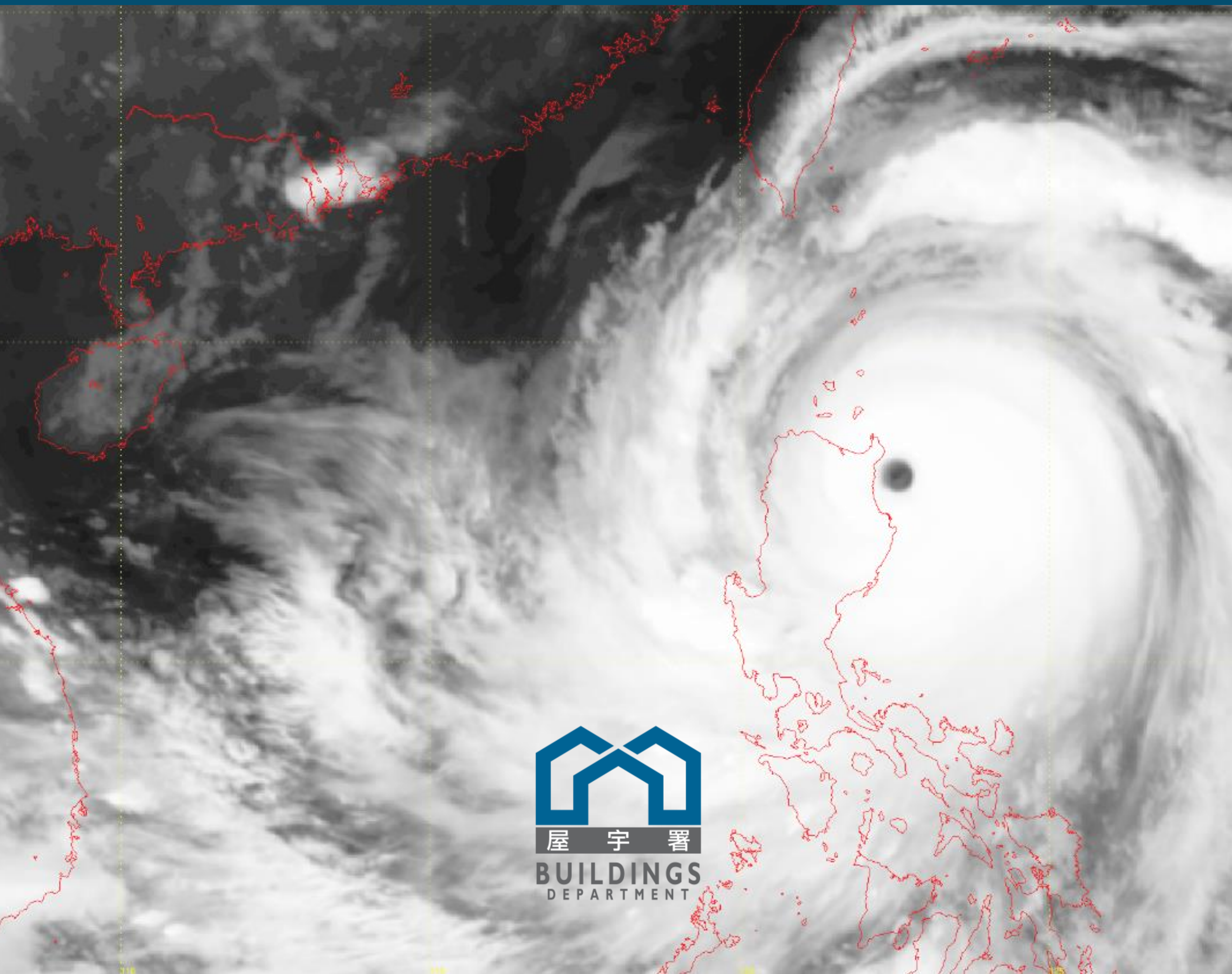
Code of Practice on Wind Effects in Hong Kong 2019



屋宇署
BUILDINGS
DEPARTMENT

Code of Practice

on

Wind Effects in Hong Kong

2019

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BUILDINGS DEPARTMENT

FOREWORD

This Code of Practice on Wind Effects in Hong Kong 2019 (Code) was prepared on the basis of a consultancy study commissioned by the Buildings Department under the direction of a Steering Committee. The Steering Committee of the consultancy included members from the academia, professional institutions and relevant government departments.

The new features introduced in this Code are:

(a) Calculation of across-wind and torsional forces

(b) Load combination factors for lateral and torsional forces for buildings

(c) Calculation of the direct sheltering effect of surrounding buildings, using the concept of displacement height to reduce the effective height of buildings for assessing reference wind pressures and force coefficients

(d) Calculation of acceleration and evaluation of occupant comfort

(e) Wind directionality factor accounting for the reduced probability of strong winds from various directions

This Code also provides information on:

(a) Force and pressure coefficients for design of typical buildings in Hong Kong

(b) An updated vertical distribution of along-wind forces, through a size and dynamic factor which increases with height

(c) Guidance for the design of building attachments

(d) Further guidance on requirements for wind tunnel testing

As the Code has been prepared in a simple format for ease of application, reference should be made to the Explanatory Notes to the Code (EN), which give a summary of background information and considerations reviewed in the formulation of the Code. The EN also explains in depth the major updates and features in the Code and to address on situations where application of the Code may require special attention.

The contributions on the formulation of the Code by the members of the Steering Committee are greatly appreciated.

Acknowledgement is given to the Hong Kong Observatory as the source of the cloud imagery on the cover page. The cloud imagery was originally captured by Himawari-8 Geostationary Meteorological Satellite of Japan Meteorological Agency.

This Code will be reviewed regularly. The Buildings Department welcomes suggestions for improving the Code.

Buildings Department
First Issue : September 2019

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1 General

1.1 Scope

The Code of Practice on Wind Effects in Hong Kong 2019 (Code) stipulates the approach for calculating the wind loads for the structural design of buildings or parts of buildings, referred hereinafter as "Standard Method". Compliance with the requirements of this Code is deemed to satisfy the relevant provisions of the Buildings Ordinance and related regulations.

Values of wind loads 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 loads.

The Standard Method is intended to cover normal building constructions. Users of this Code should satisfy themselves that the guidance is rationally applicable to the form of structure under consideration.

The Standard Method is applicable to typical buildings with a height up to 200m. The wind tunnel testing method should be used for any of the following conditions:

(a) buildings of height exceeding 200m;

(b) buildings having an unusual shape not covered by this Code;

(c) buildings in locations where complicated local topography or surroundings adversely affect the wind conditions;

(d) buildings with codified across-wind moment substantially larger than the along-wind moment as detailed in clause 2.2.3; or

(e) buildings with B/D>6, except for those satisfying the conditions in clause 2.2.4 so that the torsional load cases can be neglected.

Guidance for wind tunnel testing is provided in Section 6.

1.2 Symbols

The symbols used in this Code shall have the following meanings with respect to a structure, member or condition to which a clause is applied.

Except where specifically noted, this Code uses the SI units. Angles are given in degrees.

For subscripts, lower case letters are used.

A_z	peak acceleration at height Z (m/s^2)
B	breadth of building, the horizontal dimension of the building normal to the direction of the wind
b	scaling length defining loaded areas for pressure coefficients, taken as the smaller of B or $2H$
C_f	force coefficient determined in accordance with Section 4
C_p	net pressure coefficient, or total pressure coefficient for building elements
C_{pe}	external pressure coefficient
C_{pi}	internal pressure coefficient
D	depth of building, the horizontal dimension of the building parallel to the direction of the wind
d	diameter of circular cylinder
e_1,e_2	eccentricity for calculating variable torsional load
F_{x1}, F_{x2}	along-wind forces
F_{y1}, F_{y2}	across-wind forces
G_{ry}	peak factor on standard deviation of across-wind resonant response in one hour $= \sqrt{2\, Log_e(1800\, N_y)}$
H	height of building structure (up to the top roof) above ground level for the approaching wind direction under consideration. Note that for sloping terrain, building height for different directions may be different.
H_b	height of building structure above ground level, excluding the height of irregular roof features above main roof
H_e	effective building height, based on H, taking account of the sheltering effect of surrounding buildings. It is obtained by taking $Z = H$ for the Z_e formula in Appendix A2.
H_i	height of obstructing buildings in the surroundings
H_d	reduction in reference height due to sheltering effect ('displacement height')
H_t	height of hill defined on the windward side. See Appendix A3
h	when not subscripted, parapet height, free-standing wall height, attached canopy height, or signboard height
$I_{o,h}$	wind turbulence intensity at effective building height H_e
$I_{v,h}$	wind turbulence intensity at building height H
$I_{v,z}$	wind turbulence intensity at height Z
$I_{o,z}$	wind turbulence intensity at effective height Z_e
$L_{0.5p}$	half-perimeter length around a tributary area
$M_{xx,base}$	peak across-wind moment at base (ground) level

M_h	mass of the building above $2H_b/3$. 25% of imposed loads can be added with the dead loads together as the mass source for M_h. For E&M room, either still follow the rule or use the actual imposed loads together with dead loads for M_h.
N	frequency of fundamental mode of lateral vibration, N_x or N_y. For buildings of typical construction below 100m height, the expression, $N = 46/H$ may be used. Otherwise, the natural frequencies shall be obtained from a modal dynamic analysis using best-estimates of stiffness and mass.
N_x	fundamental frequency for a mode mainly aligned with the along-wind direction
N_y	fundamental frequency for a mode mainly aligned with the across-wind direction
P	net pressure on a surface
P_e	pressure on external surface
P_i	pressure on internal surface
$Q_{o,z}$	wind reference pressure determined from Table 3-1 at the effective height, Z_e, for open exposure in flat terrain
Q_z	wind reference pressure, $Q_{o,z}$, corrected for effects topography and wind direction at height Z
Q_h	wind reference pressure, Q_z, at effective building height, H_e
R	return period of wind (years)
r	radius
$S_{q,z}$	size and dynamic factor on applied forces for overall structure design of buildings
S_r	factor on wind pressure for return period, R (with 63.2% likelihood of exceedance within this period)
S_s	size effect factor depending on the "half-perimeter" length, $L_{0.5p}$, of the loaded area (S_s may be greater than 1.0 for small elements)
S_{si}	size effect factor for internal pressure under dominant opening case, depending on the size of the dominant opening or openings. The size factor is defined in Section 5.1.
S_t	topographic multiplier on wind pressure, evaluated at $2H/3$. See Appendix A3.
s	topographic location factor. See Appendix A3.
S_θ	directionality factor on wind pressure
ΔT_z	variable torsional load per unit height about a vertical axis through the centre of width at height, Z
V_z	mean-hourly wind speed
w	when not subscripted, width of wedge in re-entrant or chamfered corners
W_z	along-wind load per unit height, at height, Z

$W_{z,x1}$, $W_{z,x2}$	set of along-wind forces in direction X_1, X_2, etc., causing shears and moments at all heights, applied at centres of area
$X, X_1, X_2, etc.$	along-wind directions. For building that may be treated as rectangular, X_1 and X_2 will be orthogonal.
$x, x1, x2$	subscripts denoting the nominal along-wind directions
X_t	distance downwind from crest of hill or escarpment. See Appendix A3.
X_i	separation distance between the building and upwind surrounding buildings, used to calculate H_e
$Y, Y_1, Y_2, etc.$	across-wind directions
Z	height above ground level
Z_e	effective height, taking account of sheltering effect of surroundings
Z_t	height of site on a hill. See Appendix A3.
γ_w	ultimate wind load factor, taken as 1.4.
ξ_x, ξ_y	ratio of damping to critical damping in the relevant direction of vibration
θ	direction the wind comes from (rotating east from north), or wind direction from the normal to building face
ρ_a	mass density of air, taken as 1.2×10^{-3} T/m^3 (=1.2 kg/m^3)
φ	solidity ratio of walls or frames
ψ_e	effective slope of topographic feature. See Appendix A3.
ψ_u	upwind slope of topographic feature. See Appendix A3.
η_y	mode deflection variation with height in the across-wind direction $\approx (Z/H)^{\eta_y}$. This is typically in the range 1.0-2.0 for buildings, determined by comparison with modal analysis.

2 Calculation of Wind Actions

2.1 Procedure for Calculating Wind Forces

An outline of the Standard Method is given in the flowcharts shown in Figure 2-1 and Figure 2-2, showing the stages of calculation and listing the conditions for carrying out wind tunnel testing.

2.1.1 Wind Forces on Buildings

(a) Determine along-wind forces (in the direction of the wind) as in clause 2.2.1.

(b) Determine torsional forces as in clause 2.2.2.

(c) Determine across-wind base moment, if required, in clause 2.2.3.

(d) Apply the wind forces in two orthogonal directions with torsional forces to the buildings using the load combinations as in clause 2.2.4.

2.1.2 Wind Forces on Building Elements

Clause 2.3 determines wind pressures and wind forces for building elements.

2.1.3 Acceleration of Buildings Affecting Occupants

Clause 2.4.1 determines peak acceleration and clause 2.4.2 provides acceptable acceleration limits.

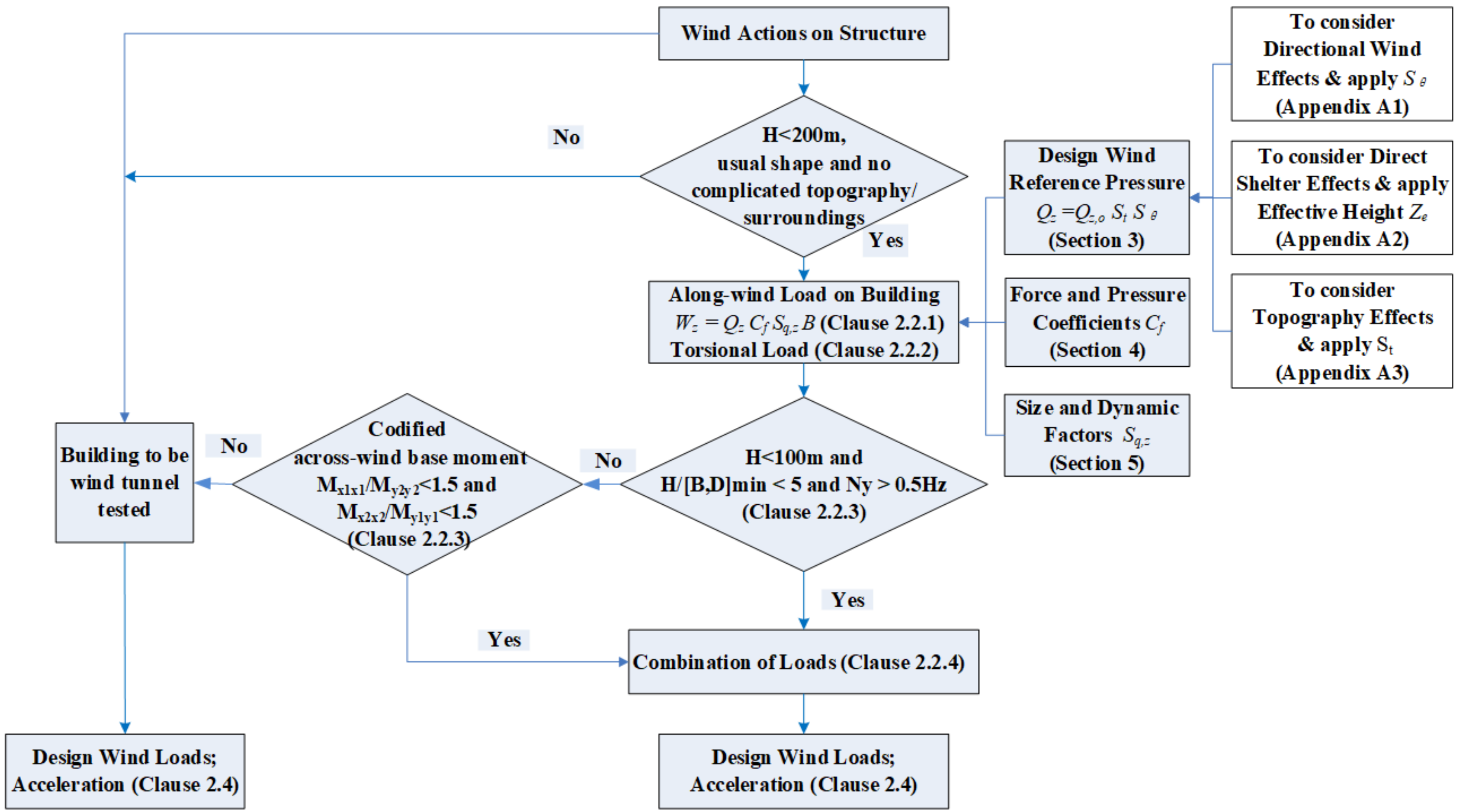


Figure 2-1 Flow-chart for wind actions on structure

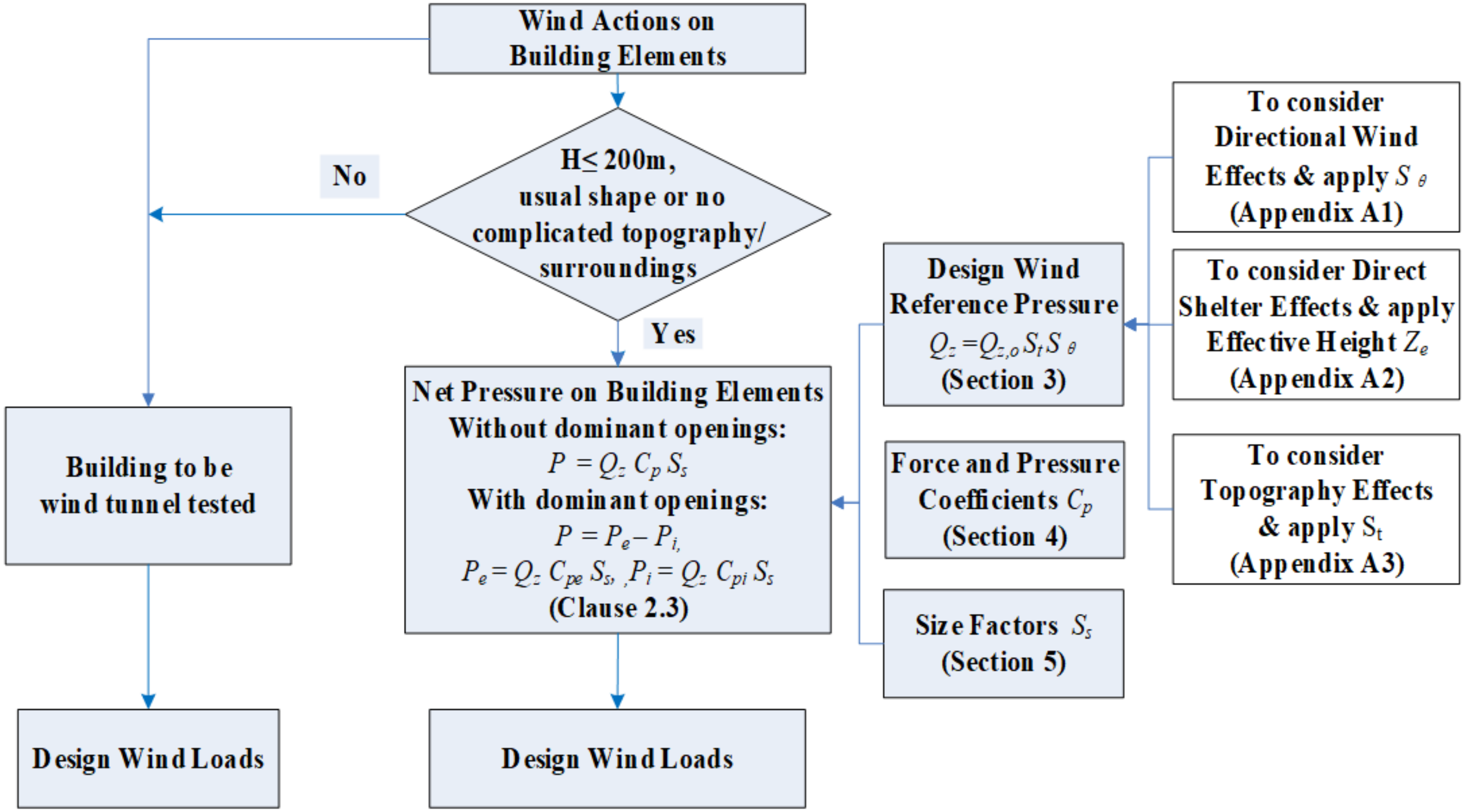


Figure 2-2 Flow-chart for wind actions on building elements

2.2 Wind Forces on Buildings

2.2.1 Along-wind Force

Wind load per unit height at a height, Z, for a building on level ground is calculated using the equation below:

