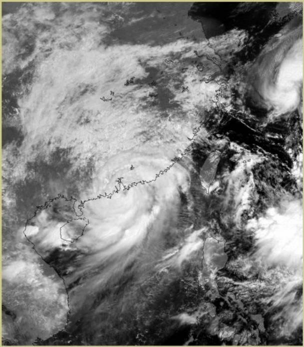
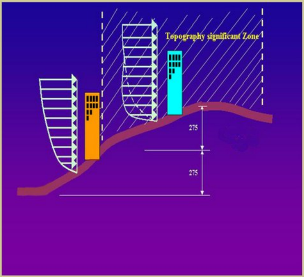
Code of Practice on Wind Effects in Hong Kong 2004





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Code of Practice on Wind Effects in Hong Kong 2004

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BUILDINGS DEPARTMENT

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FOREWORD

The Code of Practice on Wind Effects in Hong Kong 2004, prepared under the direction of the Ad hoc Committee on Review of the Code of Practice on Wind Effects, supersedes the Code of Practice on Wind Effects Hong Kong –1983.

This Code introduces several new concepts that are in keeping with developments in understanding of the response of structures to wind action and new wind speed records measured in Hong Kong.

The main changes in this code devolve from the recognition of the time varying nature of wind action. Accordingly, an assessment of resonant dynamic response is introduced with guidance given on the assessment of mean and turbulent wind characteristics.

For the assessment of resonant dynamic response, a signpost is provided to show whether resonant dynamic effect should be considered or not. In the case that it is, then several new elements of assessment are included in this code to make the estimation of dynamic response more precise. These include estimates of turbulence intensity, damping, natural frequency and other descriptors of wind energy parameters. Where the resonant dynamic response is not significant, the assessment of wind effects will be broadly similar to the Code of Practice on Wind effects Hong Kong –1983.

The two terrain categories used in the former code were replaced with a single general terrain and new guidance on the effect of topography on local wind field is given in this code.

New guidance on wind tunnel testing derived from multi-national research findings and other national wind codes is also included in this code.

Acknowledgement

The preparation of this code owes a great deal to the time and effort given by Dr. K.M. Lam, Professor Alan Jeary, Ir. J. MacArthur, Ir. K.L. Lo, Ir. K.S. Wong, Ir. P.K. Li, Ir. C.C. Wong, Ir. Y.C. Tsui and the Chairman of the Ad-hoc Committee to review the Code of Practice on Wind Effects, Ir. K.M. Cheung.

A draft of the code has been circulated for general comment to selected practicing engineers, building professionals and Government Departments. All comments and views expressed have been taken into consideration in the preparation of the code now published.

Thank is also due to the Hong Kong Observatory for providing the cloud imagery on the cover page which was originally captured with the Geostationary Meteorological Satellite (GMS-5) of Japan Meteorological Agency.

CONTENTS

APPENDICES

1. SCOPE

1.1 This Code of Practice gives general methods for calculating the wind loads to be used in the structural design of buildings or parts of buildings. The Code does not apply to buildings of an unusual shape or buildings situated at locations where complicated local topography adversely affects the wind conditions. Experimental wind tunnel data with reference to local conditions, where available, may be used in place of the values given in this Code. Necessary provisions for wind tunnel testing are given in Appendix A.

1.2 The design wind pressures given in this Code have been determined from the hourly mean wind velocities and peak gust wind velocities having a return period of 50 years. Design wind pressures on buildings where a longer period of exposure to the wind is required shall be determined from wind velocities having a return period greater than 50 years. Appendix B provides the multiplication factor for design wind pressure of return period greater than 50 years.

1.3 No buildings except those mentioned in Clause 4.3 and Clause 7.4 shall be designed with design wind pressures determined from wind velocities having a return period of less than 50 years.

2. DEFINITIONS

For the purposes of this Code, the following definitions apply:

“Building” means buildings as defined in section 2 of the Buildings Ordinance.

"Breadth" means the horizontal dimension of the building normal to the direction of the wind.

"Depth" means the horizontal dimension of the building parallel to the direction of the wind.

"Frontal projected area" means the area of the shadow projection of the building on a plane normal to the direction of the wind.

"Height" means the height of the building above the site-ground level in the immediate vicinity of the building up to the top of the building. Masts and other appendages on top of the building should not be included.

