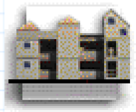


CHAPTER 9: Wind and Seismic Loads on Buildings

9.1 Wind Loads Using ASCE Standard 7-93

Description

The determination of wind loads for the structural design of buildings is a complex subject that many building codes simplify by presenting tables of net wind pressures versus height above grade. Wind loads on a building in any particular locality depend on many factors, including recorded wind speeds in the area, the terrain around the building, and the shape and height of the building. It is now common for wind tunnel model tests to be conducted for tall buildings to determine wind loads - which may be more severe than the minimum code requirements.

American Society of Civil Engineers Standard 7-93 contains detailed information and formulas for computing wind loads on buildings in various geographic locations, and can be used to establish specific requirements for localities, or to provide a more accurate assessment of the wind loads on a building for which wind tunnel tests are not believed to be justified.

This application computes the wind pressures on the windward wall, leeward wall, side walls and roof, and the net wind pressures and loads at specified height intervals, for a square or rectangular building with a flat roof.

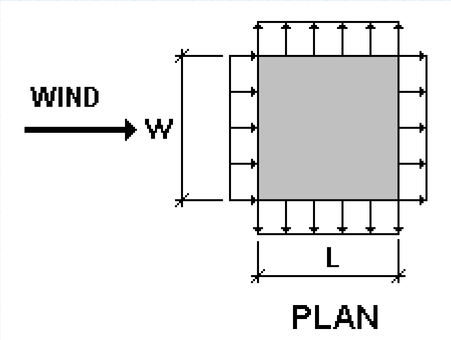
The required input includes the story heights (starting from ground level), the width of the building transverse to the wind, the length of the building parallel to the wind, and the basic wind speed, exposure category, and importance factor - determined in accordance with ASCE Standard 7-93.

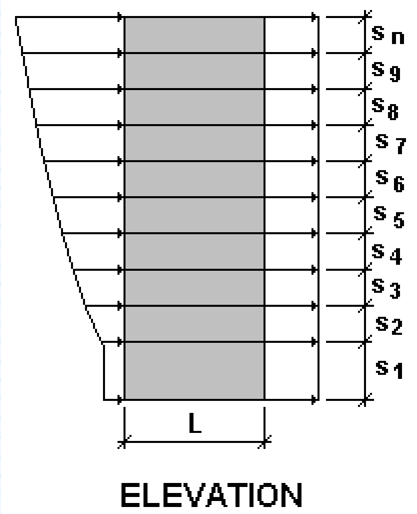
A summary of input and computed variables is shown on pages 9 and 10.

Reference:
ASCE Standard 7-93 "Minimum Design Loads for Buildings and Other Structures."

Input

Notation





Input Variables

Horizontal dimension of building measured normal to wind direction: $W := 100\ ft$

Horizontal dimension of building measured parallel to wind direction: $L := 50\ ft$

Exposure categories determined from Section 6.5.3, ASCE 7-93: $\begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$

Exposure categories A, B, C or D, as determined from Section 6.5.3, ASCE 7-93: $ExpCat := B$

Importance factor (Table 5, ASCE 7-93): $I := 1.00$

Basic wind speed (Fig. 1 & Table 7, of ASCE 7-93): $V := 84\ mph$

Story heights: $s := \left(\begin{bmatrix} 0 & 15 & 12 & 12 & 12 & 12 & 12 & 12 & 12 & 12 & 13.5 \end{bmatrix} \right)^{T} \cdot ft$

Computed Variables

h total building height

F_w net wind force per unit width of building at each level

p_w pressures on the windward wall at each level

p_l pressure on the leeward wall

p_s pressure on the side walls

p_r pressure on flat roof

Air density of standard atmosphere:

$$density := 0.0765 \cdot \frac{lbf}{ft^3}$$

Equation for constant in the equation for velocity pressure coefficient
(Equation C2, page 100, ASCE 7-93):

$$k_{air} := \frac{1}{2} \cdot \left(\frac{density}{g}\right) \cdot \left(mph \cdot 5280 \cdot \frac{ft}{mi} \cdot \frac{hr}{3600 \cdot sec}\right)^2 = 0.0026 \ \frac{lbf}{ft^2}$$

In localities where the average ambient air density is significantly different than the 0.0765 pcf assumed, the constant k_{air} may be changed. The variable g is the acceleration due to gravity.

