Wind Loads on Non-Building Structures for the Practicing Engineer

MN SEA

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May 25, 2021

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2011 NCSEA provided a survey to 9,500 engineers.

"What modifications or additions would you like to see in the wind sections of ASCE 7?"

1
2
3
4
5

2

NCSEA Recommendations to ASCE 7:

1. Reduce Number of Methods to one (1) Computational Method and one (1) Tabular Method.

2. Consolidate Wind Provision from ASCE 7 and IBC into ASCE 7 and simplify the provisions.

3. Provide criteria for commonly encountered conditions (Canopies, Tall Parapets, Mechanical Screens, PV Panels).

4. Provide design procedures for RTUs on buildings > 60'.

5. Simplify free-standing wall provisions.

6. Provide guidance for irregular building configurations.

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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Tanks and Silos
- Trellises
- Canopies

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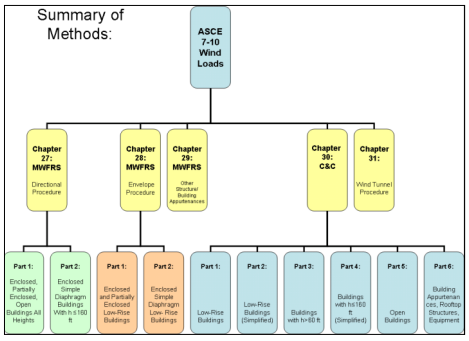
Summary of Methods:



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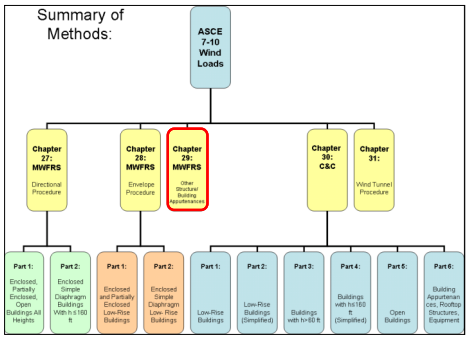
Summary of Methods:



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Main Wind Force Resisting System (MWFRS)

Chapter 29: Other Structures

- Conditions, Limitations
- Solid Freestanding Walls or Signs
- Solid Attached Signs
- Wind Loads on Rooftop Structures and Equipment
- Parapets
- Roof Overhangs
- Minimum Design Wind Loadings

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Main Wind Force Resisting System (MWFRS)

Chapter 29: Other Structures

- Scope, Conditions, Limitations
- Solid Freestanding Walls and Solid Signs
- Other Structures
  - Rooftop Structures and Equipment
  - Circular Bins, Silos, and Tanks
  - Rooftop Solar
  - Parapets
  - Roof Overhangs
  - Minimum Design Wind Loadings

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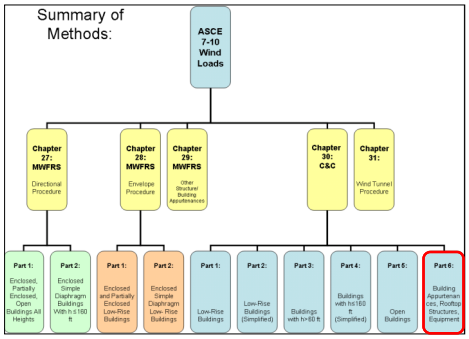

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Components & Cladding (C&C)

Chapter 30: Part 6:

C&C for Building Appurtenances and Rooftop Structures and Equipment

- Parapets
- Roof Overhangs
- Rooftop Structures and Equipment

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Components & Cladding (C&C)

Chapter 30: Part 6:

C&C for Building Appurtenances and Rooftop Structures and Equipment

- Parapets
- Roof Overhangs
- Rooftop Structures and Equipment
- Attached Canopies on Buildings < 60 ft

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Components & Cladding (C&C)

Chapter 30: Part 7:

C&C for Non-Building Structures

- Circular Bins, Silos, and Tanks with h≤120 ft
- Rooftop Solar Panels for Buildings of All Heights with Flat Roofs or Gable or Hip Roof with Slopes Less than 7°

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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Canopies

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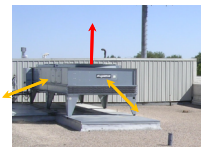
Rooftop Equipment

MWFRS: 29.4.2, 29.4.3

- $F_h = q_h(GC_r)A_f$, $1.0 \le (GC_r) \le 1.9$
- $F_v = q_h(GC_r)A_r$, $1.0 \le (GC_r) \le 1.5$



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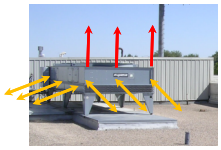
Rooftop Equipment

C&C: 30.10

- $P_h = q_h(GC_r)$, $1.0 \le (GC_r) \le 1.9$
- $P_v = q_h(GC_r)$, $1.0 \le (GC_r) \le 1.5$



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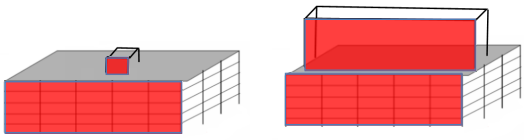
GC_r



GC_r=1.9
Area < 10% of windward wall

GC_r→1.0
Area = windward wall

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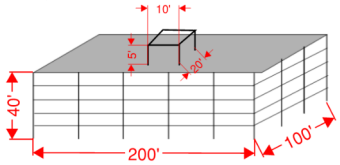
Rooftop Equipment for Buildings (MWFRS) (Section 29.4.1)

Office Building
–Wichita, KS (V=115mph)
–L = 200 ft., B = 100 ft.
–Roof Height: h = 40 ft.
–Roof Slope, Flat: 0.25:12
–Exposure Category: C



Mechanical Unit Plan Dimensions: 10' wide x 20' long
RTU Height: 4' over 1' tall curb
Projected Height: 4'+1'=5'

Lateral Force: $F_h = q_h(GC_r)A_f$ (Eq 29.5-2)
Vertical Force: $F_v = q_h(GC_r)A_r$ (Eq 29.5-3)

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Calculate q_h
q_h calculated at mean roof height of building
$q_h = 0.00256K_zK_{zt}K_dV^2$

Find K_h
K_z @ h = 40', Exposure C K_z = 1.04 (Table 29.3-1)

Height above ground level, z		Exposure		
		B	C	D
ft	(m)			
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

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Find K_d for building K_d = 0.85 (Table 26.6-1)

Structure Type	Directionality Factor K_d*
Buildings Main Wind Force Resisting System Components and Cladding	0.85 0.85
Arched Roofs	0.85
Chimneys, Tanks, and Similar Structures Square Hexagonal Round	0.90 0.95 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 All other cross sections	0.85 0.95

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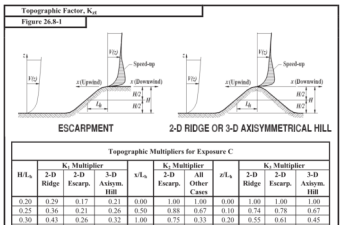
Find K_{zt}

Assume K_{zt}=1.0



Topographic Multipliers for Exposure C

H/L_h	K_1 Multiplier 2-D Ridge	K_1 Multiplier 2-D Escarp.	K_1 Multiplier 3-D Axisym. Hill	x/L_h	K_2 Multiplier 2-D Escarp.	K_2 Multiplier All Other Cases	z/L_h	K_3 Multiplier 2-D Ridge	K_3 Multiplier 2-D Escarp.	K_3 Multiplier 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

