4) for an open frame shall be taken as the sum of the projected areas of all the members projected normal to the plane of the frame.

(b) For all other cases, wind action shall be the sum of the effects calculated on individual members and attachments determined in accordance with Clause 2.5.3.3 and Clause C.2.1.

where

δ_e = effective solidity ratio for an open frame, given as follows:

= δ for flat-sided members

= $1.2\delta^{1.75}$ for circular cross-section members

where

δ = solidity ratio of the structure (surface or open frame), which is the ratio of solid area to total area of the structure

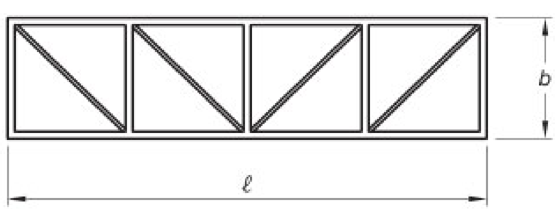

Figure C.1 — Notation for frame dimensions

C.2.3 Multiple open frames

For structures comprising a series of similar open frames in parallel, the aerodynamic shape factors for the second and subsequent frames shall be taken as the aerodynamic shape factors on the windward frame calculated as in Clause C.2.2, multiplied by the shielding factor (K_{sh}) obtained from Table C.2. The aerodynamic shape factor (C_{shp}) for the structure shall be calculated from Equation C.2(5):

$$C_{shp} = C_{shp,1} + \Sigma K_{sh} C_{shp,1} \qquad \text{C.2(5)}$$

where

$C_{shp,1}$ = aerodynamic shape factor for the first frame in the upwind direction, as given in Clause C.2.2

K_{sh} = shielding factor for shielded frames in multiple open-framed structures, as given in Table C.2

λ = spacing ratio for parallel open frames, equal to the frame spacing (centre-to-centre) divided by the smaller of l or b

Σ = summation over the second and subsequent downwind frames

In regard to Table C.2, for intermediate values of δ_e and λ, linear interpolation shall be used.

Table C.2 — Shielding factors (K_{sh}) for multiple frames

Angle of wind to frames (θ), degrees	Frame spacing ratio (λ)	Shielding factors (K_{sh})							
		Effective solidity (δ_e)							
		0	0.1	0.2	0.3	0.4	0.5	0.7	1.0
0 (wind normal to frames)	≤ 0.2	1.0	0.8	0.5	0.3	0.2	0.2	0.2	0.2
	0.5	1.0	1.0	0.8	0.6	0.4	0.2	0.2	0.2
	1.0	1.0	1.0	0.8	0.7	0.5	0.3	0.2	0.2
	2.0	1.0	1.0	0.9	0.7	0.6	0.4	0.2	0.2
	4.0	1.0	1.0	1.0	0.8	0.7	0.6	0.4	0.2
	≥ 8.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
45	≤ 0.5	1.0	0.9	0.8	0.7	0.6	0.5	0.3	0.3
	1.0	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.6
	2.0	1.0	1.0	1.0	1.0	1.0	0.9	0.8	0.6
	4.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.8
	≥ 8.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

NOTE For wind loads on industrial complexes, an approach to the wind loading porous industrial complexes such as petrochemical plants is as follows:

(a) Divide the unit into a finite number sections by planes normal to the wind direction. Four to six should be used, and for practical considerations no more than eight. The total along-wind length of the plant divided by the number of sections will determine the equivalent frame spacing, s. Sections do not need to be equally spaced and, in fact, should be chosen to coincide with the centres of key elements such as a line of columns.

(b) Calculate the individual drag coefficients the individual elements within the plant, as if they were unshielded.

(c) For the first windward section take the shielding multiplier, K_{sh}, as 1.0. For downwind sections take K_{sh} from Table C.2. In using that Table, the frame spacing ratio may be taken as the equivalent frame spacing, s, divided by a representative height of the plant. The effective solidity should be taken as combined solidity of all upwind elements looking upwind from the cross-section. Members of circular cross-section have a lower effective solidity than flat-sided members, see Clause C.2.2.

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(d) Calculate the wind drag forces on each element.

C.3 Force coefficients for structural members and simple sections

C.3.1 Rounded cylindrical shapes, sharp-edged prisms and structural sections

Values of force coefficients (C_d, $C_{F,x}$ and $C_{F,y}$) for rounded cylindrical shapes, sharp-edged prisms and some structural sections shall be as given in Tables C.3, C.4 and C.5 respectively.

Table C.4 gives values for the most common polygonal sharp-edged cross-sections except for rectangular prisms that are covered separately in Clause C.3.2.

NOTE 1 Force coefficients sharp-edged cross-sections are independent the Reynolds number.

NOTE 2 Note that in Table C.5, the dimension b, used in the definition the force coefficients, is not always normal to the flow direction, and d is not always parallel.

In the absence of experimental information for particular cables, C_d for helically wound, unwrapped cables shall be as follows:

(a) 1.2 for $bV_{des,\theta} < 0.5$ m²/s.

(b) 1.0 for $bV_{des,\theta} > 5.0$ m²/s.

For values of $bV_{des,\theta}$ between 0.5 and 5.0, use interpolation.

NOTE 3 Where icing cables is considered, the increased cross-sectional area and changed shape should be taken into account.

