Calculation of Wind Loads on Structures according to ASCE 7-10

Permitted Procedures

The design wind loads for buildings and other structures, including the Main Wind-Force Resisting System (MWFRS) and component and cladding elements thereof, shall be determined using one of the procedures as specified in the following section. An outline of the overall process for the determination of the wind loads, including section references, is provided in Figure (1).

Main Wind-Force Resisting System (MWFRS)

Wind loads for MWFRS shall be determined using one of the following procedures:

(1) Directional Procedure for buildings of all heights as specified in Chapter 27 for buildings meeting the requirements specified therein;

(2) Envelope Procedure for low-rise buildings as specified in Chapter 28 for buildings meeting the requirements specified therein;

(3) Directional Procedure for Building Appurtenances (rooftop structures and rooftop equipment) and Other Structures (such as solid freestanding walls and solid freestanding signs, chimneys, tanks, open signs, lattice frameworks, and trussed towers) as specified in Chapter 29;

(4) Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31.

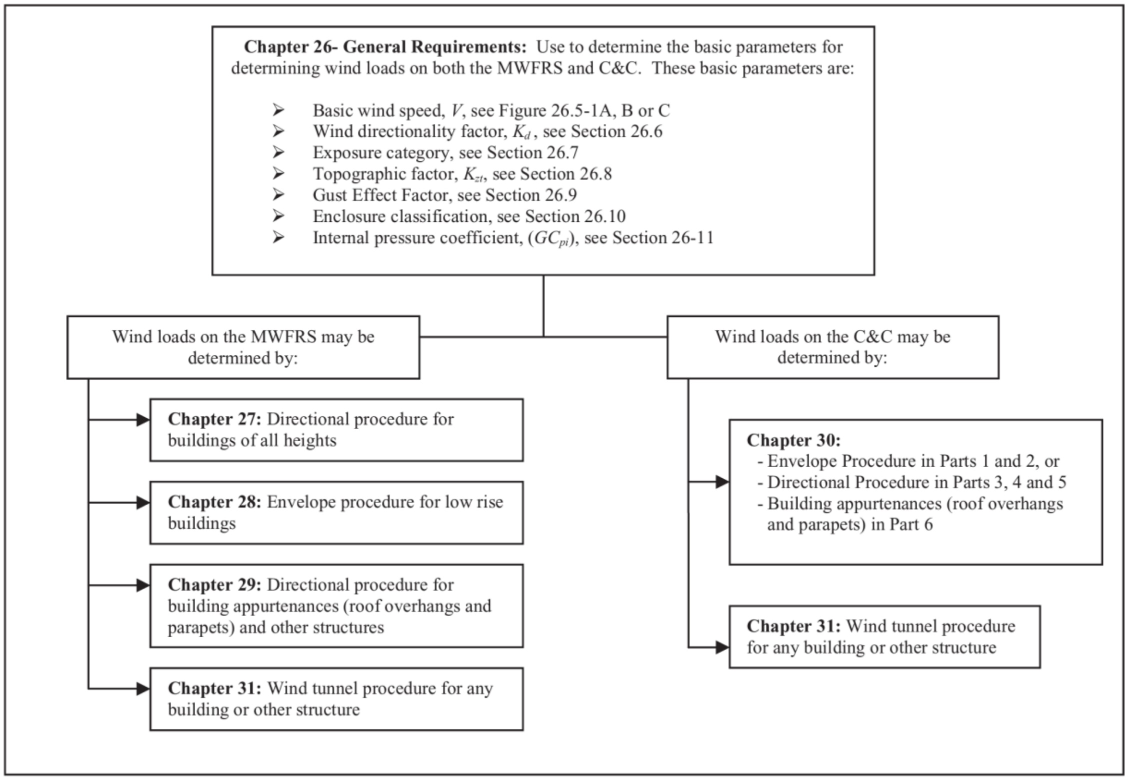


Figure (1): Dtermination of Wind Loads

Directional Procedure

Step 1: Determine risk category of building or other structure, see Table 1.5-1.

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life.	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	
Buildings and other structures designated as essential facilities.	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community.	
Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	

[a]Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

Step 2: Determine the basic wind speed, V, for the applicable risk category, see Figure 26.5-1A, B or C (United States). Basic wind speed is a three-second gust speed at 10 m above the ground in Exposure C.

Step 3: Determine wind load parameters:

- Wind directionality factor, K_d, see Table 26.6.1

Table 26.6.1: Wind directionality factor, K_d

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

- Exposure category, for each wind direction considered, the upwind exposure shall be based on ground surface roughness that is determined from natural topography, vegetation, and constructed facilities.

Surface Roughness B: Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.