$W_z = Q_z C_f S_{q,z} B$ - Equation 2-1

Where

W_z along-wind load per unit height, at height, Z

Q_z wind reference pressure adjusted for effects from sheltering, topography and wind direction in accordance with clause 3.1

C_f force coefficient determined in accordance with clause 4.2

$S_{q,z}$ size and dynamic factor from clause 5.2

B breadth of building

The components of this equation may vary with height as described in Section 3 for wind pressure, Q_z, in Section 4 for force coefficients, C_f, and in clause 5.2 for the size and dynamic factor, $S_{q,z}$.

Additional variable torsional moments at the same height, ΔT_z, are obtained by offsetting W_z from the centre of area, as described in clause 2.2.2.

2.2.2 Torsional Force

For buildings that may be treated as rectangular, the variable torsional load at height, Z, ΔT_z, is derived assuming the along-wind force, W_z, in each direction (see Figure 2-3), is applied at a point offset from the geometric centre of area by a horizontal distance given by:

$e = \pm 0.05B$ for $B/D \leq 1$

$e = \pm 0.20B$ for $B/D = 6$

Use linear interpolation for intermediate values of B/D. For extrapolation outside this range, data from wind tunnel testing should be used.

For non-rectangular building shapes that may be treated as rectangular, see clause 4.2 for relevant dimensions B and D.

For buildings that may be treated as rectangular,

$\Delta T_z = e_1 \cdot W_{z,x1}$ or $\Delta T_z = e_2 \cdot W_{z,x2}$

whichever is of greater magnitude.

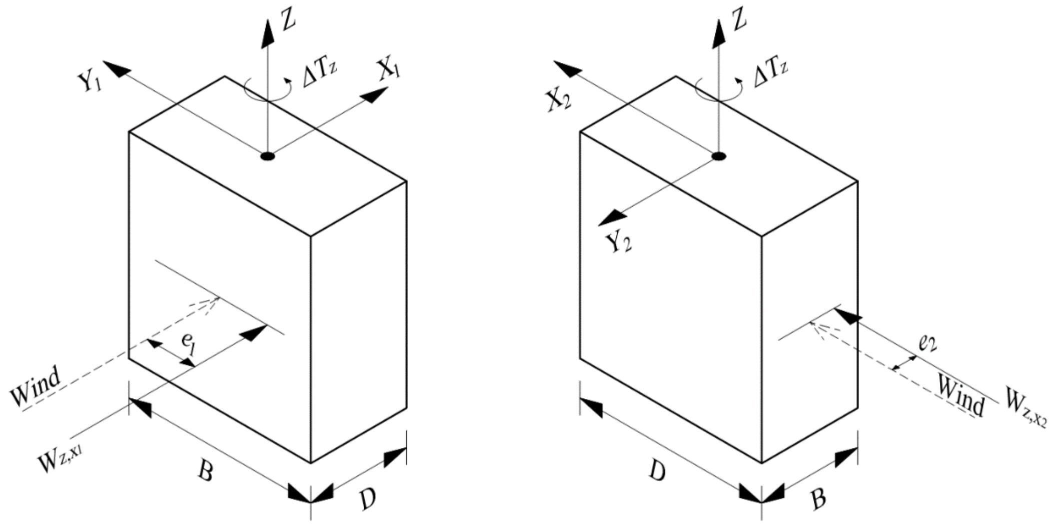


Figure 2-3 Definition of variable torsion

2.2.3 Across-wind Base Moment

Buildings with height less than 100 m, with H/B for all directions less than 5, and with fundamental frequencies greater than 0.5 Hz, will satisfy the check in this section. The calculated along-wind forces may be used without modification.

Otherwise, for buildings that may be treated as rectangular, the across-wind base moment for two orthogonal wind directions should be assessed as in Equation 2-2 and, if necessary, the along-wind forces should be increased as described below.

The across-wind base moment at ground level due to dynamic across-wind forces should be calculated as below, using consistent units, i.e. T, m, s, and kPa:

$$M_{xx,base} = \pm \frac{G_{ry}}{\gamma_w \, \xi_y{}^{0.5}} \frac{\rho_a}{N_y{}^{1.3} (BD)_b{}^{0.15}} \left(\frac{0.215\sqrt{2\gamma_w Q_h / \rho_a}}{1+3.7 I_{v,h}} \right)^{3.3} \frac{H_b{}^2}{3}$$

\- Equation 2-2

Where

G_{ry} peak factor on standard deviation of across-wind resonant response in one hour $= \sqrt{2\, Log_e(1800\, N_y)}$

γ_w ultimate wind load factor, taken as 1.4

ξ_y ratio of damping to critical damping in across-wind direction of vibration in Appendix C2

ρ_a mass density of air, taken as $1.2\text{x}10^{-3}$ T/m^3

N_y fundamental frequency for mode mainly aligned with the across-wind direction

$(BD)_b$ the average plan area of the enclosing rectangle over the top third of the building

Q_h wind reference pressure, Q_z, at effective building height, H_e

$I_{v,h}$ wind turbulence intensity at building height, H, may be taken as $I_{o,h}$ in Equation 3-3 or 3-4, from wind tunnel testing, or be calculated by the method of the Engineering Sciences Data Unit (ESDU)

H_b height of building structure above ground level, but excluding the height of irregular roof features above main roof.

Where the calculated across-wind base moment is larger than the along-wind base moment, then the along-wind forces should be factored upwards to match the across-wind moment. i.e.

(a) If $\frac{max(M_{-x1x1}, M_{+x1x1})}{|M_{-y2y2}|} > 1$, $W_{z,-x2}$ should be factored with $\frac{max(M_{-x1x1}, M_{+x1x1})}{|M_{-y2y2}|}$,

(b) If $\frac{max(M_{-x1x1}, M_{+x1x1})}{|M_{+y2y2}|} > 1$, $W_{z,+x2}$ should be factored with $\frac{max(M_{-x1x1}, M_{+x1x1})}{|M_{+y2y2}|}$,

(c) If $\frac{max(M_{-x2x2}, M_{+x2x2})}{|M_{-y1y1}|} > 1$, $W_{z,-x1}$ should be factored with $\frac{max(M_{-x2x2}, M_{x2x2})}{|M_{-y1y1}|}$

(d) If $\frac{max(M_{-x2x2},M_{+x2x2})}{|M_{+y1y1}|} > 1$, $W_{z,+x1}$ should be factored with $\frac{max(M_{-x2x2},M_{x2x2})}{|M_{+y1y1}|}$

If the factor $\frac{max(M_{-x1x1},M_{+x1x1})}{max(|M_{-y2y2}|,|M_{+y2y2}|)}$ or $\frac{max(M_{-x2x2},M_{+x2x2})}{max(|M_{-y1y1}|,|M_{+y1y1}|)}$ is greater than 1.5, then wind tunnel testing must be conducted. The along-wind and the across-wind effects for wind directions X_1 and X_2 are shown in Figure 2-4(a) and Figure 2-4(b).

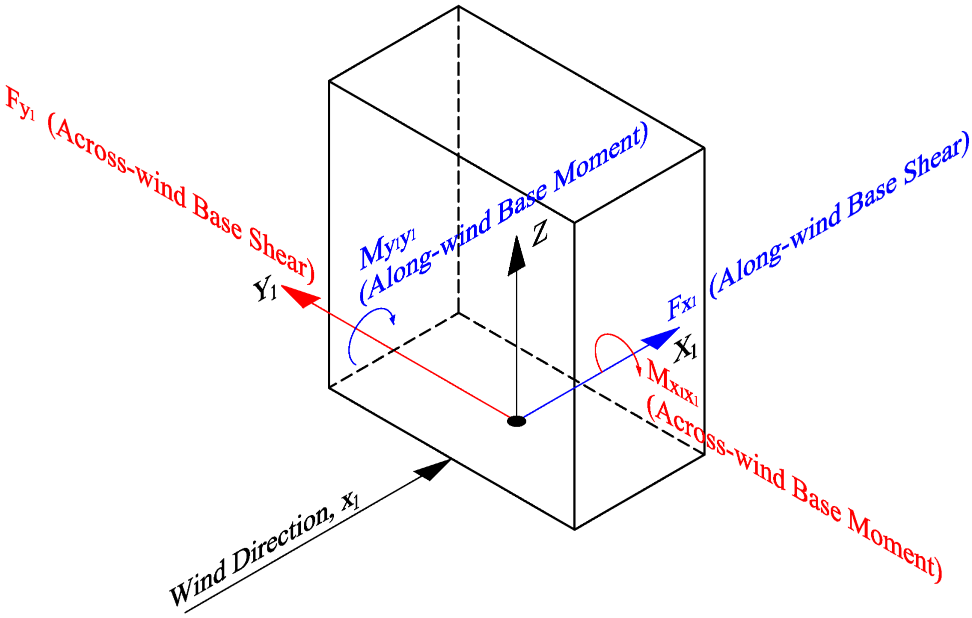


Figure 2-4(a) Co-ordinate system for along-wind and across-wind actions - Lateral loading effects due to wind from direction X_1

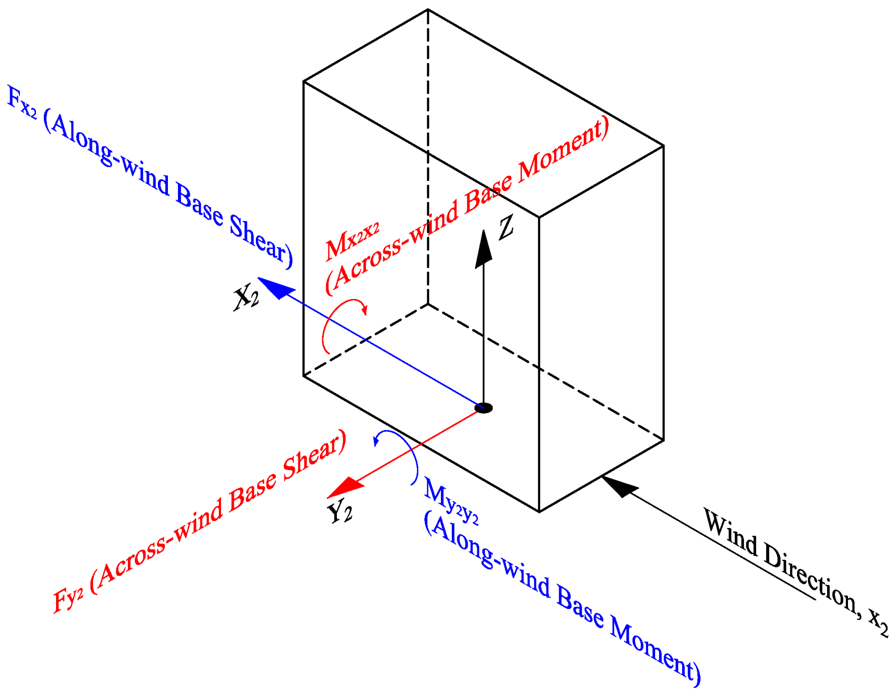


Figure 2-4(b) Co-ordinate system for along-wind and across-wind actions - Lateral loading effects due to wind from direction X_2

2.2.4 Combinations of Wind Forces for Design

The lateral loads in the two orthogonal directions and the torsional load should be applied simultaneously to the building with combination factors in Table 2-1.

Table 2-1 Load combination factors for buildings that may be treated as rectangular

Case	$W_{z,x1} = Max(W_{z,+x1}, W_{z,-x1})$	$W_{z,x2} = Max(W_{z,+x2}, W_{z,-x2})$	ΔT_z
1	±1.00	±0.55	±0.55
2	±0.55	±1.00	±0.55
3	±0.55	±0.55	±1.00

The resultant of loads at each level must act through the centre-of-area at each level (which may vary with height). The co-ordinate system is shown in Figure 2-5.

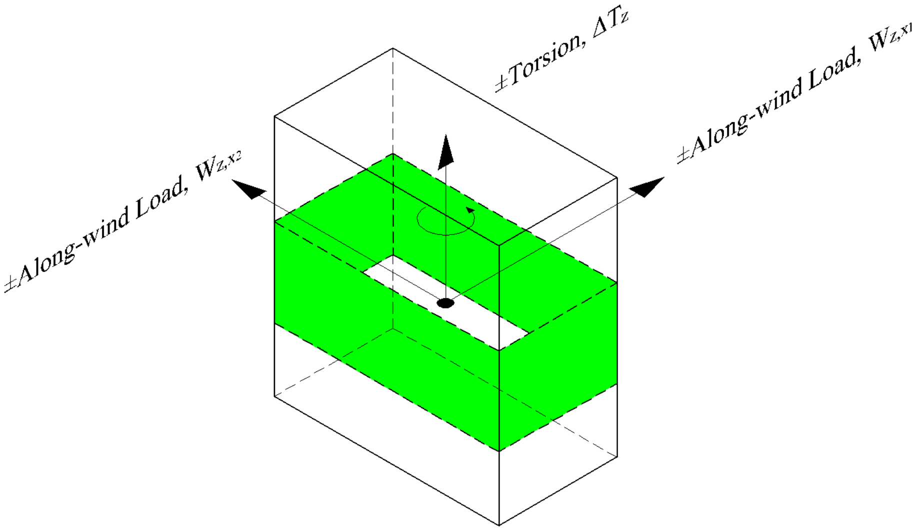


Figure 2-5 Co-ordinate system for wind forces

All buildings should be designed to be capable of resisting the torsional loads of this Code in conjunction with the lateral loads. However, if torsional loads are well resisted by certain forms of construction, the torsion loadcases above may be formally ignored in the following cases:

(a) buildings of single storey up to 10m height;

(b) buildings of up to 70 m height with a peripheral lateral load resisting construction;

(c) buildings which pass the torsional regularity check. The check is that in each lateral direction X_1 and X_2 in turn, the maximum inter-story drift in each storey due to the torsion load must be less than 25% of that due to the lateral load (for buildings with a vertically continuous lateral and torsional resisting structure, this check may be made only at the base and at higher storeys where the resisting capacity reduces by more than 25% when compared with nearby storeys); or

(d) where the torsional inter-story drift calculated above are not greater than 50% of the lateral drift, the Case 3 in Table 2-1 (primarily torsion) loadcases do not need to be calculated.

2.3 Wind Forces on Building Elements

Net pressures on solid surface areas of enclosed building without dominant openings (defined in Appendix B1.1) are given by:

$$P = Q_z C_p S_s \qquad - \qquad \text{Equation 2-3a}$$

Where

P	net pressure on surface
Q_z	wind reference pressure adjusted for effects from sheltering, topography and wind direction in accordance with clause 3.1. The reference height, Z, is defined with the pressure coefficients, but is normally the building height, H.
C_p	net pressure coefficient (total pressure coefficient including the contribution from internal pressures), in accordance with clause 4.3.1
S_s	size factor depending on the "half-perimeter" length, $L_{0.5p}$, of the loaded area. The size factor is defined in clause 5.1.

Equation 2-3a is also used for calculating the net pressures on open frameworks, building attachments and free-standing walls.

Net pressures on surface areas of buildings with dominant openings are determined from the difference between pressures on opposite surfaces. For a typical single skin cladding panel the net pressure is given by:

$$P = P_e - P_i \qquad - \qquad \text{Equation 2-3b}$$

$$P_e = Q_z C_{pe} S_s \qquad - \qquad \text{Equation 2-3c}$$

$$P_i = Q_z C_{pi} S_{s,i} \qquad - \qquad \text{Equation 2-3d}$$

Where

P	net pressure on surface
P_e	pressure on external surface
P_i	pressure on internal surface
Q_z	wind reference pressure, adjusted for sheltering, topography and wind direction in accordance with clause 3.1. The reference height, Z, is defined with the pressure coefficients, but is normally the building height, H.
C_{pe}	external pressure coefficient in accordance with Appendix B1.2
C_{pi}	internal pressure coefficient in accordance with Appendix B1.3

S_s size factor depending on the "half-perimeter" length, $L_{0.5p}$, of the loaded area. The size factor is defined in clause 5.1

$S_{s,i}$ size factor for internal pressure under dominant opening case, depending on the size of the dominant opening or openings. See clause 5.1.