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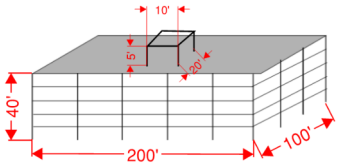
Find q_h

q_h= 0.00256$K_z K_{zt} K_d V^2$

q_h= 0.00256(1.04)(1.00)(0.85)(115)^2 = 29.9 psf



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HORIZONTAL WIND FORCE

Check projected area of unit compared with projected area of building:

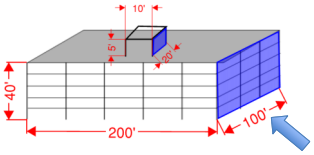
B*h = 100'(40') = 4,000 ft^2

A_f = 20'(5') = 100 ft^2

A_f < 0.1Bh: 100 ft^2< 400 ft^2

GC_r= 1.9

(GC_r) = 1.9 for rooftop structures and equipment with A_f less than (0.1Bh). (GC_r) shall be permitted to be reduced linearly from 1.9 to 1.0 as the value of A_f is increased from (0.1Bh) to (Bh)



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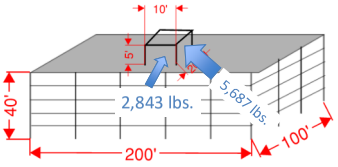
HORIZONTAL WIND FORCE

F_h= (29.9 psf)(1.9)(A_f) = 56.9psf (A_f) (Equation 29.5-2)

F_h= (56.9 psf)(100 ft^2) = 5,687 Lbs. // to long side

F_h= (56.9 psf)(50 ft^2) = 2,843 Lbs. ⊥ to long side

Horizontal wind forces applied to geometric center of vertical projected plane of unit.



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VERTICAL WIND FORCE

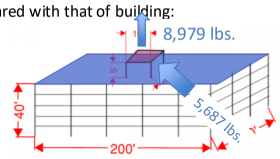
Check projected area of roof compared with that of building:

B*L = 100'(200') = 20,000 ft^2

A_r= 20'(10') = 200 ft^2

A_r<0.1BL: 200 ft^2< 2,000 ft^2

GC_r= 1.5



F_v= (29.9 psf)(1.5)(200 ft^2) = 8,979 Lbs. (Equation 29.5-2)

Vertical wind forces applied at geometric center of horizontal plane of unit.

(GC_r) = 1.5 for rooftop structures and equipment with A_r less than (0.1BL). (GC_r) shall be permitted to be reduced linearly from 1.5 to 1.0 as the value of A_r is increased from (0.1BL) to (BL)

Note: The UPLIFT pressure acts SIMULTANEOUSLY with either the parallel or perpendicular lateral pressure.

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Rooftop Equipment for Buildings (C&C) (Section 30.11)

Loads for Designing the Equipment cabinet enclosure

Lateral C & C pressures:

F_h= 5,687 Lbs. (from previous)
F_v = 8,979 Lbs. (from previous)

C & C Lateral Loads: F_h/A_f= 5,687 Lbs./100 ft^2= 56.9 psf
→ Load is applied toward or away from unit on all sides.

C & C Vertical Loads: F_v/A_f= 8,979 Lbs./200 ft^2= 44.9 psf
→ Load is applied only in the Upward direction, away from the top of the unit

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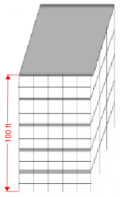
What about rooftop equipment for h>60 feet?



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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Canopies

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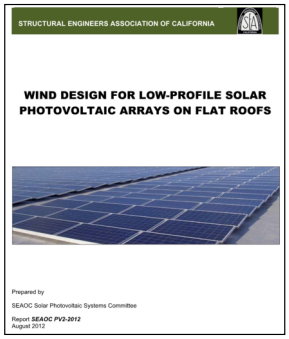
Solar PV



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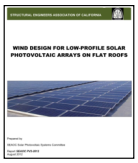

Solar PV

- The SEAOC PV committee was formed in September 2011.
- Goal: To address the lack of requirements in the code for PV systems.