Surface Roughness C: Open terrain with scattered obstructions having heights generally less than 9.1 m. This category includes flat open country and grasslands.

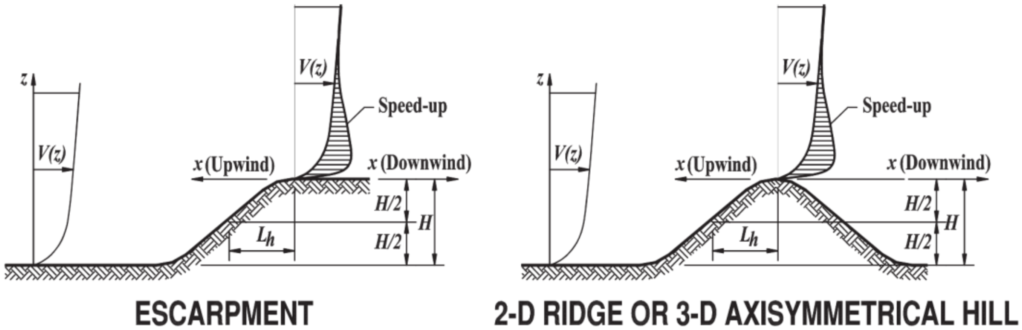
Surface Roughness D: Flat, unobstructed areas and water surfaces. This category includes smooth mud flats, salt flats, and unbroken ice.

- Topographic factor, K_{zt}, see Figure 26.8-1.

K_{zt} = $(1 + K_1K_2K_3)^2$, where K_1, K_2 and K_3 are given in Fig. 26.8-1. **For flat terrains, K_{zt} = . 0** .

Topographic Factor, K_{zt}

Figure 26.8-1



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:

1. For values of H/L_h, x/L_h and z/L_h other than those shown, linear interpolation is permitted.
2. 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.
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 ground surface at building site, in feet (meters).
   - μ: Horizontal attenuation factor.
   - γ: Height attenuation factor.

- Gust factor, G:

The gust effect factor for a rigid building is permitted to be taken as 0.85.

- Enclosure classification:

Open Building: A building having each wall at least 80 percent open. This condition is expressed for each wall by the equation $A_o \geq 0.8\ A_g$ where

A_o = total area of openings in a wall that receives positive external pressure
A_g = the gross area of that wall in which A_o is identified

Partially Enclosed Building: A building that complies with both of the following conditions:
1. The total area of openings in a wall that receives positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent.
2. The total area of openings in a wall that receives positive external pressure exceeds (0.37 m2) or 1 percent of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

Enclosed Building: It is a building that is not classified as open or partially enclosed.

- Internal pressure coefficient, GC_{pi}, see Table 26.11-1.

Table 26.11-1; Internal Pressure Coefficient

Enclosure Classification	(GC_{pi})
Open Buildings	0.00
Partially Enclosed Buildings	+0.55 -0.55
Enclosed Buildings	+0.18 -0.18

Notes:

1. Plus and minus signs signify pressures acting toward and away from the internal surfaces, respectively.
2. Values of (GC_{pi}) shall be used with q_z or q_h as specified.
3. Two cases shall be considered to determine the critical load requirements for the appropriate condition:

   (i) a positive value of (GC_{pi}) applied to all internal surfaces
   (ii) a negative value of (GC_{pi}) applied to all internal surfaces

Step 4: Determine velocity pressure exposure coefficient, $K_z \; or \; K_h$, see Table 27.3-1. Note that K_h is constant and calculated for mean height of the building, while K_z varies with heights measured from the base of the building.

Main Wind Force Resisting System – Part 1	All Heights
Velocity Pressure Exposure Coefficients, K_h and K_z	
Table 27.3-1	

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

Notes:

1. The velocity pressure exposure coefficient K_z may be determined from the following formula:

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

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

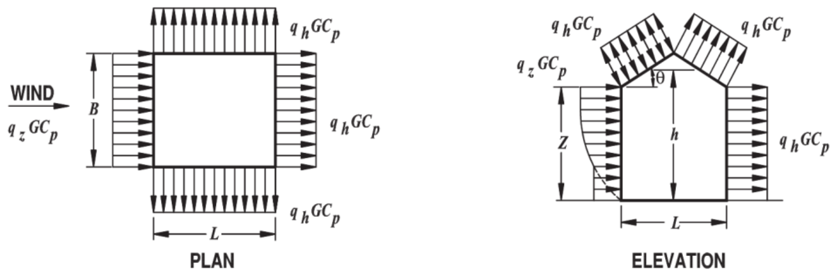
2. α and z_g are tabulated in Table 26.9.1.
3. Linear interpolation for intermediate values of height z is acceptable.
4. Exposure categories are defined in Section 26.7.