For intermediate values of $bV_{des,\theta}$, in Table C.3, linear interpolation shall be used. For circular cylindrical shapes, a value of C_d equal to 0.6 for $bV_{des,\theta}$ equal to 10 m²/s shall be assumed, for the purposes of this interpolation only.

For circular cross-sections for which $bV_{des,\theta} > 10$ m²/s, C_d shall be as follows:

$$C_d = 1.0 + 0.033\left[\log_{10}\left(V_{des,\theta}h_r\right)\right] - 0.025\left[\log_{10}\left(V_{des,\theta}h_r\right)\right]^2 \text{ or 0.6, whichever is the greater}$$

where

h_r = average height of surface roughness

Some typical values of h_r are as follows:

(i) Glass or plastic: 1.5×10^{-6} m.

(ii) Steel, galvanized: 150×10^{-6} m; light rust 2.5×10^{-3} m; heavy rust 15×10^{-3} m.

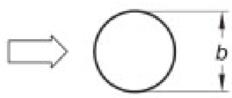
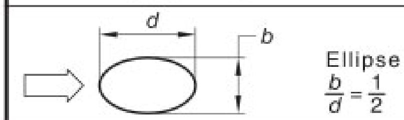
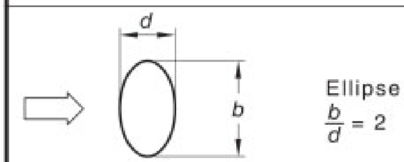
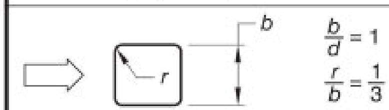
(iii) Concrete, new smooth: 60×10^{-6} m; new rough: 1×10^{-3} m.

(iv) Metal, painted: 30×10^{-6} m.

(v) Timber: 2×10^{-3} m.

Due consideration shall be taken of the projected area and drag of the attachments themselves.

Table C.3 — Drag force coefficients (C_d) for rounded cylindrical shapes

Cross-sectional shape	Description	Drag force coefficient (C_d)	
		$bV_{des,\theta} < 4\ m^2/s$	$bV_{des,\theta} > 10\ m^2/s$
	Cylindrical	1.2	See Clause C.3.1
	Ellipse narrow side to wind	0.7	0.3
	Ellipse broad side to wind	1.7	1.5
	Square with rounded corners	1.2	0.6

NOTE Attachments to circular cross-sections (e.g. ladders, pipes, etc.) projecting more than 1 % of the diameter of the cylinder will induce aerodynamic separation and in these cases C_d = 1.2.

Table C.4 — Drag force coefficient (C_d) for sharp-edged prisms

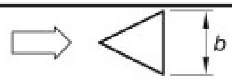
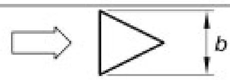
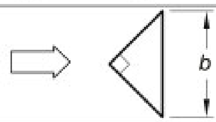
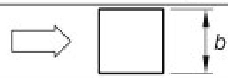
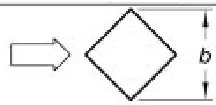
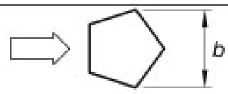
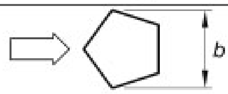
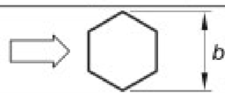
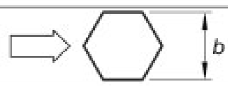
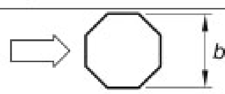
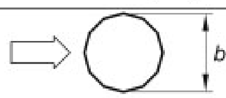
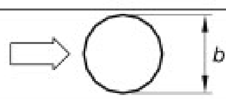
Cross-sectional shape	Drag force coefficient (C_d)
 Equilateral triangle—apex to wind	1.2
 Equilateral triangle—face to wind	2.0
 Right-angled triangle	1.55
 Square with face to wind	2.2
 Square with corner to wind	1.5
 Pentagon with face to wind	1.1
 Pentagon with corner to wind	1.7
 Hexagon with face to wind	1.2
 Hexagon with corner to wind	1.5
 Octagon	1.4
 12-sided polygon	1.3
 16-sided polygon	1.0

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Table C.5 — Force coefficients ($C_{F,x}$) and ($C_{F,y}$) for structural sections