2.4 Wind Acceleration of Buildings

2.4.1 Peak Acceleration

The peak acceleration (in m/s^2) for orthogonal wind directions may be assessed separately at any height, Z, and return period, R, using the formula below. Consistent units (i.e. T, m, s, and kPa) should be used.

$$A_z = \frac{G_{ry}\,\rho_a}{\xi_y{}^{0.5} N_y{}^{1.3} (BD)_b^{0.15}} \left(\frac{0.215\sqrt{2S_r Q_h/\rho_a}}{1 + 3.7 I_{v,h}}\right)^{3.3} \frac{H_b}{3M_h} \cdot \frac{2+\eta_y}{3} \cdot \left(\frac{Z}{H_b}\right)^{\eta_y}$$

\- Equation 2-4

G_{ry} peak factor on standard deviation of resonant response in one hour $= \sqrt{2\,Log_e(1800\,N_y)}$

ξ_y ratio of damping to critical damping in across-wind direction of vibration in Appendix C2

N_y fundamental frequency for mode mainly aligned with the across-wind direction

$(BD)_b$ is the plan area of the enclosing rectangle, averaged over the top third of the building, excluding upper level cut-backs. If $(BD)_b > H^2/9$, take $(BD)_b = H^2/9$.

S_r factor on wind pressure for different return period in Appendix A1

Q_h wind reference pressure, Q_z, at effective building height, H_e

ρ_a mass density of air, taken as 1.2x10^{-3} T/m^3

$I_{v,h}$ wind turbulence intensity at building height, H, may be taken as $I_{o,h}$ in Equation 3-3 or 3-4, from wind tunnel testing, or as calculated by the ESDU method

H_b height of building structure above ground level, but excluding the height of irregular roof features above main roof

M_h mass of the building above $2H_b/3$

η_y parameter used to describe the approximate mode deflection variation with height. Where this is not obtained by comparison with a modal analysis, it may be assumed to be 1.5 for calculation of accelerations within the top quarter height of a building.

2.4.2 Peak Acceleration Limits

The occupant comfort is considered acceptable if the 1-year and 10-year peak accelerations are less than the limits stipulated in Figure 2-6 below.

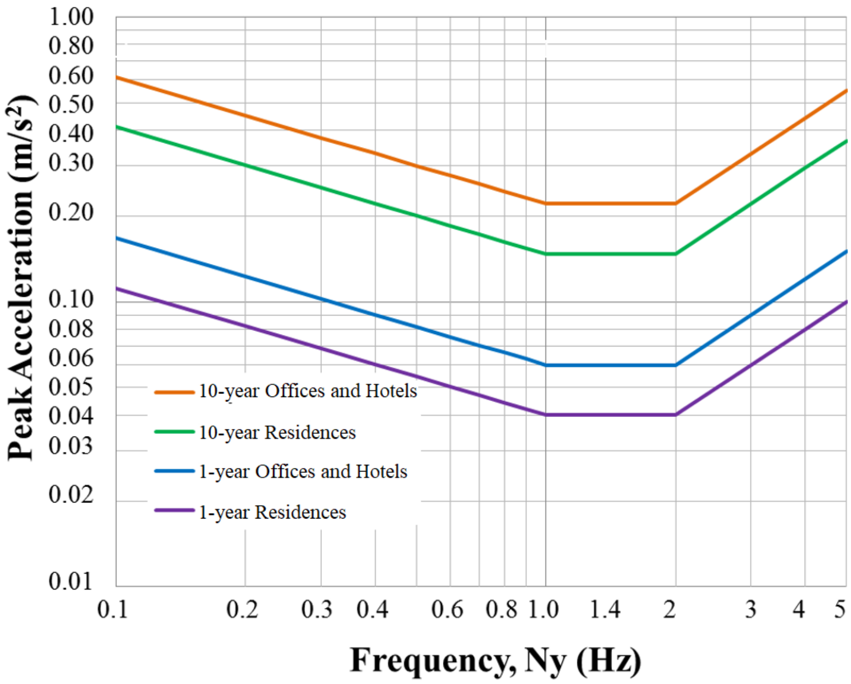


Figure 2-6 Acceptable occupant comfort level

2.5 Minimum Wind Loads for Temporary Structures

Wind loads on temporary buildings and associated constructions that are not used for residency, and which will remain in position for a period of not more than one year, may be designed for a minimum of 70% of the design loads for permanent buildings.

For designing hoarding and covered walkway associated with construction site, contractor shed, bamboo shed, tent or marquee that are not for residential use, Q_z is taken as 37% of $Q_{o,z}$ defined in clause 3.2 and no other adjustment factor should be applied.

3 Design Wind Pressures

3.1 General

Wind pressure, Q_z, is given by:

$$Q_z = Q_{o,z}\, S_t\, S_\theta \quad - \quad \text{Equation 3-1}$$

Where

$Q_{o,z}$ defined in clause 3.2,

S_t the topography factor in Section 3.4,

S_θ the wind directionality factor in Appendix A1.

3.2 Wind Reference Pressure at Effective Height

Wind reference pressures of this Code are provided at effective height for open exposure, Z_e, as in Table 3-1 below. Z_e is defined in clause 3.3.

Table 3-1 Wind reference pressure, $Q_{o,z}$

Effective height Z_e (m)	Wind reference pressure $Q_{o,z}$ (kPa)
≤ 2.5	1.59
5	1.77
10	1.98
20	2.21
30	2.36
50	2.56
75	2.73
100	2.86
150	3.05
200	3.20
250	3.31
300	3.41
400	3.57
500	3.70
>500	Seek specialist advice

For any effective height between 2.5m and 500m, the pressure can be calculated as:

$$Q_{o,z} = 3.7(Z_e/500)^{0.16} \quad - \quad \text{Equation 3-2}$$

The turbulence intensity can be taken as:

$I_{o,z} = 0.087(Z_e/500)^{-0.11}$ - Equation 3-3

Where

$Q_{o,z}$	wind reference pressure at height, Z_e
Z_e	effective height, taking account of surroundings
$I_{o,z}$	wind turbulence intensity at height Z_e

For across-wind base moment and for acceleration calculation, if $0.25 \leq H_e/H \leq 0.5$, the turbulence intensity may be modified as:

$I_{o,z} = [4 - (6H_e/H)]\ 0.087(Z_e/500)^{-0.11}$ - Equation 3-4

3.3 Sheltering Effects

The effects of direct shelter from other buildings surrounding a site may be taken into account by using a reduced height, i.e. the effective height, Z_e, for calculation of wind pressure, turbulence intensity and force coefficient. The method of calculating effective height is given in Appendix A2.

Z_e may conservatively be taken as the actual height, Z, above ground level.

3.4 Topography Effects

The effects of topography should be estimated as defined in Appendix A3.

4 Force and Pressure Coefficients

4.1 General

This section gives force and pressure coefficients for assessing total wind force on buildings and building elements respectively. They are for use in the equations of Section 2.

4.2 Force Coefficients for Buildings

For buildings, force coefficients for rectangular plan are given in clause 4.2.1. Considerations of modifications on rectangular plan are given in clauses 4.2.2 and 4.2.3. Conditions where building plans can be treated as rectangles are given in clause 4.2.4.

Force coefficients for buildings of circular plan with height to diameter ratio not larger than 6 can be taken as 0.75.

4.2.1 Rectangular Buildings

When a building varies from a simple rectangular plan, additional guidance for using the formulas below is provided in clauses 4.2.1 to 4.2.4.

The force coefficient for a rectangular building as shown in Figure 4-1 is a function of effective height, H_e, breadth, B, and depth, D, as in Figure 4-2.

For calculation of overall wind loads (cumulative shear, torsions and moments), Q_z may vary with height (or conservatively use Q_h).

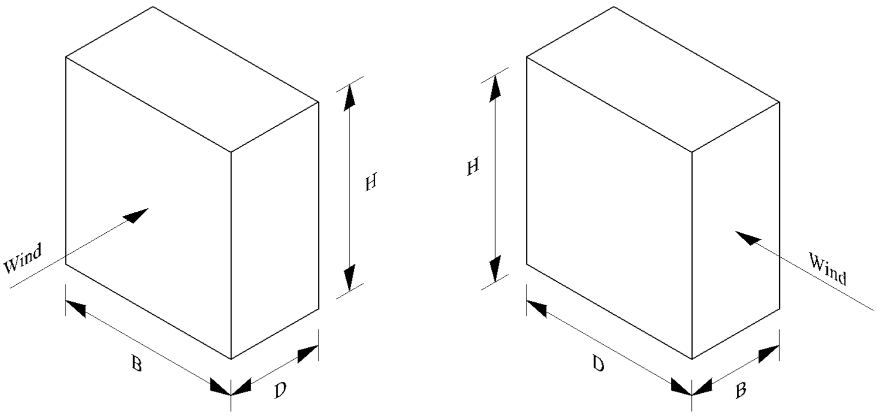


Figure 4-1 Basic definitions of building plan dimensions

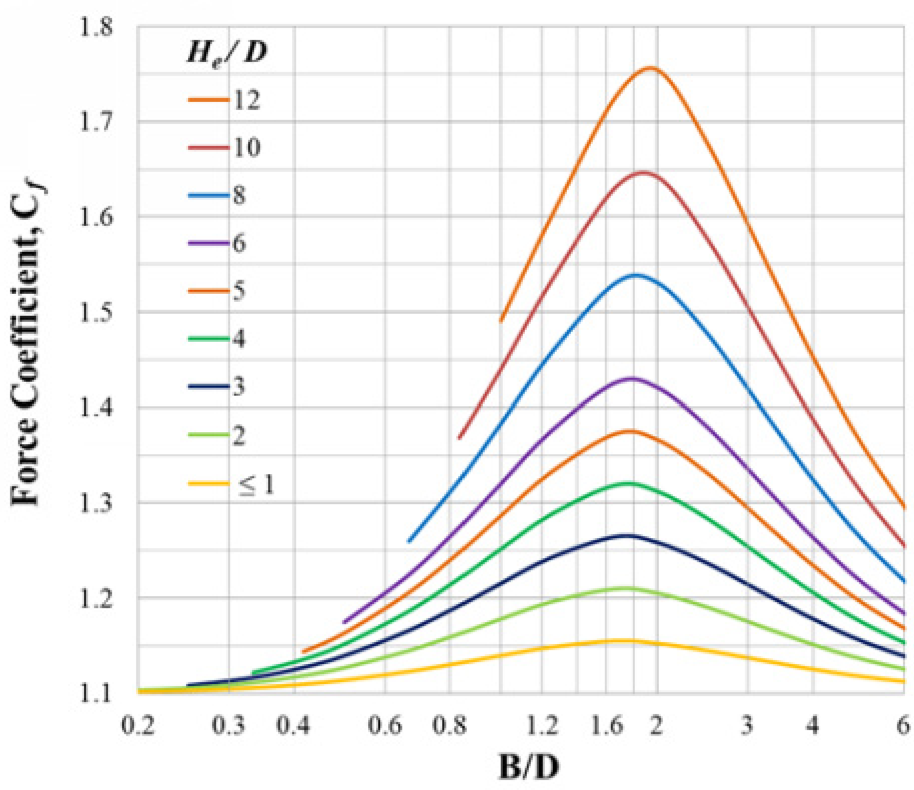


Figure 4-2 Force coefficient for simple rectangular prismatic shaped building, C_f

$$C_f = 1.1 + \frac{0.055\, H_e/D}{\exp\left\{\left|log_e[(0.6B/D)(1 - 0.011\ H_e/D)\ ]\right|^{[1.7 - 0.0013(H_e/D)^2]}\right\}}$$

- Equation 4-1

Where

H_e	effective building height, based on H, taking account of surroundings.
B	breadth of building
D	depth of building

Equation 4-1 can be used for $H_e/D \leq 12$.

4.2.2 Effect of Variation of Plan with Height

The force coefficient, C_f, at a particular height should be calculated using equation 4-1 by adopting local values for B and D, the effective building height, H_e with H_e/D equals or less than 12. Steps in plan size affecting less than 10% of H should be ignored for calculating C_f. Pressures should be applied to the actual area.

4.2.3 Effect of Corner Shapes

The force coefficient for rectangular buildings with symmetrical corner cut-outs or chamfers can be reduced using the following factor:

$$\left[1 - 2\frac{w}{B}\,(1 - \cos\theta)\right] \qquad - \qquad \text{Equation 4-2}$$

Where

w , B and θ are defined in Figure 4-3 below and $0 \leq w/B \leq 0.31$

For $w/B > 0.31$, take $w/B = 0.31$ or treat as X-shaped.

The force coefficient for rectangular buildings with rounded corners can be reduced based on smooth rounding of the corners with a radius, r, by the factor:

$$[1 - 2.5\,r/B] \qquad - \qquad \text{Equation 4-3}$$

Where

$0 \leq r/B \leq 0.1$

For $r/B > 0.1$, take $r/B = 0.1$.

For unsymmetrical corners, the corner that produces least reduction shall be taken.

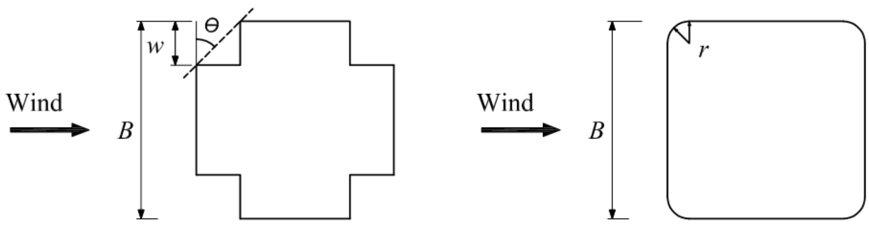


Figure 4-3 Basic dimensions for considering corner effects

4.2.4 Buildings with Wings (i.e. U-, X-, Y-, Z- and L-shaped)

For a building with wings, the force coefficients should be calculated as for a rectangular building based on the dimensions of the equivalent rectangle.

For 'U' & 'X' shapes, see Figure 4-4(a) and Figure 4-4(b) for the equivalent rectangle.

For a Y-shaped building, see Figure 4-4(c) and Figure 4-4(d) for the equivalent rectangle.

For 'Z' & 'L' shapes, see Figure 4-4(e) and Figure 4-4(f) for the equivalent rectangle.

For the above, the effect of corner shapes can be taken into account as shown in Figure 4-4(b) to Figure 4-4(d).

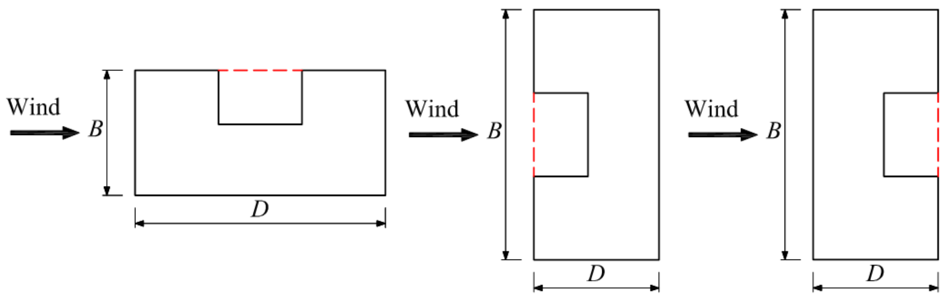


Figure 4-4(a) Basic dimensions for U-shaped buildings

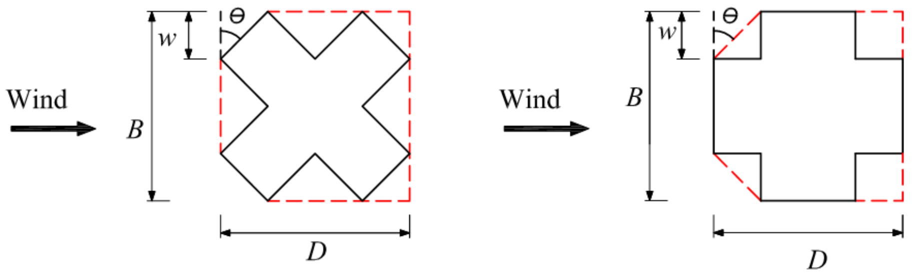


Figure 4-4(b) Basic dimensions for X-shaped buildings

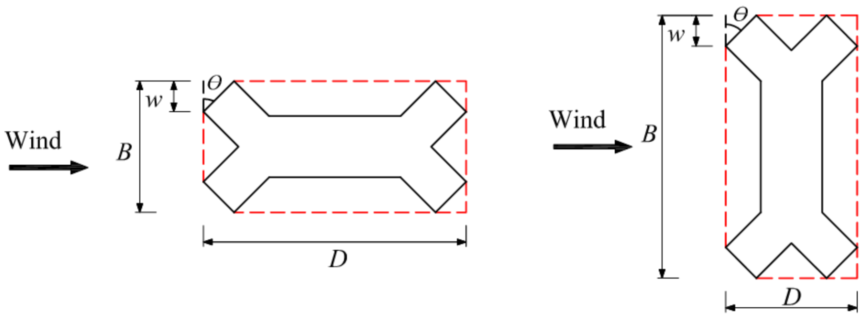


Figure 4-4(c) Basic dimensions for double Y-shaped buildings

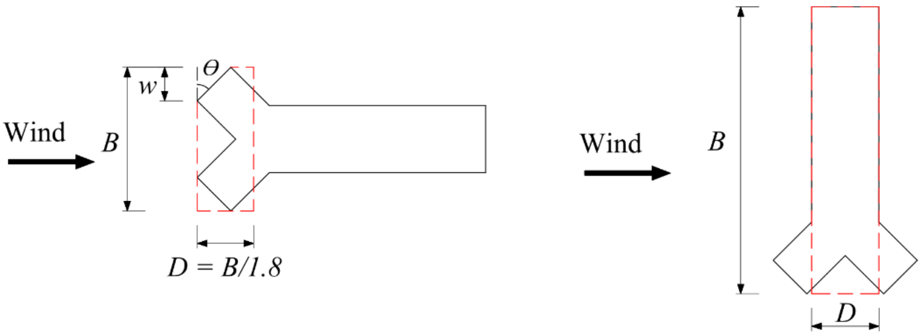
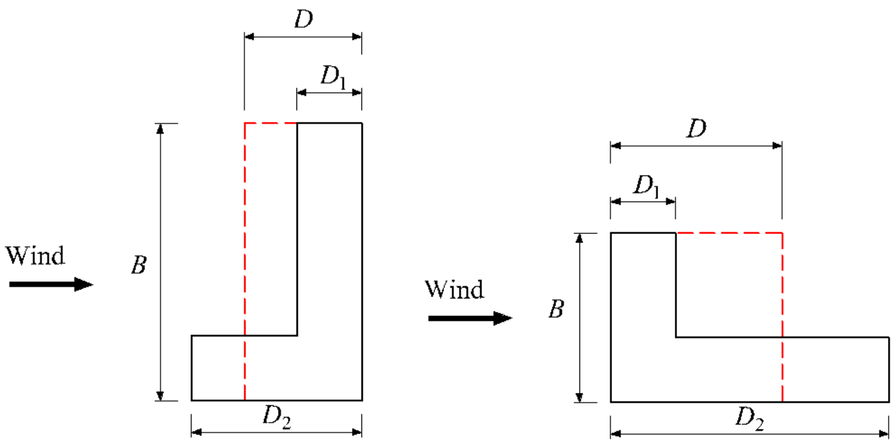


