VII CONGRESO INTERNACIONAL DE LA CONSTRUCCIÓN CON ACERO

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Clarifying Frequently Misunderstood Wind and Seismic Provisions

Emily Guglielmo, SE

Martin/Martin, Inc.

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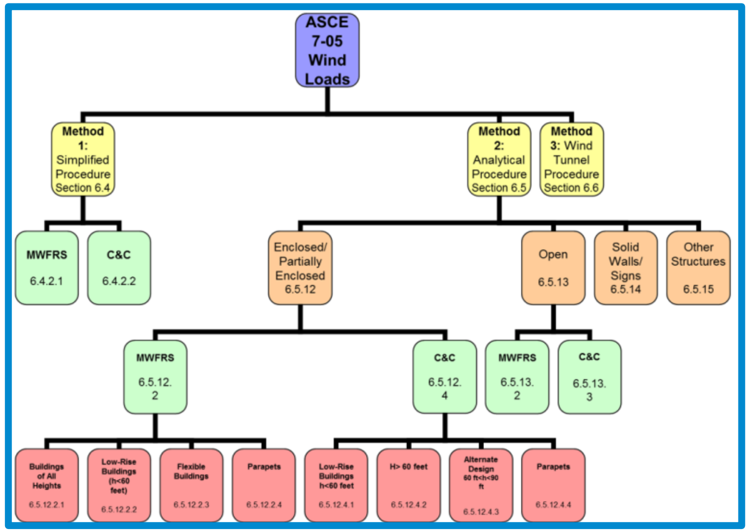
Frequently Misunderstood Wind Provisions

- Enclosure Classification
- Analysis Methods
- Canopies
- Rooftop Solar/ PV
- Rooftop Screenwalls



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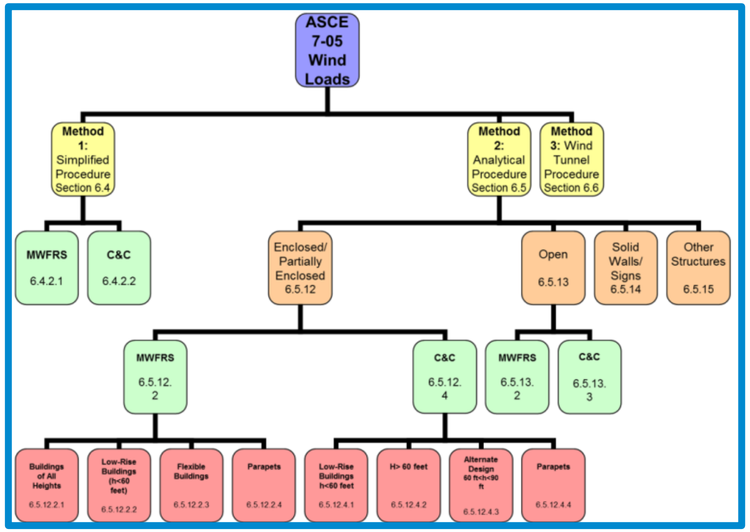
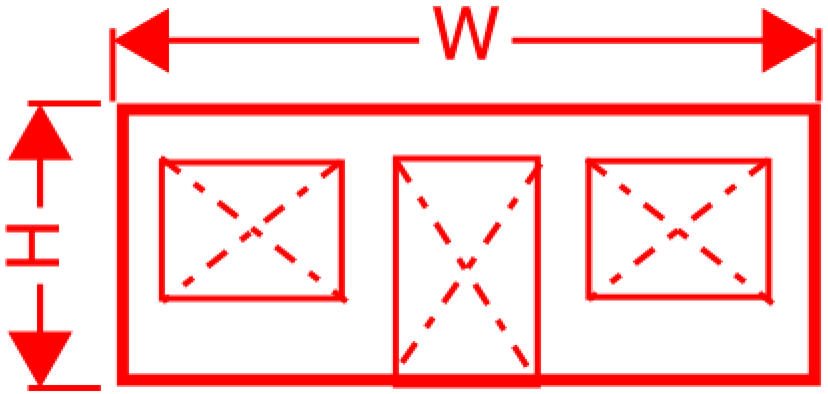


Enclosed, Partially Enclosed, Open?

Enclosure Classification (26.2):

- *Open Building*: A building having *each wall* at least 80% open.
  - $A_o \geq 0.8A_g$



$A_o = A_1 + A_2 + A_3$
$A_g = W \times H$

Enclosure Classification (26.2):

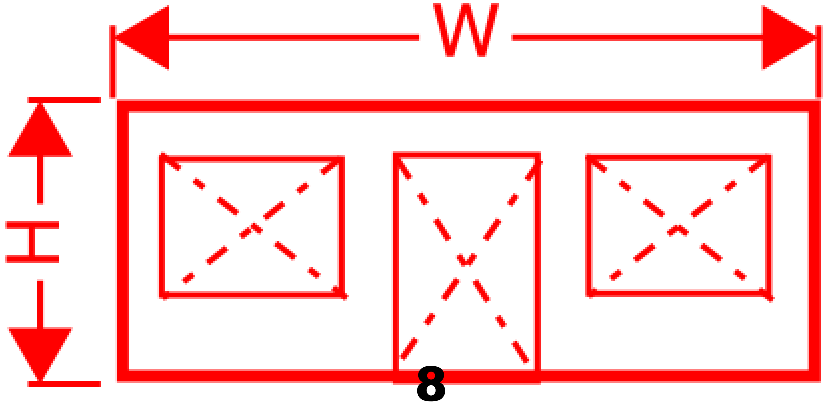
- *Partially Enclosed Building*: A building that complies with *both* of the following conditions:
    1. The total area of openings in a wall > the sum of the openings in the balance of the building envelope (walls and roof) by >10%.

       $A_o \geq 1.10 A_{oi}$

    2. The total area of openings in a wall exceeds 4ft² (or 1% of area of that wall), and the % of openings in the balance of the building <20%.

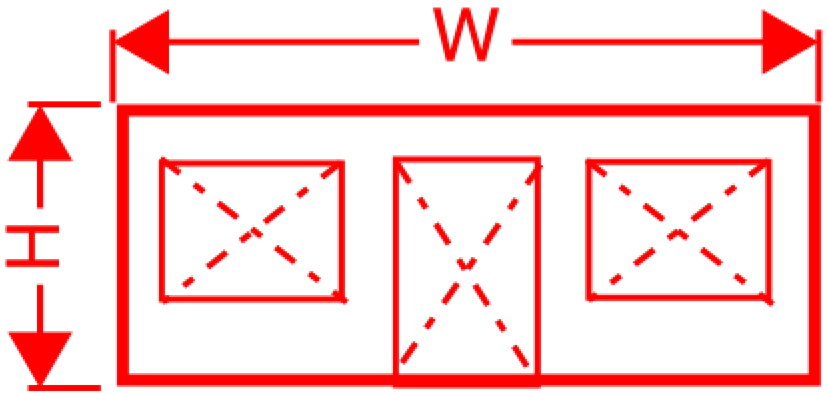
       $A_o > 4\ ft^2$ OR $> 0.01 A_g$ (Whichever is smaller)

- $$\frac{A_{oi}}{A_{gi}} \leq 0.20$$



Enclosure Classification (26.2):

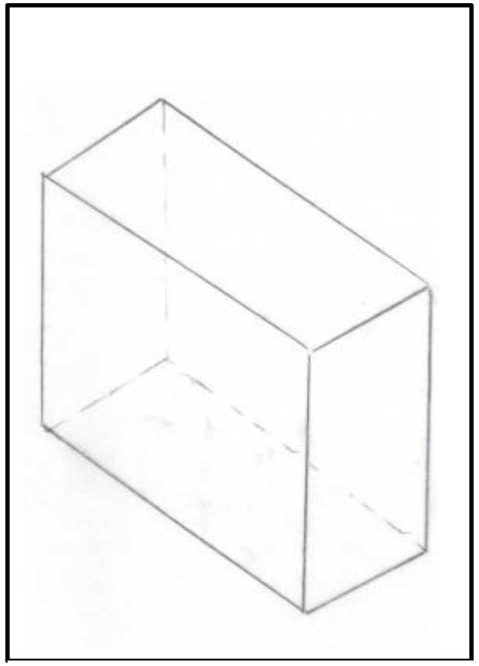
- *Enclosed Building*: A building that does not comply with the requirements for open or partially enclosed buildings.

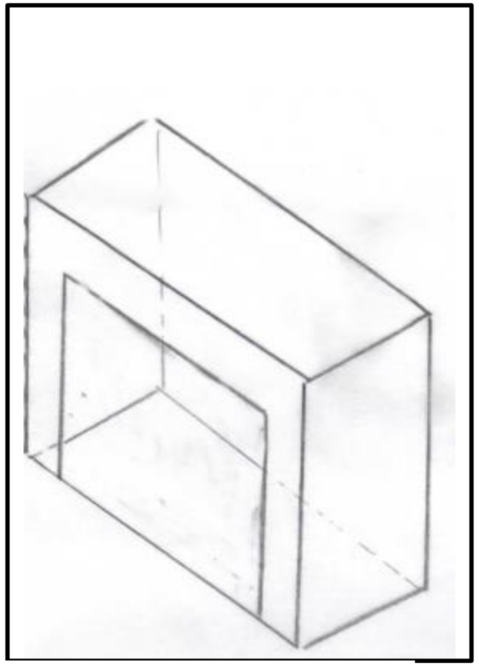


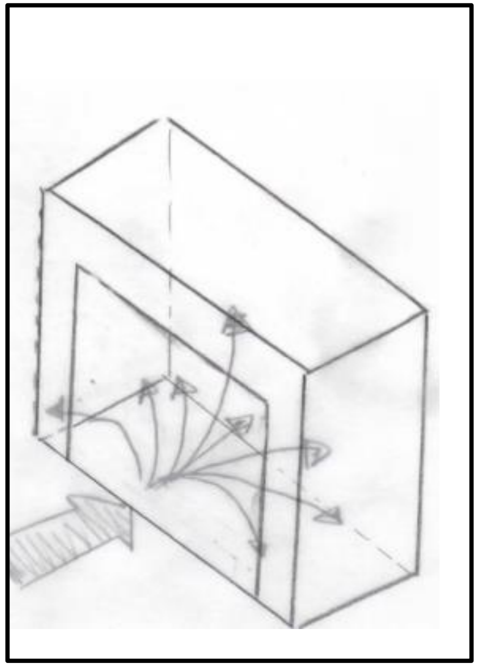
Question: What constitutes an opening?

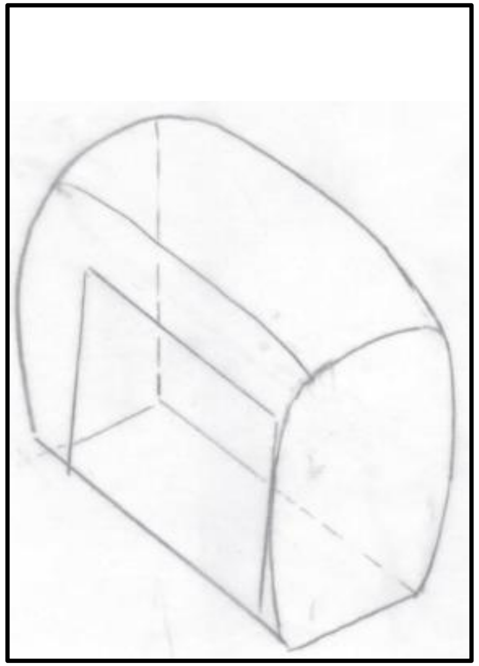
Answer: Doors, operable windows, air intake exhausts, operable louvers, *anything designed to be open during design winds.*

Question: What about windows in wind-borne debris regions?
Answer: Category II, III, IV buildings in wind-borne debris regions to be protected with impact resistant glazing, impact protective systems.

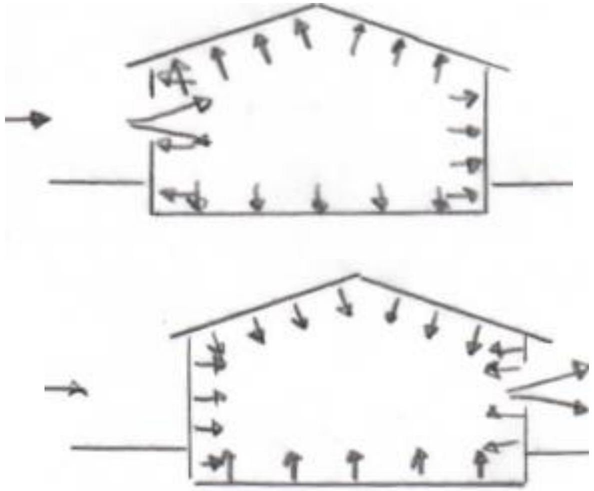








Enclosure Classification	(GC_{pi})
Open Buildings	0.00
Partially Enclosed Buildings	+0.55 -0.55
Enclosed Buildings	+0.18 -0.18

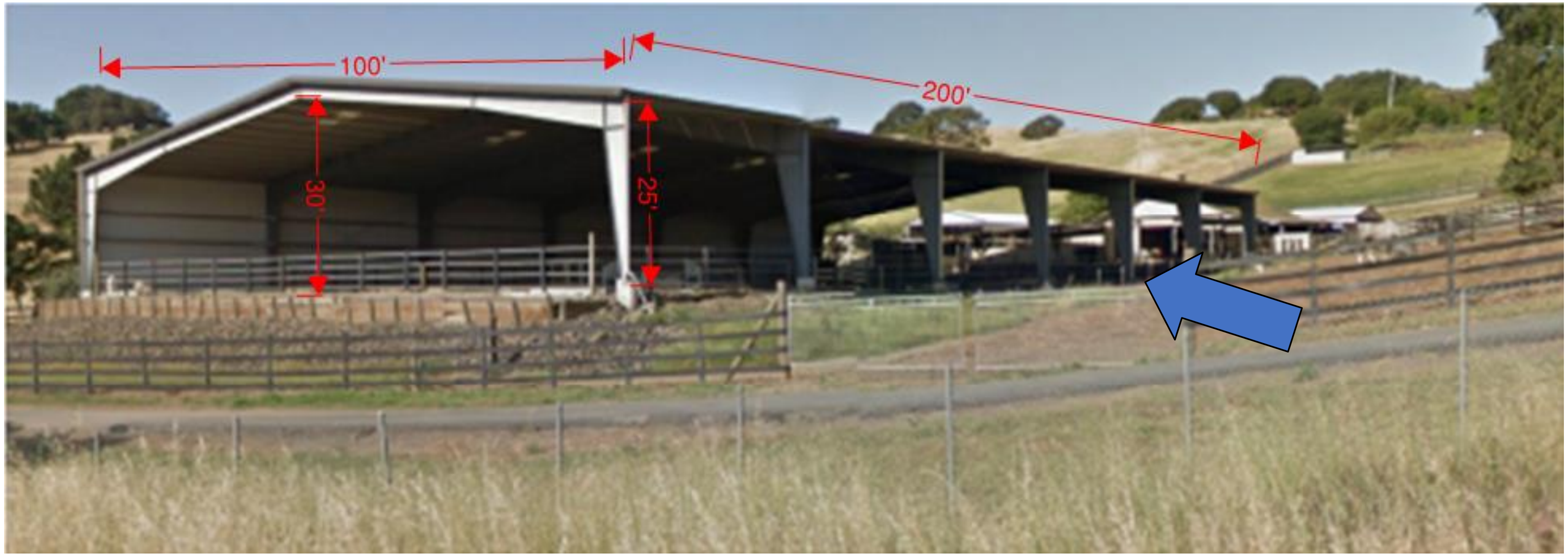


Enclosed, Partially Enclosed, Open?