2012:
- PV1-2012: Seismic Design
- PV2-2012: Wind Design → ASCE 7-16 incorporates and adopts PV2-2012

2016:
- PV2-2016: Supersedes PV2-2012
- References ASCE 7-16
- Knowledge from research since 2012
- Updated terminology, effective wind area determination, wind tunnel requirements
- In some cases, "recommended additional requirements" where the ASCE 7-16 requirements may not be adequate.

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Guide DOES Cover:
- Arrays with tilted panels on flat or low-slope roof buildings (Section 4)
- Parallel-to-roof (flush-mounted) arrays on sloped roofs (Section 5)
- Ground-mounted solar arrays (Section 8)

Guide DOES NOT Cover:
- Roof-mounted systems with tilted panels that are not low-profile
- Arrays on other roof shapes (e.g. hip, gable, saw-tooth, etc.)

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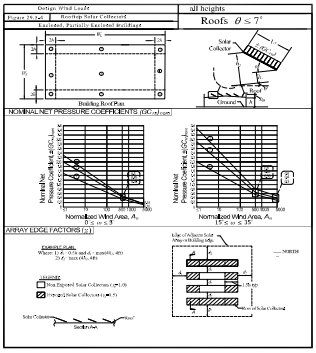
Solar PV



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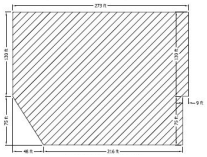
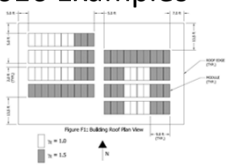
SEAOC PV2-2016 Examples





Steps:

- Roof wind zones
- Normalized wind area (A_n)
- Nominal net pressure coefficient ($(GC_{rn})_{nom}$)
- Parapet factor (γ_p)
- Chord factor (γ_c)
- Edge factor (γ_E)
- Effective wind area (A) and design wind pressure (p)
- Design of an unattached (ballast-only) array to resist uplift
- Design of an unattached (ballast-only) array to resist sliding
- Parallel-to-roof (flush-mounted) modules

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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Canopies

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Rooftop Screenwalls

Poll: What wind pressure do you use to design a rooftop screenwall?

a) Rooftop Structures and Equipment?

b) Solid Freestanding Sign with Adjustment?

c) Parapet Pressures?

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Rooftop Screenwall

ASCE 7-16: New Commentary

C29.4.1: Mechanical equipment screens commonly are used to conceal plumbing, electrical, or mechanical equipment from view… and located away from the edge of the building roof such that they are not considered parapets… Though the use of equipment screens is prevalent, little research is available to provide guidance for determining wind loads on screen walls and equipment behind screens. Accordingly, rooftop screens, equipment behind screens, and their supports and attachments to buildings should be designed for the full wind load determined in accordance with Section 29.4.1.

Where substantiating data have been obtained using the Wind Tunnel Procedure (Chapter 31), design professionals may consider wind load reductions in the design of rooftop screens and equipment. For example, studies by Zuo et al. (2011)and Erwin et al. (2011) suggest that wind loads on some types of screen materials and equipment behind screens may be overestimated by the equations defined in Section 29.4.

29.4.1 Rooftop Structures and Equipment for Buildings. The lateral force, F_h, and vertical force, F_v, for rooftop structures and equipment, except as otherwise specified for roof-mounted solar panels (Sections 29.4.3 and 29.4.4) and structures identified in Section 29.4, shall be determined as specified following.

The resultant lateral force, F_h, shall be determined from Eq. (29.4-2) and applied at a height above the roof surface equal to or greater than the centroid of the projected area, A_f.

$$F_h = q_h (GC_r) A_f \text{ (lb)} \qquad (29.4\text{-}2)$$

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What about equipment behind rooftop screens? Appropriate to consider shielding?