Figure 4-4(d) Basic dimensions for single Y-shaped buildings



$$D = \frac{D_1 + D_2}{2} \qquad D = \frac{D_1 + D_2}{2}$$

Figure 4-4(e) Basic dimensions for single L-shaped buildings

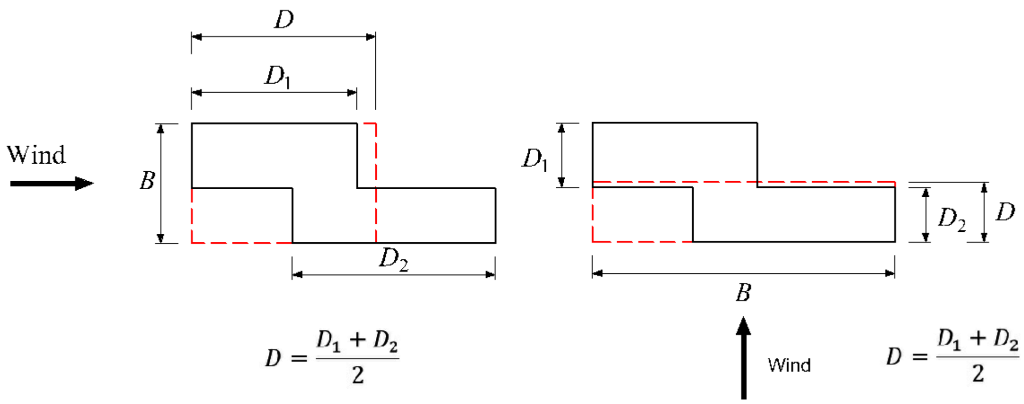


Figure 4-4(f) Basic dimensions for single Z-shaped buildings

4.3 Pressure Coefficients for Building Elements

4.3.1 Net Pressure Coefficients for an Enclosed Building Envelope without Dominant Openings

For buildings with rectangular corners, if there are no dominant openings as defined in Appendix B1.1, the net pressure coefficients (total pressure coefficient including effects of internal pressures) for the building envelope are obtained from Table 4-1.

Table 4-1 Net pressure coefficients for an enclosed building envelope without dominant openings, C_p

Case		Zones applicable	C_p
Wall	Negative pressure in edge zone	A	-1.4
	Negative pressure elsewhere	B	-1.0
	Positive pressure	A & B	+1.1
Flat roof or roof with pitch less than 30 degrees	Negative pressure in corner zone	C	-2.2
	Negative pressure in edge zone	D	-1.6
	Negative pressure elsewhere	E	-1.0
	Positive pressure	C, D, E	+0.3
Pitch roof of greater than 60 degree slope	Negative pressure in corner zone	C	-1.4
	Negative pressure in edge zone	D	-1.4
	Negative pressure elsewhere	E	-1.0
	Positive pressure	C, D, E	+1.1

Notes:

(a) Q_h should be used when calculating the net pressures.

(b) The size factor, S_s, depends on the tributary area (structural span of the panel) and may be larger than 1.0.

(c) Cladding pressures can be reduced by 20%, below a height of $0.5(H - H_e)$.

(d) Where there are significant steps in building form, i.e. podiums, the height rules for tower and podium in Figure 4.6(a) and Figure 4.6(b) should be followed.

(e) Linear interpolation is allowed for roofs with a pitch between 30 and 60 degrees.

(f) Pressure coefficients for roofs of low-rise buildings may also be obtained from reliable published sources.

For the tower set back from edge of podium as shown in Figure 4-5(a), zone definitions are given in Figure 4-6(a) and Figure 4-6(b). For podium roof areas under influence of the tower, pressures on the adjacent tower elevation/elevations should be adopted.

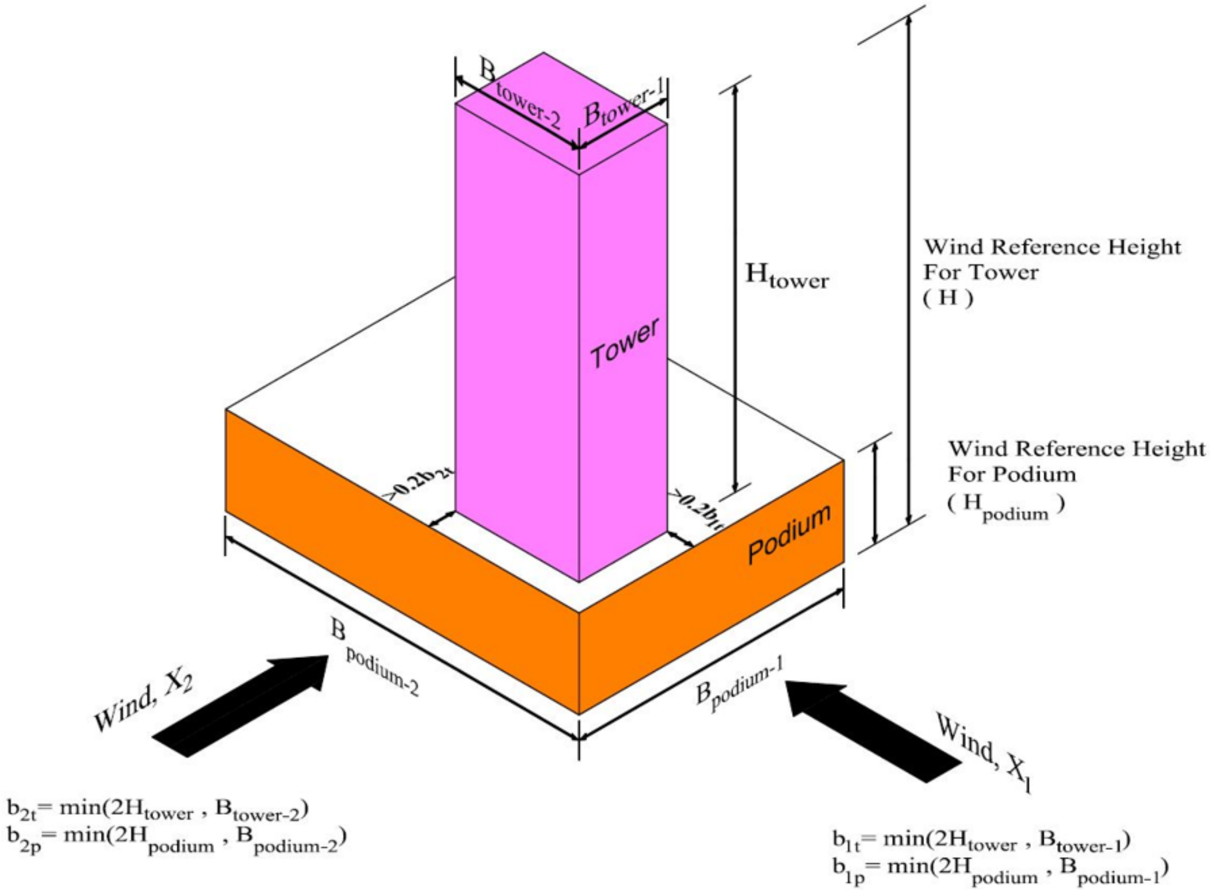


Figure 4-5(a) Wind reference height and zone scaling dimensions for a tower set back from edge of podium

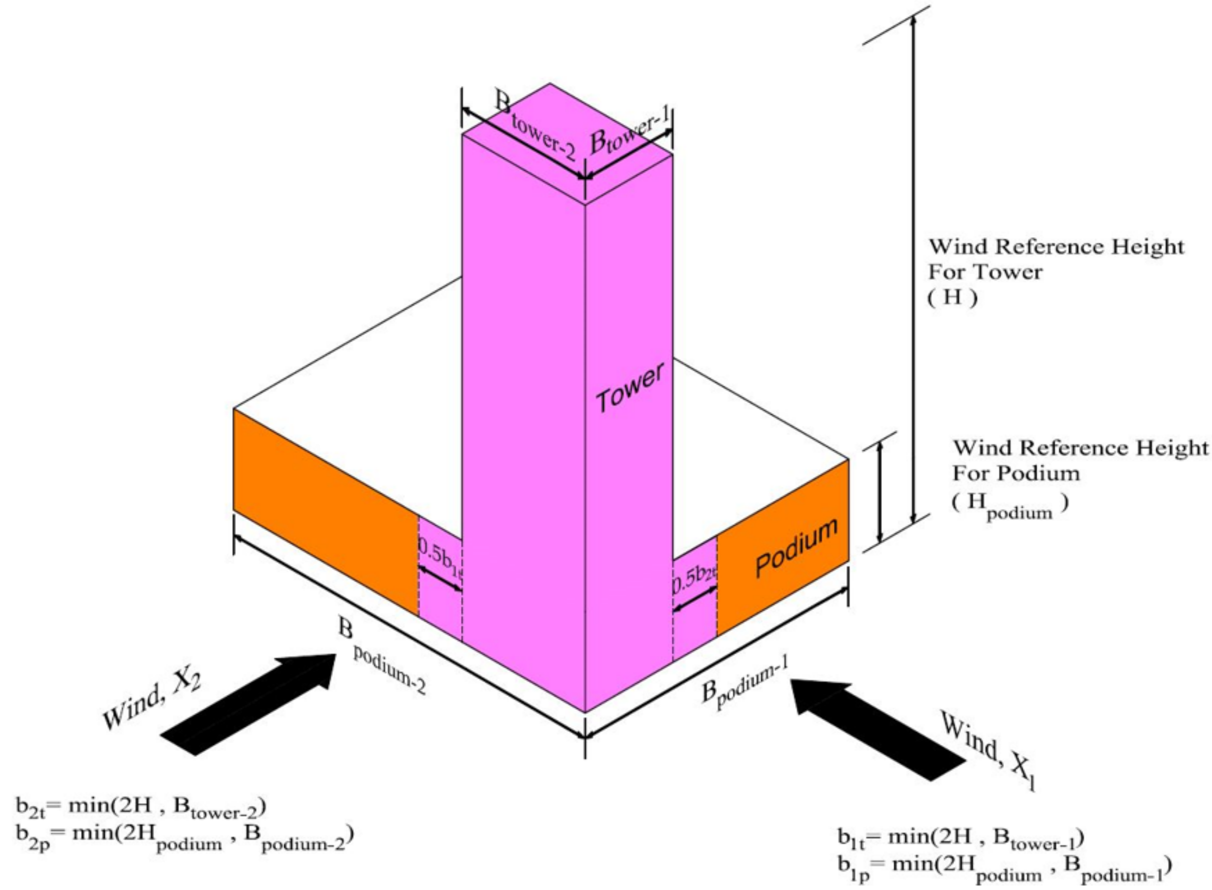


Figure 4-5(b) Wind reference height and zone scaling dimensions for tower at podium edge

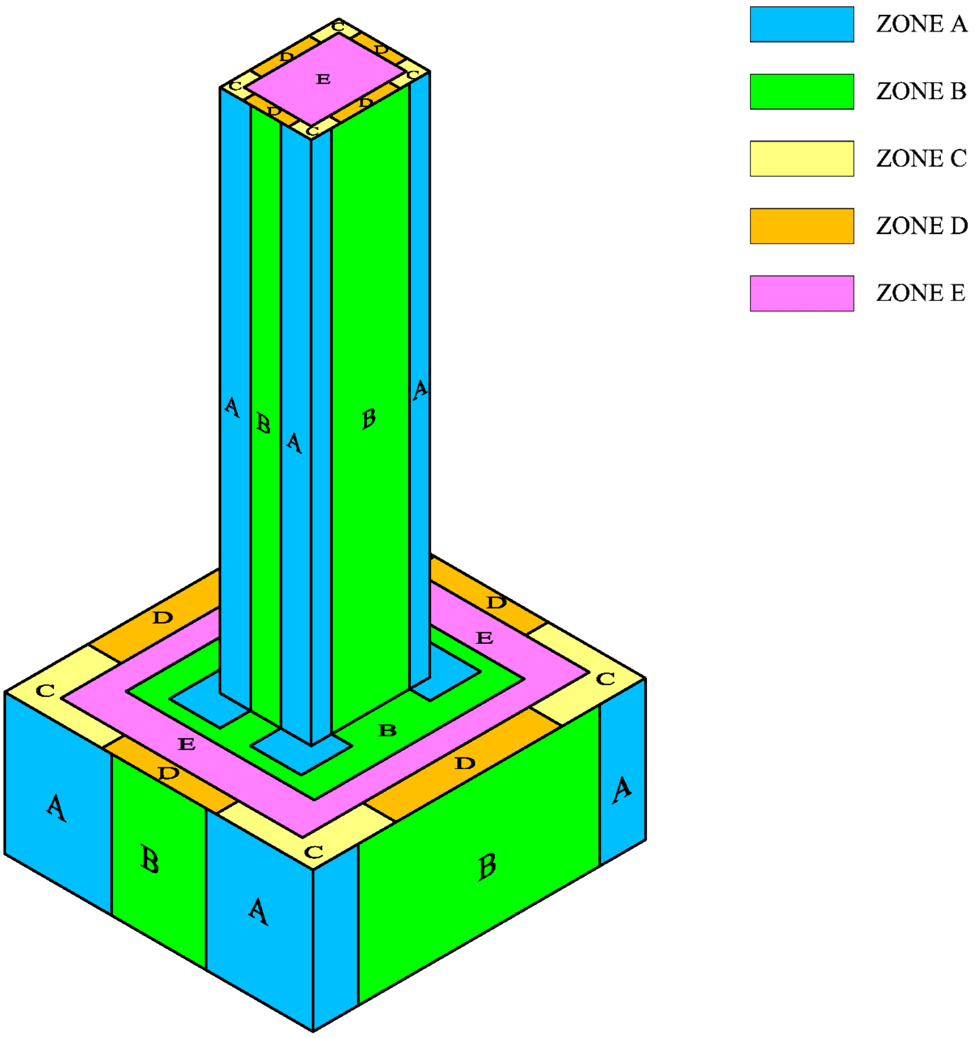


Figure 4-6(a) Zone key for pressure

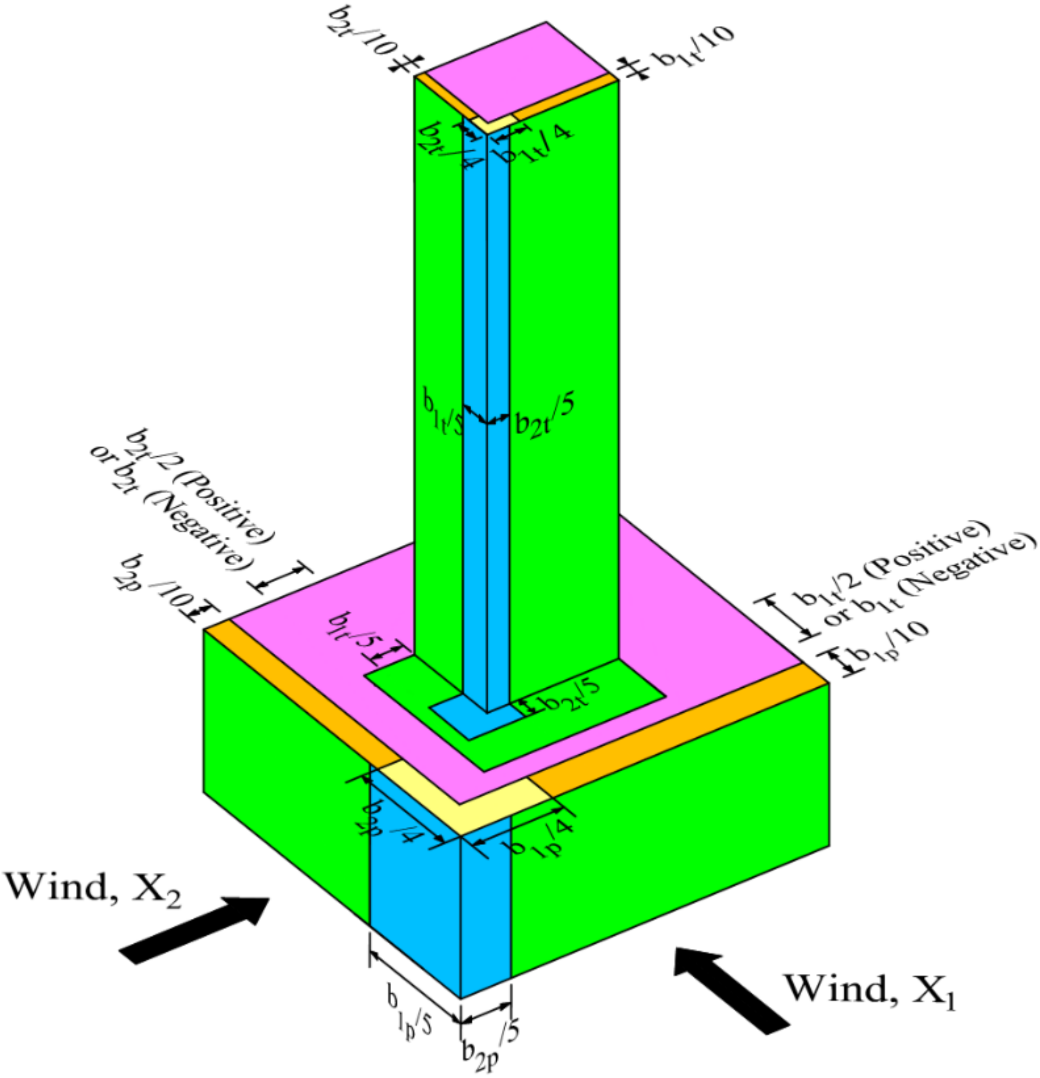


Figure 4-6(b) Dimensions for pressure zones in Figure 4-6(a)

For the tower at the edge of a podium as shown in Figure 4-5 (b), zone definitions in Figure 4-6 (a) and the extent of the zones in Figure 4-6 (b) should be used. For the design pressure on the podium, $\max(b_{1t}, b_{1p})$ and max (b_{2t}, b_{2p}) should be used for determining the extent of zone A in Figure 4-6 (b). The reference height should refer to the requirement in Figure 4-5 (b).