Open Building: A building having each wall at least 80% open.

Partially Enclosed Building: A building that complies with *both* of the conditions:

1. The total openings in a wall exceeds the sum of the openings in the balance of the building envelope by >10%.
2. The total area of openings in a wall exceeds 4ft^2 or 1% of area of that wall, *and* the percentage of openings in the balance of the building envelope ≤ 20%.



Partially Enclosed Building: A building that complies with *both* of the conditions:

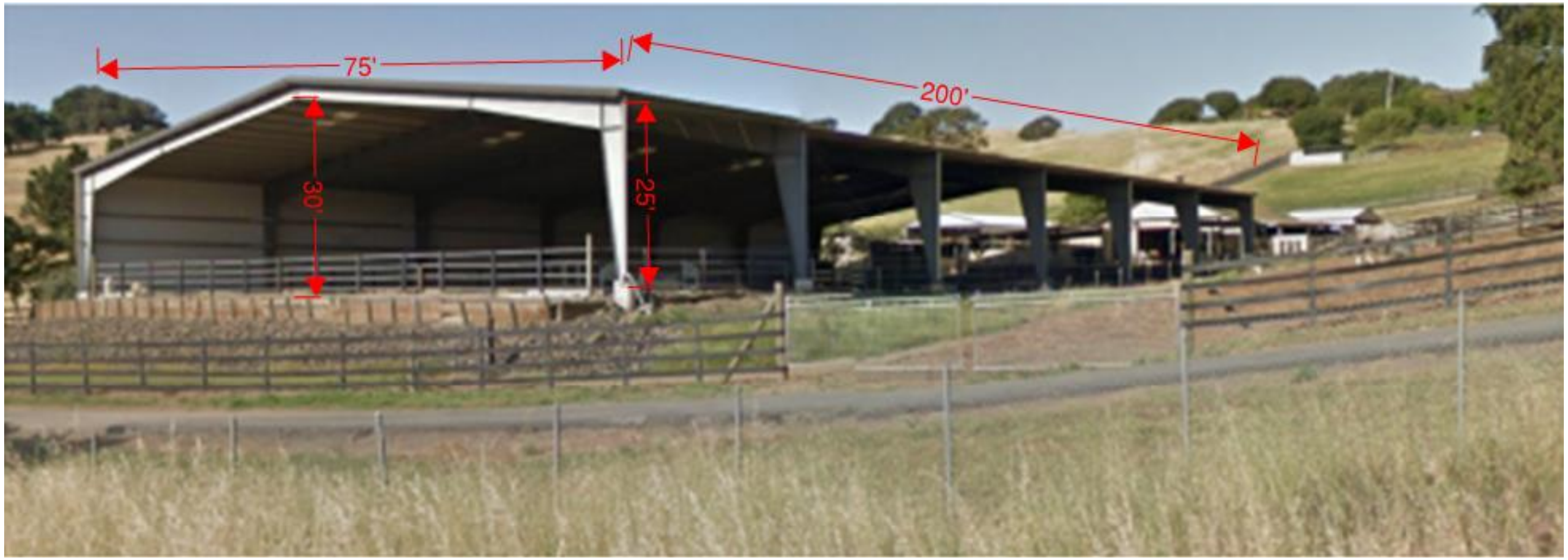
1. The total openings in a wall exceeds the sum of the areas of openings in the balance of the building envelope by >10%.

Windward wall

$$200\ ft \times 25\ ft = 5{,}000\ ft^2$$

Balance of building

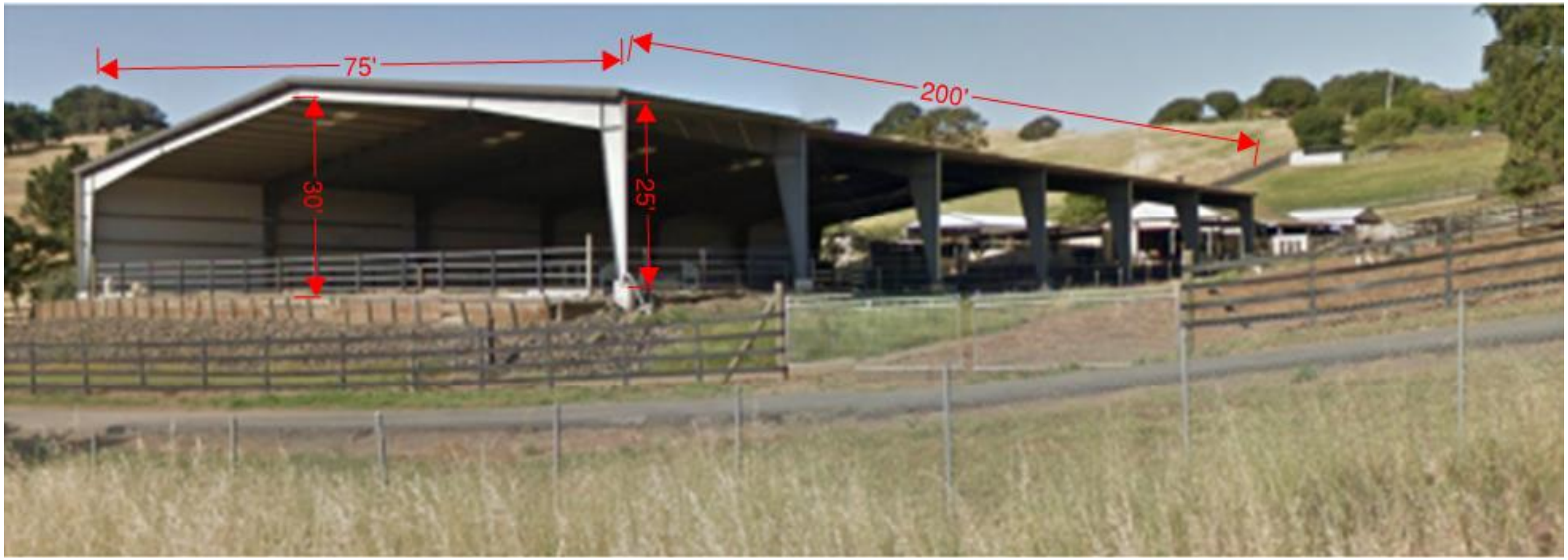
Enclosed Building: A building that does not comply with the requirements for open or partially enclosed buildings.



Partially Enclosed Building: A building that complies with *both* of the conditions:

1. The total openings in a wall exceeds the sum of the areas of openings in the balance of the building envelope by >10%.

$$200\ ft \times 25\ ft = 5{,}000\ ft^2 > 1{,}10\left[2(75\ ft \times 30\ ft)\right] = 4{,}950\ ft^2$$

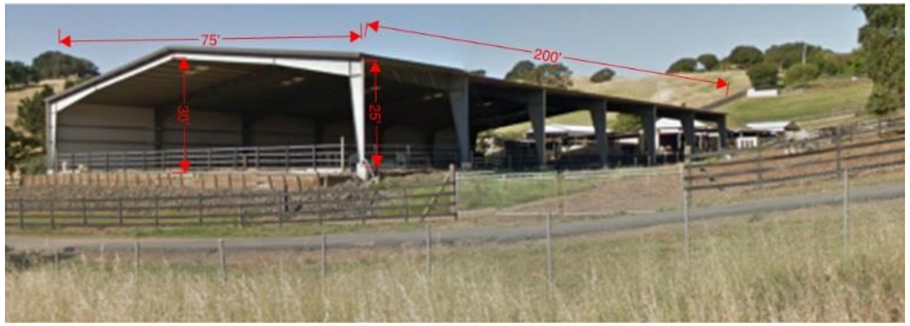


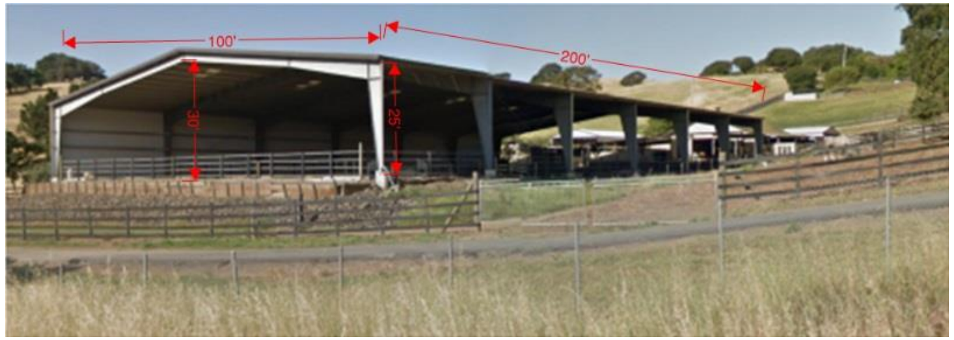
Partially Enclosed Building: A building that complies with *both* of the conditions:

2. The total area of openings in a wall that receives positive external pressure exceeds $4ft^2$ or 1% of area of that wall, and the percentage of openings in the balance of the building envelope is less than 20%.

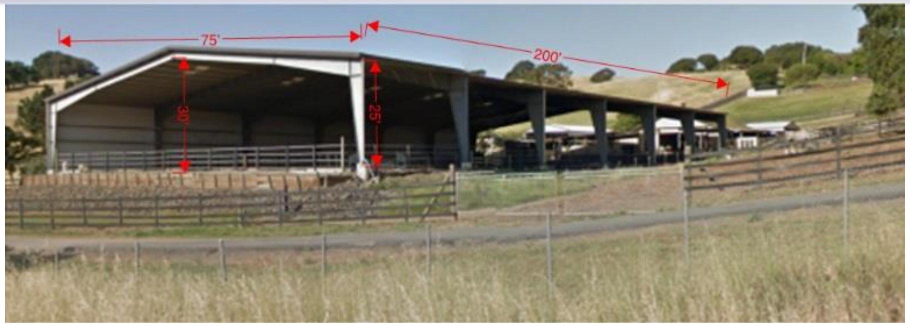
$$\frac{75\ ft \times 30\ ft \times 2}{75\ ft \times 30\ ft \times 2 + 200\ ft \times 25\ ft + 200\ ft \times 75\ ft} = .18 < .20$$

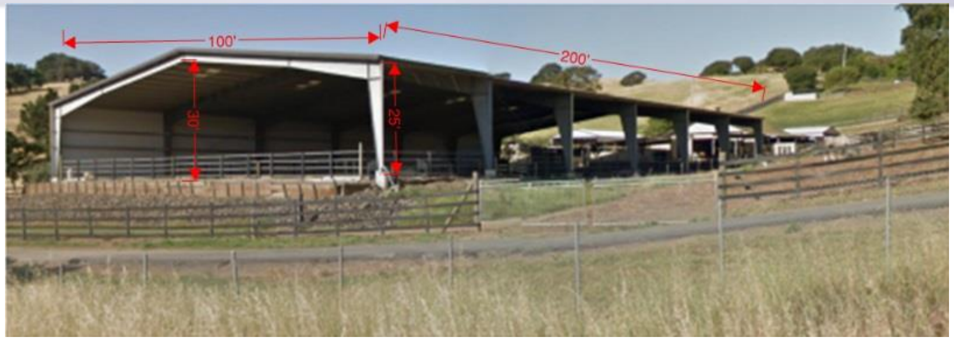
ASCE 7-16?





Is this enclosed, partially enclosed, *partially open*, or open building?