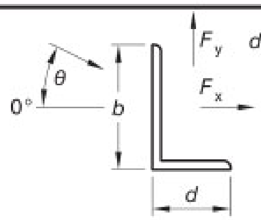
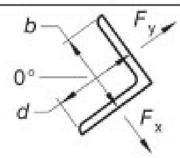
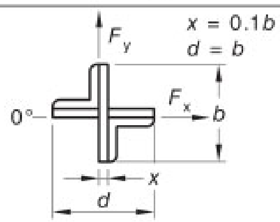
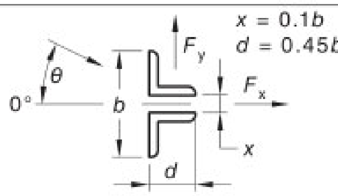
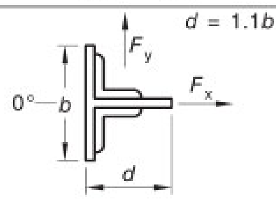
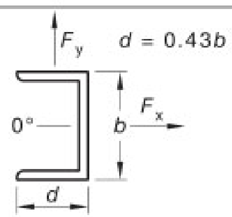
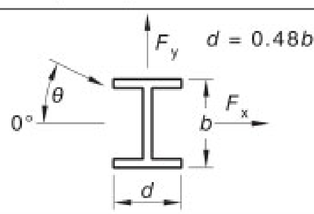
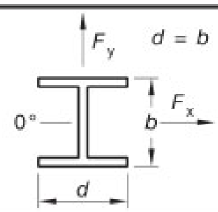
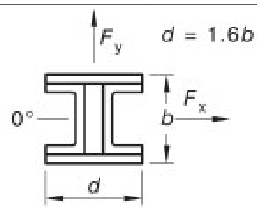
Section shape		Wind direction measured clockwise (θ, degrees)				
		0	**45**	**90**	**135**	**180**
	$C_{F,x}$	2.0	1.8	−2.0	−1.8	−1.9
	$C_{F,y}$	−0.1	0.1	−1.7	−0.8	−0.95
	$C_{F,x}$	1.8	1.8	−1.0	0.3	−1.4
	$C_{F,y}$	1.8	2.1	−1.9	−2.0	−1.4
	$C_{F,x}$	1.75	0.75	−0.1	−0.85	−1.75
	$C_{F,y}$	0.1	−0.75	−1.75	−0.85	−0.1
	$C_{F,x}$	1.6	1.5	−0.95	−0.5	−1.5
	$C_{F,y}$	0	0.1	−0.7	−1.05	0
	$C_{F,x}$	2.0	1.2	−1.6	−1.1	−1.7
	$C_{F,y}$	0	−0.9	−2.15	−2.4	±2.1
	$C_{F,x}$	2.05	1.85	0	−1.6	−1.8
	$C_{F,y}$	0	−0.6	−0.6	−0.4	0
	$C_{F,x}$	2.05	1.95	±0.5	—	—
	$C_{F,y}$	0	−0.6	−0.9	—	—

Table C.5 *(continued)*

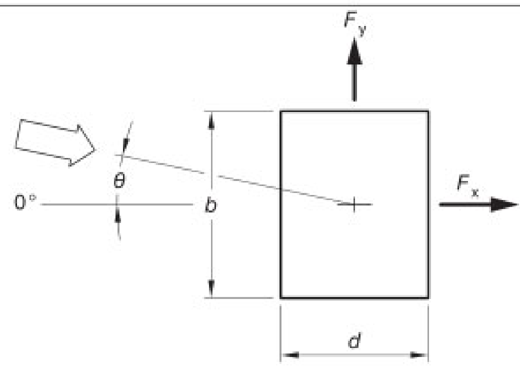
Section shape		Wind direction measured clockwise (θ, degrees)				
		0	**45**	**90**	**135**	**180**
	$C_{F,x}$	1.6	1.5	0	—	—
	$C_{F,y}$	0	−1.5	−1.9	—	—
	$C_{F,x}$	1.4	1.2	0	—	—
	$C_{F,y}$	0	−1.6	−2.2	—	—

NOTE The direction θ has been changed to clockwise and the values transposed accordingly, to align with the clockwise direction used elsewhere in the Standard. Also, dimension b, used in the definitions the force coefficients, is not always normal to the wind direction.

C.3.2 Rectangular prismatic sections

Values of force coefficients ($C_{F,x}$ and $C_{F,y}$) for rectangular prismatic cross-sections are given in Figure C.2.

NOTE Structures with rect0061ngular cross-sections can experience dynamic crosswind forces and response. Crosswind response of tall buildings is covered in Clause 6.3.2. For other structures, specialist advice should be sought.



d/b	θ =	0°	45°	90°
1	$C_{F,x}$	2.2	1.5	0
	$C_{F,y}$	0	−1.5	−2.2
1.62	$C_{F,x}$	1.7	1.5	0
	$C_{F,y}$	0	−2.7	−4.5
2.5	$C_{F,x}$	1.5	1.3	0
	$C_{F,y}$	0	−4.2	−5.6
3	$C_{F,x}$	1.3	1.2	0
	$C_{F,y}$	0	−5.1	−6.7
10	$C_{F,x}$	1.1	1.1	0
	$C_{F,y}$	0	−18	−22

NOTE The reference length for the force coefficients in Figure C.2 is b in all cases.

Figure C.2 — Force coefficients for rectangular prisms

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C.4 Lattice towers

C.4.1 General

Lattice towers shall be divided vertically into a series of sections (levels). The aerodynamic shape factors (C_{shp}) shall be calculated for each section.

NOTE A minimum 10 sections should be used where possible.

The tower sections shall be designed for winds in eight directions with $V_{des,\theta}$ being the value of $V_{sit,\beta}$ in a sector ± 22.5° from the 45° direction being considered.

The aerodynamic shape factor (C_{shp}) shall be equal to the values calculated, as follows:

(a) C_d for a tower section without ancillaries, as given in Clause C.4.2.1.

(b) C_{de}, for a tower section with ancillaries, as given in Clause C.4.2.2.