4.3.2 Pressure Coefficients for Building Envelope with Dominant Openings

Dominant openings are defined in Appendix B1, which also provides a method for deriving building envelope pressures.

Guidance on the determination of the effect of non-dominant openings is also provided in Appendix B1.

4.3.3 Pressure Coefficient for Open Frameworks

Table 4-2 provides guidance for planar frameworks such as exposed lattice beams attached to buildings.

Table 4-2 Net pressure coefficients for open frameworks

Solidity ratio φ	Pressure coefficient C_p
0.01	2.0
0.1	1.8
0.2	1.7
0.3	1.6
0.5	1.5
0.8	1.5
0.9	1.6
1.0	2.0

Notes:
(a) The solidity ratio is equal to the effective projected area of the open framework divided by the area enclosed by the boundary of the frame normal to the direction of the wind.
(b) Linear interpolation is allowed to obtain intermediate values.
(c) Pressures are applied to the solid area of the framework only.

4.3.4 Pressure Coefficients for Other Building Attachments

Additional pressure coefficients for building attachments are given in Appendix B2.1 to B2.3.

4.3.5 Pressure Coefficients for Free-standing Walls

Pressure coefficients for free-standing walls are given in Appendix B3.

5 Size Factor and Size and Dynamic Factor

5.1 Size Factor

The size factor, S_s, depends on the size and location of the loaded area. The size of the loaded area is evaluated by the half perimeter of the area, $L_{0.5p}$, and is given in Figure 5-1. The perimeter is measured around the tributary area making the main contribution to a load effect. In case of more complex shapes of loaded area, the half-perimeter is half the length the taut string that would just extend around all extremities of the area (i.e. For a circle of diameter, d, $L_{0.5p} = \pi d/2$).

Values of S_s are shown in Figure 5-2 or may be calculated using Appendix C1.

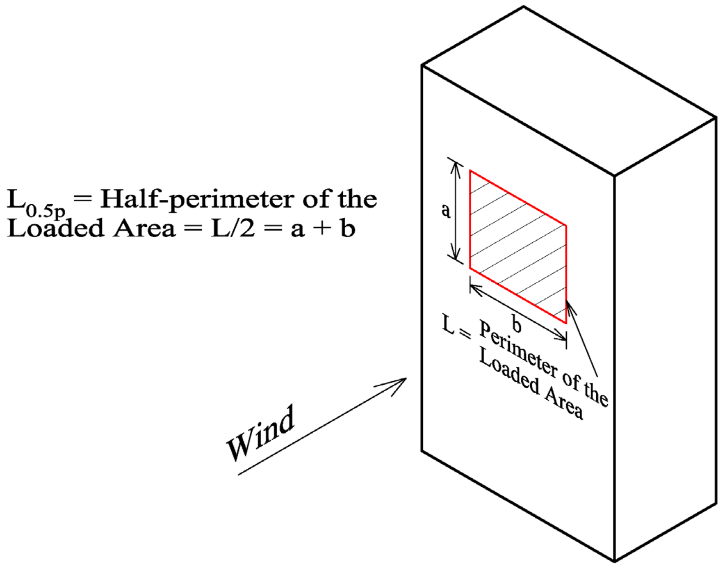


Figure 5-1 Half perimeter of the loaded area, *$L_{0.5p}$*

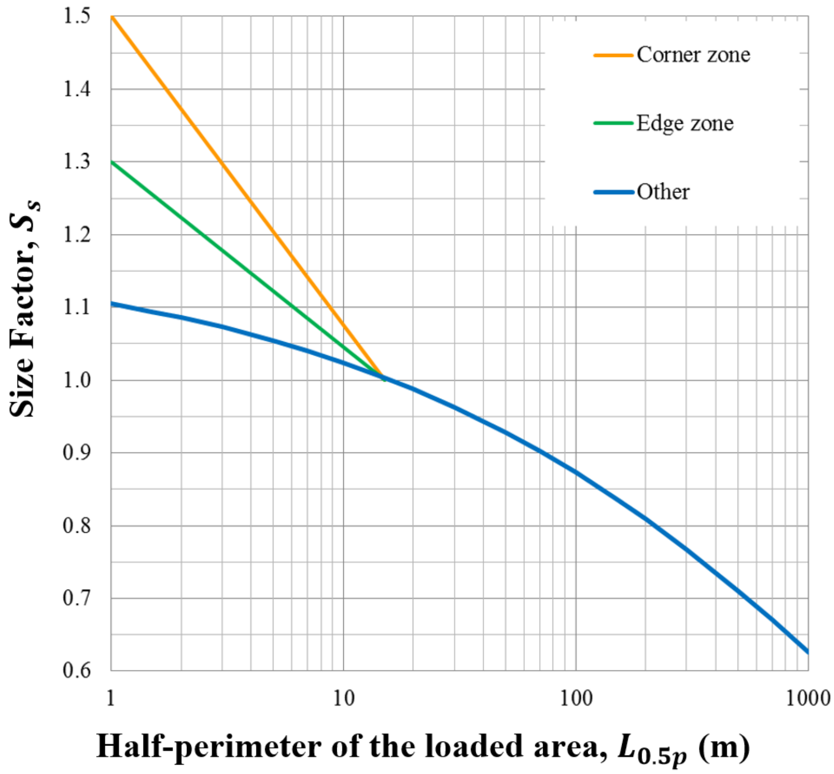


Figure 5-2 Size factor, S_s

For definition of the corner zone and the edge zone, refer to Figure 4-6(a) and Table 4-1.

When calculating internal pressures with dominant openings as defined in Appendix B1.1, the size factor, S_{si}, corresponds to the half-perimeter of the largest opening, or the notional perimeter around several openings (see Figure 5-3), which form the dominant opening as described in Appendix B1.1, and is evaluated using the 'Other' curve of Figure 5-2.

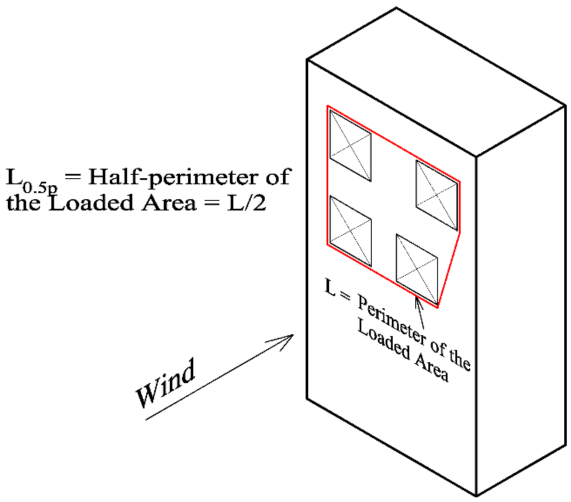


Figure 5-3 Half-perimeter of the loaded area, $L_{0.5p}$, due to several openings contributing to the dominant opening area, A_o

5.2 Size and Dynamic Factor for Buildings

The combined size and dynamic factor applied to the gust forces at the top of the building is given by:

$$S_{q,h} = 0.5 + \sqrt{\left(S_{s(L_{0.5p}=B)} - 0.5\right)^2 + \frac{0.25}{B^{0.5} H {N_x}^2 \xi_x}} \quad \text{- Equation 5-1}$$

Where

S_s size factor, depends on the half-perimeter length, $L_{0.5p} = B$ of the loaded area at the top of the building. For evaluation of S_s in Figure 5-2, the curve for 'Other' should be used.

H building height

B breadth of building

N_x fundamental frequency for mode mainly aligned with the along-wind direction

ξ_x ratio of damping to critical damping in the relevant direction of vibration

This factor can be reduced over the height of the building using the formula below:

$$S_{q,z} = S_{q,h} - 1.2\left(S_{q,h} - (10/H)^{0.14}\right)(1 - Z/H) \quad \text{- Equation 5-2}$$

These formulas are dimensional with units of metres and Hertz.

For buildings of less than 50m height, the following simplified formula can be used to calculate S_q at all heights:

$$S_q = 1.1\, S_{s(L_{0.5p}=H/1.5+2B)} \quad \text{- Equation 5-3}$$

Where

S_s size factor, depending on the half-perimeter length, $L_{0.5p}$, of the equivalent loaded area. For Equation 5-3, half-perimeter length, $L_{0.5p} = H/1.5 + 2B$ should be used.

6 Requirements for Wind Tunnel Testing

6.1 General Requirements

The guidance below is intended for modelling complete buildings as required for overall forces, accelerations and surface pressures. This applies to typical testing requirement in Hong Kong.

6.1.1 Wind Modelling and Instrumentation

(a) The natural wind is to be represented (*) (physically or analytically) to account for the variation with height of hourly mean wind speed, and the turbulence intensity and length-scales appropriate to the site.

(b) The instrumentation, its response characteristics, and data recording methods are to be appropriate to the loads under consideration.

(c) The measurements should enable peak wind loads of reliability compatible with code intentions to be derived.

(*) Frequencies of oncoming turbulence corresponding to vortex shedding processes should be modelled physically. Lower frequency turbulence may be included analytically.

6.1.2 Modelling of Dynamic Responses

Where resonant dynamic response may be significant, the structure should be accurately represented (physically or analytically) in mass distribution and stiffness in accordance with established laws of dimensional scaling and the effect of damping should be appropriately reflected.

For buildings close to prismatic form and with H/B and H/D less than 15, it may be assumed for the calculation of resonant (dynamic) amplification of the wind responses that only the lowest frequency modes in each lateral direction and in torsion (3 modes in total) need to be considered.

6.1.3 Topography Modelling

If the loading on a building may be significantly influenced by the local topography, the effect on the wind properties should be investigated by small-scale wind tunnel testing or established using reliable published data.

The topography model should normally be equal to or larger than 1:5000 scale. If the topography model scale needs to be smaller than 1:5000, further considerations are elaborated in the Explanatory Notes to the Code (EN).

The topography model should include the majority of the topographic features likely to have a significant influence on the wind conditions at the site.

A minimum of 18 wind directions at 20° intervals is necessary.

The topographic multiplier obtained from the measured wind profiles of a topographic wind tunnel test can be calculated using the formula below:

$$S_t = \left\{ \frac{[V_z(1+3.7I_{v,z})]_{topography}}{[V_z(1+3.7I_{v,z})]_{approach}} \right\}^2 \qquad \text{- Equation 6-1}$$

Where

"topography" means at the site from the topographic test

"approach" is from the wind profile approaching the test model and at the same height above ground.

6.1.4 Proximity Model

If the loading on a building is likely to be significantly influenced by the presence of surrounding buildings or topographic features, it is necessary to include the models of these proximity features in the wind tunnel testing.

The proximity model should include all buildings which may significantly affect windiness around the development. A general guide is that the extent of the proximity model should normally be not less than 400m radius from the site.

Where the local topography is too large to be sensibly accounted for in the proximity model, its effects should be accounted for as described in clause 6.1.3.

A minimum of 36 wind directions at 10° intervals is normally necessary for pressures and loads.

6.1.5 Model Scale Limitations

The geometric scale and velocity scale employed in the wind tunnel testing should enable an appropriate level of model details to be achieved and meet the requirements of a minimum Reynolds number.

A general guide is that the building model should normally be not smaller than 1:500 in scale. For building models with sharp corners, the Reynolds number based on the typical breadth of the building model should not be less than 1×10^4.

For rounded shapes, this condition is not generally sufficient, and further evidence of the suitability of the test conditions is required. This may include larger scale testing to verify suitability of additional surface 'trip' features to ensure suitable turbulence in the surface boundary layer over the model.

Measurements should be corrected appropriately for wind tunnel blockage, which may vary with wind direction. Blockage during testing should not normally be allowed to exceed 10%, including effects of surrounding buildings. If the visual blockage exceeds 10%, measurement evidence is required.

6.1.6 Wind Profiles

The variations of hourly mean wind speed, turbulence intensity and length-scales with height in the wind tunnel, with the proximity and test model removed, should be similar (after being scaled up with appropriate geometric scale and velocity scale) to the full-scale values as assessed using the methods compatible with the Harris and Deaves model, i.e. as described most fully by computer program ESDU 01008 issued by ESDU. Where the effect of topography is modelled in a separate wind tunnel study at a smaller scale, the wind profiles determined from this should be used in matching to the building model tests, noting that the wind profile in Section 3 closely represents an ESDU open sea profile.

6.1.7 Requirement to Match Wind Pressures

The relationship below should be used to match the wind pressures of the code.

$$Q_z = \frac{\rho_a}{2}\left[V_z\left(1 + 3.7I_{v,z}\right)\right]^2 \qquad \text{- Equation 6-2}$$

Where

Q_z is the target peak gust pressure

V_z is the hourly-mean matching speed to be compared with the approach wind tunnel wind speed profile with zero displacement height (e.g. as measured over a bare turntable)

$I_{v,z}$ is the turbulence intensity in the wind tunnel

In built-up terrain, the matching height, Z, should be taken at 150m (full-scale) above the height of upwind surroundings (the effective height) or at 2/3 of the building height, whichever is greater. For open terrain, Z should be taken as 2/3 of the building height. In intermediate circumstances both cases should be considered.

At the matching height, peak gust pressure (converted to full-scale), calculated by the equation above in the testing condition, should be corrected to match the target peak gust pressure (full-scale) from equation 3-1.

The requirements for calculating S_t from wind tunnel testing are described in clause 6.1.3.

6.2 Target Reliability for Loads

Wind loads for structural design should correspond to the expected peak response in one hour of exposure to ultimate wind pressures, calculated by multiplying the code reference pressures by the wind direction factor, S_θ, as introduced in clause 6.5.2 and by the wind load factor, γ_w, from the relevant structural code of practice.

6.3 Additional Requirements for Cladding

Wind loads on cladding panels should be derived for typical panel sizes, for example half-perimeter length of 2m to 5m, with an 80% chance of non-exceedance in one hour. Wind loads for panel sizes significantly larger, if they apply, may also be required for reduced wind loads.

Internal pressures should be calculated from consideration of the measured external pressures.

6.4 Minimum Loads in Sheltered Locations

Where particular adjoining or surrounding buildings could provide significant shelter (determined in Appendix A2 as the buildings that provide most shelter in each wind direction), the effect on overall building loads due to their possible removal should also be considered.

New buildings should resist a minimum of 80% of the load of the Standard Method. This limitation can be relaxed to 70% of the along-wind load of the Standard Method, if additional wind tunnel testing is conducted with significant sheltering obstructions removed (in a Removal Testing Configuration) and the adopted wind loads are not lower than 80% of the additional testing results.

The principle for removal of sheltering obstruction is that the building / building lot that provides the most significant sheltering (i.e. the most beneficial building) in each wind direction should be considered for removal. The procedure for determining the most significant sheltering obstruction is provided in Appendix A2.

New buildings beyond the scope of the Code should resist a minimum of 80% of the load obtained from the Removal Testing Configuration. The adopted wind loads should not be lower than 70% of the along-wind load of the Standard Method.

The rule is demonstrated in Figure 6-1. Otherwise the maximum loads with existing and likely future surroundings should be used.

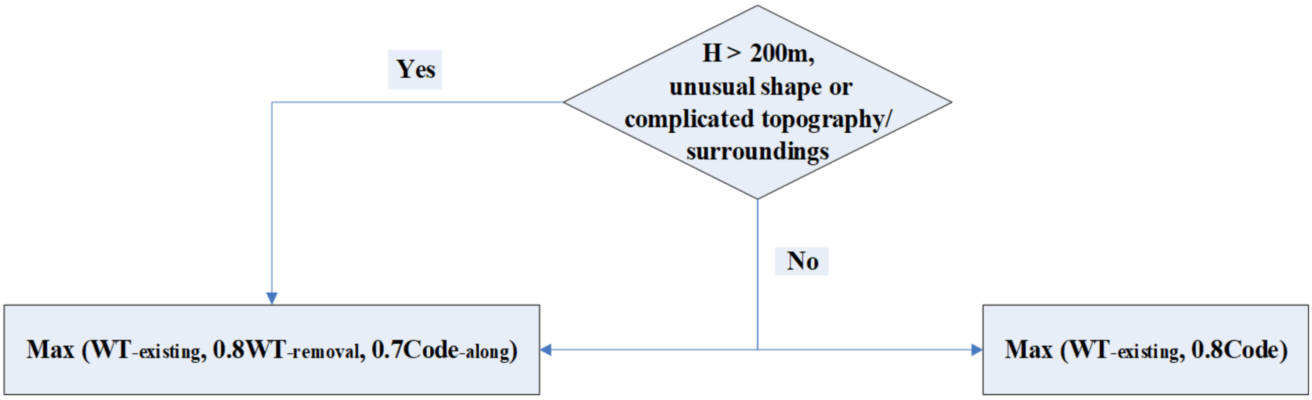


Figure 6-1 Minimum adopted wind loads from a test

6.5 Code Wind Pressures and Treatment of Wind Directionality

6.5.1 Use of Ultimate Wind Loads

Ultimate loads should be determined directly using directionally adjusted speeds multiplied by $\sqrt{\gamma_w}$, and the loads should then be calculated by dividing the ultimate loads by γ_w.

The wind loads derived here are intended to be multiplied by the appropriate load factors, including γ_w, from the material codes.

6.5.2 Directionality

The reference pressure can be adjusted to account for the reduced probability of strong winds from various wind directions using directionality factors as noted in Appendix A1 for the Sector Method.

Alternatively, $S_\theta = 1.0$ can be used for forces and pressures determined by using Storm Passage, Up-crossing, or similar methods.