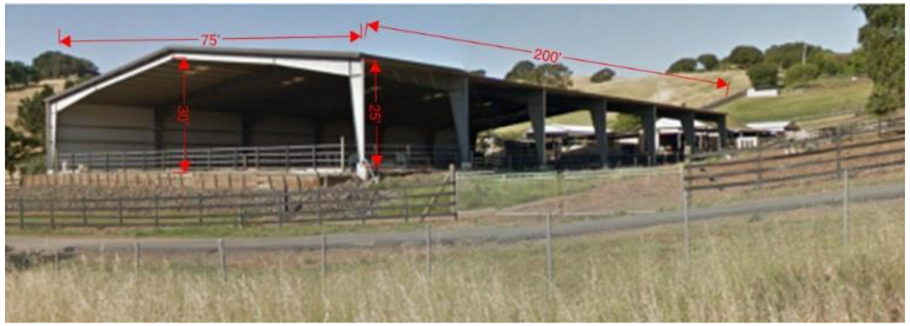


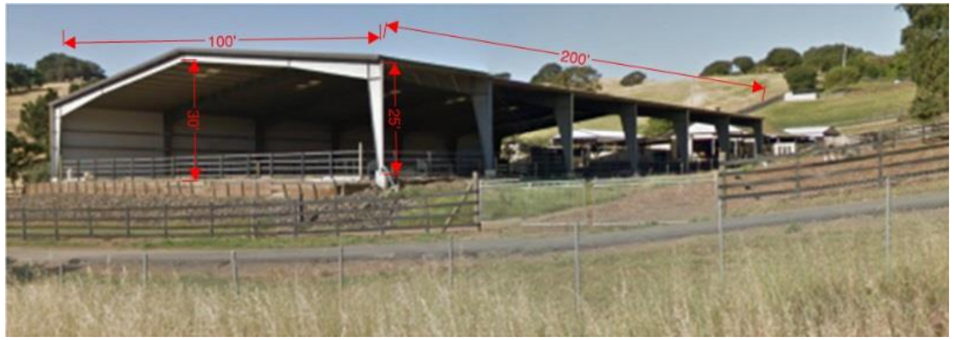


Partially Enclosed

ASCE 7-10

Enclosed





Partially Enclosed

ASCE 7-16

Partially Open

Table 26.13-1 Main Wind Force Resisting System and Components and Cladding (All Heights): Internal Pressure Coefficient, (GC_{pi}), for Enclosed, Partially Enclosed, Partially Open, and Open Buildings (Walls and Roof)

Enclosure Classification	Criteria for Enclosure Classification	Internal Pressure	Internal Pressure Coefficient, (GC_{pi})
Enclosed buildings	A_o is less than the smaller of $0.01A_g$ or 4 sq ft (0.37 m) and $A_{oi}/A_{gi} \leq 0.2$	Moderate	+0.18 −0.18
Partially enclosed buildings	$A_o > 1.1A_{oi}$ and $A_o >$ the lesser of $0.01A_g$ or 4 sq ft (0.37 m) and $A_{oi}/A_{gi} \leq 0.2$	High	+0.55 −0.55
Partially open buildings	A building that does not comply with Enclosed, Partially Enclosed, or Open classifications	Moderate	+0.18 −0.18
Open buildings	Each wall is at least 80% open	Negligible	0.00

Enclosed, Partially Enclosed, Open?

Frequently Misunderstood Wind Provisions

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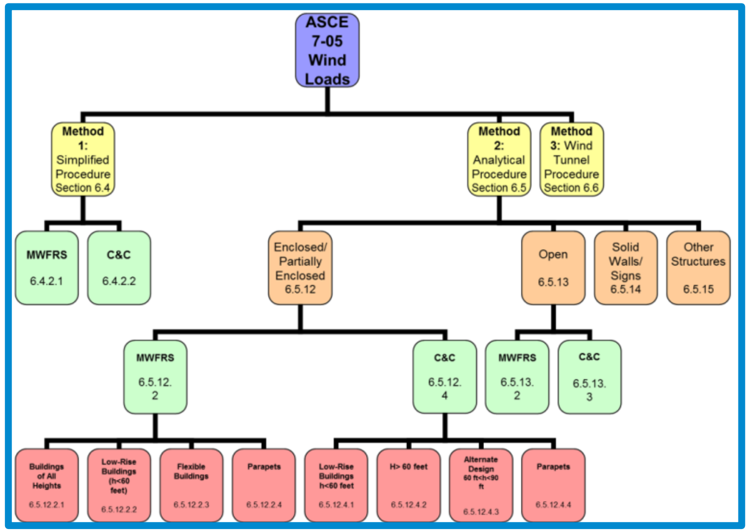
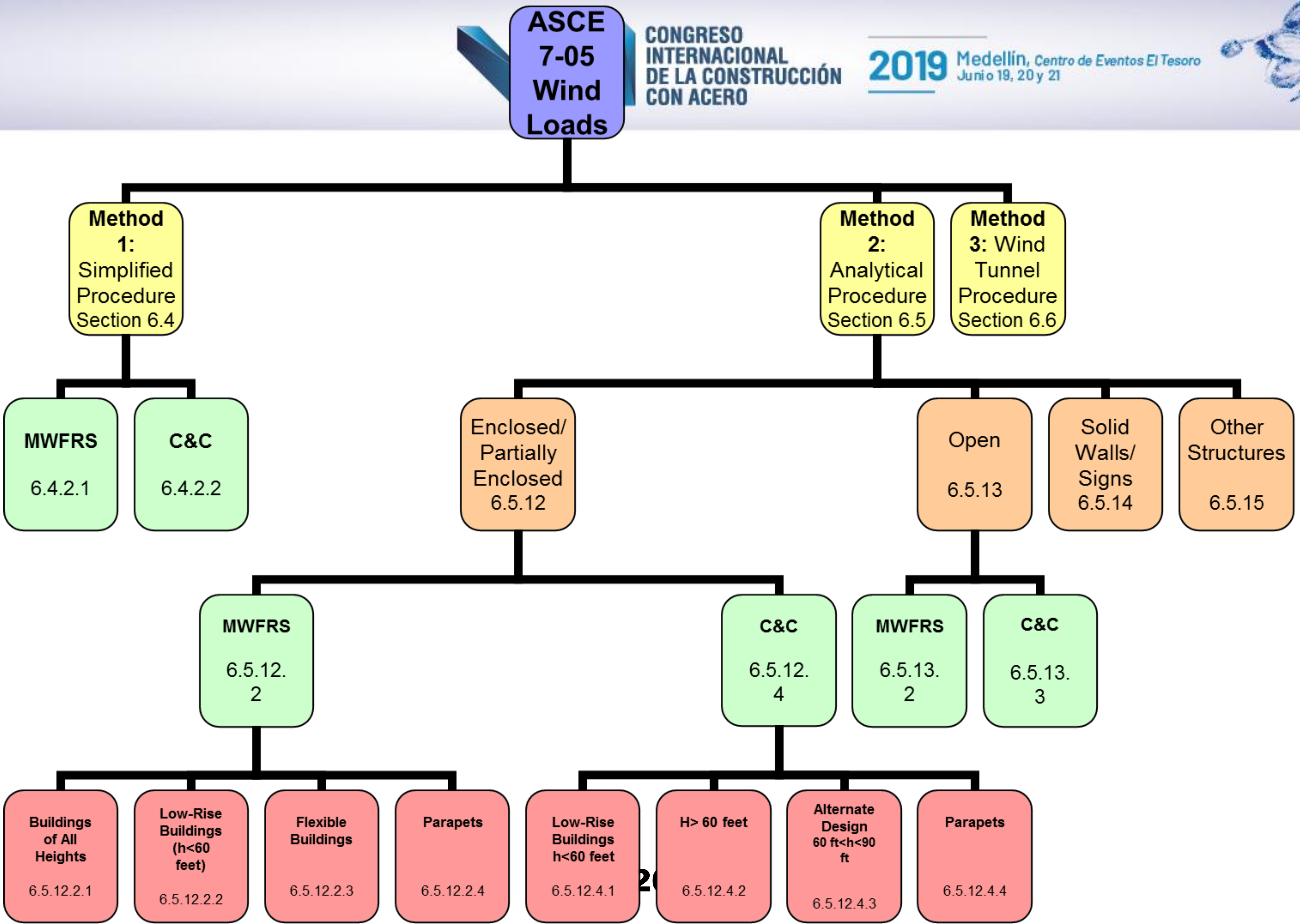


Wind Design Methods

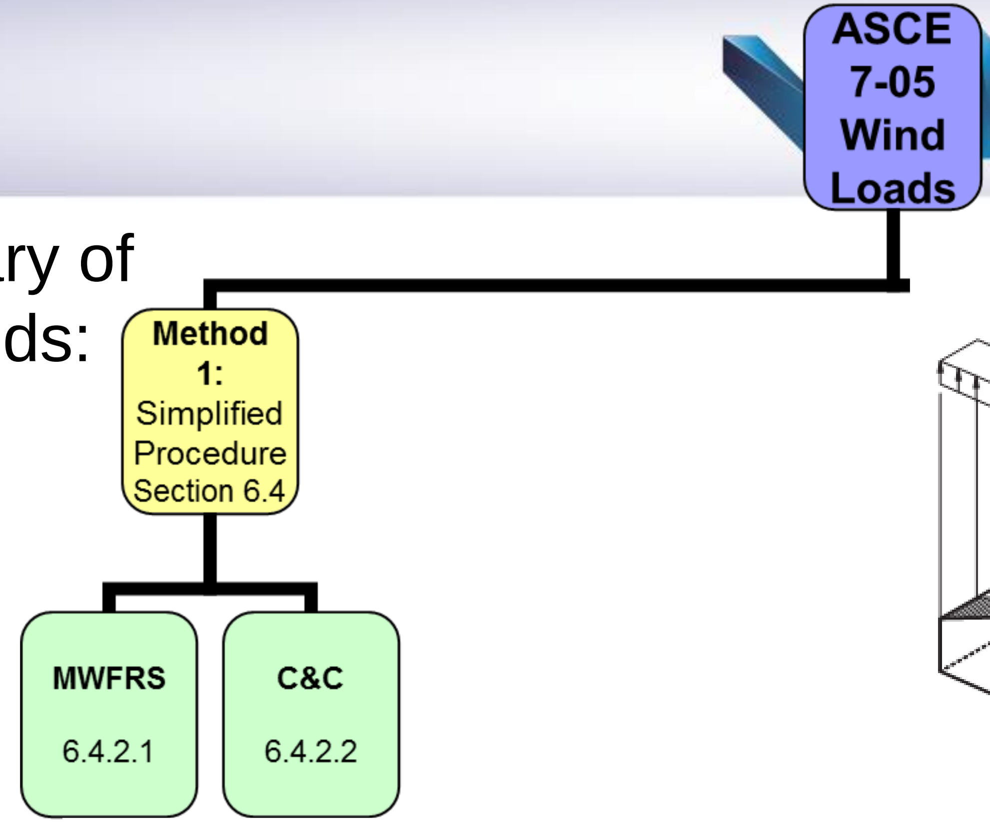
Question: What is the difference between all the Methods (analytical, simplified, directional, envelope, wind tunnel, all-heights) for calculating wind loads? *Which one should I use?*

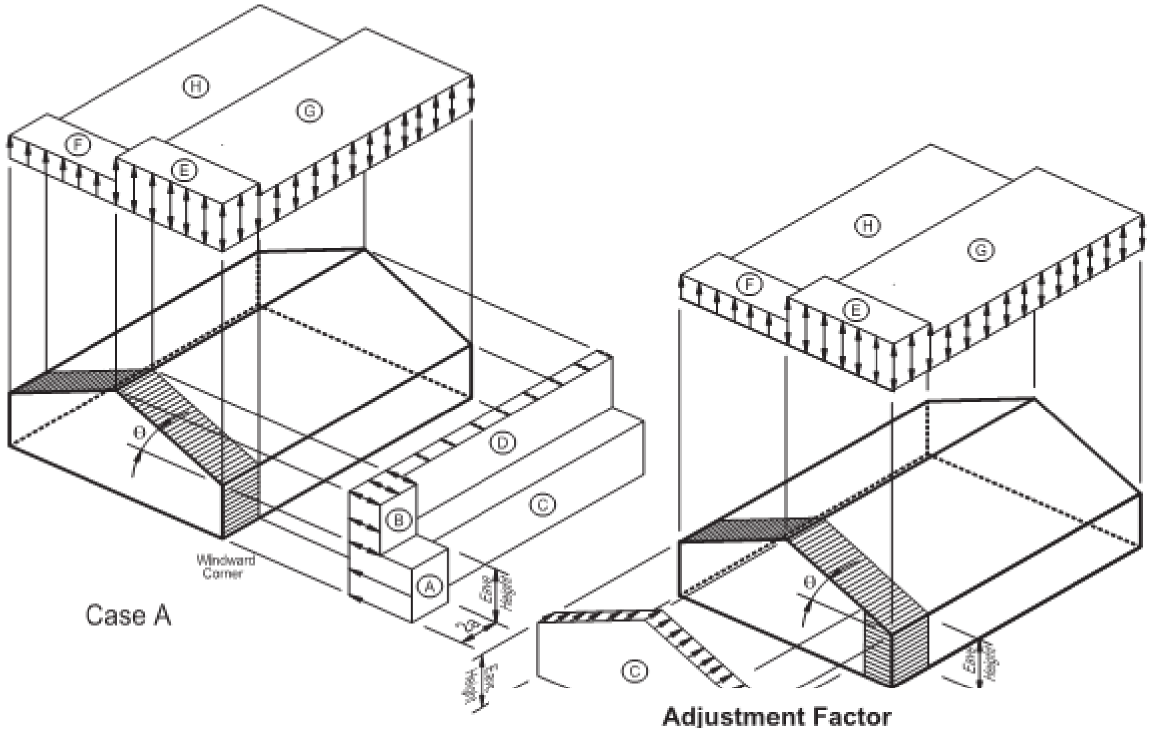
Answer:

- Main Wind Force Resisting System (MWFRS) v. Components & Cladding (C&C)
- Building Height < 60 ft v. Building Height > 60 ft
- Enclosed v. Partially Enclosed v. Open
- Flexible v. Rigid Building
- Parapet v. Wall/ Roof
- Building v. Sign/ Mechanical Equipment/ Rooftop Structures
- Regular v. Irregular Building
- Roof Configuration
- Simple Diaphragm


ASCE 7-05 Wind Loads
Method 1: Simplified Procedure Section 6.4
Method 2: Analytical Procedure Section 6.5
Method 3: Wind Tunnel Procedure Section 6.6
MWFRS 6.4.2.1
C&C 6.4.2.2
Enclosed/ Partially Enclosed 6.5.12
Open 6.5.13
Solid Walls/ Signs 6.5.14
Other Structures 6.5.15
MWFRS 6.5.12.2
C&C 6.5.12.4
MWFRS 6.5.13.2
C&C 6.5.13.3
Buildings of All Heights 6.5.12.2.1
Low-Rise Buildings (h<60 feet) 6.5.12.2.2
Flexible Buildings 6.5.12.2.3
Parapets 6.5.12.2.4
Low-Rise Buildings h<60 feet 6.5.12.4.1
H> 60 feet 6.5.12.4.2
Alternate Design 60 ft<h<90 ft 6.5.12.4.3
Parapets 6.5.12.4.4