Step 5: Determine velocity pressure, $q_z \; or \; q_h$, see equation below.

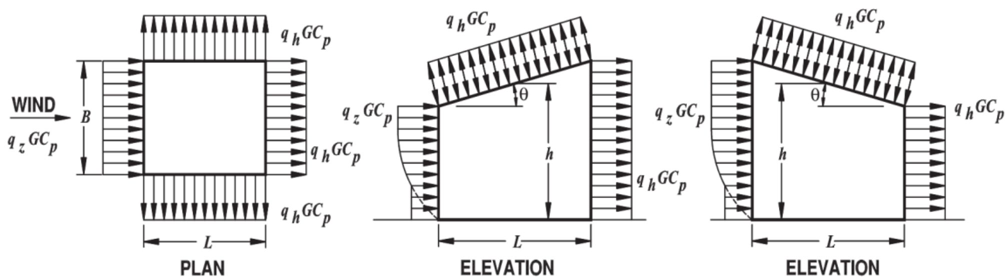
$q_z = 0.613 \; K_z \; K_{zt} \; K_d \; V^2$

where:
q_z = velocity pressure calculated at height z, (N/m^2)
q_h = velocity pressure calculated at mean roof height h, (N/m^2)
K_d = wind directionality factor
K_z = velocity pressure exposure coefficient
K_{zt} = topographic factor
V = basic wind speed, in m/s
Step 6: Determine external pressure coefficients, C_p (Figure 27.4-1)

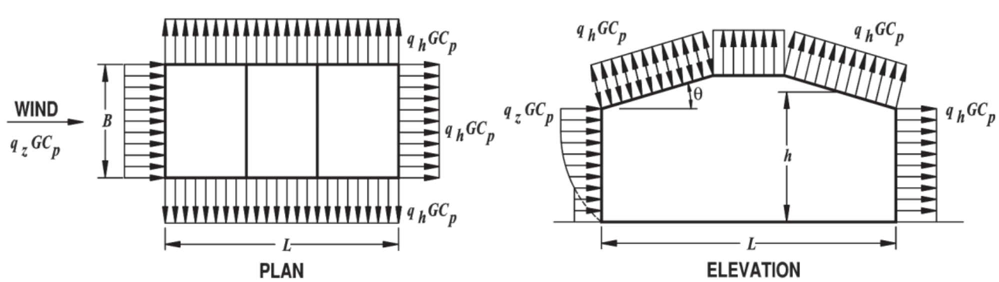
Main Wind Force Resisting System – Part 1		All Heights
Figure 27.4-1	External Pressure Coefficients, C_p	Walls & Roofs
Enclosed, Partially Enclosed Buildings		



GABLE, HIP ROOF



MONOSLOPE ROOF (NOTE 4)



MANSARD ROOF (NOTE 8)

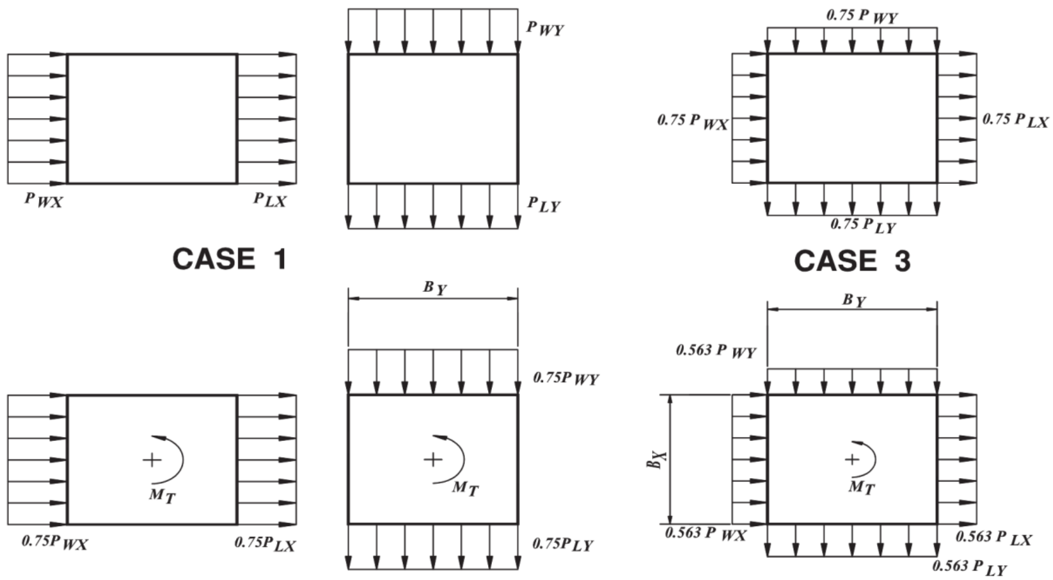
Wall Pressure Coefficients, C_p			
Surface	**L/B**	**C_p**	**Use With**
Windward Wall	All values	0.8	q_z
Leeward Wall	0-1	-0.5	q_h
	2	-0.3	
	≥4	-0.2	
Side Wall	All values	-0.7	q_h