6.5.3 Wind Pressure for Acceleration Calculation

For determination of building accelerations, the code pressures should be adjusted to an appropriate return period using the return period factors in Table A1-2 of Appendix A1.

Alternatively, the return period of accelerations can be calculated by using combined directional probability methods (i.e. Storm Passage or Up-crossing) and using the resultant (i.e. combined X, Y and rotational) responses for all wind directions.

6.6 Requirements for Verification

Where wind tunnel testing is used to substantiate design loads, sufficient detail of the test conditions and results should be provided to enable independent verification of applicability of the modelling.

Appendix A

Supplementary Information for Section 3: Design Wind Pressures

A1 Wind Climate

A1.1 Wind Directionality

The reference pressure can be adjusted to account for the reduced probability of strong winds from various wind directions using the directionality factors in Table A1-1.

Table A1-1 Directionality factor on pressure, S_θ

Wind Direction	Direction factor, S_θ
N	0.82
NE	0.84
E	0.85
SE	0.85
S	0.85
SW	0.84
W	0.82
NW	0.80

The S_θ value between any of the eight directions in Table A1-1 can be obtained by linear interpolation. The maximum S_θ value in the 90^o studied sector should be adopted when using the Standard Method.

The directionality factor does not apply to circular buildings. For circular buildings, $S_\theta = 1$ should be used.

A1.2 Wind Pressure with Selected Return Periods for Acceleration Calculation

For determination of building accelerations, the wind reference pressure should be adjusted to the appropriate return period using the return period factors in Table A1-2.

Table A1-2 Return period factor on pressure, S_r

Return Period, R (years)	Return Period Factor, S_r
1	0.25
10	0.55

A2 Exposure Adjustment for Direct Shelter

For use with the Standard Method of the Code, the effects of direct shelter from other buildings surrounding a site can be taken into account by using a reduced height, i.e. the effective height, Z_e, for calculation of wind reference pressure, turbulence intensity, and force coefficient.

The effective height, Z_e, is taken as the maximum of $(Z - H_d)$ and $(0.25Z)$, where H_d is the height of reduction and may be taken as zero or as the minimum of the following:

(a) $0.8H_i$ - Equation A2-1

(b) $1.2H_i - 0.2X_i \; but \geq 0$ - Equation A2-2

(c) $0.75H$ - Equation A2-3

Where

H is the actual building height of the proposed building

H_i is the height of obstructing building above ground level within ±45 degrees of the considered wind direction (Figure A2-1). H_i is taken as less than or equal to H.

X_i is the horizontal distance from the upwind edge of the proposed building to the obstructing building (Figure A2-2). It is sufficient to consider buildings within a distance X_i less than 6 times the proposed building height.

If there is only one obstructing building, no sheltering effect is allowed. If there are two or more obstructing buildings in the upwind direction, the reduction in height can be calculated for the building which provide the second-most sheltering effect in that direction.

Figure A2-3 can be used to determine the most and the second most obstructing buildings. The largest and the second largest H_d. Z_e are taken as the following:

$Z_e = Z - H_d$, for $Z \geq 1.33H_d$ - Equation A2-4a

$Z_e = 0.25Z$, for $Z < 1.33H_d$ - Equation A2-4b

Where the surround building heights vary across a sector of ±45 degrees of the considered wind direction, H_d should be taken as the weighted average value across the sector calculated as shown in Figure A2-4 with the effective height in each division calculated following the rule in the above paragraphs. For ease of calculation, each sector may be divided into not less than 4 equal divisions.

The obstructing building height should be the actual height of that building or the reduced height of that building calculated from the base level of the proposed building, whichever gives smaller sheltering effect. The details are discussed in the Explanatory Notes.

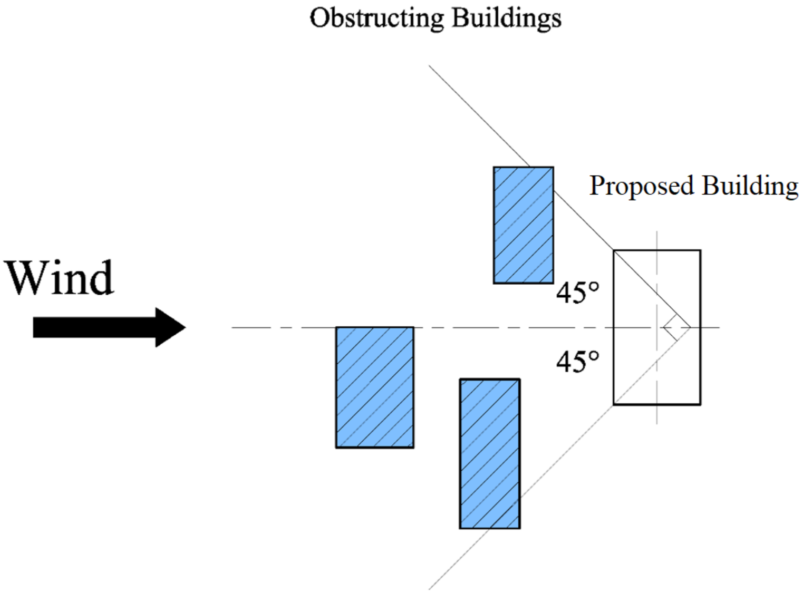


Figure A2-1 Plan showing ±45 degrees of the considered wind direction

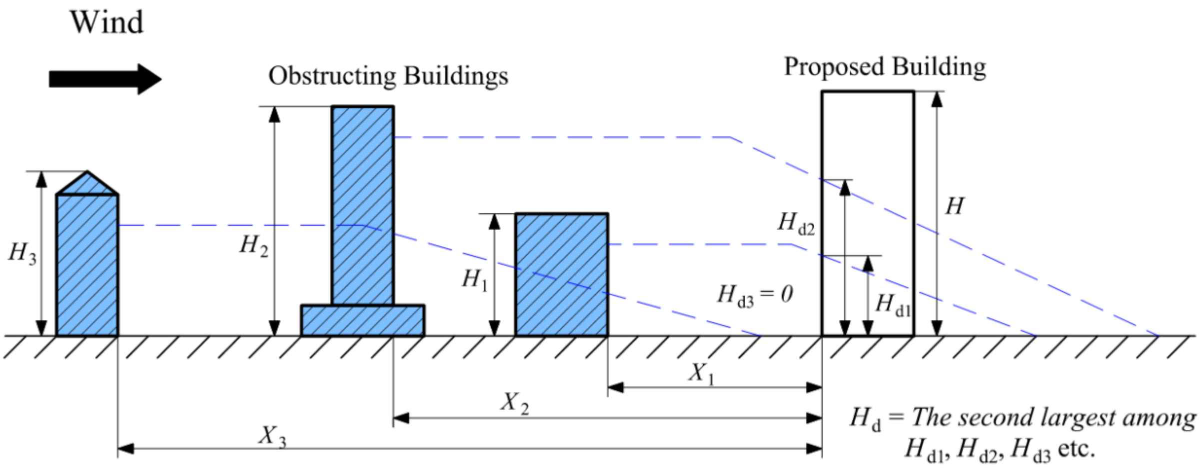


Figure A2-2 Definition of H_i and X_i (on elevation)

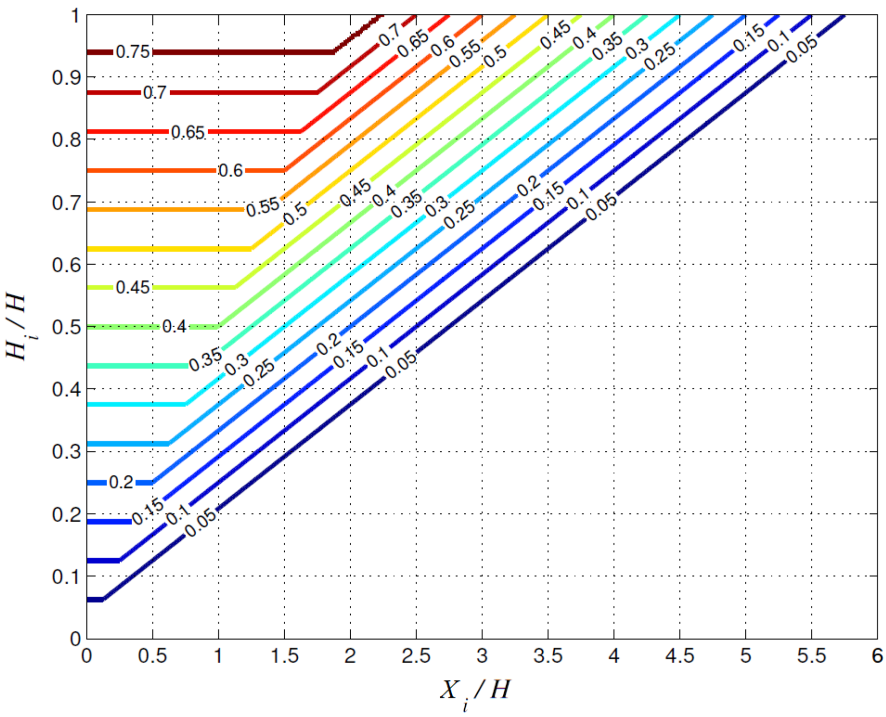


Figure A2-3 Variation of H_{di}/H with X_i/H and H_i/H

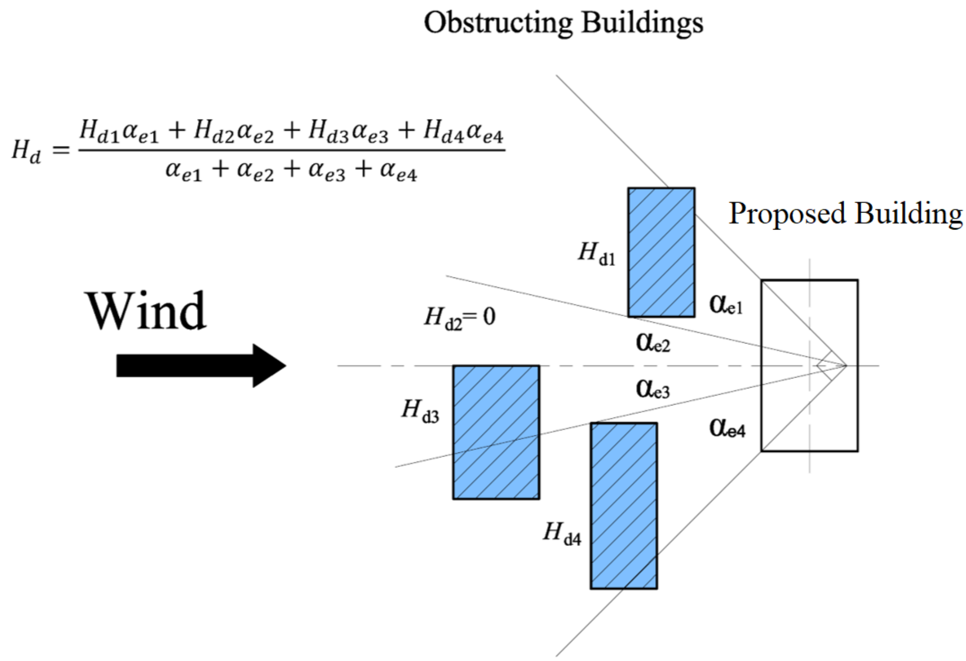


Figure A2-4 Variation of building height across sector (a demonstration case on plan with four unequal divisions)

A3 Topographic Multiplier

For use of topographic multiplier with the Standard Method, S_t can be calculated as below. The method below for calculation of the topographic multiplier is applicable to hills and ridges, or cliffs and escarpments, which, for the cross-section considered, may be taken reasonably as 2-dimensional.

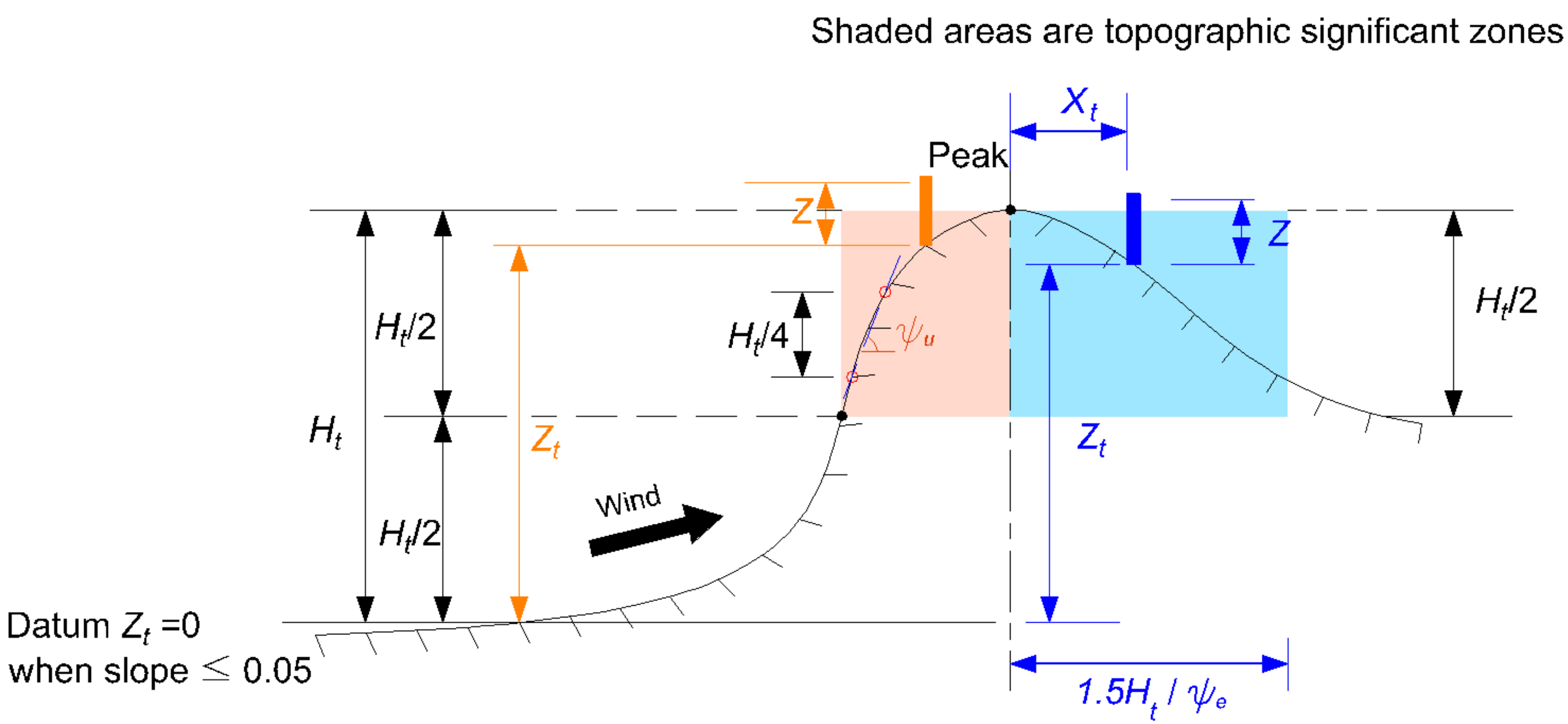
For the purpose of this Code, local topography is considered significant when $\psi_u > 0.05$ and when a site is located within the topography significant zone as shown in Figure A3-1(a) and Figure A3-1(b) and as defined below:

(a) $Z_t/H_t \geq 0.5$

(b) For sites on the downwind slope where $X_t < 1.5\, H_t/\psi_e$

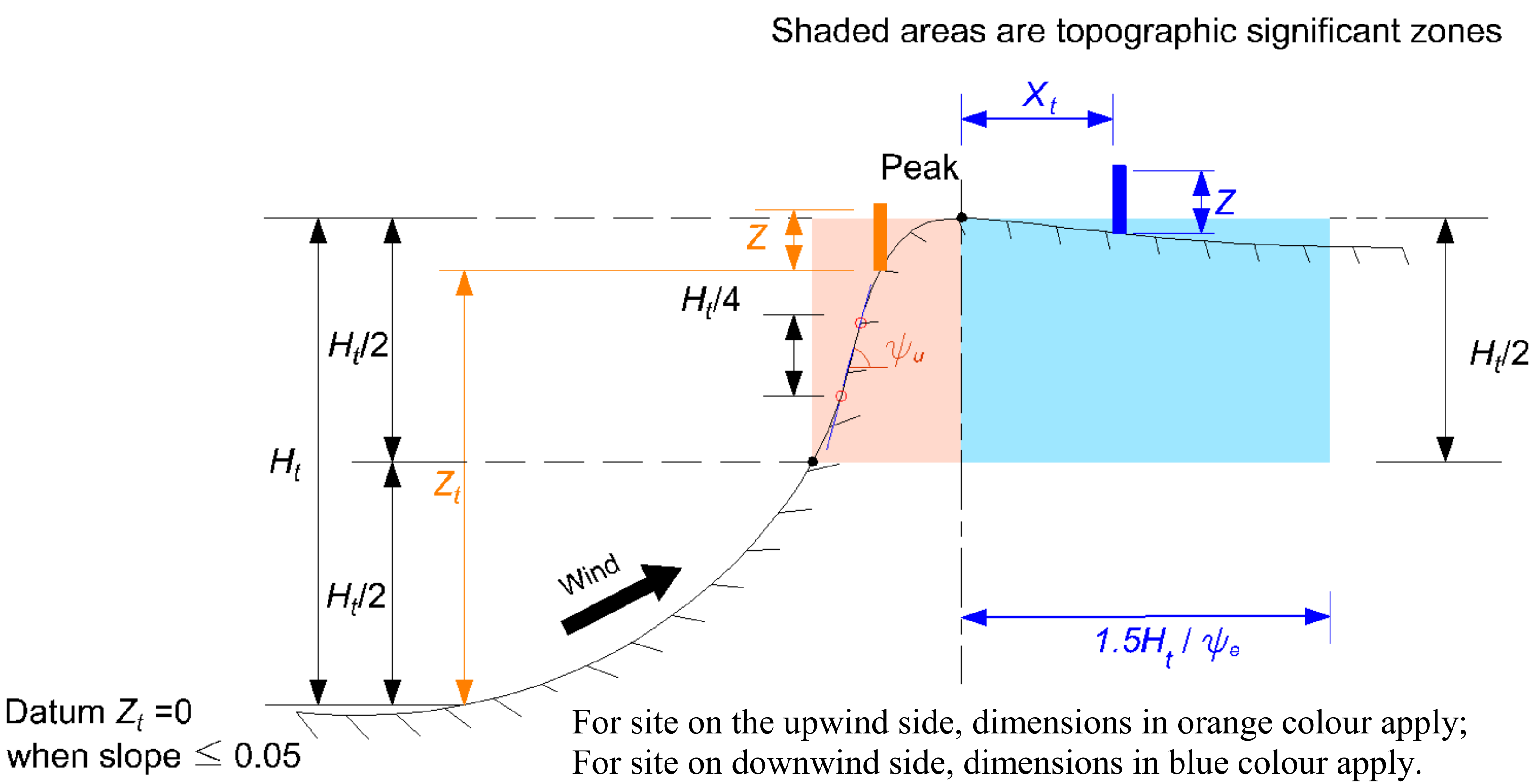
Where the following definitions of topographic form are applicable:

ψ_u	is the maximum slope for a quarter of the hill-height in the top half of the hill on the windward side
ψ_e	is the minimum of ψ_u or 0.3
H_t	is the height of the hill from the windward side above surrounding ground with a mean slope of less than or equal to 5%
Z_t	is the height of the highest part of the site measured from the same datum as H_t. (i.e. $Z_t \leq H_t$)
X_t	is the distance to the site downwind from the crest of the hill, when applicable



For site on the upwind side, dimensions in orange colour apply;
For site on downwind side, dimensions in blue colour apply.
For *s* on the downwind side, use the smaller value for hills / ridges and cliffs / escarpments.