Summary of Methods:





$$p_s = \lambda K_{zt} I p_{S30} \tag{6-1}$$

where

λ = adjustment factor for building height and exposure from Fig. 6-2

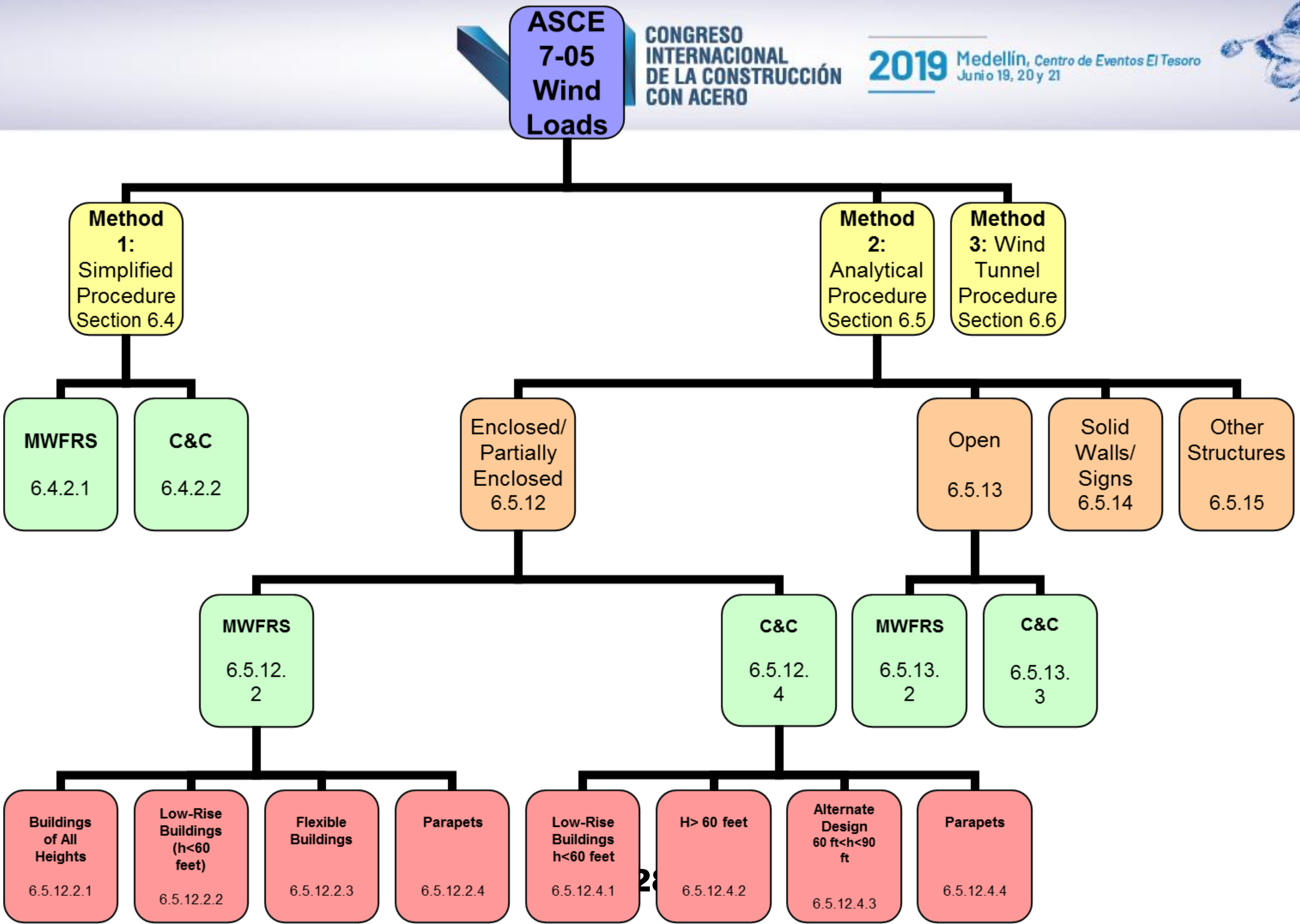
K_{zt} = topographic factor as defined in Section 6.5.7 evaluated at mean roof height, h

I = importance factor as defined in Section 6.2

p_{S30} = simplified design wind pressure for Exposure B, at h = 30 ft, and for I = 1.0, from Fig. 6-2

Adjustment Factor for Building Height and Exposure, λ

Mean roof height (ft)	Exposure B	Exposure C	Exposure D
15	1.00	1.21	1.47
20	1.00	1.29	1.55
25	1.00	1.35	1.61
30	1.00	1.40	1.66
35	1.05	1.45	1.70
40	1.09	1.49	1.74
45	1.12	1.53	1.78
50	1.16	1.56	1.81
55	1.19	1.59	1.84
60	1.22	1.62	1.87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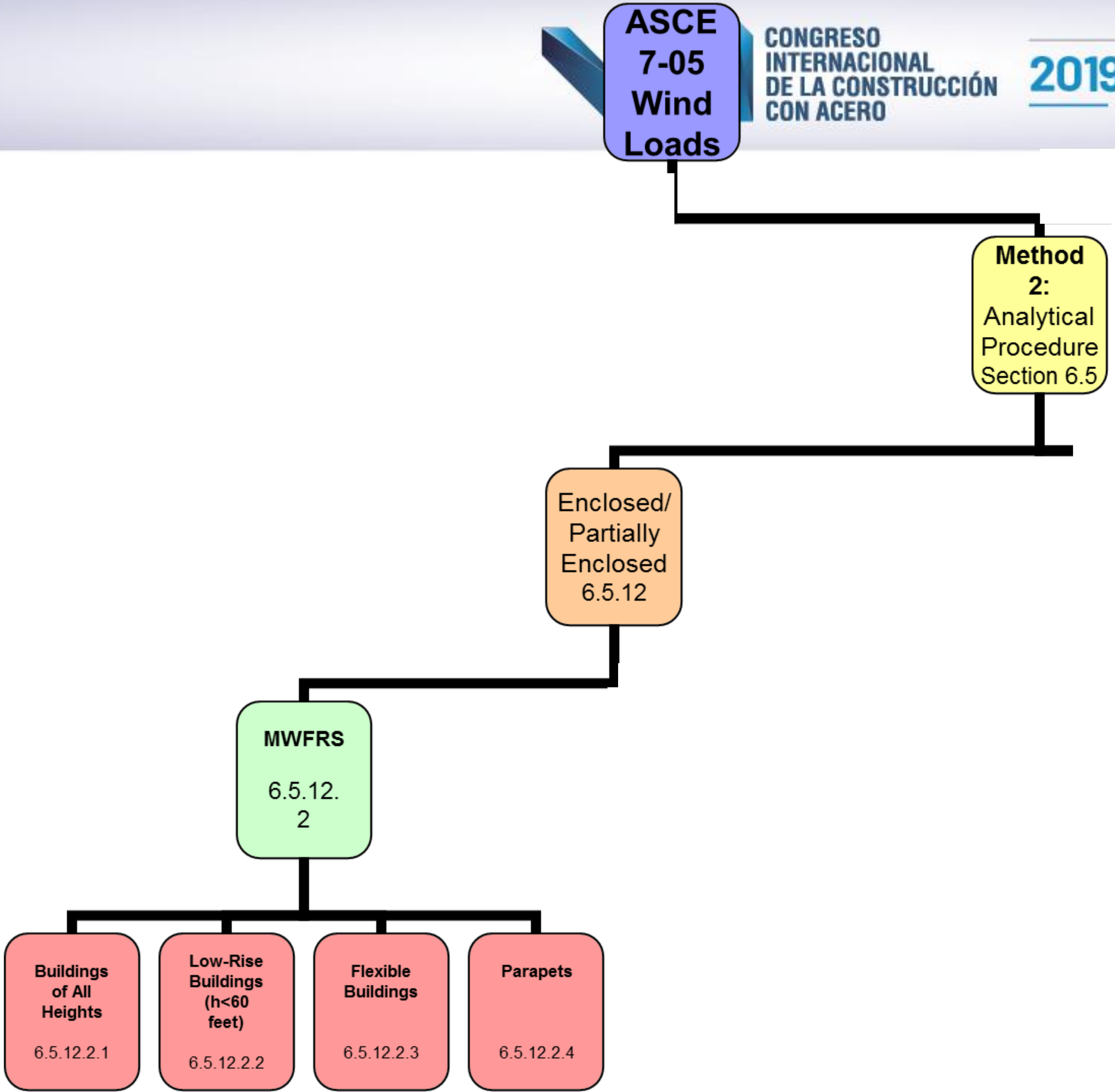
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ASCE 7-05 Wind Loads

Method 2: Analytical Procedure Section 6.5

Enclosed/ Partially Enclosed 6.5.12

MWFRS 6.5.12.2

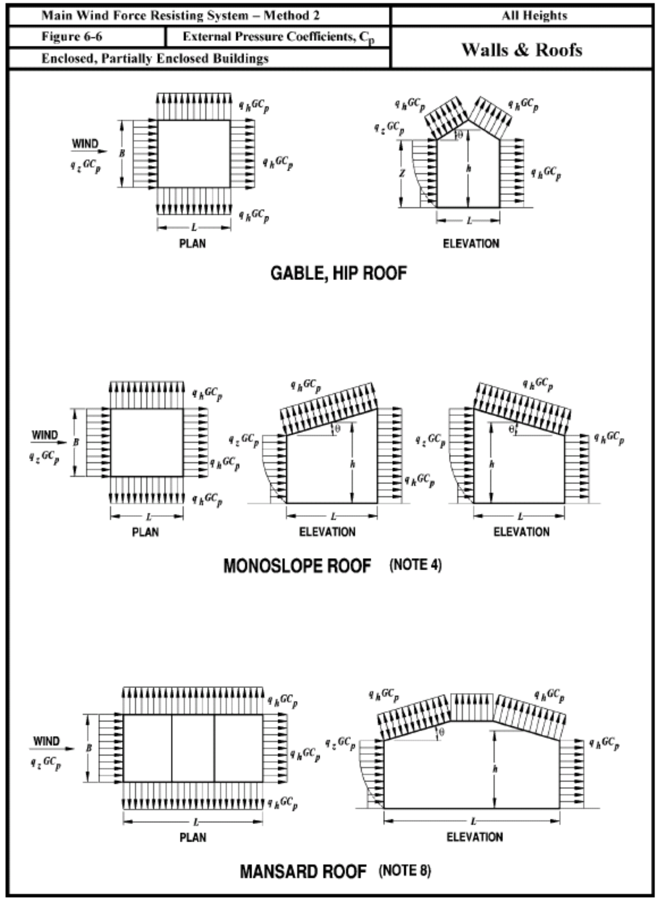
Buildings of All Heights 6.5.12.2.1

Directional Approach

6.5.12.2 Main Wind-Force Resisting Systems.

6.5.12.2.1 Rigid Buildings of All Heights. Design wind pressures for the MWFRS of buildings of all heights shall be determined by the following equation:

$$p = qGC_p - q_i(GC_{pi})\ (\text{lb/ft}^2)\ (\text{N/m}^2) \qquad (6\text{-}17)$$



ASCE 7-05 Wind Loads

Method 2: Analytical Procedure Section 6.5

Enclosed/ Partially Enclosed 6.5.12

MWFRS 6.5.12.2

Low-Rise Buildings (h<60 feet) 6.5.12.2.2

Envelope Approach

6.5.12.2.2 Low-Rise Building. Alternatively, design wind pressures for the MWFRS of low-rise buildings shall be determined by the following equation:

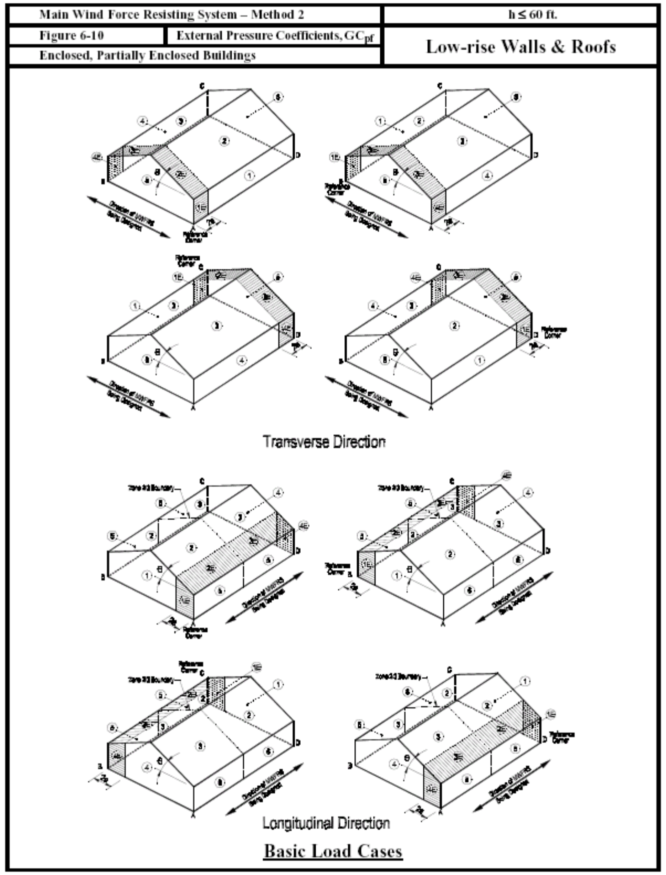
$$p = q_h[(GC_{pf}) - (GC_{pi})] \text{ (lb/ft}^2\text{) (N/m}^2\text{)} \qquad (6\text{-}18)$$

where

q_h = velocity pressure evaluated at mean roof height h using exposure defined in Section 6.5.6.3

(GC_{pf}) = external pressure coefficient from Fig. 6-10

(GC_{pi}) = internal pressure coefficient from Fig. 6-5



2011 NCSEA provided a survey to 9500 engineers.

→ 980 responses (~10%)