Calculations

Number of stories: $n := \mathrm{last}(s) = 10$

Height of each level above ground:

$$i := 0..n \qquad k := 0..n \qquad z_i := \sum_k ((k \le i) \cdot s_k)$$

$$z^{T} = [0\ \ 15\ \ 27\ \ 39\ \ 51\ \ 63\ \ 75\ \ 87\ \ 99\ \ 111\ \ 124.5]\ ft$$

Building height:

$$h := \sum s = 124.5\ ft$$

In lieu of using Tables 6 and 7 for obtaining velocity pressure coefficients K_z and gust response factors G_h and G_z, this application uses the equivalent formulas from the Commentary Section of ASCE Standard 7-93.

Exposure category constants α, z_g, and D_o

Power law coefficient α from Table C6, ASCE 7-93:

$$\alpha := \mathbf{if}(ExpCat = A, 3.0, \mathbf{if}(ExpCat = B, 4.5, \mathbf{if}(ExpCat = C, 7.0, 10.0)))$$

$$\alpha = 4.5$$

Gradient height z_g, Table C6, ASCE 7-93 (z must be less than z_g):

$$z_g := \begin{array}{|l} \text{if } ExpCat = A \\ \quad 1500\ ft \\ \text{else if } ExpCat = B \\ \quad 1200\ ft \\ \text{else if } ExpCat = C \\ \quad 900\ ft \\ \text{else} \\ \quad 700\ ft \end{array} = (1.2 \cdot 10^{3})\ ft$$

Surface drag coefficient D_o, Table C6, ASCE 7-93:

$$D_o := \mathbf{if}(ExpCat = A, 0.025, \mathbf{if}(ExpCat = B, 0.010, \mathbf{if}(ExpCat = C, 0.005, 0.003))) = 0.01$$

Equation for velocity pressure exposure coefficient, above ground level
(Equation C3, page 100, ASCE 7-93):

$$K_{z_i} := \mathrm{if}\left(z_i \le 15 \cdot ft, 2.58 \cdot \left(\frac{15 \cdot ft}{z_g}\right)^{\frac{2}{\alpha}}, \mathrm{if}\left(z_i \le z_g, 2.58 \cdot \left(\frac{z_i}{z_g}\right)^{\frac{2}{\alpha}}, 0\right)\right)$$

$$K_z^{\mathrm{T}} = [0.368\ \ 0.368\ \ 0.478\ \ 0.563\ \ 0.634\ \ 0.696\ \ 0.752\ \ 0.804\ \ 0.851\ \ 0.896\ \ 0.942]$$

Equation for velocity pressure q (Equation C1, page 100, ASCE 7-93):

$$q_i := k_{air} \cdot K_{z_i} \cdot \left(I \cdot \frac{V}{mph}\right)^2$$

$$q^{\mathrm{T}} = [6.6\ \ 6.6\ \ 8.6\ \ 10.2\ \ 11.4\ \ 12.6\ \ 13.6\ \ 14.5\ \ 15.4\ \ 16.2\ \ 17]\ psf$$

Velocity pressure evaluated at roof height h:

$$q_h := q_n = 17.007\ psf$$

Gust response factors Gz and Gh. Gh is equal to Gz evaluated at z equal to the building height, h
(combining equations C5 and C6, page 105 of ASCE Standard 7-93):

$$G_{z_i} := 0.65 + 3.65 \cdot \left(\frac{2.35 \cdot D_o^{0.5}}{\left(\frac{\mathrm{if}\left(z_i \ge 15 \cdot ft, z_i, 15 \cdot ft\right)}{30 \cdot ft}\right)^{\frac{1}{\alpha}}}\right)$$

$$G_z^{\mathrm{T}} = [1.651\ \ 1.651\ \ 1.528\ \ 1.459\ \ 1.412\ \ 1.377\ \ 1.35\ \ 1.327\ \ 1.308\ \ 1.291\ \ 1.275]$$

$$G_h := G_{z_n} = 1.275$$

External pressure coefficients, Fig. 2, page 16 ASCE Standard 7-93:

Windward wall: $C_{pw} := 0.8$

Side walls: $C_{ps} := -0.7$

Flat roofs: $C_{pr} := -0.7$

Leeward wall:

$$C_{pl} := \left\| \begin{array}{l} \text{if } \dfrac{L}{W} \le 1 \\ \quad \| -0.5 \\ \text{else if } \dfrac{L}{W} \le 2 \\ \quad \left\| -0.5 + \left(\dfrac{\dfrac{L}{W} - 1}{1} \right) \cdot (0.2) \right. \\ \text{else if } \dfrac{L}{W} \le 4 \\ \quad \left\| -0.3 + \left(\dfrac{\dfrac{L}{W} - 1}{1} \right) \cdot (0.1) \right. \\ \text{else} \\ \quad \| -0.2 \end{array} \right. = -0.5$$

Internal pressure coefficient assuming negligible wall openings, Table 9, page 20, ASCE 7-93:

$GC_{pi} := 0.25$

Internal pressure may be negative or positive, whichever produces the greater net pressure on the wall under consideration.

External wall and roof pressures on main wind force resisting systems.

Windward wall external pressures:

$p_{w\_ext_i} := q_i \cdot G_h \cdot C_{pw}$

$p_{w\_ext}^{\mathrm{T}} = [6.8\ \ 6.8\ \ 8.8\ \ 10.4\ \ 11.7\ \ 12.8\ \ 13.9\ \ 14.8\ \ 15.7\ \ 16.5\ \ 17.3]\ psf$

Leeward wall external pressure: $q_h \cdot G_h \cdot C_{pl} = -10.8\ psf$

Side wall external pressure: $q_h \cdot G_h \cdot C_{ps} = -15.2\ psf$

Flat roof external pressure: $q_h \cdot G_h \cdot C_{pr} = -15.2\ psf$

Internal pressure or suction: $q_h \cdot GC_{pi} = 4.3\ psf$

Combined external and internal pressures on main wind resisting structural system

Windward wall:

$$p_{w_i} := q_i \cdot G_h \cdot C_{pw} + q_h \cdot GC_{pi}$$

$$p_w^{\mathrm{T}} = [11\ \ 11\ \ 13\ \ 14.6\ \ 15.9\ \ 17.1\ \ 18.1\ \ 19\ \ 19.9\ \ 20.7\ \ 21.6]\ psf$$

Leeward wall: $p_l := q_h \cdot \left(G_h \cdot C_{pl} - GC_{pi}\right) = -15.095\ \boldsymbol{psf}$

Side walls: $p_s := q_h \cdot \left(G_h \cdot C_{ps} - GC_{pi}\right) = -19.433\ \boldsymbol{psf}$

Flat roof: $p_r := q_h \cdot \left(G_h \cdot C_{pr} - GC_{pi}\right) = -19.433\ \boldsymbol{psf}$

The windward wall pressure varies with height z above grade, building height h, and the ratio of L/W. Leeward and side wall pressures and the roof pressure are constant negative pressures (suctions) for any given building height. Internal pressures are constant for any given building height, and are applied as negative or suction on the windward wall and as positive outward pressure on the roof, leeward wall and side walls.

Tributary story height at each level(If a parapet is present define s_{n+1} equal to twice the parapet height):

$$s_{n+1} := 6 \cdot \boldsymbol{ft} \qquad Trib\_ht_i := \frac{s_i + s_{i+1}}{2}$$

$$Trib\_ht^{\mathrm{T}} = [7.5\ \ 13.5\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12.75\ \ 9.75]\ ft$$