(c) 1.2 $\sin^2 \theta_m$, for guy cables, using the wind speed calculated for 2/3 of the height of the cable,

where

C_{de} = effective drag force coefficient for a tower section with ancillaries

θ_m = angle between the wind direction and the longitudinal axis of the cable, in degrees

C.4.2 Drag force coefficient

C.4.2.1 Tower sections without ancillaries

The drag force coefficients (C_d) for complete lattice tower sections shall be taken from Tables C.6(A) to C.6(C).

For equilateral-triangle lattice towers with flat-sided members, the drag force coefficient (C_d) shall be assumed to be constant for any inclination of the wind to a face.

For complete-clad tower sections, C_d shall be taken as the value given in Tables C.3 and C.4, and Figure C.2 for the appropriate tower section shapes.

For UHF antenna sections, C_d shall be obtained from Table C.7 and Figure C.3. To calculate the area for the application of the pressure, breadth shall be taken as b_D or b_N, as appropriate to the wind direction.

Where used, the reduction for aspect ratio shall be carried out by multiplying by the correction factor (K_{ar}), given in Table C.1, taking l as equal to two times the height of the end-mounted antennas.

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Table C.6(A) — Drag force coefficients (C_d) for lattice frameworks and towers — Square and equilateral triangle in plan with flat-sided members

Solidity of front face (δ_e)	Square cross-section		Equilateral-triangle cross-section
	Onto face	Onto corner	
≤ 0.1	3.5	3.9	3.1
0.2	2.8	3.2	2.7
0.3	2.5	2.9	2.3
0.4	2.1	2.6	2.1
≥ 0.5	1.8	2.3	1.9

NOTE 1 A_z = area of members in one face projected horizontally normal to the face (this area does not change with wind direction). This is the reference area for the drag coefficients in Table C.6(A) in the application of Equation 2.5(3).

NOTE 2 δ = solidity ratio of the structure (surface or open frame), that is the ratio of the area A_z as defined in Note 1, to the total projected area enclosed over the section height by the boundaries the frame. For intermediate values of solidity, linear interpolation should be used.

NOTE 3 b_i = average diameter or breadth of a section of a tower member.

In Tables C.6(B) and C.6(C), linear interpolation shall be used for values of biVdes,θ between 3 and 6 m2/s.

Table C.6(B) — Drag force coefficients (C_d) for lattice frameworks and towers — Square plan with circular members

Solidity of front face (δ)	Parts of structure in sub-critical flow $b_i V_{des,\theta} < 3$ m^2/s		Parts of structure in super-critical flow $b_i V_{des,\theta} \geq 6$ m^2/s	
	Onto face	Onto corner	Onto face	Onto corner
≤ 0.05	2.2	2.5	1.4	1.6
0.1	2.0	2.3	1.4	1.6
0.2	1.9	2.3	1.5	1.7
≥ 0.3	1.9	2.3	1.7	1.9

NOTE 1 A_z = area of members in one face projected horizontally normal to the face (this area does not change with wind direction). This is the reference area for the drag coefficients in Table C.6(B) in the application of Equation 2.5(3).

NOTE 2 δ = solidity ratio the structure (surface or open frame), that is the ratio the area A_z as defined in Note 1, to the total projected area enclosed over the section height by the boundaries of the frame. For intermediate values of solidity, linear interpolation should be used.

NOTE 3 b_i = average diameter or breadth of a section of a tower member.

NOTE 4 The data for frameworks with circular members in Table C.6(B) is sparse, and should be used with caution.

Table C.6(C) — Drag force coefficients (C_d) for lattice frameworks and towers — Equilateral triangle plan with circular members

Solidity of front face (δ)	Parts of structure in sub-critical flow $b_i V_{des,\theta} < 3$ m²/s (all wind directions)	Parts of structure in super-critical flow $b_i V_{des,\theta} \geq 6$ m²/s (all wind directions)
≤ 0.05	1.8	1.2
0.1	1.7	1.2
0.2	1.7	1.3
≥ 0.3	1.7	1.4

NOTE 1 A_z = area of members in one face projected horizontally normal to the face (this area does not change with wind direction). This is the reference area for the drag coefficients in Table C.6(C) in the application of Equation 2.5(3).