NCSEA
National Council of Structural Engineers Associations

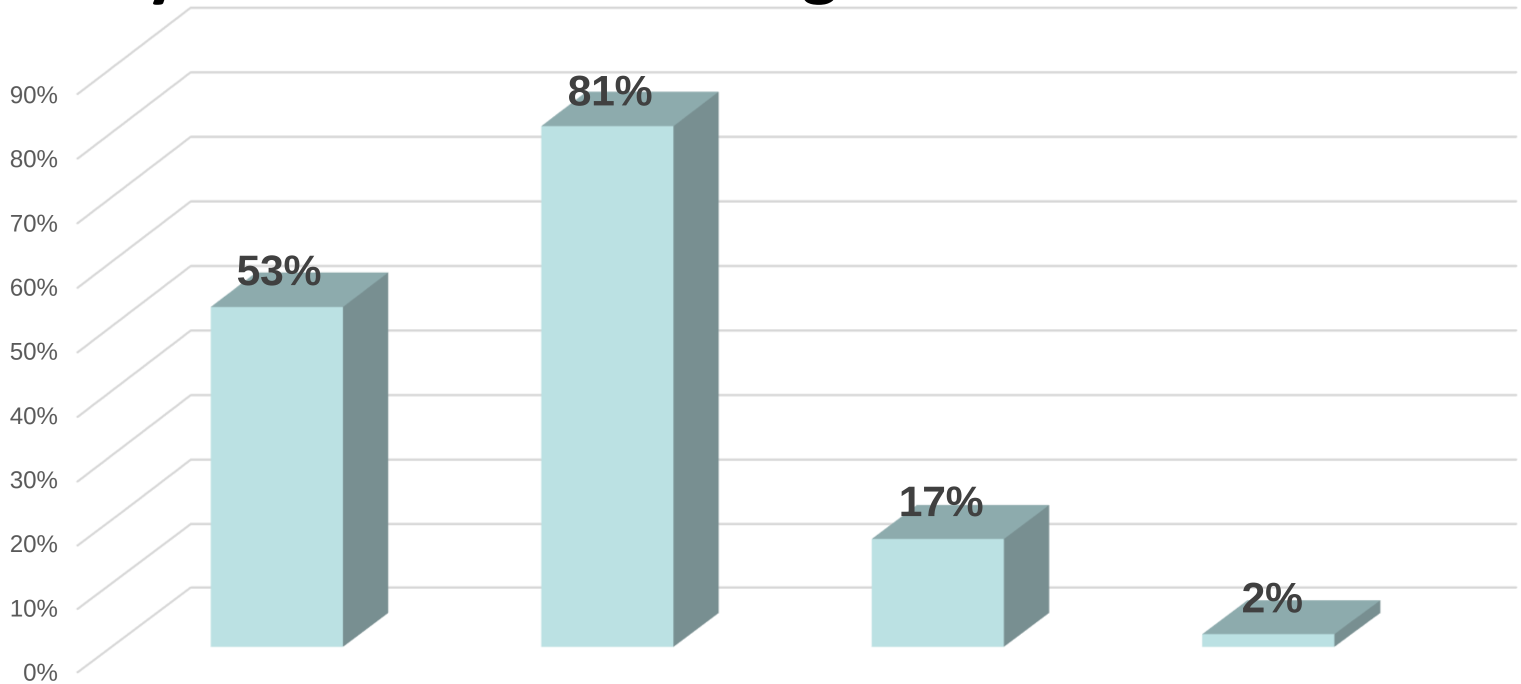
"Which provisions do you use for wind design?"

Method 1: Simplified

Method 2: All-Heights

Method 2: Low-Rise

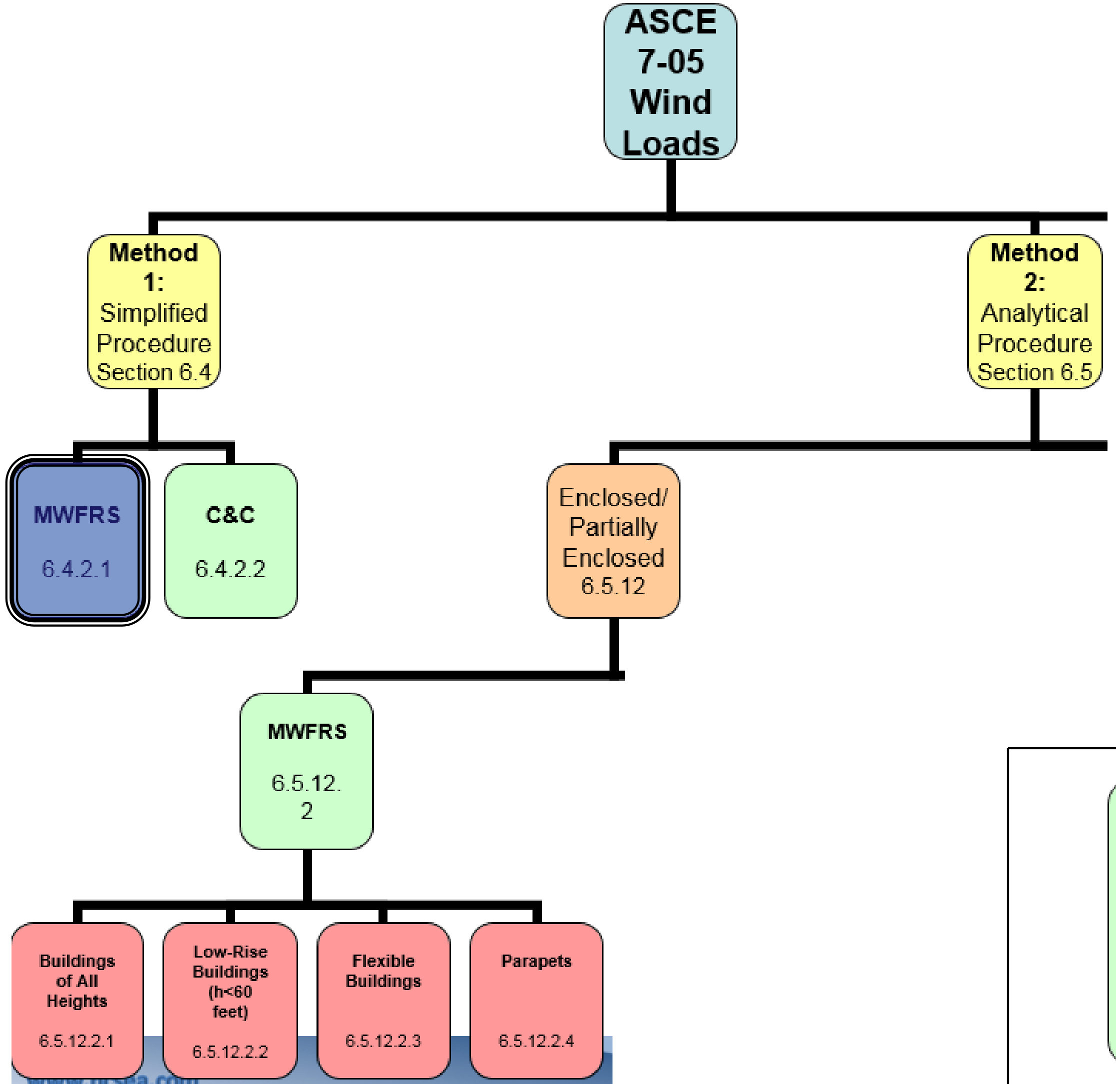
Method 3: Wind Tunnel



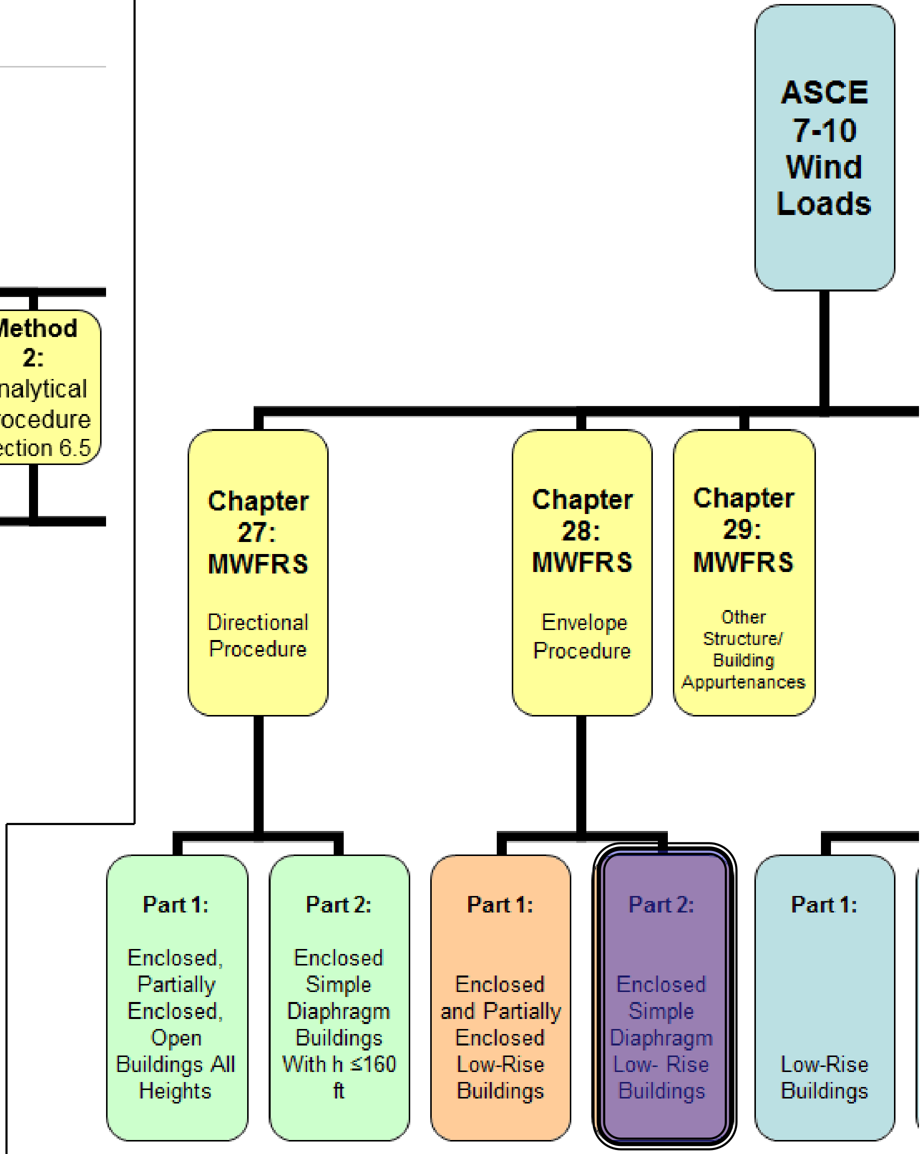
ASCE 7-10 Wind Loads

- **Chapter 27: MWFRS** Directional Procedure
  - **Part 1:** Enclosed, Partially Enclosed, Open Buildings All Heights
  - **Part 2:** Enclosed Simple Diaphragm Buildings With h ≤160 ft
- **Chapter 28: MWFRS** Envelope Procedure
  - **Part 1:** Enclosed and Partially Enclosed Low-Rise Buildings
  - **Part 2:** Enclosed Simple Diaphragm Low- Rise Buildings
- **Chapter 29: MWFRS** Other Structure/ Building Appurtenances
- **Chapter 30: C&C**
  - **Part 1:** Low-Rise Buildings
  - **Part 2:** Low-Rise Buildings (Simplified)
  - **Part 3:** Buildings with h>60 ft
  - **Part 4:** Buildings with h≤160 ft (Simplified)
  - **Part 5:** Open Buildings
  - **Part 6:** Building Appurtenances, Rooftop Structures, Equipment
- **Chapter 31: Wind Tunnel Procedure**