Step 7: Determine wind pressure, p, on each building surface (enclosed and partially enclosed).

$$p = qG\ C_p - q_i(G\ C_{pi})$$

Design wind load cases are shown in Figure 27.4-8.

Main Wind Force Resisting System – Part 1		All Heights
Figure 27.4-8	Design Wind Load Cases	



$M_T = 0.75\ (P_{WX}+P_{LX})B_X e_X$ $\quad e_X = \pm\ 0.15\ B_X$

$M_T = 0.75\ (P_{WY}+P_{LY})B_Y e_Y$ $\quad e_Y = \pm\ 0.15\ B_Y$

CASE 2

$M_T = 0.563\ (P_{WX}+P_{LX})B_X e_X + 0.563\ (P_{WY}+P_{LY})B_Y e_Y$ $\quad e_X = \pm\ 0.15\ B_X \quad e_Y = \pm\ 0.15\ B_Y$

CASE 4

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:

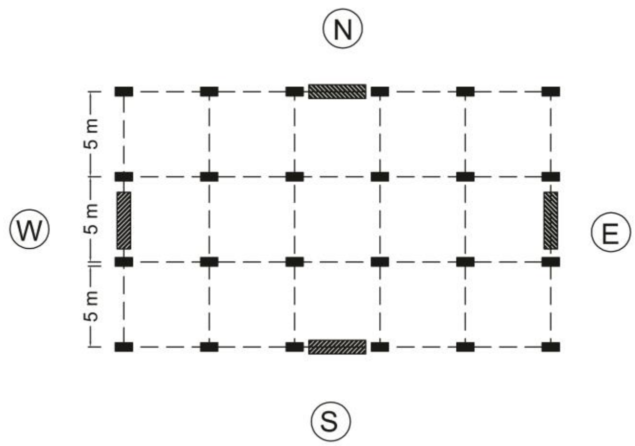
1. Design wind pressures for windward and leeward faces shall be determined in accordance with the provisions of 27.4.1 and 27.4.2 as applicable for building of all heights.
2. Diagrams show plan views of building.
3. Notation:

   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.

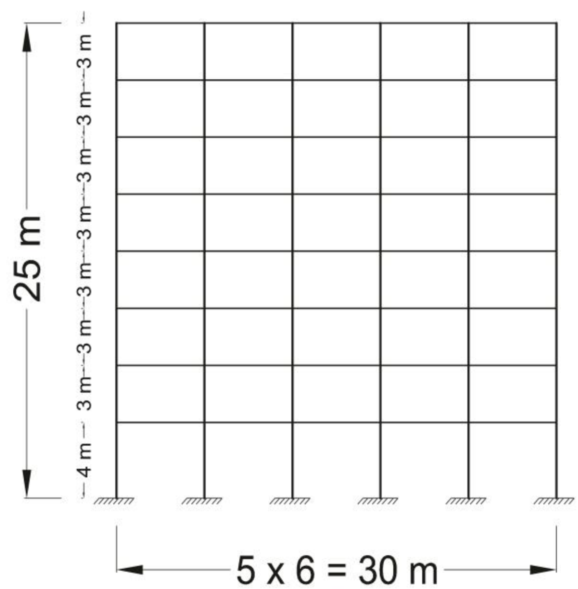
Example:

It is required to calculate the lateral wind loads acting on the 8-story building, considering the wind is acting first in the North-South direction. The building which is used as headquarter for police operation, is 30 m x 15 m in plan as shown in the figure (enclosed), and located right on the Gaza Beach (flat terrain).

Note: Use a basic wind speed of 100 Km/hr and ASCE 7-10 Directional Procedure.



Plan



Elevation

Step 1: Building risk category:

- Based on Table 1.5-1, building risk category is IV.

Step 2: Basic wind speed:

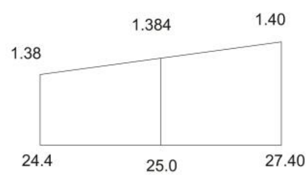
- It is given as 100 km/hr.

