

## Lecture notes for CE 248 Behavior of plastic design of steel structures

Topic: Wind Loads

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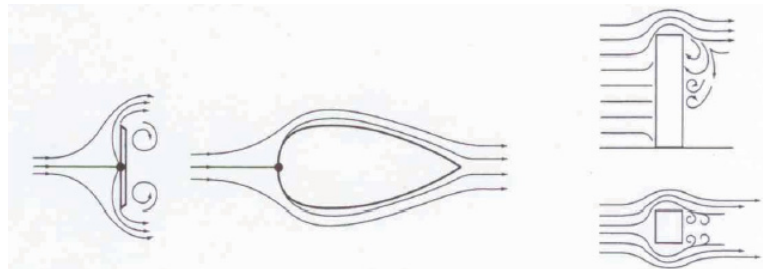
Date: September 5<sup>th</sup> 2006

Text:

1. ASCE 7 – 02 (or 05): Minimum Design Loads for Building and Other Structures.
2. Structural analysis 3<sup>rd</sup> edition by A. Kassimali.
3. Fundamental of structural analysis 2<sup>nd</sup> edition by K. Leet and C.M. Uang.
4. Structural analysis 6<sup>th</sup> edition by R.C. Hibbeler.

### Wind loads:

- What creates wind?
  - As the sun shines on the earth different parts of the land and sea heat at different speeds. This results in high and low pressure areas and leads to the lift and fall of air masses across the entire globe. Due to the angle of the earth while rotating the majority of the heat falls upon the middle of the world (equator) and much less towards the ice caps of the northern and southern hemisphere this means that as the warm air rises on the equator the cold air is pulled in from the ice caps. This spreads the warmth across the globe and results in moving air patterns.
  - See Figure 2.1.
- What is wind load?
  - Wind is air in motion. Structure deflects or stops the wind, converting the wind's kinetic energy into potential energy of pressure, thus create wind loads.
- The intensity of the wind pressure depends on
  - Shape of structure.
  - Angle of the induce wind.
  - Velocity of air.
  - Density of air.
  - Stiffness of structure.
- Wind velocity increases with the power of the structural height.
  - Because of friction effect on the ground surface.
  - See Figure 2.2.
- Air flow
  - The more the air is streamed, the less the reaction force exerted by the structure.



Structural analysis 3<sup>rd</sup> edition by A. Kassimali.

- Figure 2.6, 2.13.
- Situation of closely packed structures.
- Dynamic effects of wind
  - Vortex shedding.
    - As wind moved at constant speed and suddenly the air particle are stopped by the surface friction. Small mass of the restrained air will periodically break off and created the process of vortex shedding. The change in velocity causes the change in pressure and creates excitation to the structure.
    - See Figure 2.13
  - Resonance.
    - Tacoma narrows bridge.
- Solutions to prevent resonance caused by vortex shedding
  - Spoilers
  - Dampers
  - Modify the natural period of the structure to be away from the resonance.
- Design procedures: **ASCE 7-02 Section 6** (pg 23).
  - Static: wind force is replaced by equivalent static force.
    - Simplified procedure: **ASCE 7-02 Section 6.4** (pg 26)
    - Analytical procedure: **ASCE 7-02 Section 6.5** (pg 27)
  - Dynamic: wind tunnel testing.
    - Wind tunnel procedure: **ASCE 7-02 Section 6.6** (pg 34)
- Analytical procedure:
  - **6.5.1 Scope.** A building or other structure whose design wind loads are determined in accordance with this section shall meet all of the following conditions:
    1. The building or other structure is a regular-shaped building or structure as defined in Section 6.2.
    2. The building or other structure does not have response characteristics making it subject to across wind loading, vortex shedding, instability due to galloping or flutter; or does not have a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration.
  - Bernoulli equation for fluid flow,  $q$ 
    - $q = \frac{1}{2} \bar{\rho} V^2$  [psf]
    - Where  $\bar{\rho} =$  mass density of air  $= \rho/g$ ,  $\rho =$  air density  $= 0.07651$  pcf (at about  $15^0$ ),  $g =$  gravitational constant  $= 32.185 \text{ ft/sec}^2$  and  $V =$  wind velocity in mph.  $1 \text{ mph} = 1.46636 \text{ ft/sec}$ .  
 $\Rightarrow q = \frac{1}{2} \bar{\rho} V^2 = \frac{1}{2} \frac{0.07651}{32.185} (1.46635)^2 = 0.00256 V^2$ .
    - $q = 0.00256 K_z K_{zr} K_d V^2 I$  [psf] **ASCE 7-02 Equation 6-15** (pg 31)
  - Basic wind speed:  $V$

- **ASCE 7-02 Figure 6-1** (pg 36) except as provided in **ASCE 7-02 section 6.5.4.1** and **section 6.5.4.2**.
    - Measured by anemometer located 33 ft above the ground in open terrain and represents the wind speed that have 2% probability of exceeding in any given year.
  - Wind directionality factor:  $K_d$ 
    - The factor accounts for two effects: 1) reduced the possibility of maximum winds coming from any direction and 2) reduced the probability of maximum pressure coefficient occurring for any given wind direction.
    - **ASCE 7-02 Table 6.4** (pg 76)
    - In the previous ASCE 7 edition, a load factor of 1.3 has been assigned to wind load that includes a wind directionality factor of 0.85, but this version has decided to take this factor out from the load combination. Hence a footnote has been added to Table 6.4 to indicate the  $K_d$  factor should only be used when combined with the load combination factor presented in **ASCE 7-02 Section 2.4.2 and Section 2.4.3**.
  - Importance factor:  $I$ 
    - **ASCE 7-02 Table 6.1** (pg 73)
  - Velocity pressure exposure coefficient:  $K_z, K_h$ 
    - Accounts for influence of both height above ground and exposure factor.
    - Definition of exposure categories => **ASCE 7-02 Section 6.5.6** (pg 28).
    - Surface roughness categories. **ASCE 7-02 Section 6.5.6.2** (pg 28).  
Exposure categories: **ASCE 7-02 Section 6.5.6.3** (pg 29).

Exposure	Categories	Zg [ft]	$\alpha$
Urban, suburban and wooded area. The terrain must prevail in the upwind direction for a distance of 2630 ft or 10 time the structure height, which ever is greater	B	1200	7
Applies to all building not in B or D	C	900	9.5
Flat, unobstructed areas and water surfaces outside hurricane prone area. The terrain must prevail in the upwind direction for a distance of 5000 ft or 10 time the structure height, which ever is greater	D	700	11.5



- Background response  $Q = \sqrt{\frac{1}{1 + 0.63 \left( \frac{B+h}{L_z} \right)^{0.63}}}$
- $L_z = l \left( \bar{Z} / 33 \right)^{\bar{\epsilon}}$ ,  $l$  and  $\bar{\epsilon}$  are obtained from ASCE 7-02 Table 6.2 (pg 74)
  - Flexible structure or dynamic sensitive structure:
    - $G_f = 0.925 \left( \frac{1 + 1.7 I_z \sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1 + 1.7 g_v I_z} \right)$
    - See ASCE 7-02 Section 6.5.8.2 (pg 30) for more details.
- Pressure coefficient:  $C_p$ 
  - ASCE 7-02 Figure 6-6, 6-7 and 6-8 (pg 51 ~ 53).
- Combine  $G C_p$ 
  - ASCE 7-02 Figure 6-10 to 6-17 (pg 55 ~ pg 67).
- Define enclosure classifications:
  - ASCE 7-02 Section 6.5.9 (pg 30).
  - Categories: **enclosed, partially enclosed and open.**
- Design wind load on enclosed and partially enclosed building
  - ASCE 7-02 Section 6.5.12 (pg 32).
  - Rigid building of all height
    - $p = q G C_p - q_i G C_{pi}$
- Design wind load for signs
  - ASCE 7-02 Section 6.5.13 (pg 34).
  - $F = q_z G C_f A_f$
  - $C_f$  = net force coefficient => ASCE 7-02 Figure 6-18 to 6-22 (pg 68 ~ pg 72).
- Minimum horizontal wind pressure for design building = 10 psf.
- Additional notes:
  - $F = q \times A$ . How to reduce the forces as  $z$  increases?
    - $z$  increase =>  $q$  increase. To reduce  $F$  at higher level,  $A$  can be reduced => for example: Eiffel tower.