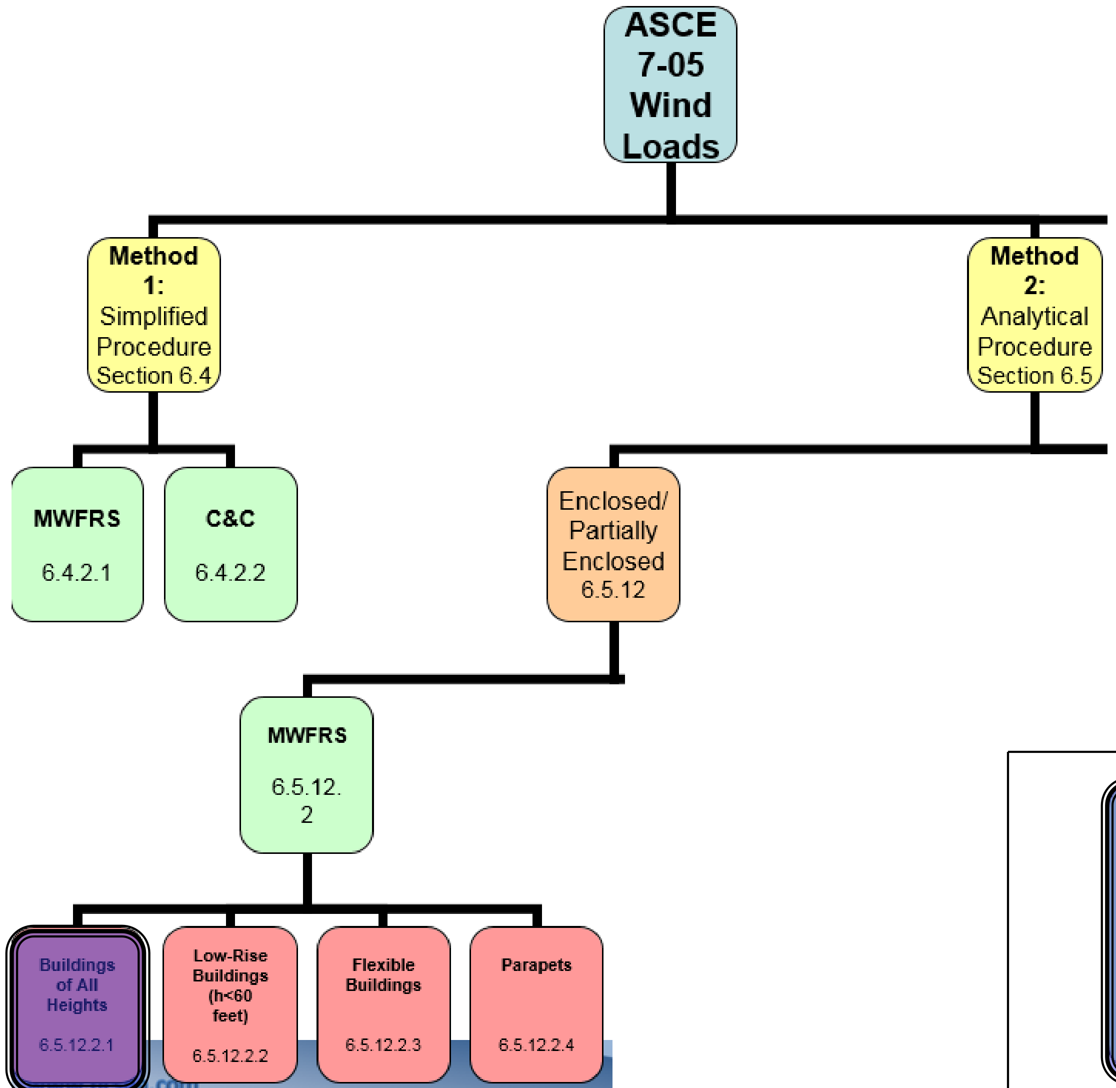
ASCE 7-05



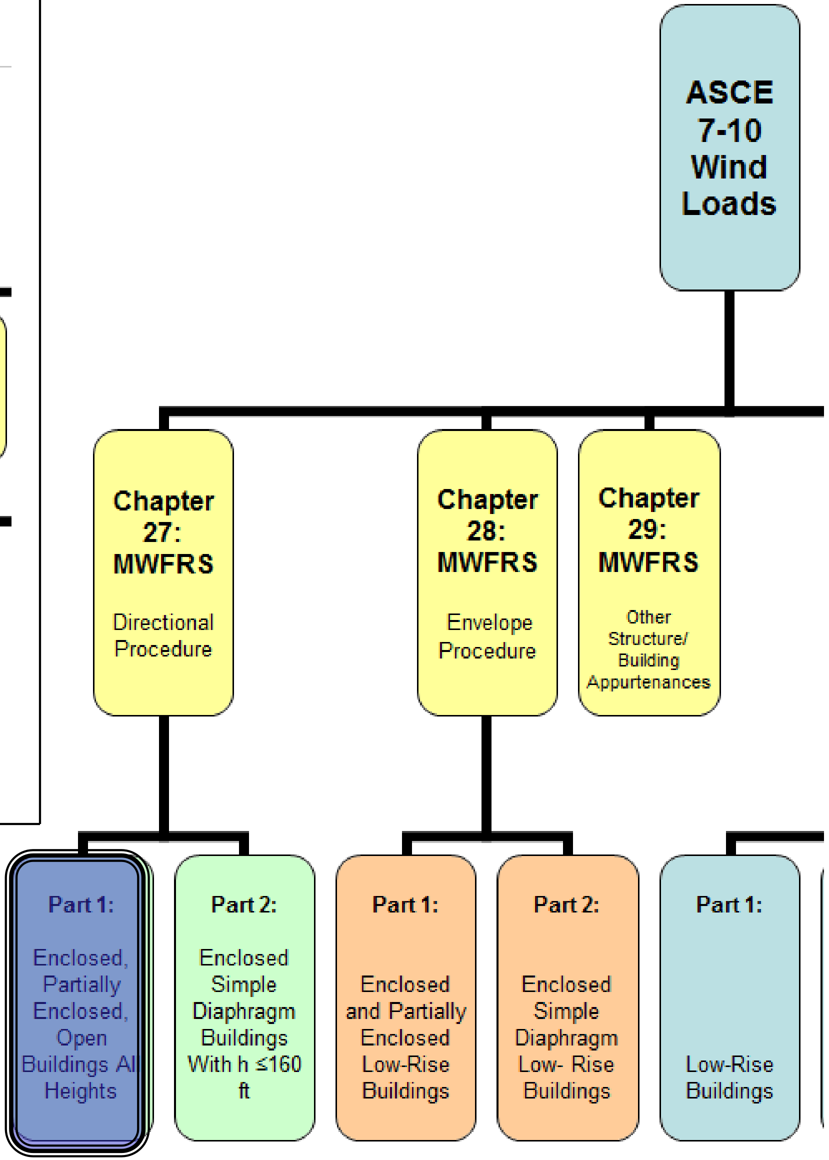
ASCE 7-10



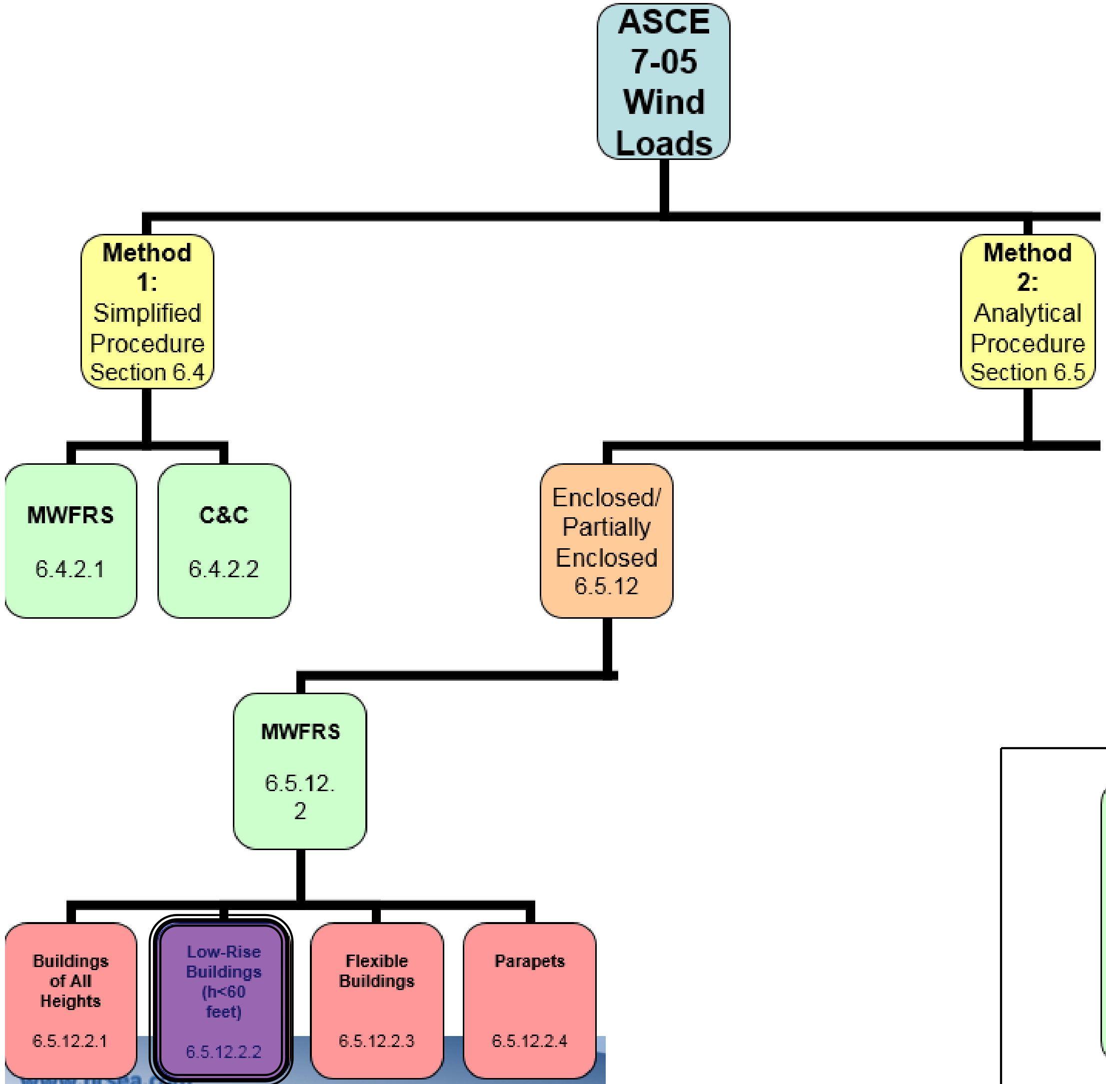
ASCE 7-05



ASCE 7-10



ASCE 7-05



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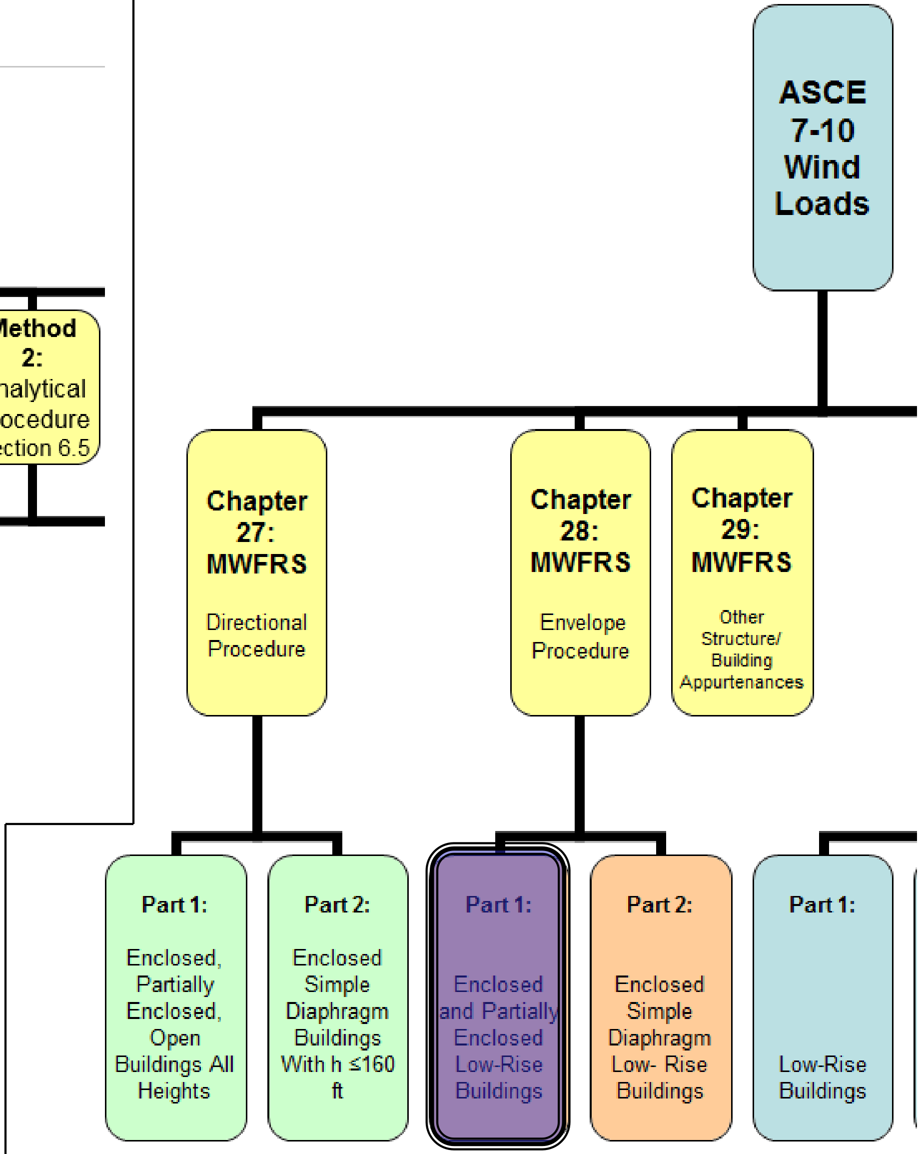
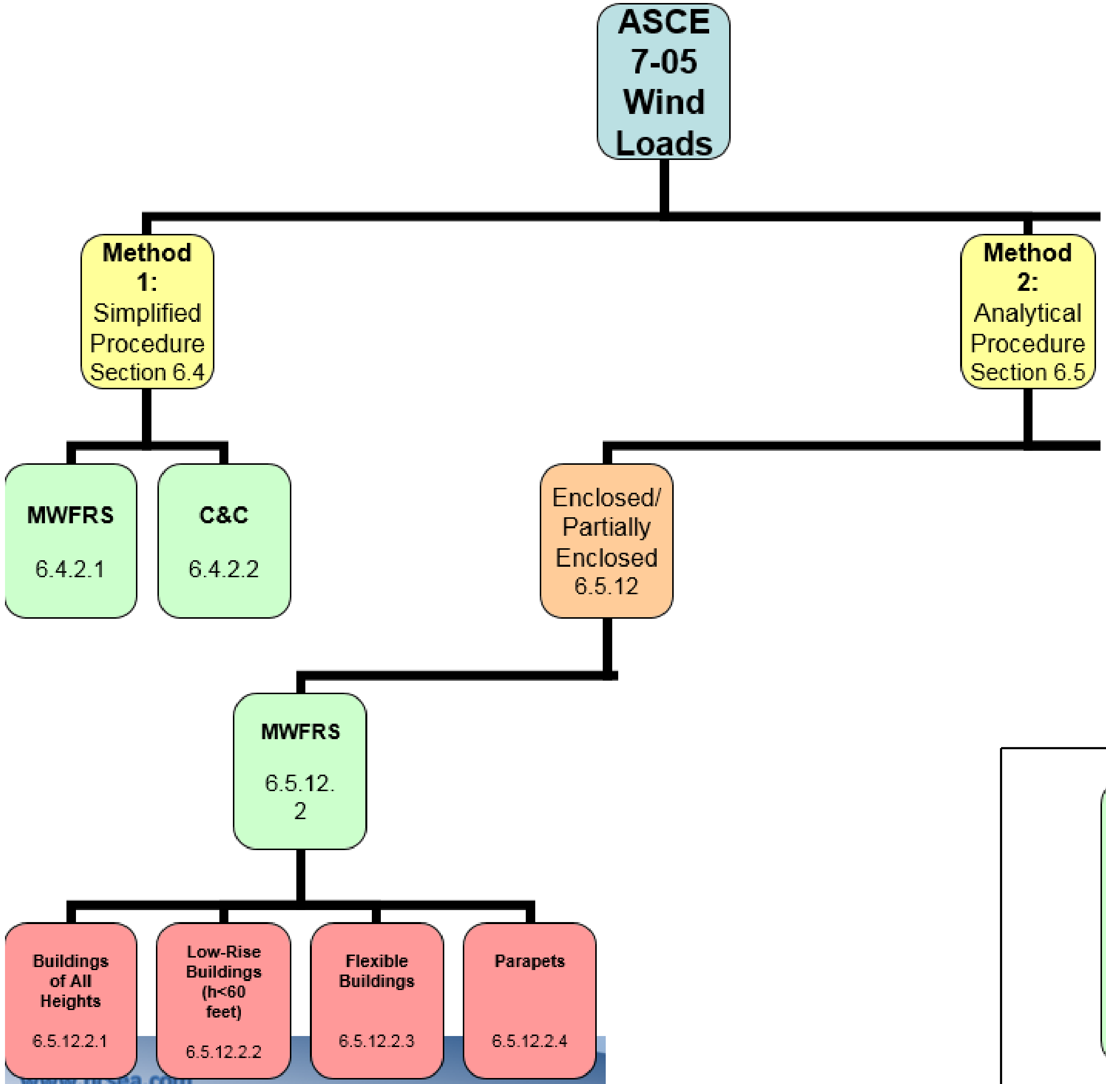