3. CALCULATION OF WIND LOADS

3.1 The design wind force on a building or parts of a building shall be calculated in accordance with sections 4, 5 and 6 unless the building has significant resonant dynamic response.

3.2 A building with significant resonant dynamic response requires a more detailed analysis than those exhibiting an essentially static type of behaviour.

3.3 For the purpose of this Code, a building is considered to be one with significant resonant dynamic response if it has either of the following properties, unless it could be justified that the fundamental natural frequency of the building is greater than 1 Hz :-

(a) The height exceeds five times the least horizontal dimension.

(b) The height of the building is greater than 100 m.

For the purpose of this clause, the least horizontal dimension shall be taken as the smallest dimension of the rectangular envelope enclosing the main vertical structural elements of the building.

3.4 The along-wind forces on a building with significant resonant dynamic response shall be assessed in accordance with section 7.

4. DESIGN WIND PRESSURES

4.1 Except as provided in Clause 4.3, the design wind pressure q_z at height z shall be taken as the value given in Table 1.

4.2 Where topography is considered significant, the design wind pressure shall be multiplied by a topography factor assessed in accordance with Appendix C.

4.3 Temporary buildings or buildings which will remain in position for a period of not more than one year may be designed with wind pressures of not less than 70 per cent of the pressures given in Table 1.

4.4 No allowance shall be made for the general or specific shielding of other structures or natural features.

Table 1 : Design wind pressure

Height above site-ground level	Design wind pressure q_z (kP_a)
≤ 5m	1.82
10 m	2.01
20 m	2.23
30 m	2.37
50 m	2.57
75 m	2.73
100 m	2.86
150 m	3.05
200m	3.20
250m	3.31
300m	3.41
400m	3.58
≥ 500 m	3.72

Note : For intermediate values of height, linear interpolation is permitted.

5. FORCES ON BUILDINGS

5.1 The total wind force F on a building shall be taken to be the summation of the pressures acting on the effective projected areas of the building and shall be determined by the following equation :

$$F = C_f \sum q_z A_z \quad \text{...} \quad (1)$$

Where C_f is the force coefficient for the building, determined in accordance with Appendix D;

q_z is the design wind pressure at height z, determined in accordance with section 4; and

A_z is the effective projected area of that part of the building corresponding to q_z.

5.2 The effective projected area of an enclosed building shall be the frontal projected area. The effective projected area of an open framework structure such as sign frames and lattice towers shall be the aggregate projected area of all members on a plane normal to the direction of the wind.

5.3 Every building shall be designed for the effects of wind pressures acting along each of the critical directions.

6. FORCES ON BUILDING ELEMENTS

6.1 The total wind force F_p acting in a direction normal to the individual elements such as walls, roofs, cladding panels or members of open framework structures shall be determined by the following equation:

$$F_p = C_p q_z A_m \quad (2)$$

where C_p is the total pressure coefficient for individual elements, determined in accordance with Appendix E;

q_z is the design wind pressure corresponding to the height z of the element, determined in accordance with section 4; and

A_m is the surface area of the element.

6.2 Except for members of open framework structures, the design wind pressure, q_z shall be a constant value over the lower part of the building. The height up to which this constant value occurs is to be taken as the breadth of the building or the actual height of the building whichever is the lesser. The constant value shall be taken as the design wind pressure at this height.

7. DYNAMIC EFFECTS

7.1 The total along-wind force F on an enclosed building with significant resonant dynamic response shall be determined by the following equation :

$$F = G C_f \sum \overline{q_z} A_z \quad (3)$$

where G is the dynamic magnification factor to be determined in accordance with Appendix F;

C_f is the force coefficient for the structure, determined in accordance with Appendix D;

$\overline{q_z}$ is the design hourly mean wind pressure at height z given in Table 2; and

A_z is the effective projected area of that part of the building corresponding to $\overline{q_z}$.

7.2 Pressures and forces on the individual elements such as walls, roofs, cladding panels of a building with significant resonant dynamic response or members of open framework structures shall be determined in accordance with section 6.

Table 2 : Design hourly mean wind pressure

Height above site-ground level	Design hourly mean wind pressure $\overline{q_z}$ (kP$_a$)
≤ 5 m	0.77
10 m	0.90
20 m	1.05
30 m	1.15
50 m	1.28
75 m	1.40
100 m	1.49
150 m	1.63
200m	1.74
250m	1.83
300m	1.90
400m	2.03
≥ 500 m	2.13

Note: For intermediate values of height, linear interpolation is permitted.