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Phase 1 IBHS Research Center & ASHRAE Testing: Preliminary Findings

- Equipment height above top of screen increases wind loads.
- Fully enclosed configurations lower wind loads.
- Partially enclosed screen configurations do not provide significant wind load reduction.
- Screen type does not significantly change wind loads.

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Phase 2 IBHS Research Center & ASHRAE Testing

- Evaluate wind loads on screenwalls themselves.

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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Canopies

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Solid Freestanding Walls and Signs

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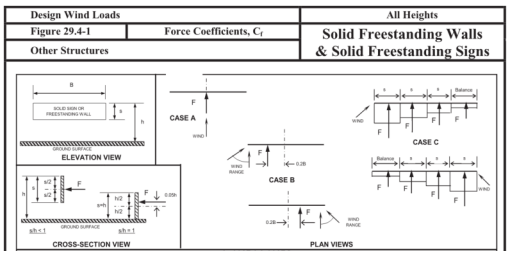
Solid Freestanding Walls and Signs

Design Wind Loads		All Heights
Figure 29.4-1	Force Coefficients, C_f	Solid Freestanding Walls & Solid Freestanding Signs
Other Structures		



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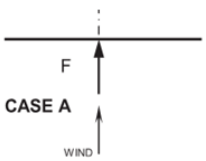
Solid Freestanding Walls and Signs



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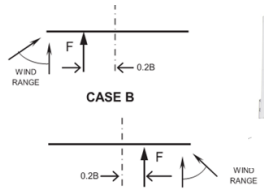
Solid Freestanding Walls and Signs



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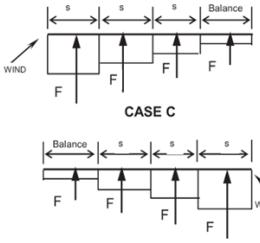
Solid Freestanding Walls and Signs



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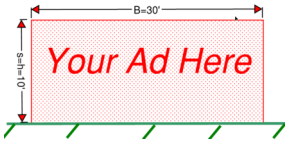
Solid Sign at Ground Level
(Exposure C, 115 mph)

$F = q_h G C_f A_s$ (lb) (Eq 29.4-1)

30' Wide x 10' High → s=10', B=30', h=10'



K_h = 0.85 (Table 29.3-1)
K_d= 0.85 (Table 26.6-1)
K_{zt}=1.0 (assumed)

q_h= 0.00256 $K_h K_{zt} K_d V^2$
q_h= 0.00256(0.85)(1.00)(0.85)(115)^2= **24.5 psf**

G = 0.85 (Section 26.9 – Rigid Structure)

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Figure 29.4-1 for C_f $\frac{B}{s} = \frac{30'}{10'} = 3.0$ Aspect Ratio

$\frac{s}{h} = \frac{10'}{10'} = 1.0$ Clearance Ratio

C_f, CASE A & CASE B

Clearance Ratio, s/h	Aspect Ratio, B/s ≤ 0.05	0.1	0.2	0.5	1	2	4	5	10	20
1	1.80	1.70	1.65	1.55	1.45	1.40	1.35	1.35	1.30	1.30
0.9	1.85	1.75	1.70	1.60	1.55	1.50	1.45	1.45	1.40	1.40
0.7	1.90	1.85	1.75	1.70	1.65	1.60	1.60	1.55	1.55	1.55
0.5	1.95	1.85	1.80	1.75	1.75	1.70	1.70	1.70	1.70	1.70
0.3	1.95	1.90	1.85	1.80	1.80	1.80	1.80	1.80	1.80	1.85
0.2	1.95	1.90	1.85	1.80	1.80	1.80	1.80	1.80	1.85	1.90
≤ 0.16	1.95	1.90	1.85	1.85	1.80	1.80	1.85	1.85	1.85	1.90

For B/s = 2: C_f= 1.40
For B/s = 4: C_f= 1.35
→ Interpolating for B/s 3.0, **C_f= 1.375**

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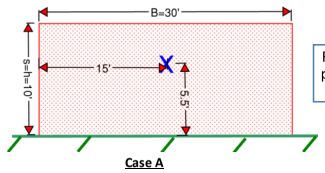
Figure 29.4-1 for C_f

$F = q_h G C_f A_s$ (Eq 29.4-1)

$F = (24.5\ psf)(0.85)(1.375)A_s = 28.59\ psf * A_s$

A_s= B x s = 30'x10' = 300 ft^2

$F = 28.6\ psf * A_s = 28.6\ psf(300\ ft^2) = 8{,}577$ Lbs.