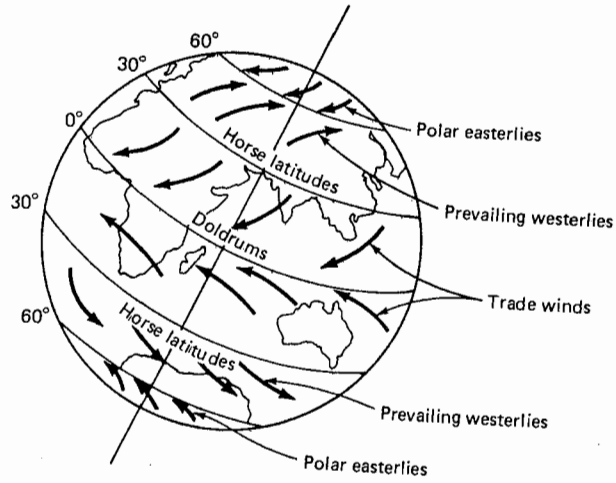


Figure 2.1 Circulation of world's winds.

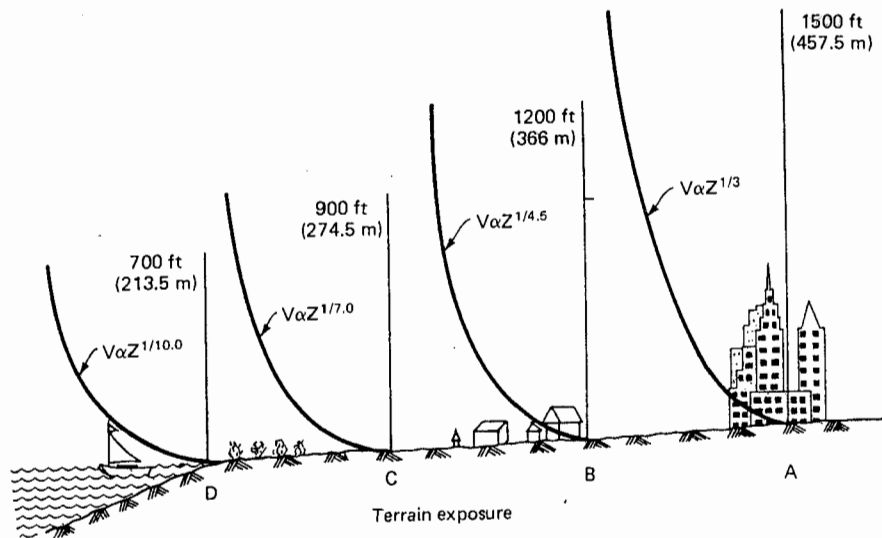


Figure 2.2 Variation of wind velocity with height.

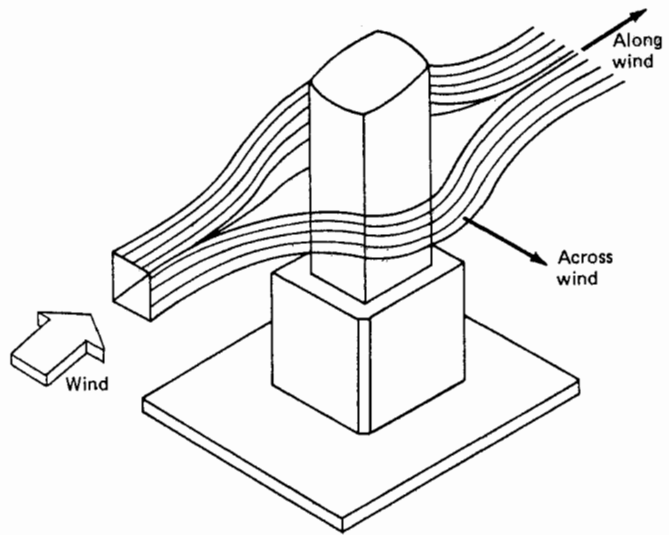


Figure 2.6 Simplified two-dimensional flow of wind.