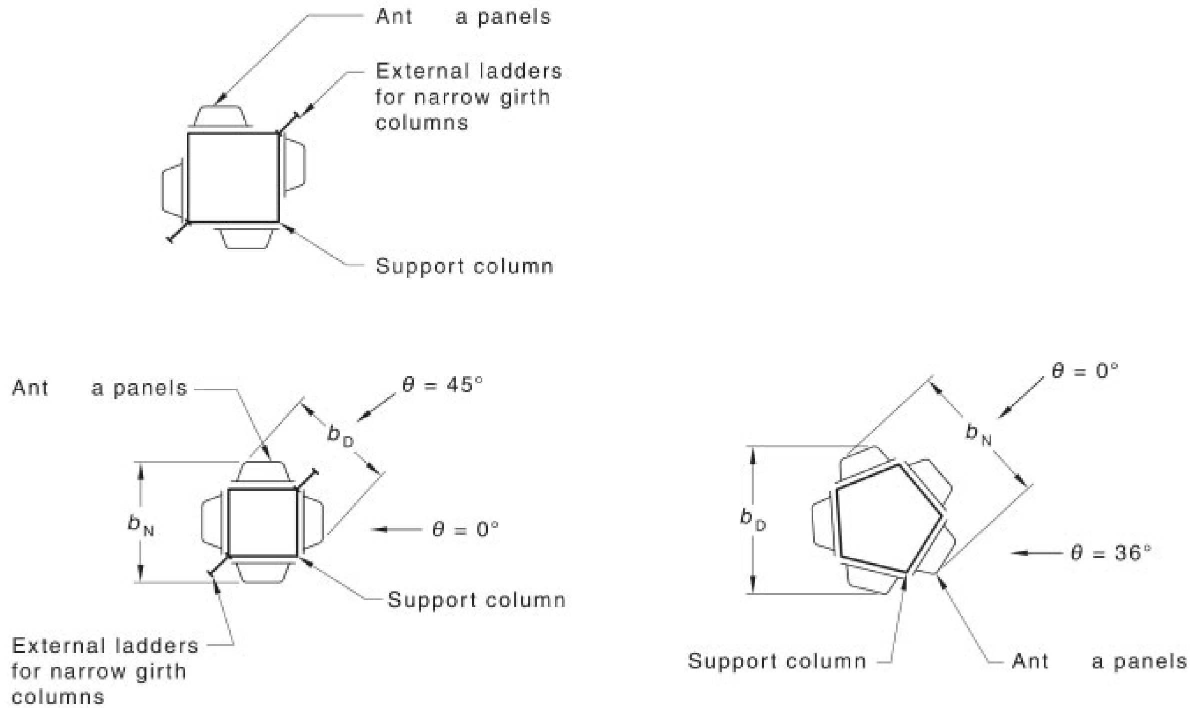
NOTE 2 δ = solidity ratio of the structure (surface or open frame), that is the ratio of the area A_z as defined in Note 1, to the total projected area enclosed over the section height by the boundaries of the frame. For intermediate values of solidity, linear interpolation should be used.

NOTE 3 b_i = average diameter or breadth of a section of a tower member.

NOTE 4 The data for frameworks with circular members in Table C.6(C) is sparse, and should be used with caution.

Table C.7 — Drag force coefficient (C_d) for UHF antenna sections (see Figure C.3)

Antenna type	Wind direction (θ) degrees	Drag force coefficient (C_d)
1 (4 sided)	0, 45	1.4
2 (5 sided)	0	1.5
2 (5 sided)	36	1.3



(a) Ant a Type 1
Square support column

(b) Ant a Type 2
Pentagonal support column

Plan view

NOTE Reduction for aspect ratio may be carried out by multiplying by the correction factor (K_{ar}) given in Table C.1, taking l as equal to two times the height of the end-mounted antennas.

Figure C.3 — Drag force coefficients (C_d) for section of UHF antennas

To calculate the area (A_z) in Equation 2.5(3), breadth (b_D) or (b_N) in Figure C.3 shall be used as appropriate to the wind direction.

C.4.2.2 Tower sections with ancillaries

The effective drag force coefficient (C_{de}) for a tower section with ancillaries shall be calculated as follows:

(a) Where ancillaries are attached symmetrically to all faces, their projected area shall be added to the projected area of the tower members (A_z).

(b) Where ancillaries are not symmetrically placed, the total effective drag force coefficient (C_{de}) for a tower section shall be taken from Equation C.4(1):

$$C_{de} = C_d + \Sigma \Delta C_d \tag{C.4(1)}$$

where

ΔC_d = additional drag coefficient due to an ancillary attached to one face or located inside the tower section, given by Equation C.4(2):

$$= C_{da} K_{ar} K_{in} \left(A_a / A_z \right) \tag{C.4(2)}$$

where

C_{da} = value of drag force coefficient (C_d) on an isolated ancillary on a tower, as given in Tables C.3 and C.4 and Figure C.2

K_{ar} = aspect ratio correction factor for individual member forces

= as given in Table C.1, for linear ancillaries with aspect ratios less than 40

= 1.0, for all other cases

K_{in} = correction factor for interference, as given in Clause C.4.2.3

A_a = reference area of ancillaries on a tower

= lb

where

l is the length of the linear ancillary and b is defined in Figure C.4 and Tables C.3 and C.4

$A_{z,s}$ = total projected area of the tower section at height z

C.4.2.3 Correction factor for interference

The correction factor for interference (K_{in}) shall be calculated as follows:

(a) For ancillaries attached to the face of the tower:

(i) To the face of a square tower [see Figure C.4(a)], use Equation C.4(3):

$$K_{in} = \left[1.5 + 0.5\cos 2(\theta_a - 90°)\right]\exp\left[-1.2(C_d\delta)^2\right] \quad \text{C.4(3)}$$

(ii) To the face of a triangular tower [see Figure C.4(b)], use Equation C.4(4):

$$K_{in} = \left[1.5 + 0.5\cos 2(\theta_a - 90°)\right]\exp\left[-1.8(C_d\delta)^2\right] \quad \text{C.4(4)}$$

(b) For lattice-like ancillaries inside the tower, K_{in} shall be taken either as 1.0 or determined as follows:

(i) Inside a square tower [see Figure C.4(c)], use Equation C.4(5):

$$K_{in} = \exp\left[-1.4(C_d\delta)^{1.5}\right] \quad \text{C.4(5)}$$

(ii) Inside a triangular tower [see Figure C.4(d)], use Equation C.4(6):

$$K_{in} = \exp\left[-1.8(C_d\delta)^{1.5}\right] \quad \text{C.4(6)}$$

(c) For cylindrical ancillaries inside the tower, K_{in} shall be taken either as 1.0 or determined as follows:

(i) Inside a square tower [see Figure C.4(e)], using Equations C.4(7) and C.4(8):

$$K_{in} = \exp\left[-a(C_d\delta)^{1.5}\right] \quad \text{C.4(7)}$$

$$a = 2.7 - 1.3\exp\left[-3(b/w)^2\right] \quad \text{C.4(8)}$$

(ii) Inside a triangular tower [see Figure C.4(f)], using Equations C.4(9) and C.4(10):

$$K_{\text{in}} = \exp\left[-c\left(C_{\text{d}}\delta\right)^{1.5}\right] \qquad \text{C.4(9)}$$

$$c = 6.8 - 5\exp\left[-40\left(b/w\right)^{3}\right] \qquad \text{C.4(10)}$$

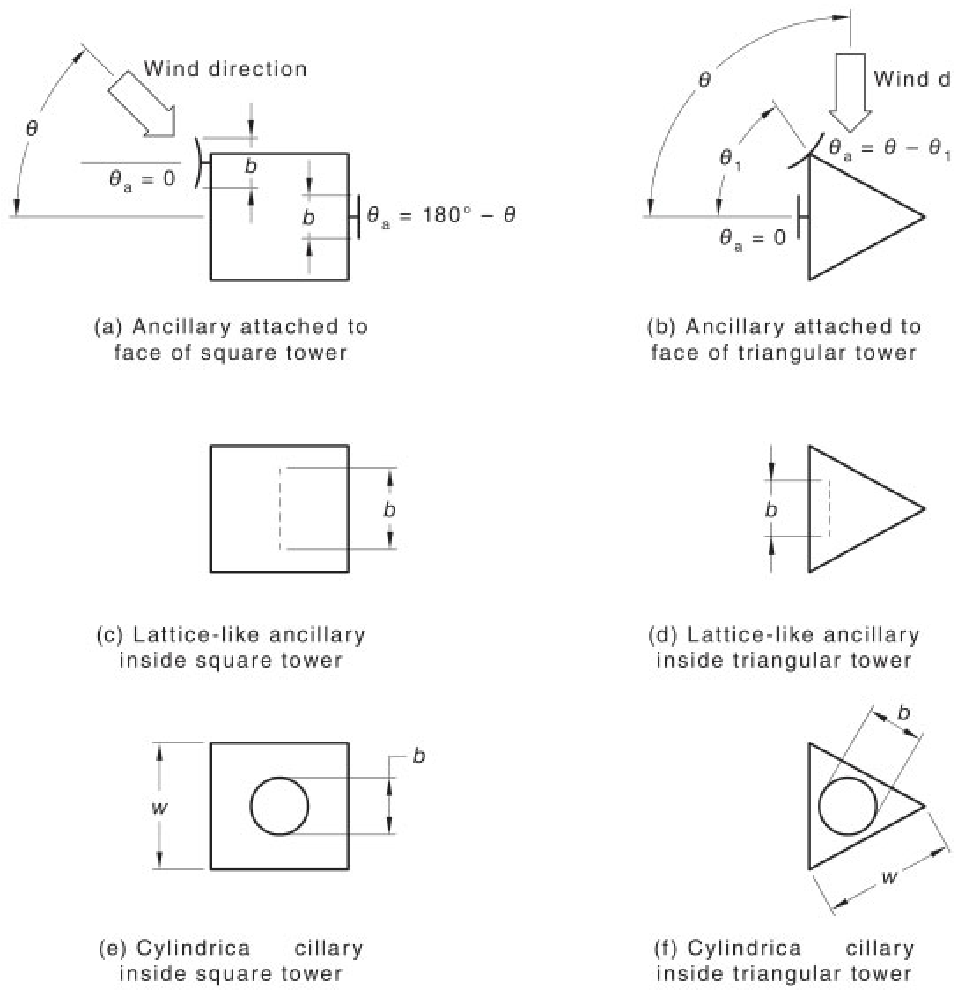
where

θ_{a} = angle of deviation of the wind stream from the line joining the centre of the tower cross-section to the centre of the ancillary, in degrees

δ = solidity ratio of the structure, as given in Clause C.4.2.1

a, c = exponential decay parameters

b/w = ratio of the average diameter of an ancillary to the average width of a structure



(a) Ancillary attached to face of square tower

(b) Ancillary attached to face of triangular tower

(c) Lattice-like ancillary inside square tower

(d) Lattice-like ancillary inside triangular tower

(e) Cylindrica cillary inside square tower

(f) Cylindrica cillary inside triangular tower

Figure C.4 — Tower sections with ancillaries

Appendix D
(normative)

Flags and circular shapes

D.1 General

This Appendix shall be used to calculate aerodynamic shape factors (C_{shp}) for drag forces on flags, discs and spherical shapes.

All pressure coefficients shall be used with the value of wind speed applying at the mid-height of the component being considered.

D.2 Flags

The aerodynamic shape factor (C_{shp}) for flags is as follows:

(a) Fixed flag shall be treated as elevated hoarding (see Appendix B).