Figure A3-1(a) Definition of topographic dimensions for hills and ridges



For site on the upwind side, dimensions in orange colour apply;
For site on downwind side, dimensions in blue colour apply.
For *s* on the down wind side, use the smaller value for hills / ridges and cliffs / escarpments.

Figure A3-1(b) Definition of topographic dimensions for cliffs and escarpments

If a topographic adjustment is not required, then

$$S_t = 1.0$$

Otherwise, S_t , the topographic multiplier of wind pressure, is calculated as below:

$$S_t = \left[1 + \frac{2\psi_e s}{1+3.7I_{v,z}}\right]^2 \quad - \quad \text{Equation A3-1}$$

Where

s is the topographic location factor given in Figures A3-2(a, b or c) or calculated with the Equations A3-2 to A3-11.

s and $I_{v,z}$ should be calculated at height, $Z = 2/3H$

$I_{v,z}$ may be taken as $I_{o,z}$ in Equations 3-3 or 3-4.

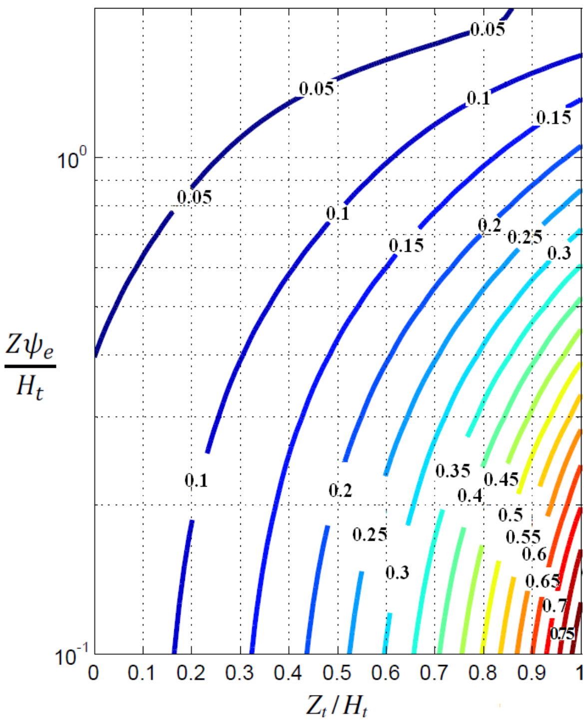


Figure A3-2(a) Topographic location factor, *s*, for upwind section for both hills / ridges and cliffs / escarpments (significant zone in orange colour in Figure A3-1(a) and Figure A3-1(b))

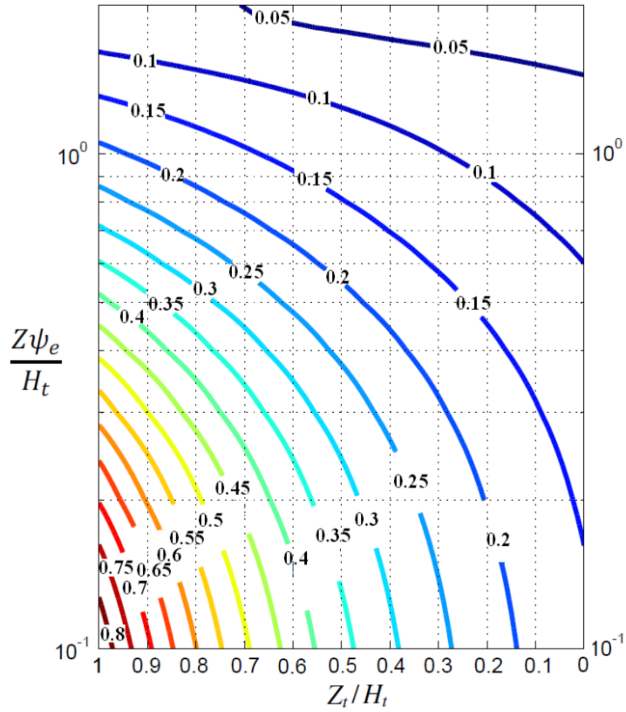


Figure A3-2(b) Topographic location factor, *s*, for downwind section for hills and ridges (significant zone in blue colour in Figure A3-1(a))

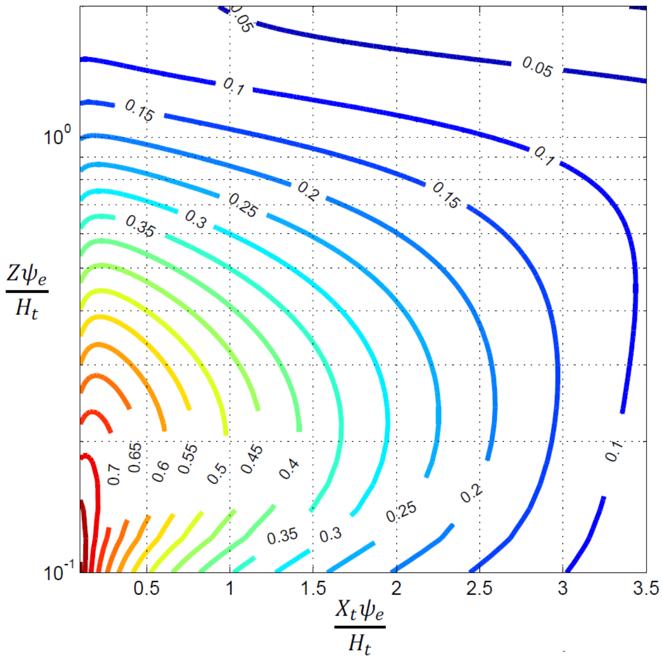


Figure A3-2(c) Topographic location factor, *s*, for downwind section for cliffs and escarpments (significant zone in blue colour as defined in A3-1(b))

(a) For upwind section for both hills / ridges, and cliffs / escarpments (significant zone in orange colour in Figure A3-1), if the following conditions:

$$0.5 \leq \frac{Z_t}{H_t} \leq 1.0 \text{ and } 0 \leq \frac{Z\psi_e}{H_t} \leq 2.0$$

are satisfied, s shall be calculated as:

$$s = K_{u1} \cdot e^{\left[-K_{u2}\left(1-\frac{Z_t}{H_t}\right)\right]} \qquad \text{- Equation A3-2}$$

Where $K_{u1} = 0.1552\left(\frac{Z\psi_e}{H_t}\right)^4 - 0.8575\left(\frac{Z\psi_e}{H_t}\right)^3 + 1.8133\left(\frac{Z\psi_e}{H_t}\right)^2 - 1.9115\left(\frac{Z\psi_e}{H_t}\right) + 1.0124$

- Equation A3-3

$$K_{u2} = 0.3542\left(\frac{Z\psi_e}{H_t}\right)^2 - 1.0577\left(\frac{Z\psi_e}{H_t}\right) + 2.6465$$

- Equation A3-4

Otherwise, $s = 0$.

(b) For downwind section for hills and ridges (significant zone in blue colour), if following conditions:

$$0.5 \leq \frac{Z_t}{H_t} \leq 1.0 \text{ and } 0 \leq \frac{Z\psi_e}{H_t} \leq 2.0$$

are satisfied, s shall be calculated as:

$$s = K_{d1} \cdot e^{\left[K_{d2}\left(1-\frac{Z_t}{H_t}\right)\right]} \qquad \text{- Equation A3-5}$$

Where $K_{d1} = 0.1552\left(\frac{Z\psi_e}{H_t}\right)^4 - 0.8575\left(\frac{Z\psi_e}{H_t}\right)^3 + 1.8133\left(\frac{Z\psi_e}{H_t}\right)^2 - 1.9115\left(\frac{Z\psi_e}{H_t}\right) + 1.0124$

- Equation A3-6

$$K_{d2} = -0.3056\left(\frac{Z\psi_e}{H_t}\right)^2 + 1.0212\left(\frac{Z\psi_e}{H_t}\right) - 1.7637$$

- Equation A3-7

Otherwise, $s = 0$.

(c) For downwind section for cliffs and escarpments only (significant zone in blue colour), if following conditions:

$$0 < \frac{X_t \psi_e}{H_t} \le 3.5 \text{ and } 0 < \frac{Z\psi_e}{H_t} \le 2.0$$

are satisfied, the equations below should be used to calculate the value, s, taking $\frac{X_t \psi_e}{H_t} \ge 0.1$ and $\frac{z\psi_e}{H_t} \ge 0.1$

$$s = K_{e1}\left[\log_{10}\left(\frac{X_t \psi_e}{H_t}\right)\right]^2 + K_{e2}\left[\log_{10}\left(\frac{X_t \psi_e}{H_t}\right)\right] + K_{e3}$$

- Equation A3-8

Where $K_{e1} = -1.3420\left[\log_{10}\left(\frac{Z\psi_e}{H_t}\right)\right]^3 - 0.8222\left[\log_{10}\left(\frac{Z\psi_e}{H_t}\right)\right]^2 + 0.4609\ \log_{10}\left(\frac{Z\psi_e}{H_t}\right) - 0.0791$

- Equation A3-9

$$K_{e2} = -1.0196\left[\log_{10}\left(\frac{Z\psi_e}{H_t}\right)\right]^3 - 0.8910\left[\log_{10}\left(\frac{Z\psi_e}{H_t}\right)\right]^2 + 0.5343\ \log_{10}\left(\frac{Z\psi_e}{H_t}\right) - 0.1156$$

- Equation A3-10

$$K_{e3} = 0.8030\left[\log_{10}\left(\frac{Z\psi_e}{H_t}\right)\right]^3 + 0.4236\left[\log_{10}\left(\frac{Z\psi_e}{H_t}\right)\right]^2 - 0.5738\ \log_{10}\left(\frac{Z\psi_e}{H_t}\right) + 0.1606$$

- Equation A3-11

For the range $0 < \frac{Z\phi_e}{H_t} < 0.1$, the formula above should be used by taking $\frac{Z\phi_e}{H_t} = 0.1$.

For the range $0 < \frac{X_t\phi_e}{H_t} < 0.1$, linear interpolation of s should be made between the values of s at the crest of the hill, $s(0)$, calculated using formula in Section (a), and that of $s(0.1)$ in an escarpment in this section by taking $\frac{X_t\phi_e}{H_t} = 0.1$.

Downwind of the hill crest, the lower value of s for hills and ridges, or s for cliffs and escarpments should be used.

If the condition $0 < \frac{X_t \psi_e}{H_t} \le 3.5$ or $0 < \frac{Z\psi_e}{H_t} \le 2.0$, does not apply, it should take $s = 0$.

Appendix B

Supplementary Information
for Section 4:
Force and Pressure Coefficients

B1 Pressure Coefficients for Building Envelope with Dominant Openings

B1.1 Definition of Dominant Opening

A dominant opening occurs if the opening area, $A_o > 1.5A_{tot}$, where

A_o Area of the largest opening, or sum of areas of openings of similar sizes and within the same or similar pressure zone/zones on the same building face

A_{tot} Sum of areas of openings on other faces, including leakage. The leakage contribution to A_{tot} is defined as 0.1% of the total external surface area of the other surfaces. Other numbers may be used with justification and specialist advice may be sought.

Where openings that are not dominant the internal pressures may be calculated from consideration of the balance of airflow. See the Explanatory Notes.

B1.2 External Pressure Coefficients for Building Envelope

For buildings with rectangular corners in plan, the external pressure coefficients for the building envelope are given in Table B1-1.

Zone definitions are given in Figure 4-6(a) and Figure 4-6(b). For buildings with plan shape other than simple rectangles, the zone definitions can be referred to the Explanatory Notes.

Table B1-1 External pressure coefficients for building envelope with dominant openings, C_{pe}

Case		Zones applicable	C_{pe}
Wall	Negative pressure in edge zone	A	-1.2
	Negative pressure elsewhere	B	-0.8
	Positive pressure	A & B	+0.8
Flat roof or roof pitch less than 30 degrees	Negative pressure in corner zone	C	-2.0
	Negative pressure in edge zone	D	-1.4
	Negative pressure elsewhere	E	-0.8
	Positive pressure	C, D, E	0.0
Pitched roof greater than 60 degrees	Negative pressure in corner zone	C	-1.2

	Negative pressure in edge zone	D	-1.2
	Negative pressure elsewhere	E	-0.8
	Positive pressure	C, D, E	+0.8

Notes:

(a) Q_h should be used for the external pressure calculation.

(b) The size factor, S_s , depends on the tributary area (structural span of the panel) and may be larger than 1.0.

(c) Cladding pressures can be reduced by 20%, below a height of $0.5(H - H_e)$.

(d) Where there are significant steps in building form, i.e. podiums, reference height for tower and podium in Figure 4.6(a) and Figure 4.6(b) should be followed.

(e) Linear interpolation is allowed for pitch angles between 30 and 60 degrees.

(f) Pressure coefficients for roofs of low-rise construction can also be obtained from reliable published sources.

(g) The net pressure coefficients of Table 4-1 can be obtained from the above by considering internal pressure coefficients of +0.2 and -0.3.

B1.3 Internal Pressure Coefficients for Building Envelope with Dominant Openings

Internal pressure coefficients for buildings with dominant openings are given in Table B1-2.

Table B1-2 Internal pressure coefficients for building envelope with dominant openings, C_{pi}

Case	C_{pi}
1. Dominant opening cases (See B1.1 for definition of A_o and A_{tot})	$\dfrac{C_{pe}}{\left[1 + \left(\frac{A_{tot}}{A_o}\right)^2\right]}$
2. Cases with opening/openings not qualified as dominant opening cases	See the Explanatory Notes.

Notes:

(a) Internal pressure coefficients should be adopted in combination with the external coefficients to generate the worst net pressure coefficients.

(b) The reference height for calculating internal pressure should be taken as that for calculating external pressure at the same location.

Figures B1-1 to B1-4 describe combinations of external and internal pressures to be considered.

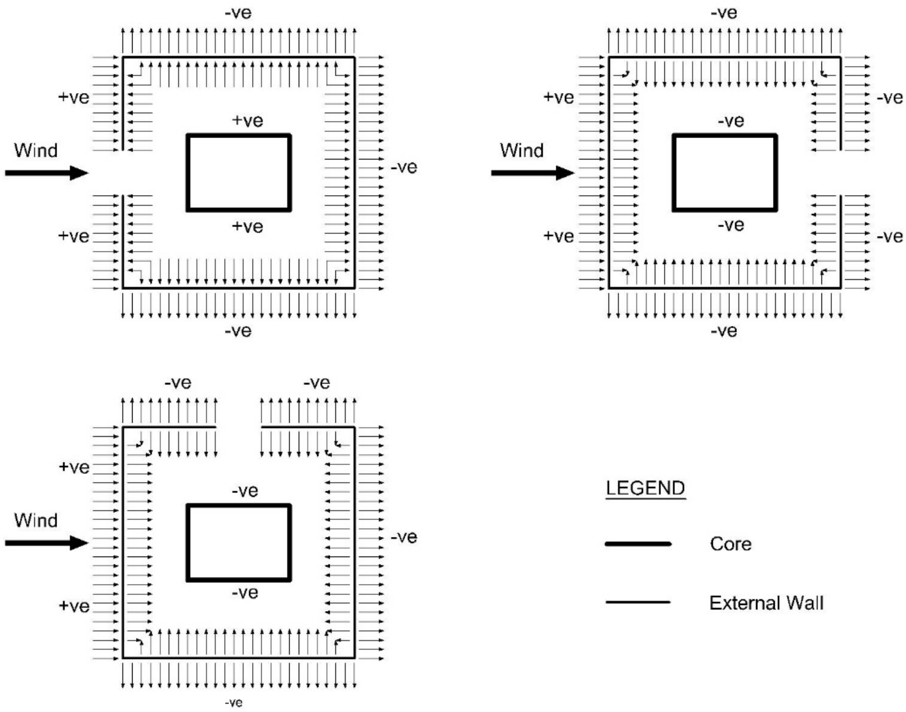


Figure B1-1 Wind pressure on external walls due to dominant opening

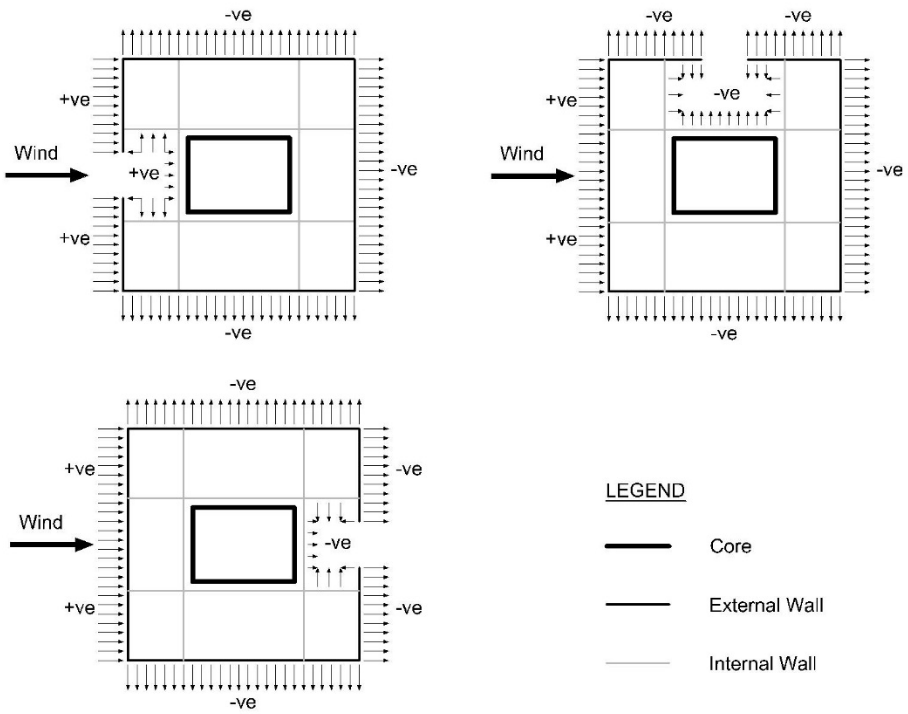


Figure B1-2 Wind pressure on internal walls due to dominant opening not located in corner