Step 3: Building wind load parameters:

- $K_d = 0.85$ (wind directionality factored evaluated from Table 26.6.1)
- Exposure category is *D*
- $K_{zt} = 1.0$ (Topographic factor for flat terrain)
- Gust factor, G , is 0.85 for rigid buildings
- Building is enclosed
- Internal pressure coefficient for enclosed buildings, GC_{pi} , is ± 0.18

Step 4: Velocity pressure coefficients, K_h and K_z :

- $K_h = 1.384$ (Interpolating from Table 27.3-1) and K_z varies with height



Step 5: Determine velocity pressure, q_h and q_z :

- $q_h = 0.613 K_h\ K_{zt}\ K_d\ V^2$

$$= 0.613(1.384)(1.0)(0.85)\left(\frac{100{,}000}{60*60}\right)^2 = 556.43\ N/m^2$$

- $q_z = 0.613\ K_z\ K_{zt}\ K_d\ V^2$

$$= 0.613(K_z)(1.0)(0.85)\left(\frac{100{,}000}{60*60}\right)^2 = 402.05\ K_z\ N/m^2$$

Step 6: External pressure coefficients, C_p :

For $L/B = \frac{15}{30} = 0.5$ and using Figure 27.4.1, the external pressure coefficients are shown in the figure.

Step 7: Wind pressure, p :

For the windward walls,

$$p = q_z\, G C_p - q_i \left(G C_{pi}\right)$$
$$= q_z\,(0.85)(0.8) - 556.43(0.85)(\pm 0.18)$$
$$= (0.68\, q_z \pm 85.13)\ N/m^2 \text{ (max)}$$

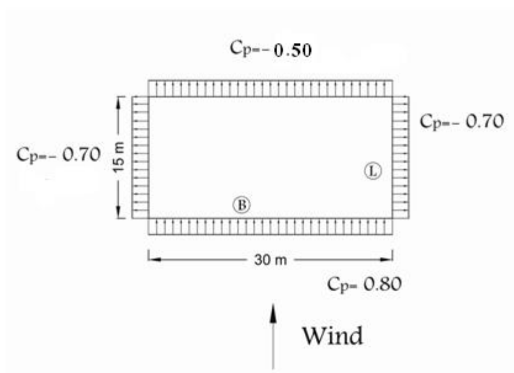
For the leeward walls,

$$p = q_h\, G C_p - q_i \left(G C_{pi}\right)$$
$$= 556.43(0.85)(-0.5) - 556.43(0.85)(\pm 0.18)$$
$$= -321.62\ N/m^2 \text{ (max)}$$

For the side walls,

$$p = q_h\, G C_p - q_i \left(G C_{pi}\right)$$
$$= 556.43(0.85)(-0.7) - 556.43(0.85)(\pm 0.18)$$
$$= -416.21\ N/m^2 \text{ (max)}$$

Height, meters	K_z	q_z	p
0 to 4.6 m	1.03	414.17	366.76
4.6 to 6.1m	1.08	434.17	380.36
6.1 to 7.6 m	1.12	450.28	391.32
7.6 to 9.1 m	1.16	466.39	402.27
9.1 to 12.2 m	1.22	490.56	418.71
12.2 to 15.2 m	1.27	510.56	432.31
15.2 to 18 m	1.31	526.67	443.26
18 to 21.3 m	1.34	538.89	451.57
21.3 to 24.4 m	1.38	554.72	462.34
24.4 to 25 m	1.40	562.78	467.82



Requirements for Structural Integrity

A structure is said to have structural integrity if localized damage does not spread progressively to other parts of the structure. Experience has shown that the overall integrity of a structure can be substantially enhanced by minor changes in detailing of reinforcement.

The 1989 ACI Code introduced section 7.13. which provides details to improve the integrity of joist construction, beams without stirrups and perimeter beams. These requirements were updated, and shown below.

- In detailing of reinforcement and connections, members of a structure shall be effectively tied together to improve integrity of the overall structure.
- In joist construction, at least one bottom bar shall be continuous and shall be anchored to develop f_y at the face of supports..
- Beams along the perimeter of the structure shall have continuous reinforcement consisting of:

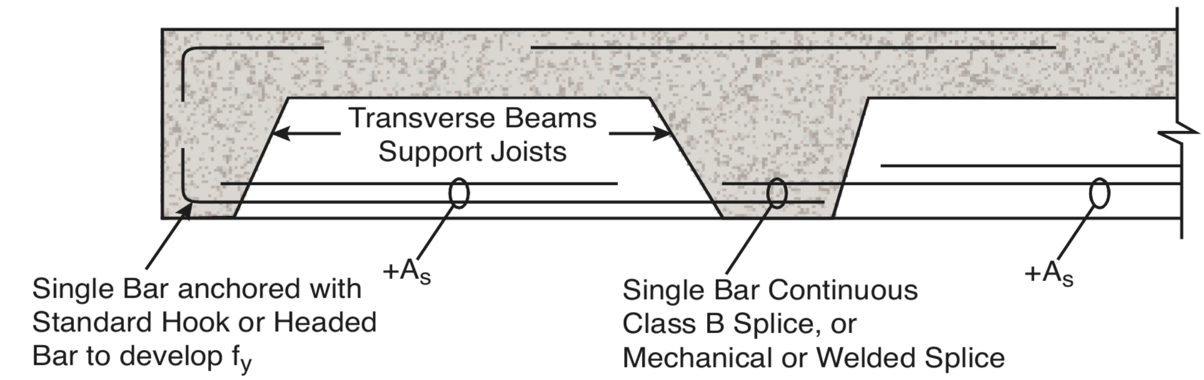
(a) at least 1/6 of the tension reinforcement required for negative moment at the support, but not less than 2 bars;

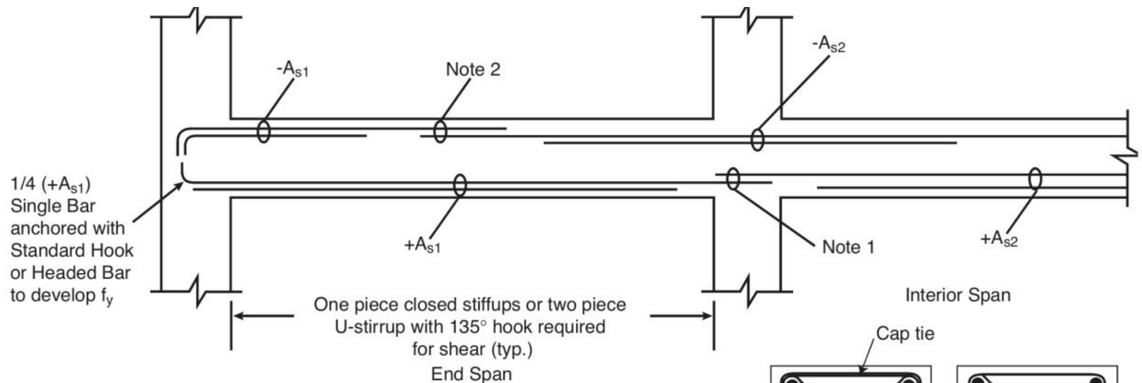
(b) at least ¼ of the tension reinforcement required for positive moment at mid span , but not less than 2 bars.

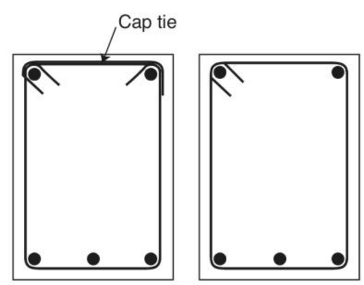
- The above reinforcement shall be enclosed by close stirrups or hoops along the clear span of the beam.

- Where splices are needed to provide the required continuity, top reinforcement shall be spliced at or near mid span and bottom reinforcement shall be spliced at or near the support. Splices shall be Class **B** tension lap splices or mechanical or welded splices.

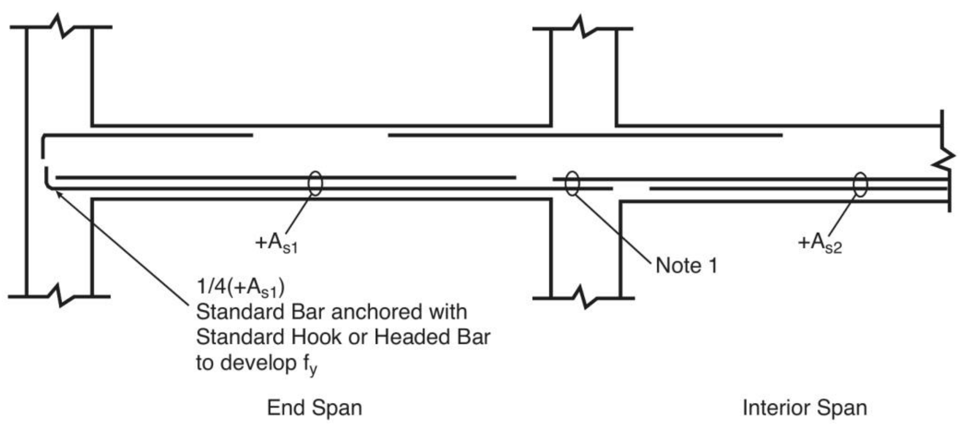
- In other than perimeter beams, structural integrity reinforcement shall be in accordance with (a) or (b):
  (a) At least 1/4 of the positive moment reinforcement required at mid span, but not less than 2 bars.
  (b) Longitudinal reinforcement shall be enclosed by closed stirrups or hoops along the clear span of the beam.