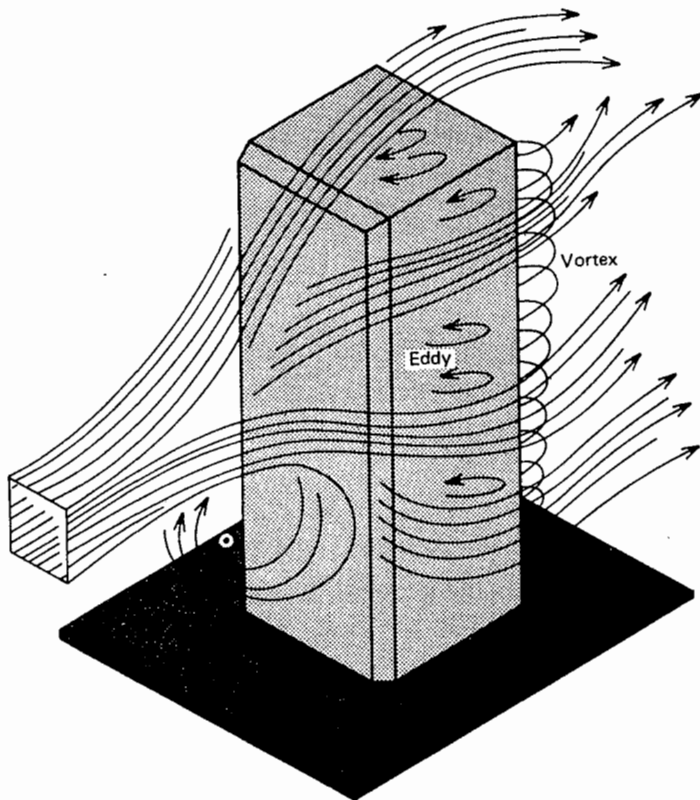


Fig. 2.13

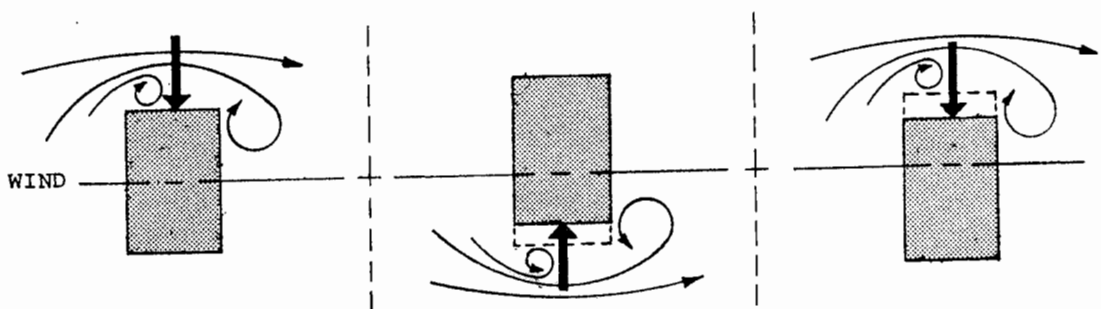
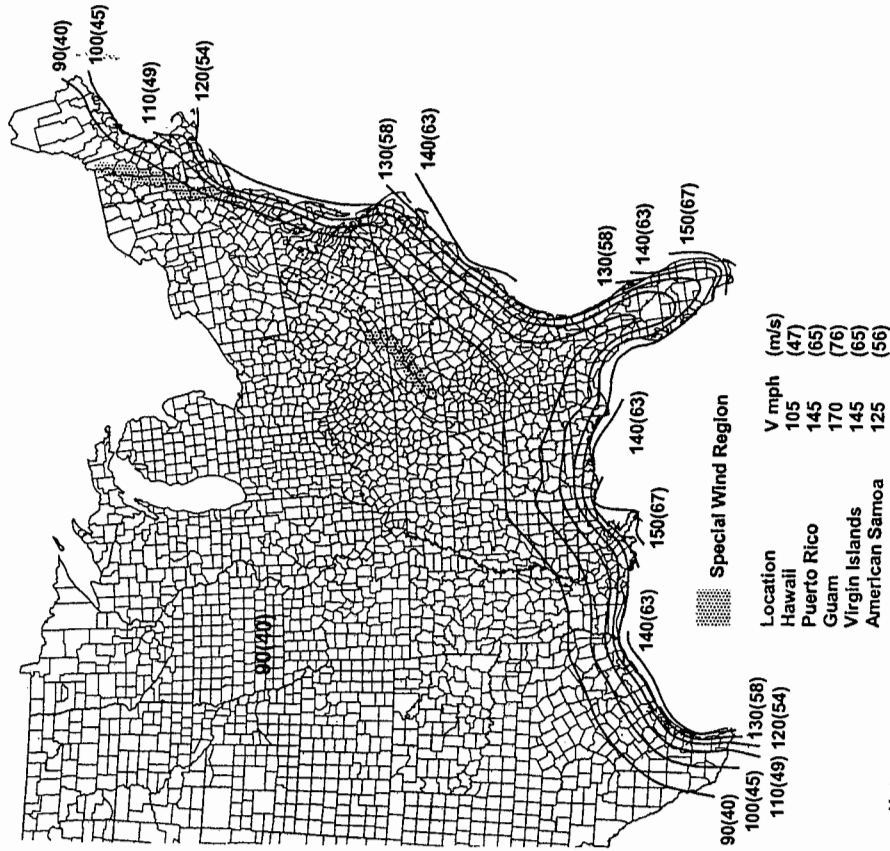


Fig. 2.14



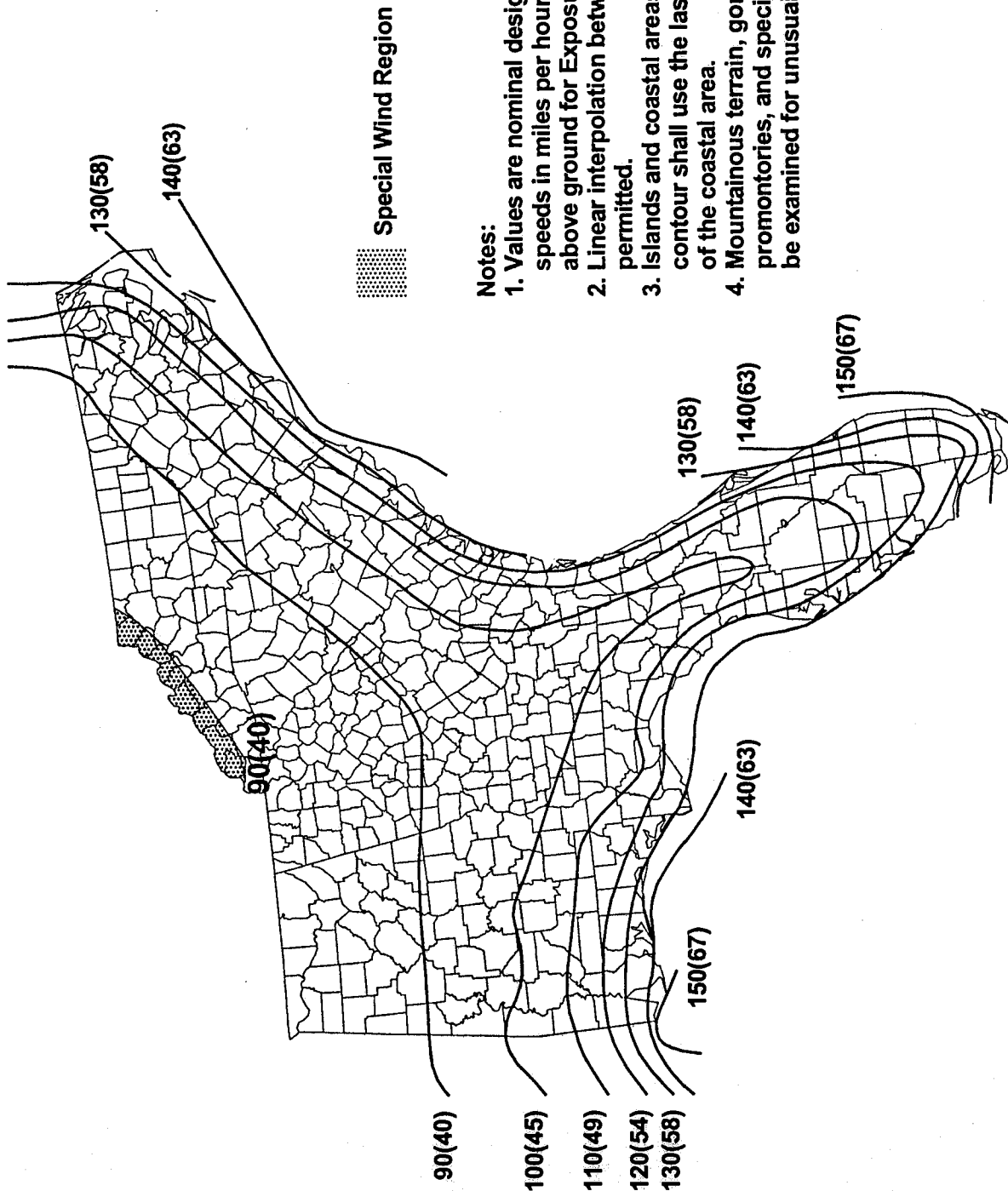
FIGURE 6-1  
BASIC WIND SPEED



Notes:

1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

FIGURE 6-1 -- continued  
BASIC WIND SPEED



Notes:

1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

FIGURE 6-1b  
BASIC WIND SPEED — EASTERN GULF OF MEXICO AND SOUTHEASTERN US HURRICANE COASTLINE

**Wind Directionality Factor,  $K_d$** **Table 6-4**

Structure Type	Directionality Factor $K_d$ *
<b>Buildings</b>	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
<b>Arched Roofs</b>	0.85
<b>Chimneys, Tanks, and Similar Structures</b>	
Square	0.90
Hexagonal	0.95
Round	0.95
<b>Solid Signs</b>	0.85
<b>Open Signs and Lattice Framework</b>	0.85
<b>Trussed Towers</b>	
Triangular, square, rectangular	0.85
All other cross sections	0.95

\*Directionality Factor  $K_d$  has been calibrated with combinations of loads specified in Section 2. This factor shall only be applied when used in conjunction with load combinations specified in 2.3 and 2.4.