7.3 Where the topography is considered significant, the design hourly mean wind pressure shall be multiplied by a topography factor assessed in accordance with Appendix C.

7.4 Temporary buildings or buildings which will remain in position for a period of not more than one year may be designed with design hourly mean wind pressures of not less than 70 per cent of the pressures given in Table 2.

7.5 No allowance shall be made for the general or specific shielding of other structures or natural features.

7.6 In the case of an open framed building with significant resonant dynamic response or a building for which the fundamental natural frequency is less than 0.2 Hz, or the cross wind resonant response / torsional resonant response may be significant, the resonant dynamic effects should be investigated in accordance with recommendations given in published literature and/or through the use of dynamic wind tunnel model studies. The total response of such a building would usually be calculated from the combination of the response in the three fundamental modes of vibration.

APPENDIX A : NECESSARY PROVISIONS FOR WIND TUNNEL TESTING

A1. Static Structures

(a) The natural wind is to be modelled to account for the variation with height of hourly mean wind speed and turbulence intensity appropriate to the site.

(b) The instrumentation and its response characteristics are to be appropriate to the loads required.

(c) The measurements should enable peak wind loads consistent with the intentions of this code to be properly determined.

A2. Dynamic Structures

Where resonant dynamic response may be significant, the provisions for static structures shall be met and, in addition, the structure shall be accurately represented (physically or mathematically) in mass distribution and stiffness in accordance with established laws of dimensional scaling and the effect of structural damping shall be appropriately reflected.

A3. Topography Modelling

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

A4. Proximity Model

If the loading on a building is 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. 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 A3. Where particular adjoining or surrounding buildings could provide significant shelter, the effect of their possible removal should also be considered.

A5. Model Scale Limitations

The geometric scale and velocity scale employed in the wind tunnel testing should meet the requirement of a minimum Reynolds number. For building models with sharp corners, the Reynolds number based on the breadth of the building model should not be less than 1×10^4. A general guide is that the building model should normally be not smaller than 1:500 in scale and that the test wind speed should be greater than 10% of the full-scale wind speed.

For rounded shapes sensitive to Reynolds number effects, these conditions may not be sufficient and further evidence of the suitability of the test conditions may be required.

The blockage in the wind tunnel should normally be less than 10% unless a blockage tolerant tunnel is being used. If blockage exceeds 10%, special forms of blockage correction may be required.

A6. Wind Profiles and Design Wind Pressure

The variations of hourly mean wind speed and turbulence intensity with height in the wind tunnel, with the proximity and test model removed, should be similar to (after being scaled up with appropriate geometric scale and velocity scale) the full-scale hourly mean wind speed and the turbulence intensity given in Appendix F.

Calibration between wind tunnel values and full-scale values should be made so that the peak gust wind pressure at a reference height in the wind tunnel testing should match the design wind pressure given in Table 1. The reference height to be used shall normally correspond to 90m (full-scale) or 2/3 of the building height, whichever is greater.

Where the effect of topography is modelled as described in Clause A3, the wind profiles determined from the small-scale topographic model shall be used in the building model tests.

For matching purposes, the peak gust wind pressure in the wind tunnel shall be calculated as below:

$$q = 1/2\, \rho\, \overline{V}^2 (1+3.7\, I)^2$$

ρ = density of air 0= 1.2 kg/m^3

$\overline{V}$ = hourly mean wind velocity

I = turbulence intensity

APPENDIX B : MULTIPLICATION FACTOR FOR RETURN PERIOD GREATER THAN 50 YEARS

The design wind pressures given in this code have been determined from the hourly mean and peak gust velocities having a return period of 50 years. The design wind pressures on buildings where the period of exposure to wind is longer than 50 years shall be multiplied by the following factor:-

$$\left(\frac{5 + \ln(R)}{5 + \ln(50)} \right)^2$$

where R is the period of exposure to wind in years.

APPENDIX C : TOPOGRAPHY FACTOR

C1. For the purpose of this Code, local topography is considered significant for a site located within the topography significant zone as defined in Figure C1.