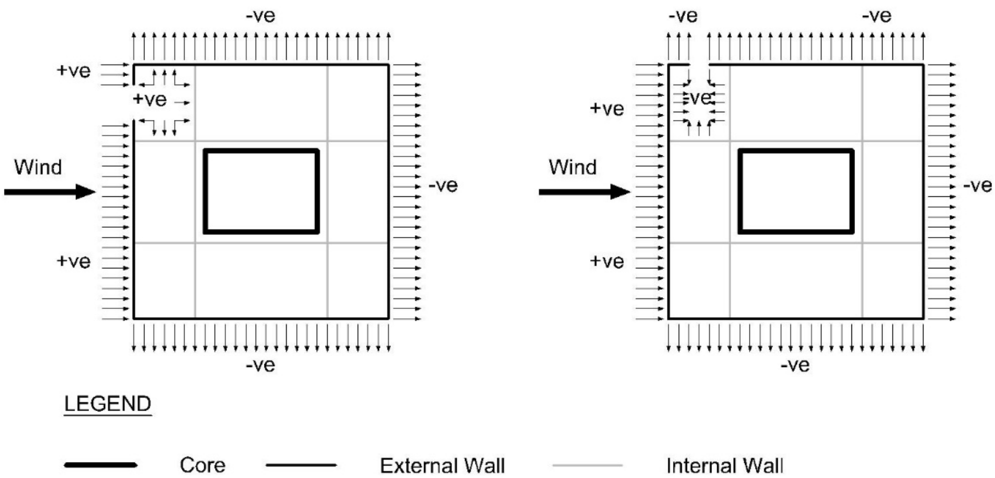


Figure B1-3 Wind pressure on internal walls due to dominant opening located in upwind corner

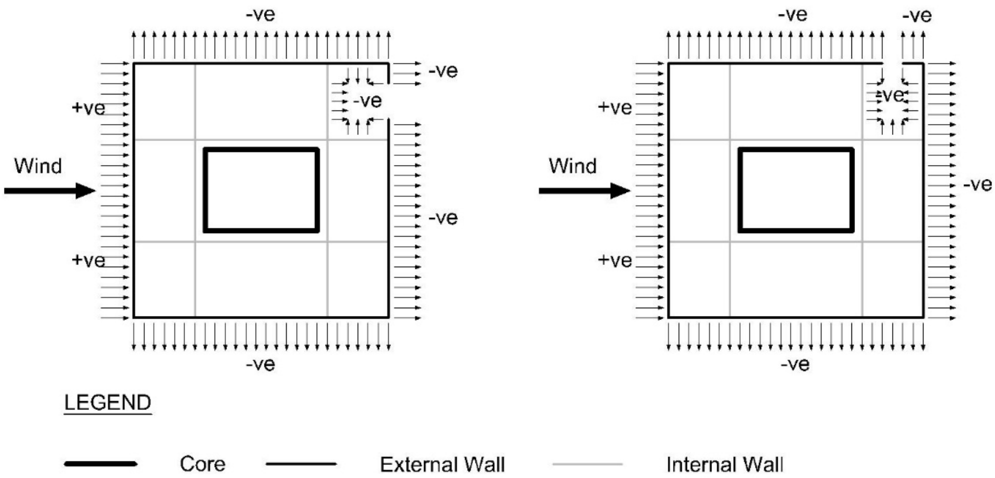


Figure B1-4 Wind pressure on internal walls due to dominant opening located in downwind corner

B2 Pressure Coefficients for Building Attachments

B2.1 Sunshades, Architectural Fins and Signboards

Net pressure coefficients, C_p, for calculating the net wind loads on sunshades, architectural fins and signboards attached to the walls of buildings are given in Table B2-1.

Effect on overall structural forces should refer to Section 4.

Table B2-1 Net pressure coefficients for sunshades, architectural fins and signboards

Case	At Edge Zones of Building	Other Zones of Building
1. Directly attached to facade	±1.8	±0.9
2. Spaced away from facade*	±3.0	±1.5

* When the gap between the element and the façade is less than 2/3 of the element width, the load can be taken as Case 1, assuming that the gap is closed. Resulting load should be applied at the centre of the area. See Figure B2-1(d) and Figure B2-1(e).

Notes:

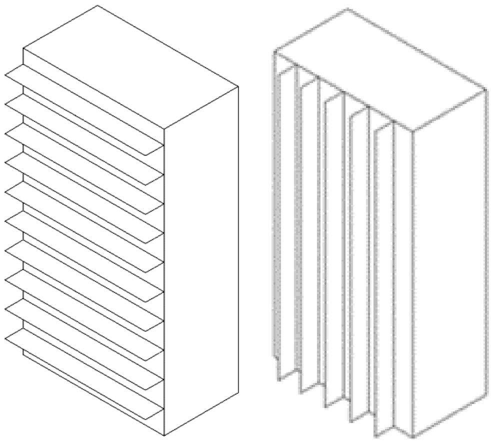
(a) Q_h should be used for the net pressure calculation.

(b) Figure B2-1(c) provides edge zone definitions.

(c) It should take S_s = 1.0.

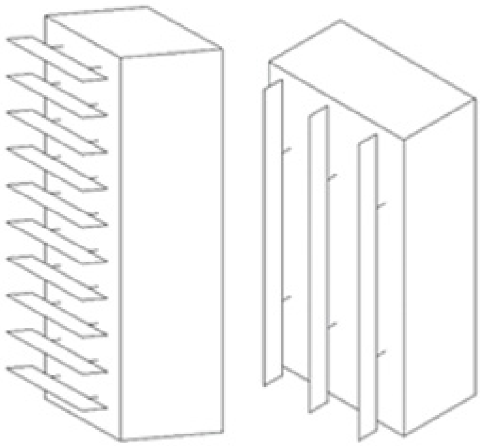
(d) Pressures can be reduced by 20%, below a height of $0.5(H - H_e)$.

(e) For Case 2, $C_{p-case1} \times A_{gross}$ or $C_{p-case2} \times A_{net}$, whichever is of smaller magnitude should be used. See Figure B2-1(d) and Figure B2-1(e).



Case 1: Horizontal / vertical arrangement
(directly attached to facade)

Figure B2-1(a)



Case 2: Horizontal / vertical arrangement
(spaced away from facade)

Figure B2-1(b)

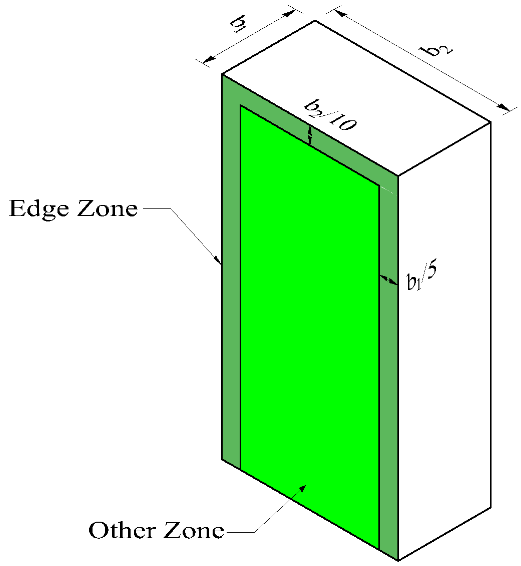


Figure B2-1(c) Zone definition (b is the smaller value of B and 2H)

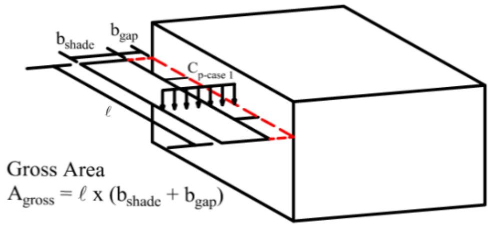


Figure B2-1(d)

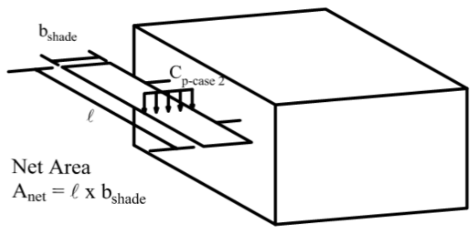


Figure B2-1(e)

Figure B2-1 Sunshades, architectural fins and signboards

B2.2 Balconies

A net pressure coefficient, C_p, for balcony walls, slabs and balustrades is given in Table B2-2. This coefficient is referenced to the pressure at the roof height of the building to which the balconies are attached.

Table B2-2 Net pressure coefficients for balcony slabs, balcony walls and balustrades, C_p

Location	C_p
balcony walls and balustrades	±1.8
balcony slabs	+0.9 and -1.8

Notes:

(a) Q_h should be used as reference pressure and S_s = 1.0 should be taken.

(b) Pressures can be reduced by 20%, below a height of 0.5(H-H_e).

B2.3 Canopies Attached to Buildings

For canopies attached below half-way up the building ($h/H < 0.5$) and below a height of twice the canopy projection the net pressure coefficients can be taken as + 0.9 and -1.3. Q_h should be used as reference pressure. Positive pressures act downwards.

B3 Pressure Coefficient for Free-standing Walls

For free-standing walls and parapets, the net pressure coefficient C_p for Zones A, B, C and D (indicated on Figure B3-1) are given in Table B3-1.

Values are given in Table B3-1 for two different solidity ratios. The reference area in both cases is the gross area. Linear interpolation may be used for solidity ratios between 0.8 and 1.

Table B3-1 Net pressure coefficient for free-standing walls

<table>
<tr><th>Solidity</th><th colspan="2">Zone</th><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td rowspan="4">$\varphi = 1$</td><td rowspan="3">Without return corners</td><td>$l/h \leq 3$</td><td>2.3</td><td>1.4</td><td>1.2</td><td></td></tr>
<tr><td>$l/h = 5$</td><td>2.9</td><td>1.8</td><td>1.4</td><td>1.2</td></tr>
<tr><td>$l/h \geq 10$</td><td>3.4</td><td>2.1</td><td>1.7</td><td>1.2</td></tr>
<tr><td colspan="2">With return corners of length $\geq h$ (a)</td><td>2.1</td><td>1.8</td><td>1.4</td><td>1.2</td></tr>
<tr><td>$\varphi = 0.8$ (b)</td><td colspan="2">All cases</td><td>1.2</td><td>1.2</td><td>1.2</td><td>1.2</td></tr>
<tr><td colspan="7">Notes:
(a) Linear interpolation may be used for return corner lengths between 0 and h.
(b) Use Table 4-2 for open frameworks, if solidity ratio < 0.8.</td></tr>
</table>

The reference height for calculation of pressures on free-standing walls and building parapets is the top height of the wall above ground level. For a wall cantilevering from a continuous base, the size factor should be calculated using $L_{0.5p} = 2h$. In other cases, the relevant tributary area should be used.

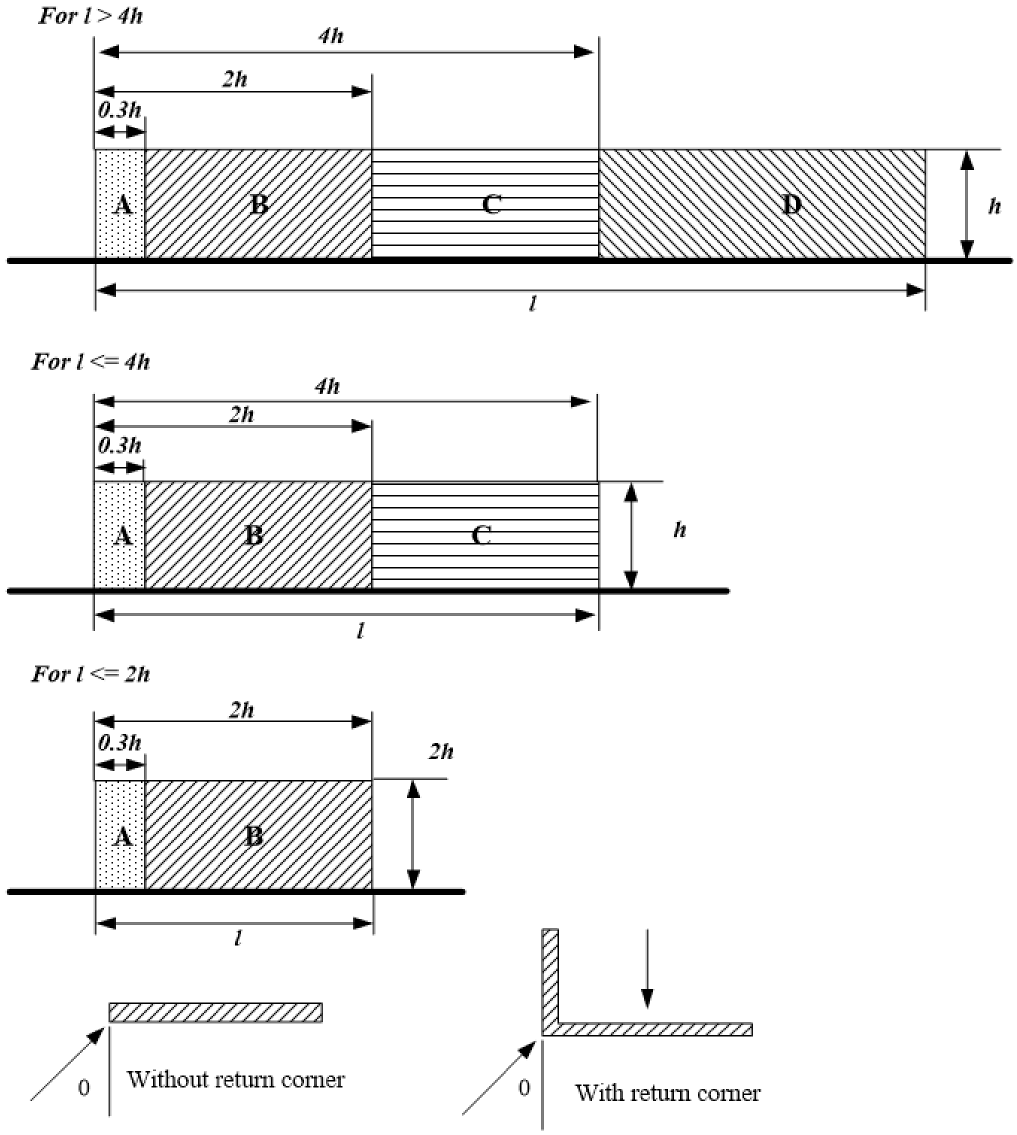


Figure B3-1 Pressure zone definition for free-standing walls

Appendix C

Supplementary Information for Section 5: Size Factor and Size and Dynamic Factor

C1 Equations for Calculation of Size Factor

The size factor, S_s, depends on the loaded area and is defined by the half-perimeter of the area, $L_{0.5p}$ as shown in Figure 5-2. Alternatively, S_s, may be calculated using the formulas below:

Other zones and for Overall Wind Loads

$$S_{s=L_{0.5p}} = Exp\left(0.17 - 0.07\, {L_{0.5p}}^{0.32}\right) \quad - \quad \text{Equation C1-1a}$$

Edge zones if $L_{0.5p}$ < 15m

$$S_{s=L_{0.5p}} = 1.3 - \log_n\left(L_{0.5p}\right)/9.0 > 1.0 \quad - \quad \text{Equation C1-1b}$$

Corner zones if $L_{0.5p}$< 15m

$$S_{s=L_{0.5p}} = 1.5 - \log_n(L_{0.5p})/5.4 > 1.0 \quad - \quad \text{Equation C1-1c}$$

Where

S_s	size factor depending on the half-perimeter length, $L_{0.5p}$, of the loaded area (this may be greater than 1.0 for small elements)
$L_{0.5p}$	half-perimeter length around a tributary area

C2 Damping of Buildings and Other Structures

Values of damping used in assessment of dynamic responses should be established from reliable measurements from similar structures. The tables below give damping ratios of the fundamental mode for typical buildings. For composite steel/concrete constructions, intermediate values should be used.

For particularly slender buildings, lower values may be appropriate and specialist advice should be sought.

The aspect ratio should be calculated from the overall structural depth of the building in the direction of vibration. The aspect ratio for the purpose of assessing the damping, is the total tower height, above foundation level divided by the dimension of the tower lateral load resisting structure in the direction of the vibration. If there are plan set-backs, the aspect ratio shall also be checked with height above the set-back divided by the overall structural depth above the set-back and the largest value shall be used. Towers constructed on shared podium slabs shall be similarly checked above podium level.

Table C2-1 Damping ratio for typical RC buildings, ξ_x, ξ_y

Aspect ratio in the direction of vibration	Recommended damping ratio for accelerations	Tentative damping ratio for structural loads
	Maximum damping ratio	Maximum damping ratio
≥ 8	0.010	0.015
7	0.011	0.017
6	0.013	0.020
5	0.016	0.024
<4	0.020	0.030

Table C2-2 Damping ratio for typical steel buildings, ξ_x, ξ_y

Aspect ratio in the direction of vibration	Recommended damping ratio for accelerations	Tentative damping ratio for structural loads
	Maximum damping ratio	Maximum damping ratio
≥ 8	0.005	0.008
7	0.006	0.009
6	0.007	0.010
5	0.008	0.012
<4	0.010	0.015