ASCE 7-05



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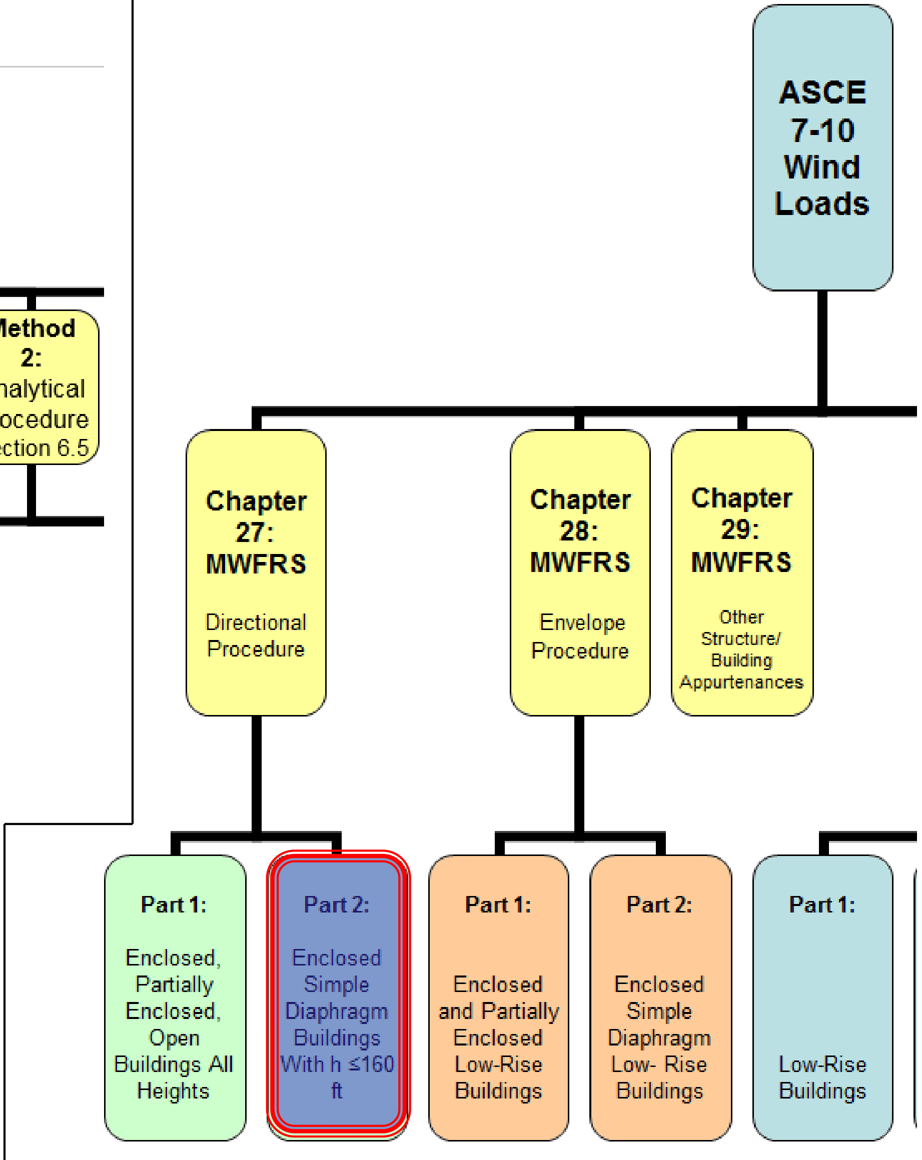


Wind Design Methods

Question: What's the difference between Analytical (Method 2)/ Simplified (Method 1) [ASCE 7-05] and Directional/ Envelope [ASCE 7-10]?

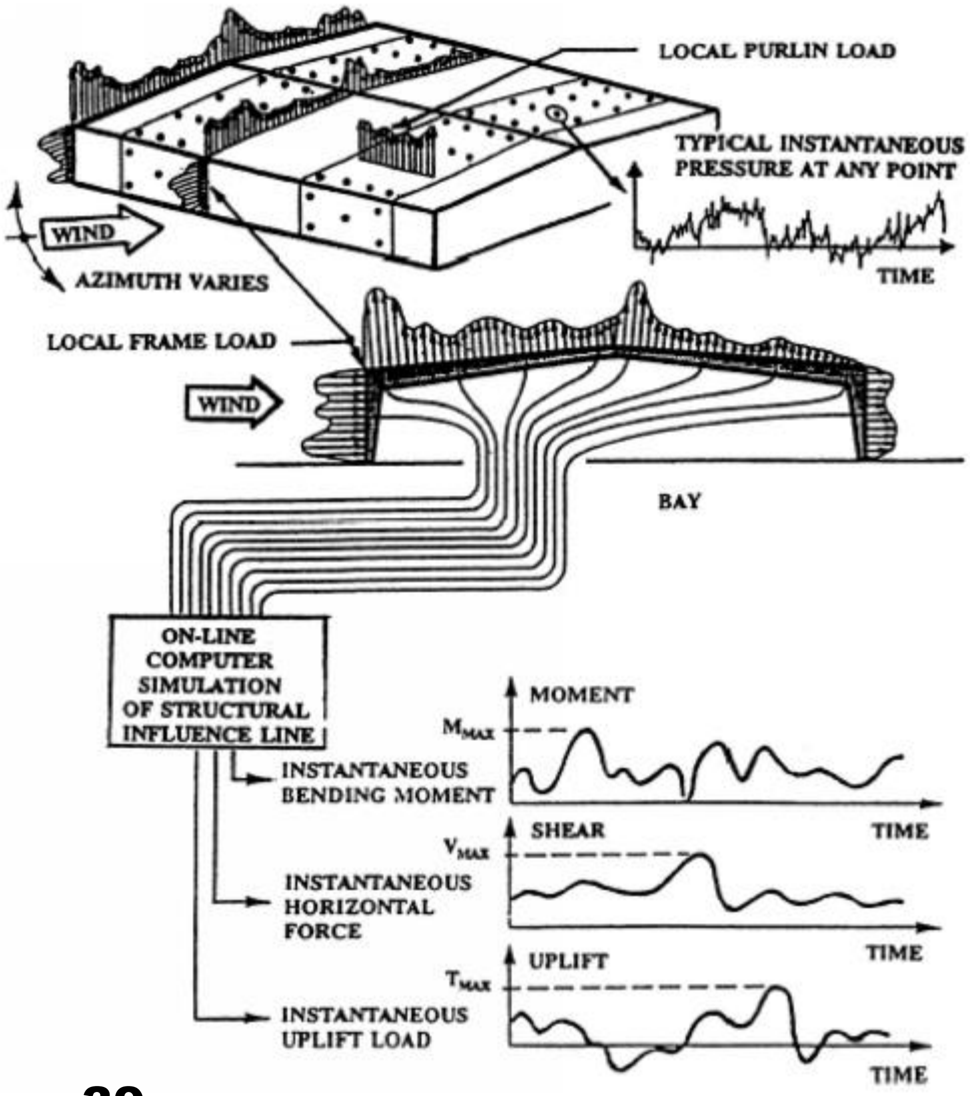
Answer:

Analytical/ Method 2 (ASCE 7-05) = Directional (ASCE 7-10) Chapter 27	Simplified/ Method 1 (ASCE 7-05) = Envelope (ASCE 7-10) Chapter 28
Pressure coefficients reflect actual loading on each surface as a function of wind direction.	Pressure coefficients represent "pseudo" loading that envelope the desired moment, shear, uplift…

Wind Design Methods

Simplified/ Method 1 (ASCE 7-05) = Envelope (ASCE 7-10) Chapter 28

Pressure coefficients represent "pseudo" loading that envelope the desired moment, shear…



Enclosed

- **ASCE 7-10 Wind Loads**
  - **Chapter 27: MWFRS** Directional Procedure
    - **Part 1:** Enclosed, Partially Enclosed, Open Buildings All Heights
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  - **Chapter 30: C&C**
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    - **Part 5:** Open Buildings
    - **Part 6:** Building Appurtenances, Rooftop Structures, Equipment
  - **Chapter 31: Wind Tunnel Procedure**

ASCE 7-10 Wind Loads

Partially Enclosed

Chapter 27: MWFRS
Directional Procedure

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Other Structure/ Building Appurtenances

Chapter 30: C&C

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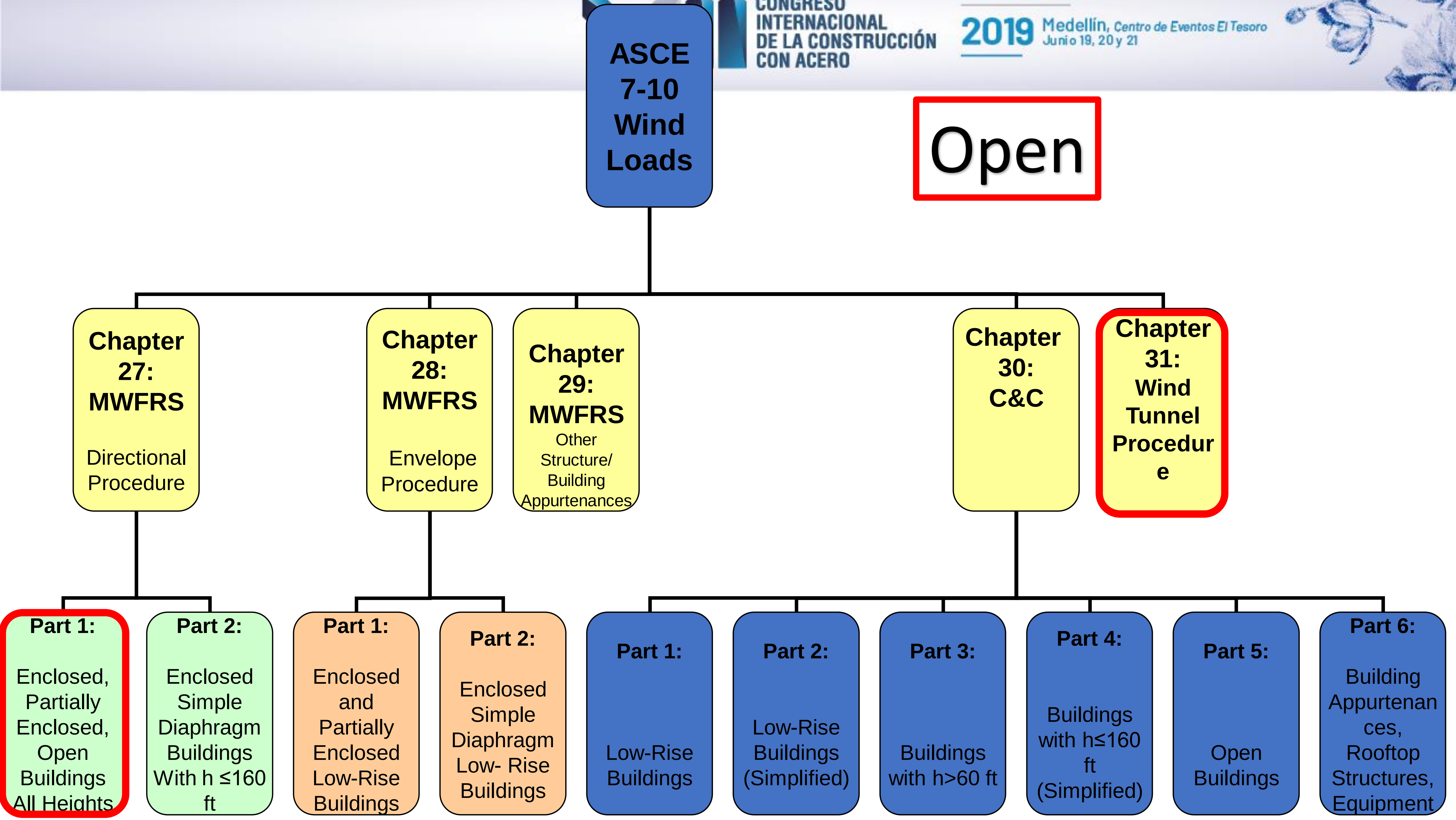
Chapter 31: Wind Tunnel Procedure

Open


ASCE 7-10 Wind Loads
Chapter 27: MWFRS Directional Procedure
Chapter 28: MWFRS Envelope Procedure
Chapter 29: MWFRS Other Structure/ Building Appurtenances
Chapter 30: C&C
Chapter 31: Wind Tunnel Procedure
Part 1: Enclosed, Partially Enclosed, Open Buildings All Heights
Part 2: Enclosed Simple Diaphragm Buildings With h ≤160 ft
Part 1: Enclosed and Partially Enclosed Low-Rise Buildings
Part 2: Enclosed Simple Diaphragm Low- Rise Buildings
Part 1: Low-Rise Buildings
Part 2: Low-Rise Buildings (Simplified)
Part 3: Buildings with h>60 ft
Part 4: Buildings with h≤160 ft (Simplified)
Part 5: Open Buildings
Part 6: Building Appurtenances, Rooftop Structures, Equipment

Height>60 ft


ASCE 7-10 Wind Loads
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Part 6: Building Appurtenances, Rooftop Structures, Equipment

Height>160 ft

- **ASCE 7-10 Wind Loads**
  - **Chapter 27: MWFRS** Directional Procedure
    - **Part 1:** Enclosed, Partially Enclosed, Open Buildings All Heights
    - **Part 2:** Enclosed Simple Diaphragm Buildings With h ≤160 ft
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  - **Chapter 31: Wind Tunnel Procedure**

≠Simple Diaphragm

- **ASCE 7-10 Wind Loads**
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Time to retire? Move to Appendix?