For CASE A, Load is applied at plan center and at (s/2)+(0.05h) = 5.5' above base.

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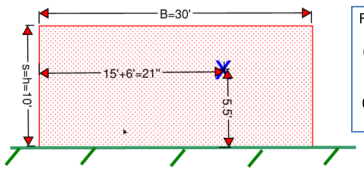
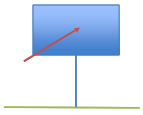


For CASE B, load is applied at 5.5' above base and at 0.2B offset from either side of plan centerline.

0.2B = 0.2(30') = 6.0' either side of plan centerline.



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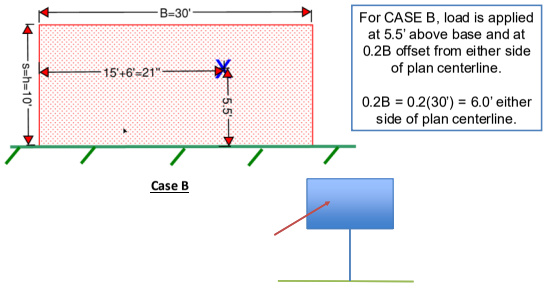

For CASE B, load is applied at 5.5' above base and at 0.2B offset from either side of plan centerline.

0.2B = 0.2(30') = 6.0' either side of plan centerline.

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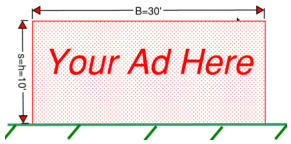
Check if CASE C must be considered (note 3, Figure 29.4-1)

→ If B/s ≥ 2.0, CASE C must be considered.

$$\frac{B}{s} = \frac{30'}{10'} = 3.0 > 2.0$$

→ Consider CASE C.



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Enter Figure 29.4-1 for C_f, under CASE C $\frac{B}{s} = \frac{30'}{10'} = 3.0$

Region (horizontal distance from windward edge)	C_f, CASE C: Aspect Ratio, B/s						
	2	3	4	5	6	7	8
0 to s	2.25	2.60	2.90	3.10*	3.30*	3.40*	3.55*
s to 2s	1.50	1.70	1.90	2.00	2.15	2.25	2.30
2s to 3s		1.15	1.30	1.45	1.55	1.65	1.70
3s to 10s			1.10	1.05	1.05	1.05	1.05

0-s → C_f= 2.60 from 0 to 10 ft.
s-2s → C_f= 1.70 from 10 to 20 ft.
2s-3s → C_f= 1.15 from 10 to 30 ft.

Footnote 4:

For CASE C, where s/h > 0.8, C_f may be multiplied by reduction factor (1.8 – s/h).
s/h = 1.0 > 0.8

→ (1.8 – s/h) = (1.8 – 1.0) = 0.8

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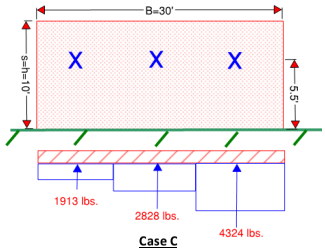
$F = q_h G C_f A_s$ (Eq 29.4-1)

F_1 = (24.5 psf)(0.85)(2.60)(0.8)(10'x10') = 4,324 lbs.
F_2 = (24.5 psf)(0.85)(1.70)(0.8)(10'x10') = 2,828 lbs.
F_3 = (24.5 psf)(0.85)(1.15)(0.8)(10'x10') = 1,913 lbs.