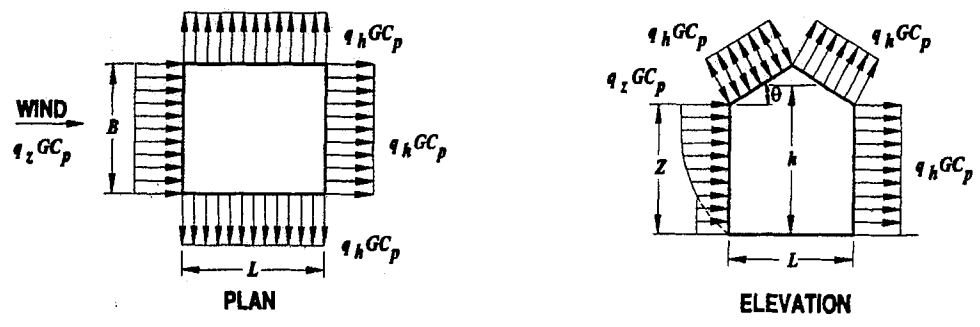
**Importance Factor, I (Wind Loads)****Table 6-1**

<b>Category</b>	<b>Non-Hurricane Prone Regions and Hurricane Prone Regions with V = 85-100 mph and Alaska</b>	<b>Hurricane Prone Regions with V &gt; 100 mph</b>
<b>I</b>	0.87	0.77
<b>II</b>	1.00	1.00
<b>III</b>	1.15	1.15
<b>IV</b>	1.15	1.15

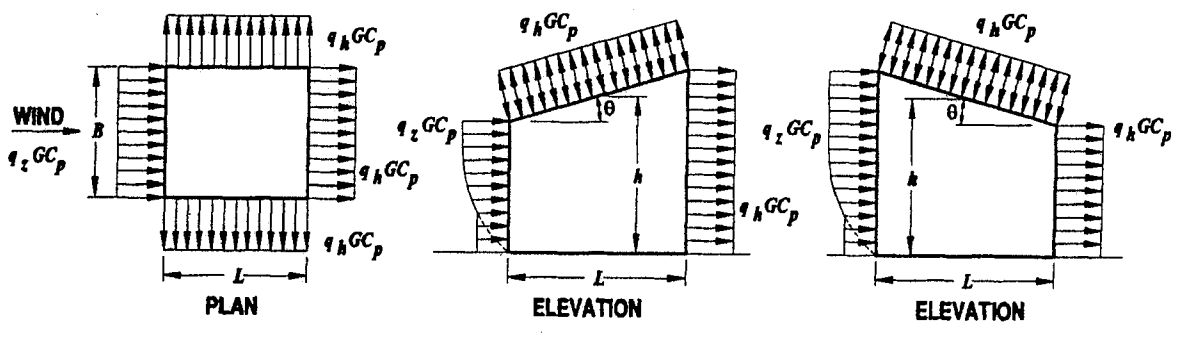
**Note:**

1. The building and structure classification categories are listed in Table 1-1.

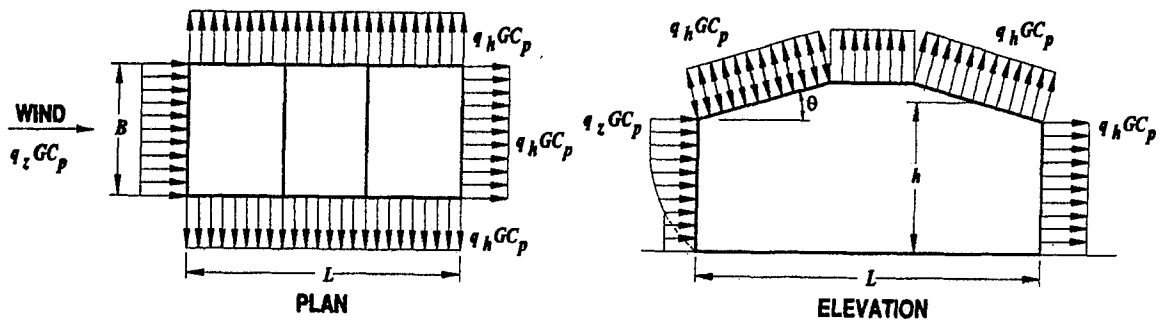
Main Wind Force Resisting System – Method 2		All Heights
Figure 6-6	External Pressure Coefficients, $C_p$	Walls & Roofs
Enclosed, Partially Enclosed Buildings		



GABLE, HIP ROOF



MONOSLOPE ROOF (NOTE 4)



MANSARD ROOF (NOTE 8)

Main Wind Force Resisting System – Method 2		All Heights
Figure 6-6 (con't)	External Pressure Coefficients, $C_p$	Walls & Roofs
Enclosed, Partially Enclosed Buildings		

Wall Pressure Coefficients, $C_p$			
Surface	L/B	$C_p$	Use With
Windward Wall	All values	0.8	$q_z$
Leeward Wall	0-1	-0.5	$q_h$
	2	-0.3	
	$\geq 4$	-0.2	
Side Wall	All values	-0.7	$q_h$

Roof Pressure Coefficients, $C_p$ , for use with $q_h$												
Wind Direction	Windward									Leeward		
	Angle, $\theta$ (degrees)											
	h/L	10	15	20	25	30	35	45	$\geq 60^\#$	10	15	$\geq 20$
Normal to ridge for $\theta \geq 10^\circ$	$\leq 0.25$	-0.7 -0.18	-0.5 0.0*	-0.3 0.2	-0.2 0.3	-0.2 0.3	0.0* 0.4	0.4	0.01 $\theta$	-0.3	-0.5	-0.6
	0.5	-0.9 -0.18	-0.7 -0.18	-0.4 0.0*	-0.3 0.2	-0.2 0.2	-0.2 0.3	0.0* 0.4	0.01 $\theta$	-0.5	-0.5	-0.6
	$\geq 1.0$	-1.3** -0.18	-1.0 -0.18	-0.7 -0.18	-0.5 0.0*	-0.3 0.2	-0.2 0.2	0.0* 0.3	0.01 $\theta$	-0.7	-0.6	-0.6
Normal to ridge for $\theta < 10^\circ$ and Parallel to ridge for all $\theta$	$\leq 0.5$	Horiz distance from windward edge			$C_p$		*Value is provided for interpolation purposes. **Value can be reduced linearly with area over which it is applicable as follows					
		0 to h/2			-0.9, -0.18							
		H/2 to h			-0.9, -0.18							
		h to 2h			-0.5, -0.18							
$\geq 1.0$	$> 2h$				-0.3, -0.18		Area (sq ft)		Reduction Factor			
		0 to h/2			-1.3**, -0.18		$\leq 100$ (9.3 sq m)		1.0			
		$> h/2$			-0.7, -0.18		200 (23.2 sq m)		0.9			
					$\geq 1000$ (92.9 sq m)		0.8					