Notes: (1) Larger of (1/4) ($+A_{s1}$) or (1/4) ($+A_{s2}$) but not less than two bars continuous or spliced with Class B splices or mechanical or welded splices
(2) Larger of (1/6) ($-A_{s1}$) or (1/6) ($-A_{s2}$) but not less than two bars continuous or spliced with Class B splices or mechanical or welded splices



Notes: (1) Larger of (1/4)($+A_{s1}$) or (1/4)($+A_{s2}$) but not less than two bars continuous or spliced with Class B Splices or mechanical or welded splices

Diaphragm Key Components

Diaphragm Slab:

It is the component of the diaphragm which acts primarily to resist shear forced developed in the plane of the diaphragm.

Diaphragm Chords:

They are components along the diaphragm edges with increased longitudinal and transverse reinforcement, acting primarily to resist tension and compression forces generated by bending in the diaphragm.

Diaphragm Collectors:

They are components that serve to transmit the internal forces within the diaphragm to elements of the lateral force resisting system. They shall be monolithic with the slab, occurring either within the slab thickness or being thickened.

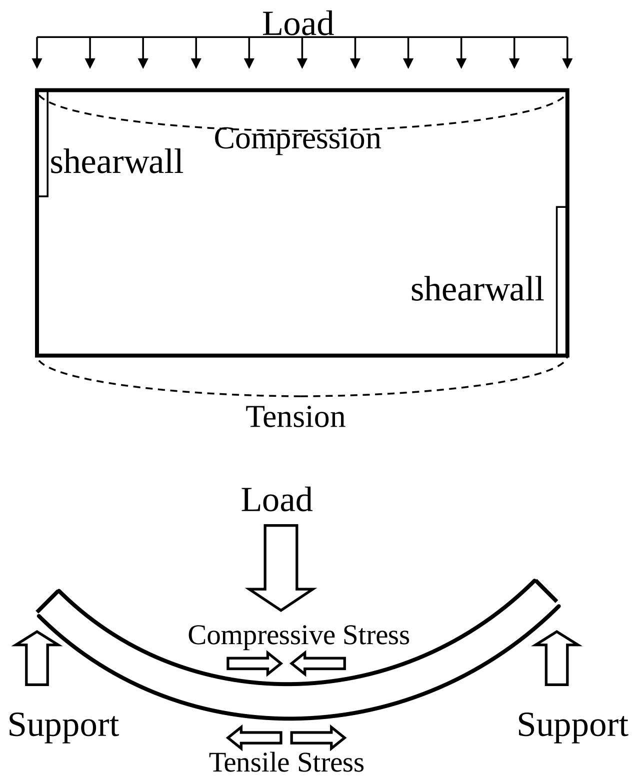
Diaphragm Struts:

They are components of a structural diaphragm used to provide continuity around an opening in the diaphragm. They shall be monolithic with the slab, occurring either within the slab thickness or being thickened.

Distribution of Forces:

For rigid diaphragms the distribution of forces to vertical elements will be essentially in proportion to their relative stiffness with respect to each other.