For CASE C, apply F_1, F_2, and F_3 at plan centerline of each length, s.

Apply F_1, F_2 and F_3 at 5.5' above base.

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Solid Freestanding Walls and Signs: ASCE 7-16

- New research and provision cover deeper signs (electronic).
- Minor revisions to the provisions.

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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Canopies

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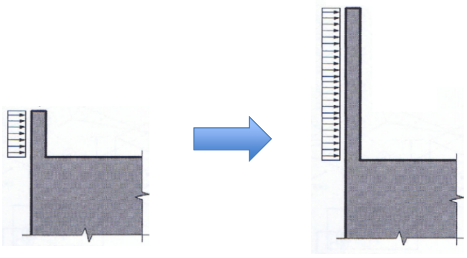
Tall Parapets



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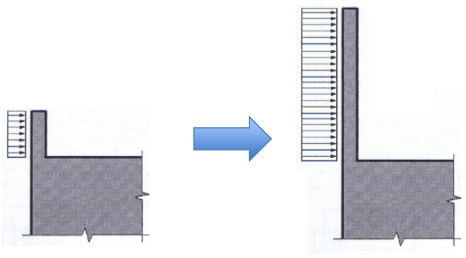
Tall Parapets



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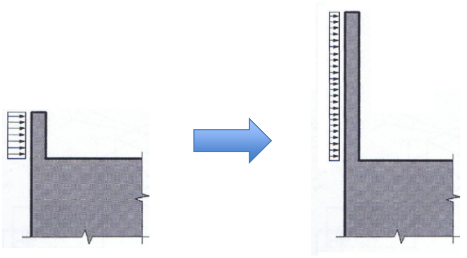
Tall Parapets



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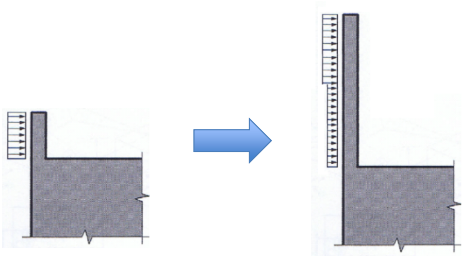
Tall Parapets



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History of Parapet Design

- Before ASCE 7-02 there were no provisions for wind loads on parapets.
- ASCE 7-02 a method was introduced based on "the committee's collective experience, intuition, and judgement".
- ASCE 7-05 provisions were updated with research from University of Western Ontario and Concordia University.

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Parapet Research To-Date

- There are many studies on parapets effects on the roof loads.
- Due to instrumentation limitations, there are limited studies on wind forces on the parapet itself.
- Results of tests suggest wind loads on parapets are independent of parapet height[1]

[1]Reference: Wind Loads on Parapets: Part 2: Structural and Local Cladding Loading on the Parapet Itself, C. Mans/ G. Kopp/ D. Surry, BLWT-SS37-2001/June 2001

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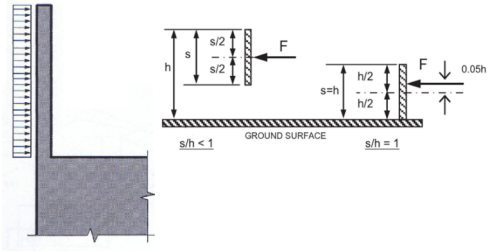
Tall Parapets



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Topics:

WIND LOADS ON:

- Rooftop Equipment
- Solar PV
- Rooftop Screenwalls
- Freestanding Walls and Signs
- Tall Parapets
- Canopies

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Canopies and Awnings

External Pressure Coefficient, C_p

- One of the oldest figures of ASCE 7.
- Helps us understand wind behavior.