(b) Free flag (including dynamic effects from flutter) shall be calculated from Equation D.2:

$$C_{shp} = 0.05 + 0.7 \frac{m_f}{\rho_{air} c} \left(\frac{A_{ref}}{c^2} \right)^{-1.25} \text{, but not greater than 0.76} \quad \text{D.2}$$

where

m_f = mass per unit area of flag, in kilograms per square metre

ρ_{air} = density of air which shall be taken as 1.2 kg/m^3

c = net height of flag (see Figure D.1)

l_f = flag length (see Figure D.1)

A_{ref} = reference area of flag, as given in Figure D.1 (area of flag perpendicular to the wind direction)

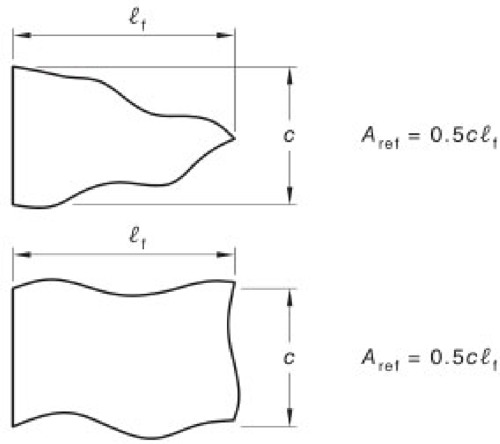
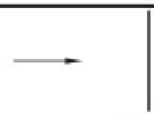
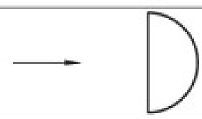
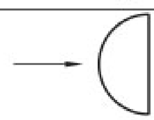
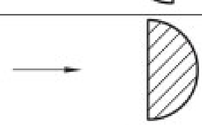
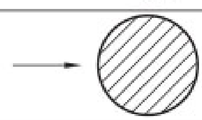


Figure D.1 — Reference area for flags

D.3 Circular shapes

The aerodynamic shape factor (C_{shp}) for calculating drag forces on circular shapes shall be as given in Table D.1. The reference area A_{ref} for shapes in Table D.1 shall be the projected area normal to the wind direction.

Table D.1 — Aerodynamic shape factor for circular shapes

Cross-sectional shape	Description of shape	Aerodynamic shape factor (C_{shp})
	Circular disc	1.3
	Hemispherical bowl (cup to wind)	1.4
	Hemispherical bowl	0.4
	Hemispherical solid (flat to wind)	1.2
	Spherical solid	0.5 for $bV_{des,\theta} < 7$ m²/s 0.2 for $bV_{des,\theta} \geq 7$ m²/s

Appendix E
(informative)

Accelerations and rotational velocities for wind-sensitive structures

E.1 Acceleration for serviceability

Equation E.1 may be used as an indicator of motion serviceability. For wind-sensitive buildings, mostly exposed to free stream flow, acceptable wind acceleration levels may be exceeded if:

$$h^{1.3}/m_0 > 0.0016 \qquad \text{E.1}$$

where

h = average roof height of a structure above the ground, in metres

m_0 = average mass per unit height

In conditions of high turbulence, due to interference from other buildings, a more conservative approach to the use of this indicator should be taken. If the inequality indicates likely high acceleration levels, then the designer should undertake more detailed analysis or wind tunnel model studies.

NOTE Examples acceptable maximum peak acceleration levels for tall buildings are provided in ISO 10137.

E.2 Peak along-wind acceleration for serviceability

The peak acceleration at the top of a structure in the along-wind direction ($\ddot{x}_{max}$) in metres per second squared, is given by Equation E.2:

$$\ddot{x}_{max} = \frac{3}{m_0 h^2} \times \text{resonant component of peak base bending moment}$$

$$= \frac{3}{m_0 h^2} \frac{\rho_{air} g_R I_h \sqrt{\frac{SE_t}{\zeta}}}{\left(1+2g_v I_h\right)} \left\{ C_{fig,\,windward} \sum_{z=0}^{h} \left[V_{des,\theta}(z)\right]^2 b_z z \Delta z - C_{fig,\,leeward} \left[V_{des,\theta}(h)\right]^2 \sum_{z=0}^{h} b_z z \Delta z \right\} \qquad \text{E.2}$$

where

m_0 = average mass per unit height

ρ_{air} = density of air which is taken as 1.2 kg/m^3

$V_{des,\theta}(z)$ = building orthogonal design wind speeds as a function of height z

$V_{des,\theta}(h)$ = building orthogonal design wind speeds evaluated at height h

b_z = average breadth of the structure at the section at height z

Δz = height of the section of the structure upon which the wind pressure acts

ζ = ratio of structural damping to critical damping of the structure

NOTE Users should seek advice on possible values damping as a function height the structure and amplitude of vibration.

E.3 Crosswind acceleration for serviceability of tall buildings and towers of rectangular cross-section

E.3.1 General

This Clause gives methods for determining peak accelerations at the top of tall enclosed buildings and towers of rectangular cross-section. Calculation of crosswind response is not required for porous lattice towers.