C2. The relevant dimensions of the topography are defined in Figure C2.
The effective slope α_e and the effective slope length L_e are defined in terms of these dimensions by the following :

(a) For shallow upwind slopes $0.05 < \alpha_u < 0.3$:

$$\alpha_e = \alpha_u \text{ and } L_e = L_u$$

(b) For steep upwind slopes $\alpha_u > 0.3$:

$$\alpha_e = 0.3 \text{ and } L_e = H/0.3$$

C3. When topography is considered significant, the design wind pressure at height z shall be multiplied by a topography factor S_a at that height. The topography factor S_a at height z above site ground level shall be determined by the following equation:-

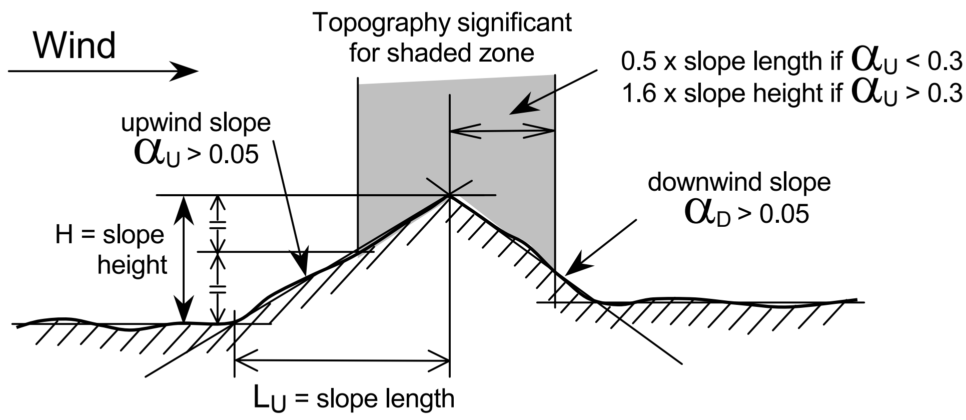
$$S_a = (1 + 1.2\,\alpha_e .\, s)^2$$

where α_e is the effective slope of the topographic features as defined in Clause C2 above.

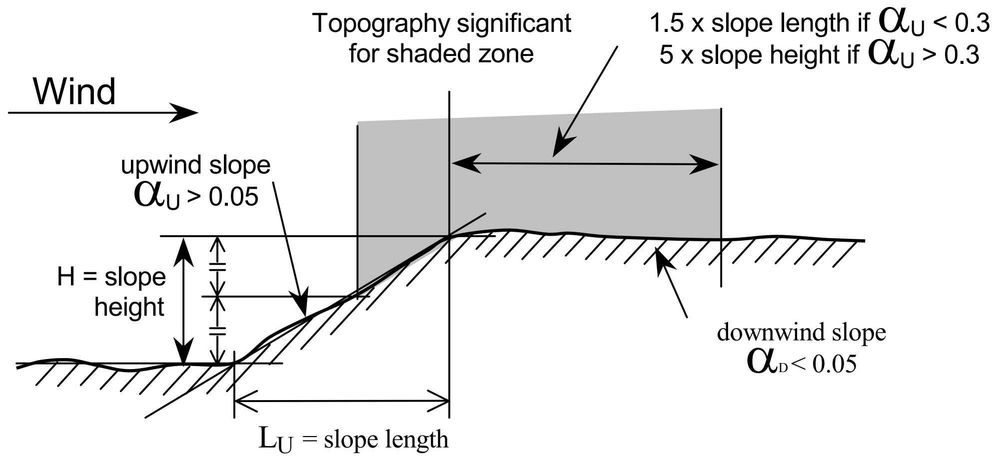
s is a topography location factor, the values of which are given for hills and ridges in Figure C3 and for cliffs and escarpments in Figure C4.

C4. For cases of complicated topography, specialist advice should be sought and/or wind tunnel model testing should be conducted.

Acknowledgement : Figures C1, C2, C3, C4 in Appendix C were modified from figures extracted from British Standards with the permission of BSI under licence number 2002/SK0004. British Standards can be obtained from BSI Customer Services, 389 Chiswick High Road, London W4 4AL, United Kingdom. (Tel +44(0)2089969001).