Diaphragm Chord / Beam Analogy



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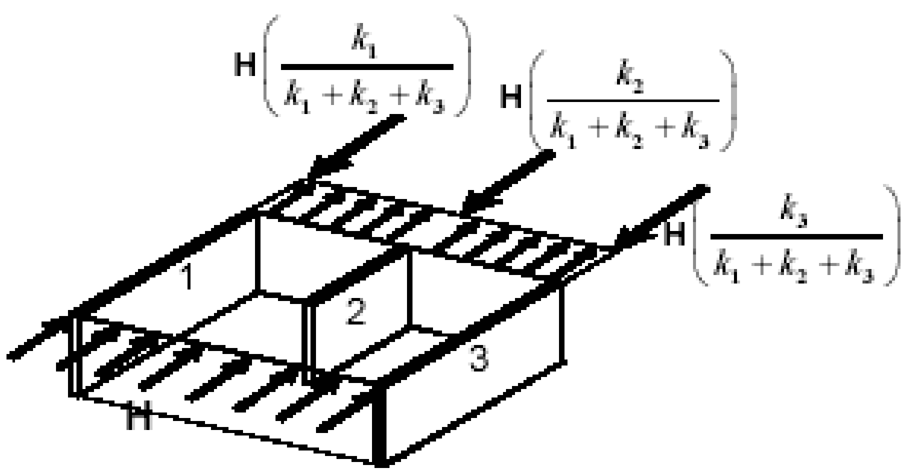
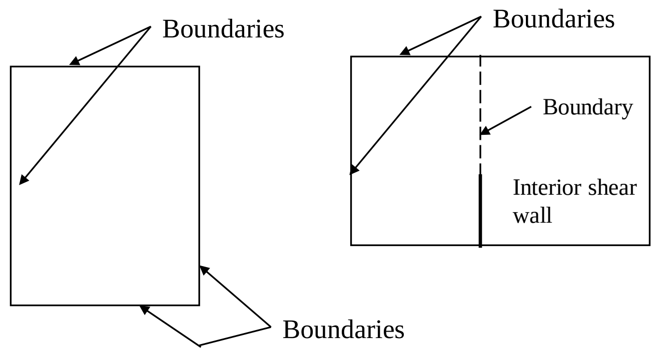
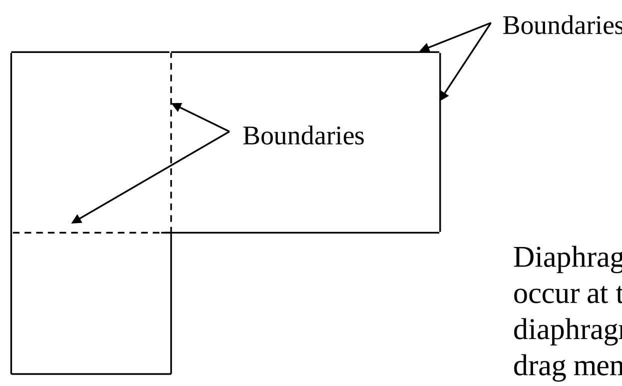


k_1, k_2 and k_3 are lateral stiffness of walls 1, 2 and 3 respectively.

Horizontal Diaphragm Boundaries





Diaphragm boundaries may not just occur at the perimeter of the diaphragm. Interior shear walls and drag members create diaphragm boundaries.

12

Requirements for Structural Diaphragms

Floor and roof slabs acting as structural diaphragms to transmit design actions induced by earthquake ground motions shall be designed in accordance with section 18.12 of ACI Code.

1- Scope:

Diaphragms are used in building construction are structural elements such as floors and roofs that provide some or all of the following actions:

- Support for building elements such as walls, partitions, and cladding resisting horizontal forces but not acting as part of the building vertical lateral force resisting system.
- Transfer of lateral forces from the point of application to the building vertical lateral force resisting system.
- Connection of various components of the building lateral force resisting system with appropriate stiffness so the building responds as intended in the design.

2- Minimum Thickness of Slab:

- Concrete slabs serving as structural diaphragms used to transmit earthquake forces shall not be less than 5 cm thick.

3- Reinforcement:

- The minimum reinforcement ratio for structural diaphragms shall not be less than the shrinkage and temperature reinforcement ratio. Reinforcement spacing each way shall not exceed 45 cm
- Diaphragm chord members and collector elements with compressive stresses exceeding $0.2 f_c'$ at any section shall have transverse reinforcement over the length of the element as per special moment resisting frame transverse reinforcement. The special transverse reinforcement is allowed to be discontinued at a section where the calculated compressive stress is less than $0.15 f_c'$. Stresses are calculated for the factored forces using a linearly elastic model and gross-section properties of the elements considered.

- All continuous reinforcement in diaphragms, chords and collector elements shall be anchored and spliced in accordance with the provisions for tension reinforcement discussed in joints of special moment frame provisions.

4- Design Forces:

The seismic design forces for structural diaphragms shall be obtained from the lateral load analysis in accordance with the design load combinations.

5- Shear Strength:

Nominal shear strength V_n of structural diaphragms shall not exceed

$$V_n = A_{cv}\left(0.53\sqrt{f_c'} + \rho_n\, f_y\right) \;\le 2.12\, A_{cv}\,\sqrt{f_c'}$$

6- Boundary Elements:

- Boundary elements of structural diaphragms shall be proportioned to resist the sum of the factored axial forces acting in the plane of the diaphragm and the force obtained from dividing the factored moment at the section by the distance between the boundary elements of the diaphragm at that section.
- Reinforcement for chord and collectors at splices and anchorage zones shall have either:

(a) A minimum center-to-center spacing of three longitudinal bar diameters, but not less than 4 cm, and a minimum concrete cover of $2.5\, d_b$, but not less than 5 cm;

(b) Transverse reinforcement as required per minimum shear reinforcement in beams, except where compressive stresses exceed $0.2\, f_c'$.