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

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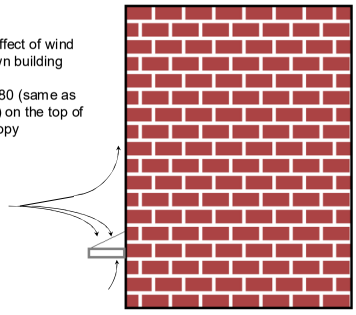
Canopies and Awnings

Down-draft effect of wind flowing down building

→ Use C_p=0.80 (same as windward wall) on the top of canopy



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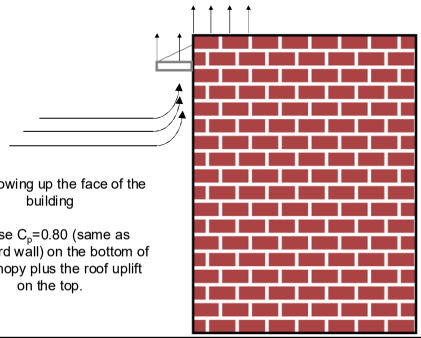
Canopies and Awnings



Wind flowing up the face of the building

→ Use C_p=0.80 (same as windward wall) on the bottom of the canopy plus the roof uplift on the top.

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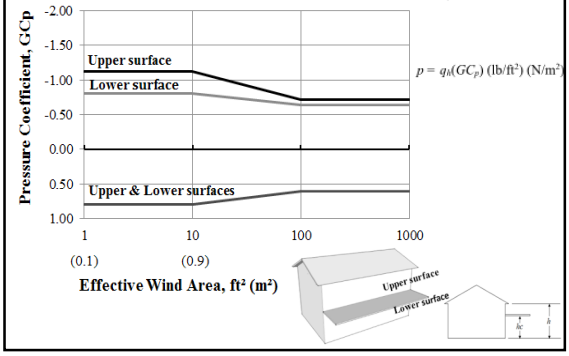
ASCE 7-16 – Attached Canopies



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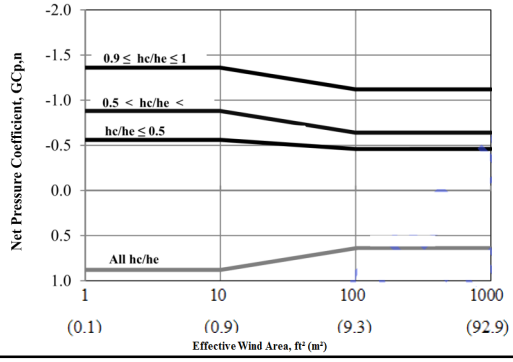
ASCE 7-16 – Attached Canopies



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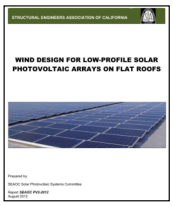
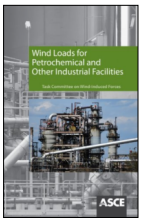
Additional Resources

- Wind Loads for Petrochemical and Other Industrial Facilities
- SEAOC Wind Design for Low-Profile Solar Photovoltaic Arrays on Flat Roofs





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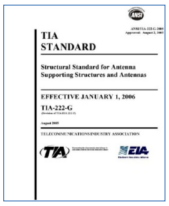
Additional Resources

- Guide Specifications for Design of Metal Flagpoles, ANSI/NAAMM FP1001-97, 4th Edition
- Structural Standards for Steel Antenna Towers and Antenna Supporting Structures, ANSI/TIA-222-G



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Additional Resources

- Wind Loads on Small Roof-Mounted Air-Conditioning Units, IBHS Research Center

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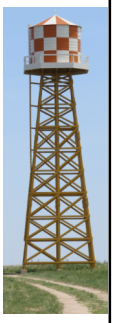
Summary

- There are attempts to address commonly encountered conditions (canopies, h>60', screenwalls, solar PV).
- Even when the code doesn't address an issue, we can extrapolate to find a solution.
- Use resources from related industries for guidance on non-building wind loads.



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