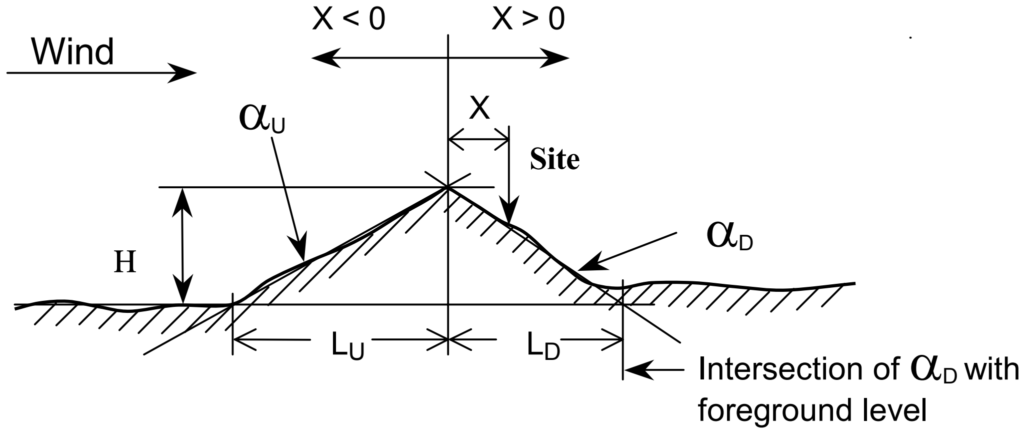


a) Hill and ridge (upwind slope > 0.05; downwind slope > 0.05)

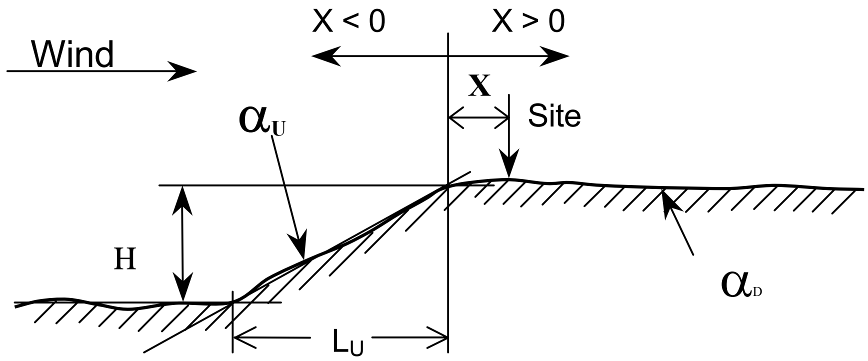


b) Escarpment (0.3 > upwind slope > 0.05; downwind slope < 0.05) and cliff (upwind slope > 0.3; downwind slope < 0.05)

Figure C1 Definition of significant topography



a) Hill and ridge (α_U > 0.05, α_D > 0.05)



b) Escarpment (0.3 > α_U > 0.05, α_D < 0.05) and cliff (α_U > 0.3, α_D < 0.05)

Legends

L_D	Length of the downwind slope in the wind direction
L_U	Length of the upwind slope in the wind direction
X	Horizontal distance of the site from the crest
H	Effective height of the feature
α_U	Upwind slope H / L_U in the wind direction
α_D	Downwind slope H / L_D in the wind direction