**Notes:**

1. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
  2. Linear interpolation is permitted for values of L/B, h/L and  $\theta$  other than shown. Interpolation shall only be carried out between values of the same sign. Where no value of the same sign is given, assume 0.0 for interpolation purposes.
  3. Where two values of  $C_p$  are listed, this indicates that the windward roof slope is subjected to either positive or negative pressures and the roof structure shall be designed for both conditions. Interpolation for intermediate ratios of h/L in this case shall only be carried out between  $C_p$  values of like sign.
  4. For monoslope roofs, entire roof surface is either a windward or leeward surface.
  5. For flexible buildings use appropriate  $G_f$  as determined by Section 6.5.8.
  6. Refer to Figure 6-7 for domes and Figure 6-8 for arched roofs.
  7. Notation:  
 B: Horizontal dimension of building, in feet (meter), measured normal to wind direction.  
 L: Horizontal dimension of building, in feet (meter), measured parallel to wind direction.  
 h: Mean roof height in feet (meters), except that eave height shall be used for  $\theta \leq 10$  degrees.  
 z: Height above ground, in feet (meters).  
 G: Gust effect factor.  
 $q_z, q_h$ : Velocity pressure, in pounds per square foot ( $N/m^2$ ), evaluated at respective height.  
 $\theta$ : Angle of plane of roof from horizontal, in degrees.
  8. For mansard roofs, the top horizontal surface and leeward inclined surface shall be treated as leeward surfaces from the table.
  9. Except for MWFRS's at the roof consisting of moment resisting frames, the total horizontal shear shall not be less than that determined by neglecting wind forces on roof surfaces.
- #For roof slopes greater than  $80^\circ$ , use  $C_p = 0.8$

**Terrain Exposure Constants**

**Table 6-2**

Exposure	$\alpha$	$z_g$ (ft)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	$l$ (ft)	$\bar{\epsilon}$	$z_{min}$ (ft)*
<b>B</b>	7.0	1200	1/7	0.84	1/4.0	0.45	0.30	320	1/3.0	30
<b>C</b>	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
<b>D</b>	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

\* $z_{min}$  = minimum height used to ensure that the equivalent height  $\bar{z}$  is greater of  $0.6h$  or  $z_{min}$ .  
 For buildings with  $h \leq z_{min}$ ,  $\bar{z}$  shall be taken as  $z_{min}$ .

Velocity Pressure Exposure Coefficients,  $K_h$  and  $K_z$

Table 6-3

Height above ground level, z		Exposure (Note 1)			
		B		C	D
ft	(m)	Case 1	Case 2	Cases 1 & 2	Cases 1 & 2
0-15	(0-4.6)	0.70	0.57	0.85	1.03
20	(6.1)	0.70	0.62	0.90	1.08
25	(7.6)	0.70	0.66	0.94	1.12
30	(9.1)	0.70	0.70	0.98	1.16
40	(12.2)	0.76	0.76	1.04	1.22
50	(15.2)	0.81	0.81	1.09	1.27
60	(18)	0.85	0.85	1.13	1.31
70	(21.3)	0.89	0.89	1.17	1.34
80	(24.4)	0.93	0.93	1.21	1.38
90	(27.4)	0.96	0.96	1.24	1.40
100	(30.5)	0.99	0.99	1.26	1.43
120	(36.6)	1.04	1.04	1.31	1.48
140	(42.7)	1.09	1.09	1.36	1.52
160	(48.8)	1.13	1.13	1.39	1.55
180	(54.9)	1.17	1.17	1.43	1.58
200	(61.0)	1.20	1.20	1.46	1.61
250	(76.2)	1.28	1.28	1.53	1.68
300	(91.4)	1.35	1.35	1.59	1.73
350	(106.7)	1.41	1.41	1.64	1.78
400	(121.9)	1.47	1.47	1.69	1.82
450	(137.2)	1.52	1.52	1.73	1.86
500	(152.4)	1.56	1.56	1.77	1.89

Notes:

- Case 1:**

  - All components and cladding.
  - Main wind force resisting system in low-rise buildings designed using Figure 6-10.

**Case 2:**

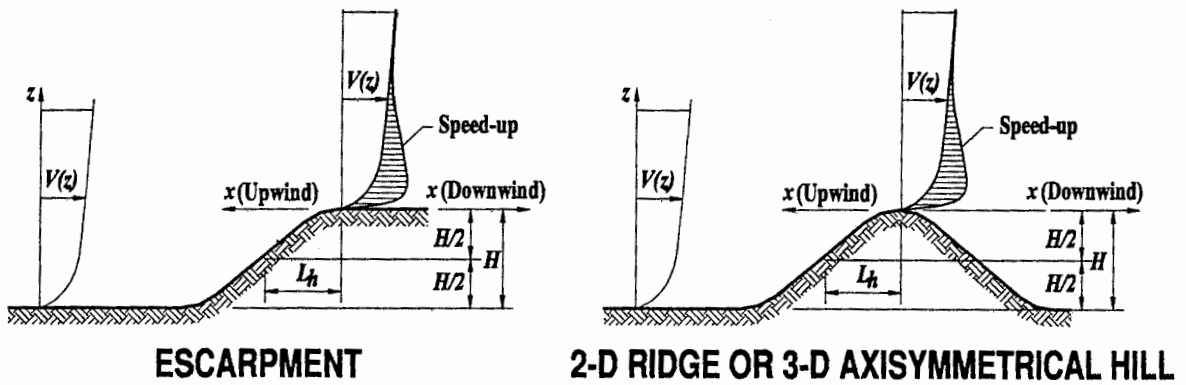
  - All main wind force resisting systems in buildings except those in low-rise buildings designed using Figure 6-10.
  - All main wind force resisting systems in other structures.
- The velocity pressure exposure coefficient  $K_z$  may be determined from the following formula:

For $15 \text{ ft.} \leq z \leq z_g$	For $z < 15 \text{ ft.}$
$K_z = 2.01 (z/z_g)^{2/\alpha}$	$K_z = 2.01 (15/z_g)^{2/\alpha}$

Note: z shall not be taken less than 30 feet for Case 1 in exposure B.
- $\alpha$  and  $z_g$  are tabulated in Table 6-2.
- Linear interpolation for intermediate values of height z is acceptable.
- Exposure categories are defined in 6.5.6.

Topographic Factor,  $K_{zt}$  – Method 2

Figure 6-4



ESCARPMENT

2-D RIDGE OR 3-D AXISYMMETRICAL HILL

Topographic Multipliers for Exposure C

$H/L_h$	$K_1$ Multiplier			$x/L_h$	$K_2$ Multiplier		$z/L_h$	$K_3$ Multiplier		
	2-D Ridge	2-D Escarp.	3-D Axisym. Hill		2-D Escarp.	All Other Cases		2-D Ridge	2-D Escarp.	3-D Axisym. Hill
0.20	0.29	0.17	0.21	0.00	1.00	1.00	0.00	1.00	1.00	1.00
0.25	0.36	0.21	0.26	0.50	0.88	0.67	0.10	0.74	0.78	0.67
0.30	0.43	0.26	0.32	1.00	0.75	0.33	0.20	0.55	0.61	0.45
0.35	0.51	0.30	0.37	1.50	0.63	0.00	0.30	0.41	0.47	0.30
0.40	0.58	0.34	0.42	2.00	0.50	0.00	0.40	0.30	0.37	0.20
0.45	0.65	0.38	0.47	2.50	0.38	0.00	0.50	0.22	0.29	0.14
0.50	0.72	0.43	0.53	3.00	0.25	0.00	0.60	0.17	0.22	0.09
				3.50	0.13	0.00	0.70	0.12	0.17	0.06
				4.00	0.00	0.00	0.80	0.09	0.14	0.04
							0.90	0.07	0.11	0.03
							1.00	0.05	0.08	0.02
							1.50	0.01	0.02	0.00
							2.00	0.00	0.00	0.00

Notes:

- For values of  $H/L_h$ ,  $x/L_h$  and  $z/L_h$  other than those shown, linear interpolation is permitted.
- For  $H/L_h > 0.5$ , assume  $H/L_h = 0.5$  for evaluating  $K_1$  and substitute  $2H$  for  $L_h$  for evaluating  $K_2$  and  $K_3$ .
- Multipliers are based on the assumption that wind approaches the hill or escarpment along the direction of maximum slope.