E.3.2 Peak crosswind acceleration for serviceability

The peak acceleration in the crosswind direction $(\ddot{y}_{\max})$ in metres/second squared, at the top of a structure with constant mass per unit height (m_0) should be determined from Equation E.3(1):

$$\ddot{y}_{\max} = \frac{1.5 b g_R}{m_0} \left[\frac{0.5 \rho_{air} \left[V_{des,\theta} \right]^2}{\left(1 + g_v I_h\right)^2} \right] K_m \sqrt{\frac{\pi C_{fs}}{\zeta}} \qquad \text{E.3(1)}$$

where

b = breadth of a structure, normal to the wind stream

g_R = peak factor for resonant response (10 min period) given by Equation E.3(2):

$$\sqrt{\left[1.2 + 2 log_e \left(600 n_c\right)\right]} \qquad \text{E.3(2)}$$

n_c = first mode natural frequency of vibration of a structure in the crosswind direction, in hertz

m_0 = average mass per unit height

g_v = peak factor for the upwind velocity fluctuations, which may be taken as 3.4

I_h = turbulence intensity, obtained from Table 6.1 by setting $z = h$

K_m = mode shape correction factor for crosswind acceleration, given by:

= $0.76 + 0.24k$

where

k = mode shape power exponent for the fundamental mode and values of the exponent k should be taken as:

= 1.5 for a uniform cantilever

= 0.5 for a slender framed structure (moment resisting)

= 1.0 for a building with central core and moment resisting façade

= 2.3 for a tower decreasing in stiffness with height, or with a large mass at the top

= the value obtained from fitting $\phi_1(z) = (z/h)^k$ to the computed modal shape of the structure

$\phi_1(z)$ = first mode shape as a function of height z, normalized to unity at $z = h$

C_{fs} = crosswind force spectrum coefficient generalized for a linear mode shape given in Clause 6.3.2.3

ζ = ratio of structural damping to critical damping of the structure

E.4 Rotational velocities

The following calculation procedure may be utilized to estimate the peak rotational velocity at the highest occupiable level of the tower. Note that rotational velocities at other levels of the tower may be determined by applying the relevant normalized torsion mode shape value.

NOTE A commonly used criterion is that the annual maximum peak rotational velocity should not exceed 1.5 millirad/s.

A translational force in the along-wind direction which is offset from the reference axis produces a torsion response of the structure. The resonant component of the translational force can be derived from the resonant component of the along-wind base moment using Equation E.4(1):

$$F_{res} = \frac{M_{res}}{0.67h} \quad \text{E.4(1)}$$

where

M_{res} = resonant component of the base moment (see Equation E.2)

h = reference height of the tower

From this, the resonant component of the torsion response should be calculated by Equation E.4(2):

$$M_{z,res} = 0.2bF_{res} \quad \text{E.4(2)}$$

The resulting peak rotational displacement (in radians) can be determined by Equation E.4(3):

$$\theta \approx \frac{M_{\theta,res}}{M_{I,\theta}} \quad \text{E.4(3)}$$

where

$M_{I,\theta}$ = inertial torsion moment, and is calculated from the floor masses and normalized mode shapes of the tower

The peak rotational velocity (in radians per second) should then be determined by Equation E.4(4):

$$\hat{\dot{\theta}} \approx \left(2\pi n_{\theta}\right)\theta \quad \text{E.4(4)}$$

where

n_{θ} = natural frequency of the torsion mode

E.5 Peak torsional acceleration

The component of peak accelerations on a building due to torsion may be calculated based on an extension of the methodology used for estimating the peak rotational velocities from Equation E.5:

$$\hat{\ddot{z}} = \left(2\pi n_{\theta}\right)^{2} \theta R \tag{E.5}$$

where

R = furthest point away from the centre of rigidity at the highest occupied level of the building

n_{θ} = natural frequency of the torsion mode of the structure

E.6 Combined peak acceleration

The combined standard deviation acceleration should be calculated by Equation E.6(1):

$$\sigma_{a(x,y,z)}^{2} = \sqrt{\sigma_{a(x)}^{2} + \sigma_{a(y)}^{2} + \sigma_{a(z)}^{2}} \tag{E.6(1)}$$

where

$\sigma_{a(x,y,z)}$ = combined standard deviation acceleration

$\sigma_{a(x)}$ = component of the standard deviation acceleration acting along the x-axis

$\sigma_{a(y)}$ = component of the standard deviation acceleration acting along the y-axis

$\sigma_{a(z)}$ = component of the standard deviation acceleration acting about the z-axis

The combined peak acceleration is the maximum of the largest component and the adjusted vector sum of the three components of the peak acceleration, obtained from Equation E.6(2):

$$\hat{a}_{(x,y,z)} = \left(\frac{\rho}{\sqrt{1+\rho^{2}}}\right)\sqrt{\hat{\ddot{x}}^{2} + \hat{\ddot{y}}^{2} + \hat{\ddot{z}}^{2}} \tag{E.6(2)}$$

where

$\hat{a}_{(x,y,z)}$ = combined peak acceleration

ρ = ratio of the highest component of peak acceleration to the second highest component of peak acceleration (>1)

$\hat{\ddot{x}}$ = component of the peak acceleration acting along the x-axis

$\hat{\ddot{y}}$ = component of the peak acceleration acting along the y-axis

$\hat{\ddot{z}}$ component of the peak acceleration acting about the z-axis

NOTE Equation E.6(2) applies to cases where there is generally no significant coupling between the three components. The relation in Equation E.6(2) is used rather than the fixed value 0.8 as this relates better to the effect of a dominant mode contribution, where the combination factor can approach 1.0. The greater of the combined result as per Equation E.6(2) and the highest acceleration due to rotation about any one axis is adopted as the maximum.

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