Figure C2 Definition of topographic dimensions

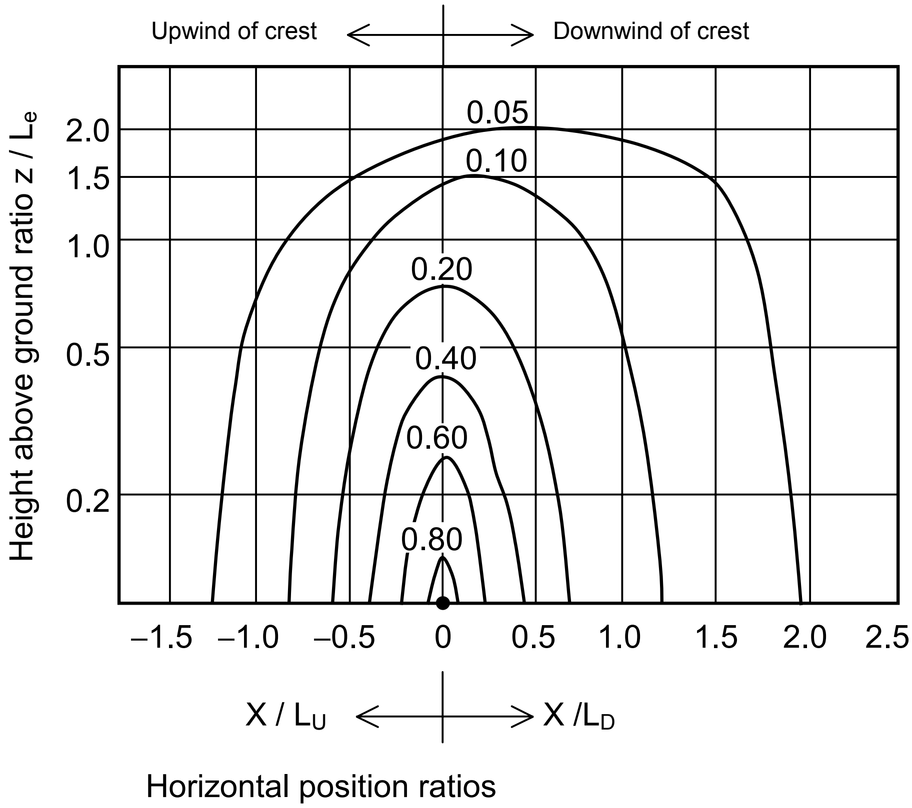


Figure C3 Topographic location factor s for hills and ridges

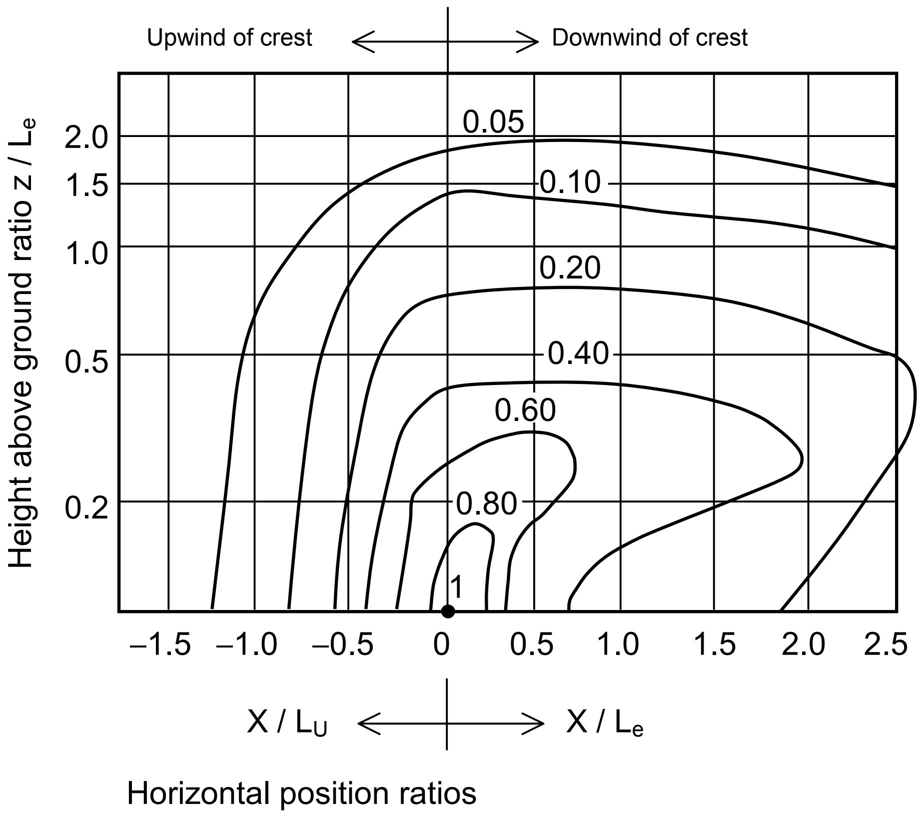


Figure C4 Topographic location factor s for cliffs and escarpments

APPENDIX D : FORCE COEFFICIENTS

D1. Enclosed building

D1.1 The force coefficient C_f for an enclosed building shall be--

(a) the product of the height aspect factor C_h and the shape factor C_s given in Table D1 and Table D2 respectively; or

(b) the appropriate value specified in other International Codes acceptable to the Building Authority.

D1.2 The force coefficient shall be applied to the enclosed building as a whole provided that :

(a) In the case of a building with isolated blocks projecting above a general roof level, individual force coefficients corresponding to the height and shape of each block shall be applied.

(b) In the case of a building composed of similar contiguous structures separated by expansion joints, the force coefficients shall be applied to the entire building.

D1.3 If the frontal projected area of that part of the building for which C_f operates is greater than 500 m^2 the force coefficient determined by Clause D1.1 may be multiplied by a reduction factor R_A given in Table D3. This reduction factor should not be applied to the total wind force calculated in accordance with Section 7.