4. Notation:

- H: Height of hill or escarpment relative to the upwind terrain, in feet (meters).
- $L_h$ : Distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment, in feet (meters).
- $K_1$ : Factor to account for shape of topographic feature and maximum speed-up effect.
- $K_2$ : Factor to account for reduction in speed-up with distance upwind or downwind of crest.
- $K_3$ : Factor to account for reduction in speed-up with height above local terrain.
- x: Distance (upwind or downwind) from the crest to the building site, in feet (meters).
- z: Height above local ground level, in feet (meters).
- $\mu$ : Horizontal attenuation factor.
- $\gamma$ : Height attenuation factor.

**Topographic Factor,  $K_{zt}$  – Method 2**

**Figure 6-4 (cont'd)**

**Equations:**

$$K_{zt} = (1 + K_1 K_2 K_3)^2$$

$K_1$  determined from table below

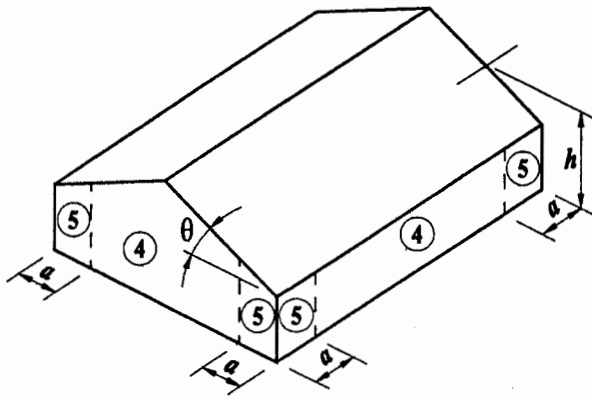
$$K_2 = \left(1 - \frac{|x|}{\mu L_h}\right)$$

$$K_3 = e^{-\gamma z/L_h}$$

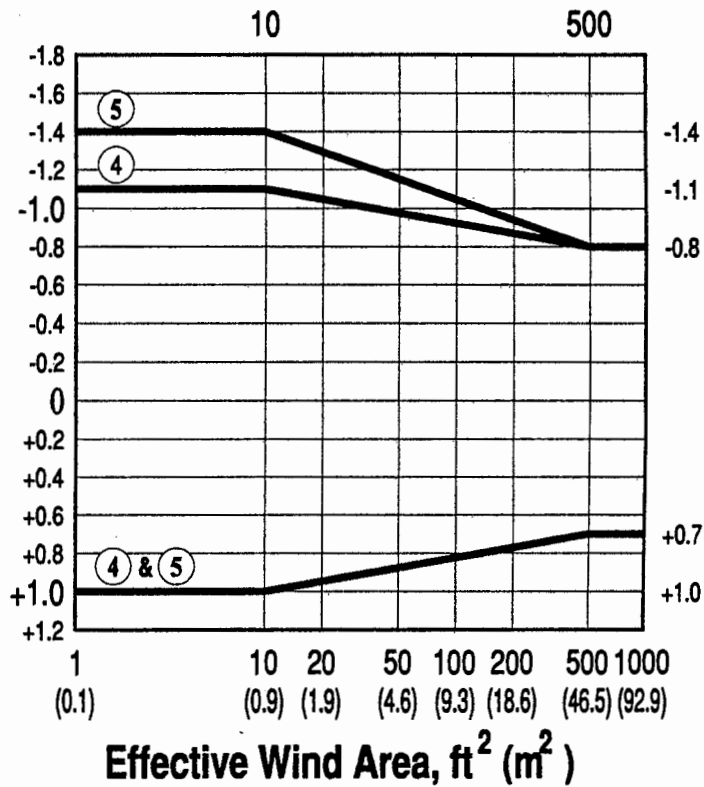
**Parameters for Speed-Up Over Hills and Escarpments**

Hill Shape	$K_1/(H/L_h)$			$\gamma$	$\mu$	
	Exposure				Upwind of Crest	Downwind of Crest
	B	C	D			
2-dimensional ridges (or valleys with negative H in $K_1/(H/L_h)$ )	1.30	1.45	1.55	3	1.5	1.5
2-dimensional escarpments	0.75	0.85	0.95	2.5	1.5	4
3-dimensional axisym. hill	0.95	1.05	1.15	4	1.5	1.5

<b>Main Wind Force Res. Sys. / Comp and Clad. – Method 2</b>		<b>All Heights</b>								
<b>Figure 6-5</b>	<b>Internal Pressure Coefficient, <math>GC_{pi}</math></b>	<b>Walls &amp; Roofs</b>								
<b>Enclosed, Partially Enclosed, and Open Buildings</b>										
<table border="1"> <thead> <tr> <th><b>Enclosure Classification</b></th> <th><b><math>GC_{pi}</math></b></th> </tr> </thead> <tbody> <tr> <td><b>Open Buildings</b></td> <td>0.00</td> </tr> <tr> <td><b>Partially Enclosed Buildings</b></td> <td>+0.55 -0.55</td> </tr> <tr> <td><b>Enclosed Buildings</b></td> <td>+0.18 -0.18</td> </tr> </tbody> </table>			<b>Enclosure Classification</b>	<b><math>GC_{pi}</math></b>	<b>Open Buildings</b>	0.00	<b>Partially Enclosed Buildings</b>	+0.55 -0.55	<b>Enclosed Buildings</b>	+0.18 -0.18
<b>Enclosure Classification</b>	<b><math>GC_{pi}</math></b>									
<b>Open Buildings</b>	0.00									
<b>Partially Enclosed Buildings</b>	+0.55 -0.55									
<b>Enclosed Buildings</b>	+0.18 -0.18									
<p><b>Notes:</b></p> <ol style="list-style-type: none"> <li>1. Plus and minus signs signify pressures acting toward and away from the internal surfaces, respectively.</li> <li>2. Values of <math>GC_{pi}</math> shall be used with <math>q_z</math> or <math>q_h</math> as specified in 6.5.12.</li> <li>3. Two cases shall be considered to determine the critical load requirements for the appropriate condition: <ol style="list-style-type: none"> <li>(i) a positive value of <math>GC_{pi}</math> applied to all internal surfaces</li> <li>(ii) a negative value of <math>GC_{pi}</math> applied to all internal surfaces</li> </ol> </li> </ol>										