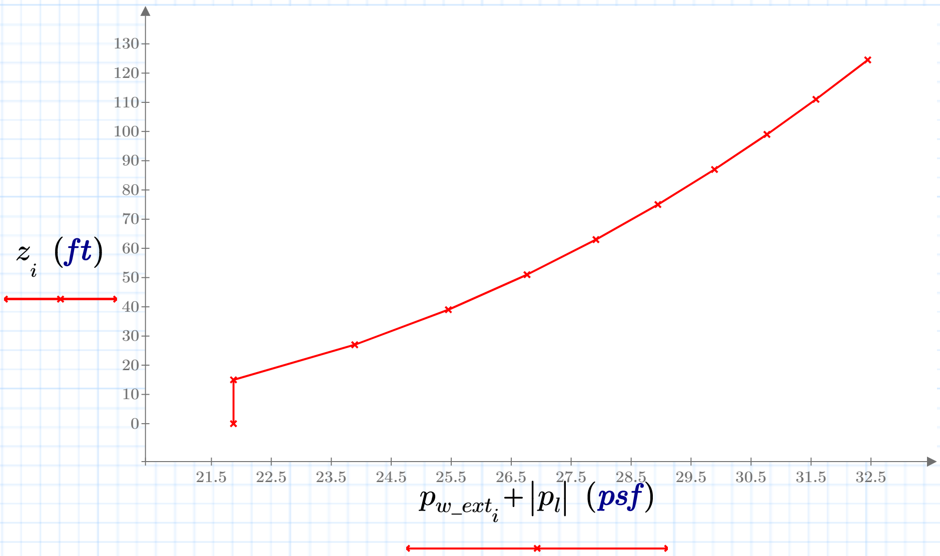
Net wind force on building frame per unit width of building, at each level:

$$F_{w_i} := Trib\_ht_i \cdot \left(p_{w\_ext_i} + \left|p_l\right|\right)$$

$$F_w^{\mathrm{T}} = [164\ \ 295.2\ \ 286.7\ \ 305.4\ \ 321.2\ \ 335\ \ 347.4\ \ 358.7\ \ 369.2\ \ 402.7\ \ 316.3]\ \frac{lbf}{ft}$$

Local building codes may express wind loads in terms of a net pressure acting on the windward side only. For comparison, the net pressure is plotted below.

Height z of each level above ground versus net wind pressure on building frame:



Net pressure

Level:	Height z above ground:	Net pressures on building frame at each story:

$$i = \begin{bmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \end{bmatrix} \qquad z_i = \begin{bmatrix} 0 \\ 15 \\ 27 \\ 39 \\ 51 \\ 63 \\ 75 \\ 87 \\ 99 \\ 111 \\ 124.5 \end{bmatrix} \; ft \qquad p_{w\_ext_i} + |p_l| = \begin{bmatrix} 21.869 \\ 21.869 \\ 23.891 \\ 25.453 \\ 26.764 \\ 27.913 \\ 28.946 \\ 29.89 \\ 30.765 \\ 31.582 \\ 32.445 \end{bmatrix} \; psf$$

Summary

Input Variables

Horizontal dimension of building measured normal to wind direction: $W = 100\ ft$

Exposure categories A, B, C or D, as determined from Section 6.5.3, ASCE 7-93 with A = 1, B = 2, C = 3, D = 4: $ExpCat = 2$

Basic wind speed from Fig. 1 and Table 7 of ASCE 7-93: $V = 84\ mph$

Horizontal dimension of building measured parallel to wind direction: $L = 50\ ft$

Importance factor from Table 5, ASCE 7-93: $I = 1$

Story heights: $s := ([0\ \ 15\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 13.5])^{T} \cdot ft$

Computed Variables

Building height: $h = 124.5\ ft$

Net wind force per unit width of building and combined external and internal pressures on main wind resisting structural system:

Leeward wall: $p_l = -15.095\ psf$

Side walls: $p_s = -19.433\ psf$

Flat roof: $p_r = -19.433\ psf$

Level:	Net wind force per unit width of building at each level:	Pressures on the windward wall at each level:
$i = \begin{bmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \end{bmatrix}$	$F_{w_i} = \begin{bmatrix} 164.017 \\ 295.231 \\ 286.693 \\ 305.433 \\ 321.171 \\ 334.959 \\ 347.352 \\ 358.686 \\ 369.18 \\ 402.676 \\ 316.341 \end{bmatrix} \dfrac{lbf}{ft}$	$p_{w_i} = \begin{bmatrix} 11.025 \\ 11.025 \\ 13.047 \\ 14.609 \\ 15.921 \\ 17.07 \\ 18.102 \\ 19.047 \\ 19.921 \\ 20.739 \\ 21.602 \end{bmatrix} psf$