D2. Open framework buildings

D2.1 The force coefficient C_f for an open framework building shall be--

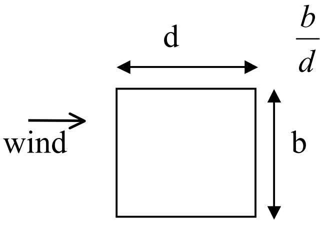
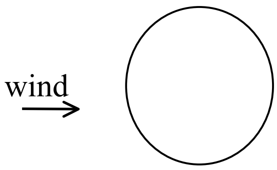
(a) the value given in Table D4; or

(b) appropriate value specified in other International Codes acceptable to the Building Authority.

Table D1 : Height aspect factors C_h for enclosed building of generally uniform section

$\frac{\text{Height}}{\text{Breadth}}$	Height aspect factor C_h
1.0 or less	0.95
2.0	1.0
4.0	1.05
6.0	1.1
10.0	1.2
20.0 and over	1.4
Note : Linear interpolation may be used to obtain intermediate values.	

Table D2 : Shape factors C_s for enclosed buildings of generally uniform section

General plan shape	Shape factor C_s
Rectangular  $\frac{b}{d}$ = [1.0 or less 2.0 3.0 and over	1.0 1.1 1.3 Interpolate linearly
Circular  	0.75
Other shapes	Value of C_s for the respective enclosing rectangular shape in the direction of the wind.

Note: When the actual shape of a building renders it to become sensitive to wind acting not perpendicular to its face, the diagonal wind effects and torsional wind effects should be considered.

Table D3 : Reduction factors R_A for enclosed buildings according to frontal projected area

Frontal projected area, m^2	Reduction factor R_A
500 or less	1.00
800	0.97
1 000	0.96
3 000	0.92
5 000	0.89
8 000	0.86
10 000	0.84
15 000 and over	0.80
Note : 1. Linear interpolation may be used to obtain intermediate values.	

Table D4 : Force coefficients C_f for open framework buildings

Solidity ratio φ	Force coefficient C_f
0.01	2.0
0.1	1.9
0.2	1.8
0.3	1.7
0.4	1.7
0.5	1.6
0.8	1.6
0.9	1.8
1.0	2.0

Note :
1. The solidity ratio φ is equal to the effective projected area of the open framework building divided by the area enclosed by the boundary of the frame normal to the direction of the wind.
2. Linear interpolation may be used to obtain intermediate values.

APPENDIX E : TOTAL PRESSURE COEFFICIENTS C_p FOR INDIVIDUAL ELEMENTS

E1. The total pressure coefficient C_p for individual elements in a particular area of an enclosed building shall be :-

(a) in the case where there is only a negligible probability of a dominant opening occurring during a severe storm, the value given in Table E1; and

(b) in the case where a dominant opening is likely to occur during a severe storm, the value determined with the aid of other published materials acceptable to the Building Authority or through the use of wind tunnel model studies.

E2. The total pressure coefficient C_p for individual members of an open framework building shall be :-

(a) 2.0; or

(b) appropriate value specified in other International Codes acceptable to Building Authority.

Table E1 : Total pressure coefficients C_p for individual elements of enclosed buildings with negligible probability of dominant opening

Walls and claddings			
(a) edge zones of the building	- 1.4 or + 1.0		
(b) other surfaces	- 1.0 or + 1.0		
Flat roofs			
(a) edge zones of the roof	- 2.2		
(b) other surfaces	- 1.2		
	roof angle		
	10°	30°	60°
Pitched roofs			
(a) edge zones of roof	- 2.2	- 1.7	- 1.0
(b) ridge zones of the roof	- 1.4	- 1.3	- 1.0
(c) other surfaces :			
(i) wind across ridge, windward surface	- 1.4	- 1.2 or + 0.3	+1.0
(ii) wind across ridge, leeward surface	- 0.8	- 0.7	- 0.8
(iii) wind parallel to ridge	- 1.0	- 1.0	- 1.0
	(interpolate linearly)		

Canopies (a) edge zones (b) other areas	 +2.0 and -2.0 +1.2 and -1.2

Note : 1. Negative value of Cp indicates that the resultant force is outwards or upwards.

2. Where alternative coefficients are given the element should be designed to accept both loading conditions.

3. Edge zones of the building are the areas within a distance from the edge of the building equal to 0.25 times the lesser horizontal dimension of the building.