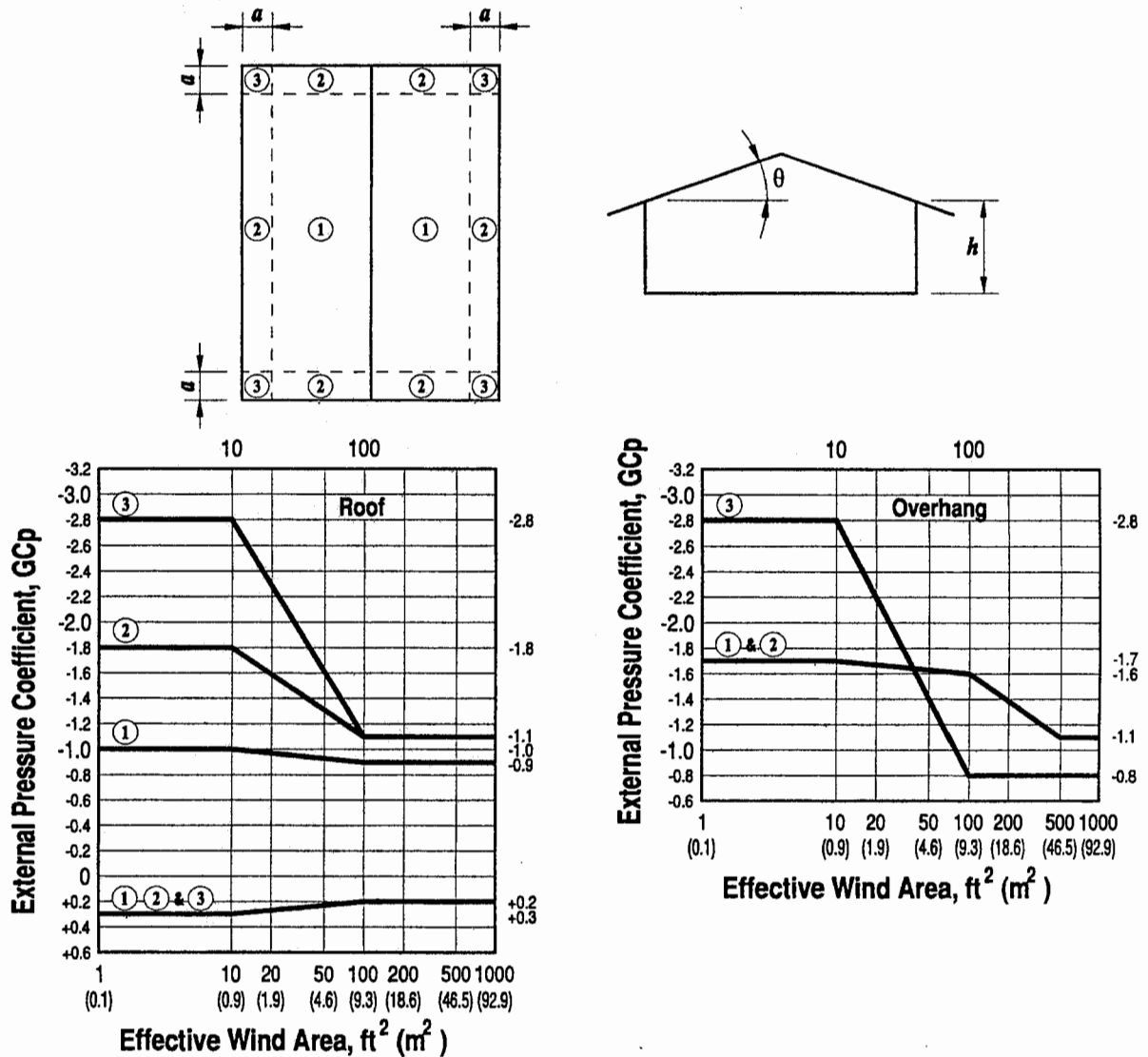


External Pressure Coefficient,  $GC_p$



Notes:

1. Vertical scale denotes  $GC_p$  to be used with  $q_h$ .
2. Horizontal scale denotes effective wind area, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Each component shall be designed for maximum positive and negative pressures.
5. Values of  $GC_p$  for walls shall be reduced by 10% when  $\theta \leq 10^\circ$ .
6. Notation:
  - a: 10 percent of least horizontal dimension or  $0.4h$ , whichever is smaller, but not less than either 4% of least horizontal dimension or 3 ft (0.9 m).
  - h: Mean roof height, in feet (meters), except that eave height shall be used for  $\theta \leq 10^\circ$ .
  - $\theta$ : Angle of plane of roof from horizontal, in degrees.



**Notes:**

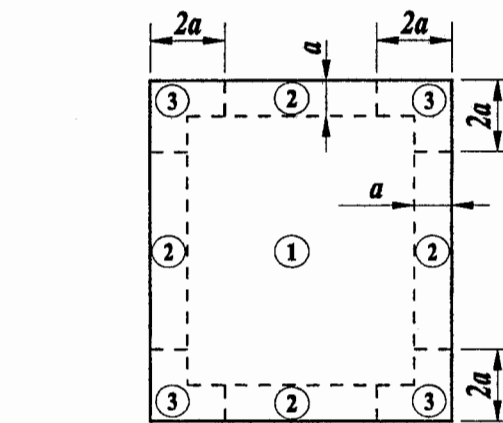
1. Vertical scale denotes  $GC_p$  to be used with  $q_h$ .
2. Horizontal scale denotes effective wind area, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Each component shall be designed for maximum positive and negative pressures.
5. If a parapet equal to or higher than 3 ft (0.9m) is provided around the perimeter of the roof with  $\theta \leq 7^\circ$ , Zone 3 shall be treated as Zone 2.
6. Values of  $GC_p$  for roof overhangs include pressure contributions from both upper and lower surfaces.
7. Notation:
  - $a$ : 10 percent of least horizontal dimension or  $0.4h$ , whichever is smaller, but not less than either 4% of least horizontal dimension or 3 ft (0.9 m).
  - $h$ : Eave height shall be used for  $\theta \leq 10^\circ$ .
  - $\theta$ : Angle of plane of roof from horizontal, in degrees.

Figure 6-17

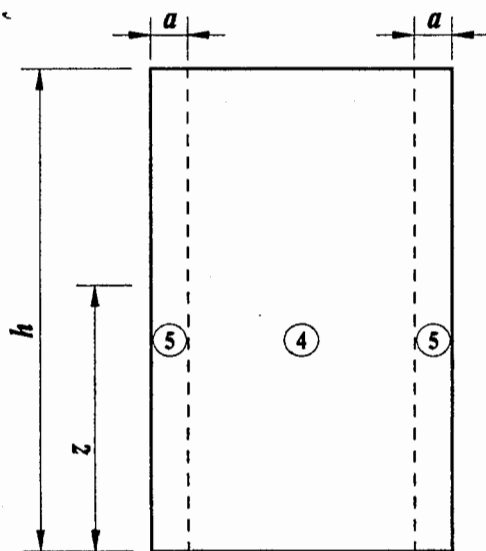
External Pressure Coefficients,  $GC_p$

Enclosed, Partially Enclosed Buildings

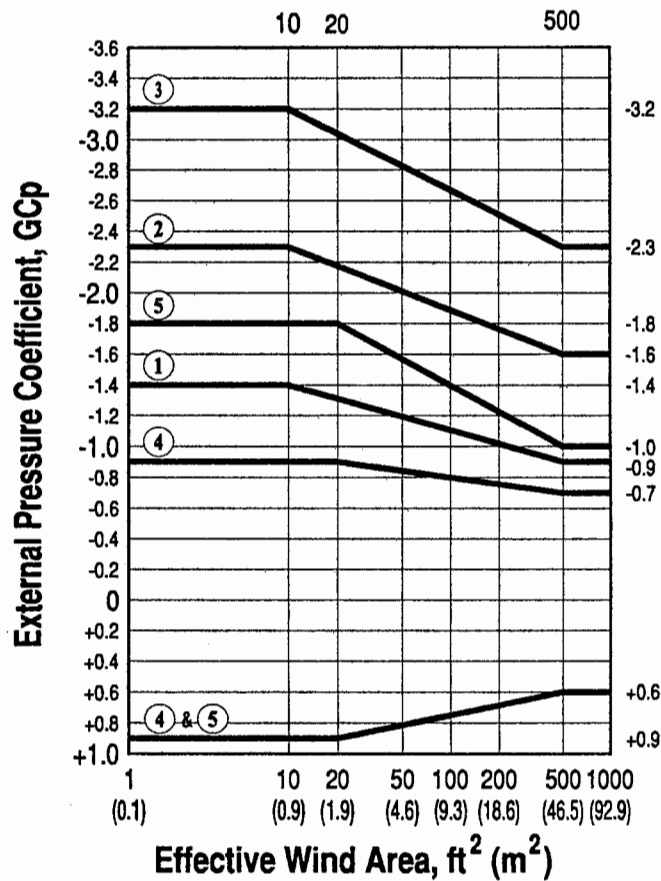
Walls & Roofs



ROOF PLAN



WALL ELEVATION



Notes:

1. Vertical scale denotes  $GC_p$  to be used with appropriate  $q_z$  or  $q_h$ .
2. Horizontal scale denotes effective wind area  $A$ , in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Use  $q_z$  with positive values of  $GC_p$  and  $q_h$  with negative values of  $GC_p$ .
5. Each component shall be designed for maximum positive and negative pressures.
6. Coefficients are for roofs with angle  $\theta \leq 10^\circ$ . For other roof angles and geometry, use  $GC_p$  values from Fig. 6-11 and attendant  $q_h$  based on exposure defined in 6.5.6.
7. If a parapet equal to or higher than 3 ft (0.9m) is provided around the perimeter of the roof with  $\theta \leq 10^\circ$ , Zone 3 shall be treated as Zone 2.
8. Notation:
  - $a$ : 10 percent of least horizontal dimension, but not less than 3 ft (0.9 m).
  - $h$ : Mean roof height, in feet (meters), except that eave height shall be used for  $\theta \leq 10^\circ$ .
  - $z$ : height above ground, in feet (meters).
  - $\theta$ : Angle of plane of roof from horizontal, in degrees.

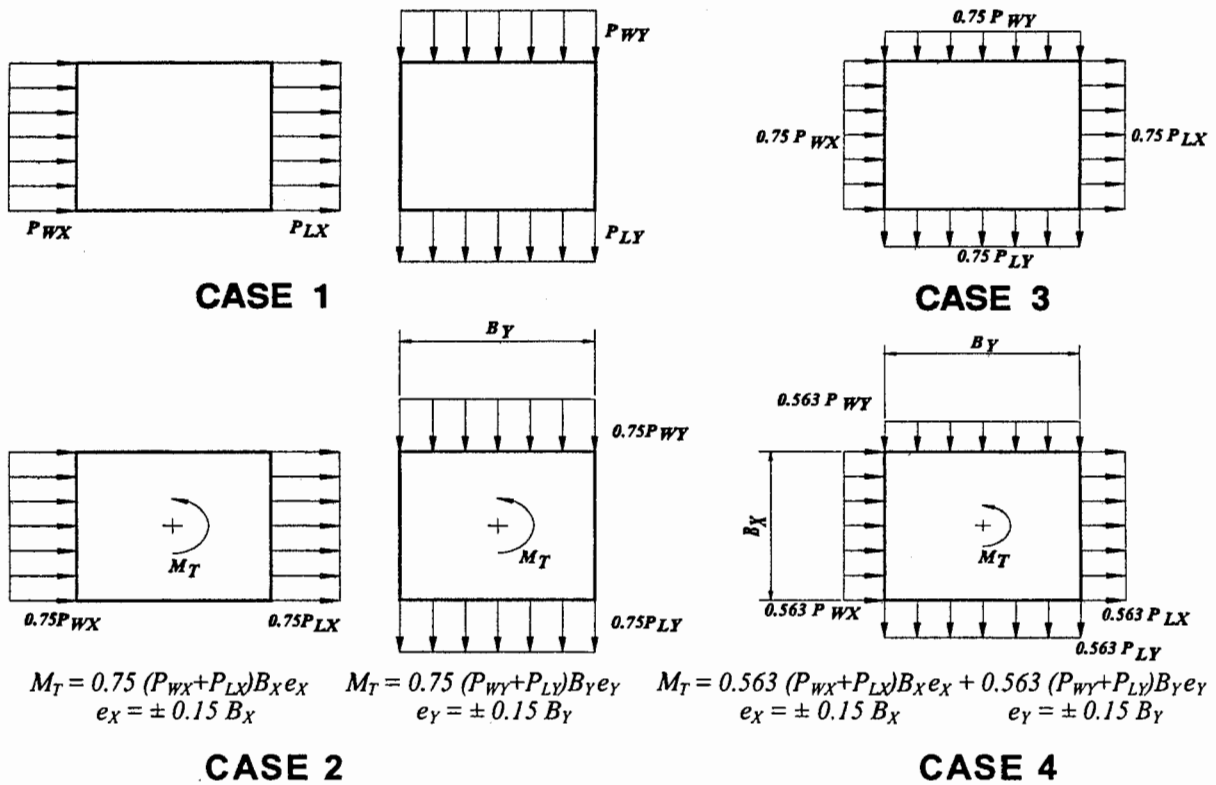
<b>Main Wind Force Resisting System – Method 2</b>		<b>All Heights</b>
<b>Figure 6-18</b>	<b>Force Coefficients, <math>C_r</math></b>	<b>Monoslope Roofs</b>
<b>Open Buildings</b>		

Roof angle $\theta$ degrees	L/B						
	5	3	2	1	1/2	1/3	1/5
10	0.2	0.25	0.3	0.45	0.55	0.7	0.75
15	0.35	0.45	0.5	0.7	0.85	0.9	0.85
20	0.5	0.6	0.75	0.9	1.0	0.95	0.9
25	0.7	0.8	0.95	1.15	1.1	1.05	0.95
30	0.9	1.0	1.2	1.3	1.2	1.1	1.0

Roof angle $\theta$ degrees	Center of Pressure X/L		
	L/B		
	2 to 5	1	1/5 to 1/2
10 to 20	0.35	0.3	0.3
25	0.35	0.35	0.4
30	0.35	0.4	0.45

**Notes:**

1. Wind forces act normal to the surface. Two cases shall be considered: (1) wind forces directed inward; and (2) wind forces directed outward.
2. The roof angle shall be assumed to vary  $\pm 10^\circ$  from the actual angle and the angle resulting in the greatest force coefficient shall be used.
3. Notation:
  - B*: dimension of roof measured normal to wind direction, in feet (meters);
  - L*: Dimension of roof measured parallel to wind direction, in feet (meters);
  - X*: Distance to center of pressure from windward edge of roof, in feet (meters); and
  - $\theta$ : Angle of plane of roof from horizontal, in degrees.



- Case 1.** Full design wind pressure acting on the projected area perpendicular to each principal axis of the structure, considered separately along each principal axis.
- Case 2.** Three quarters of the design wind pressure acting on the projected area perpendicular to each principal axis of the structure in conjunction with a torsional moment as shown, considered separately for each principal axis.
- Case 3.** Wind loading as defined in Case 1, but considered to act simultaneously at 75% of the specified value.
- Case 4.** Wind loading as defined in Case 2, but considered to act simultaneously at 75% of the specified value.

**Notes:**

- Design wind pressures for windward and leeward faces shall be determined in accordance with the provisions of 6.5.12.2.1 and 6.5.12.2.3 as applicable for building of all heights.
- Diagrams show plan views of building.
- Notation:

$P_{WX}, P_{WY}$ : Windward face design pressure acting in the x, y principal axis, respectively.

$P_{LX}, P_{LY}$ : Leeward face design pressure acting in the x, y principal axis, respectively.

$e (e_x, e_y)$ : Eccentricity for the x, y principal axis of the structure, respectively.

$M_T$ : Torsional moment per unit height acting about a vertical axis of the building.