4. Edge zones of the roof are the areas within a distance from the edge of the roof equal to 0.15 times the lesser horizontal dimension of the roof.

5. Ridge zones of the roof are the areas within a distance from the ridge of the roof equal to 0.15 times the span of the pitched roof.

6. Canopies means any structure which projects more than 500 mm from any wall of any building to provide protection from rain or sun and at a height of not more than 7.5m above the level of ground.

7. Edge zones of the canopy are the areas within a distance from the edge of the canopy equal to 0.2 times the span of the canopy.

APPENDIX F : DYNAMIC ANALYSIS

F1. The along-wind dynamic response of a building shall be assessed using the gust response factor method. The method involves an assessment of dynamic magnification factor which represents the amount by which the hourly mean wind forces shall be multiplied to account for dynamic behaviour. The dynamic magnification factor G may be taken as the values from Table F1 or Table F2, or determined by using the following equation :-

$$G = 1 + 2\,I_h \sqrt{g_v^{\,2} B + \frac{g_f^{\,2} S E}{\zeta}}$$

where I_h is the turbulence intensity at the top of the building which shall be taken as $0.1055\ (h\ /\ 90)^{-0.11}$ where h is equal to the height of the building in metres.

g_v is the peak factor for background response which is taken to be 3.7

g_f is the peak factor for resonance response and is equal to $\sqrt{2 \log_e (3600\, n_a)}$ where n_a is the fundamental natural frequency of the building in Hertz which can be taken as 46/h or determined by a more detailed analysis.

B is a background factor which is a measure of the slowly varying background component of the fluctuating response caused by the lower frequency wind speed variation and is equal to

$$\frac{1}{1 + \dfrac{\sqrt{36 h^2 + 64 b^2}}{L_h}}$$

where h = height of the building in metres

b = the breadth of the building in metres

L_h = the effective turbulence length scale $= 1000 \left(\dfrac{h}{10}\right)^{0.25}$

E is the wind energy spectrum and is equal to $\dfrac{0.47N}{\left(2 + N^2\right)^{5/6}}$

Where N = effective reduced frequency $= \dfrac{n_a L_h}{\bar{V}_h}$

S is the size factor to account for the correlation of pressures over a building and is equal to

$$\frac{1}{\left[1+\frac{3.5\, n_a h}{\overline{V}_h}\right]\left[1+\frac{4\, n_a b}{\overline{V}_h}\right]}$$

where n_a = the fundamental natural frequency of the building in hertz
= 46/h, or determined by a more detailed analysis

$\overline{V}_h$ = the design hourly-mean wind speed at height h which shall be taken as the values given in Table F3.

E is the wind energy spectrum and is equal to $\dfrac{0.47N}{\left(2+N^2\right)^{5/6}}$

Where $N = \text{effective reduced frequency} = \dfrac{n_a L_h}{\overline{V}_h}$

ζ is the damping ratio of the fundamental mode. This shall normally be taken as 1.5% for steel structures and 2% for reinforced concrete structures. For particularly slender buildings, lower values may be appropriate and specialist advice should be sought. Stocky buildings may have higher damping values.

Table F1 : Dynamic Magnification Factor G for ζ = 1.5%

Breadth (m) / Height (m)	20	30	40
200	1.994	1.955	1.922
180	1.983	1.943	1.909
160	1.972	1.930	1.896
140	1.959	1.916	1.882
120	1.945	1.902	1.868
100	1.929	1.886	1.853

Note : For intermediate values, linear interpolation is permitted.

Table F2: Dynamic Magnification Factor G for $\zeta = 2.0\%$

Height (m) \ Breadth (m)	20	30	40
200	1.907	1.874	1.847
180	1.900	1.867	1.840
160	1.894	1.859	1.832
140	1.886	1.851	1.824
120	1.879	1.843	1.816
100	1.871	1.836	1.808

Note : For intermediate values, linear interpolation is permitted.

Table F3 : Design hourly-mean wind velocity

Height above site-ground level	Design hourly-mean wind velocity $\overline{V}$ (m/s)
≤ 5 m	35.8
10 m	38.7
20 m	41.7
30 m	43.6
50 m	46.2
75 m	48.3
100 m	49.8
150 m	52.1
200m	53.8
250m	55.1
300m	56.2
400m	58.0
>500m	59.5

Note : For intermediate values of height, linear interpolation is permitted.