ASCE 7-10 Wind Loads

- **Chapter 27: MWFRS** Directional Procedure
  - **Part 1:** Enclosed, Partially Enclosed, Open Buildings All Heights
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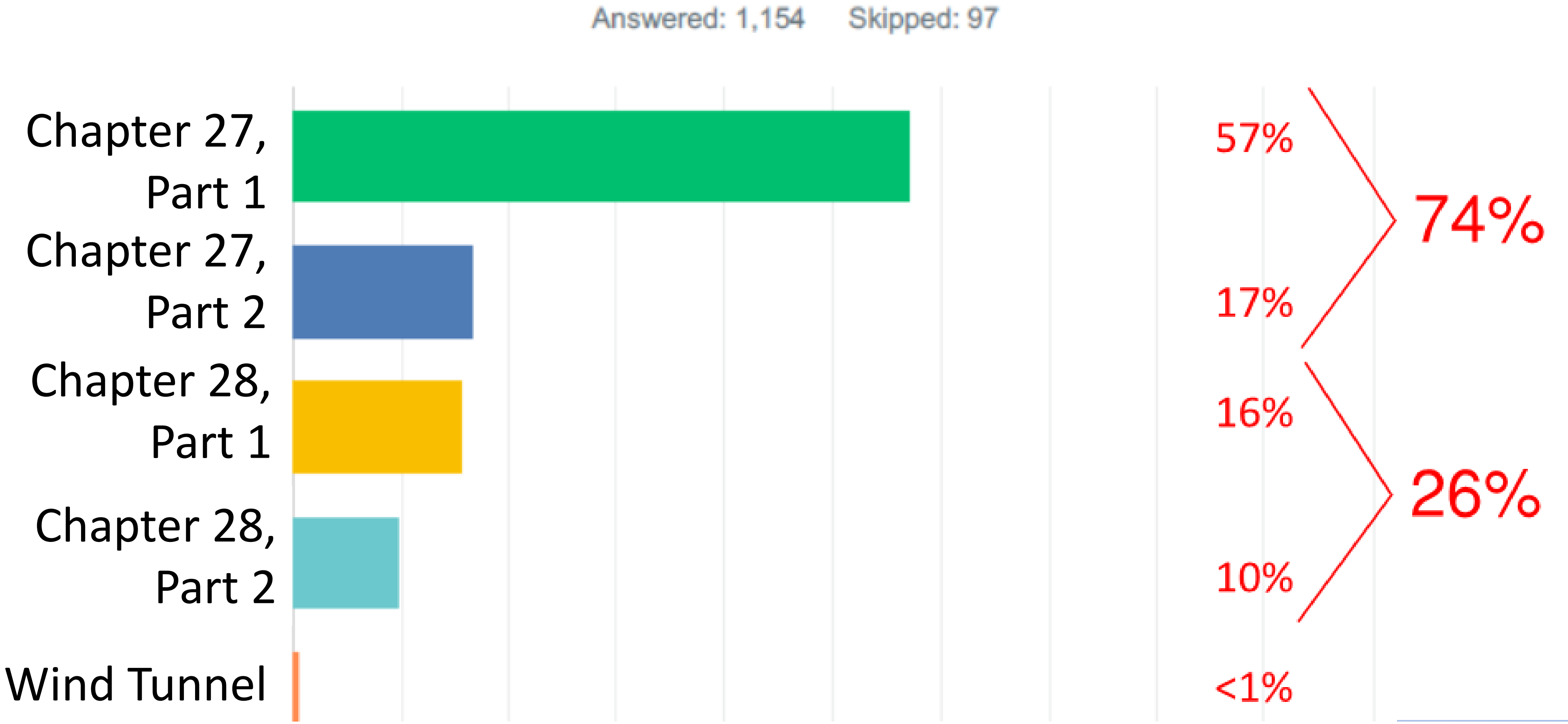
- **Chapter 31: Wind Tunnel Procedure**

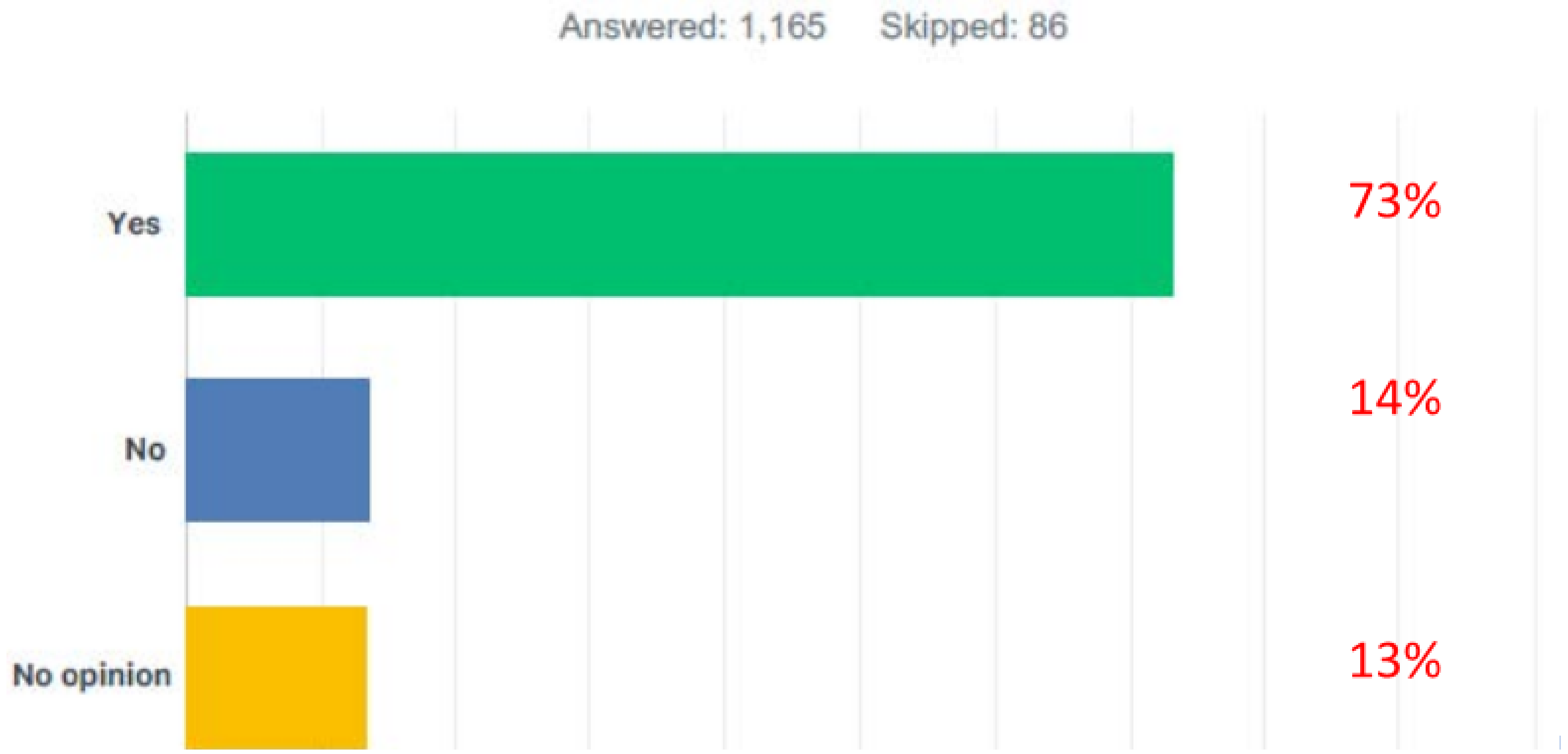
2017 NCSEA Wind Survey Results

- Q21 – What is the primary method you use for determining wind loads on structures?



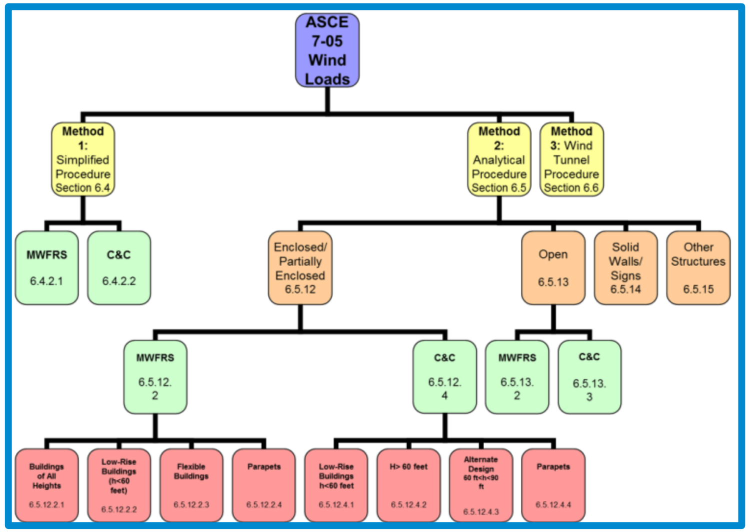
2017 NCSEA Wind Survey Results

- Q23 – Are you in favor of reducing the number of methods in ASCE 7 for determining wind loads on structures to (1) computational method and (1) tabular method?



Frequently Misunderstood Wind Provisions

- Enclosure Classification
- Analysis Methods
- Canopies
- Rooftop Solar/ PV
- Rooftop Screenwalls



Canopies and Awnings

External Pressure Coefficient, C_p

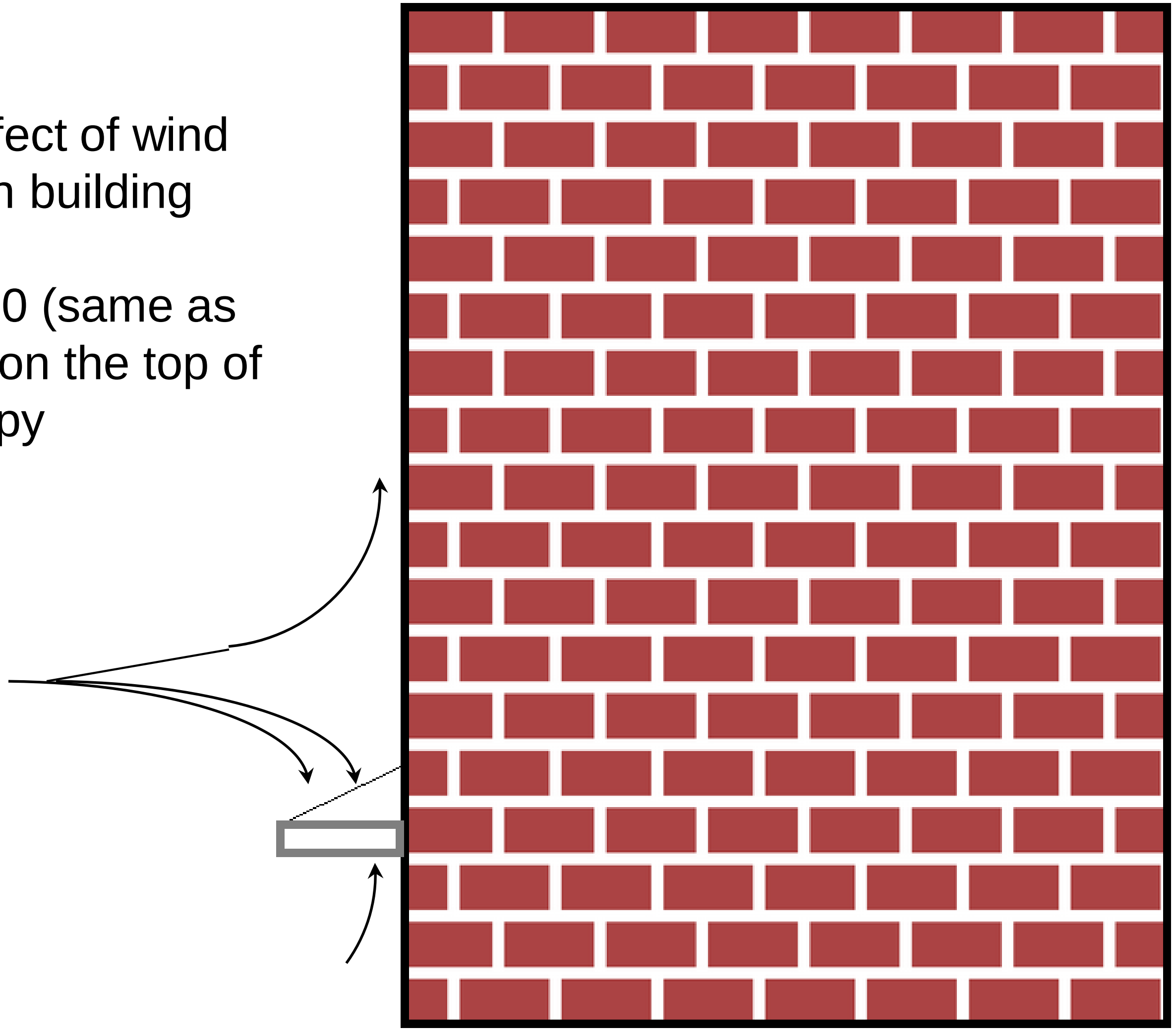
- One of the oldest figures of ASCE 7.
- Helps us understand wind behavior.

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

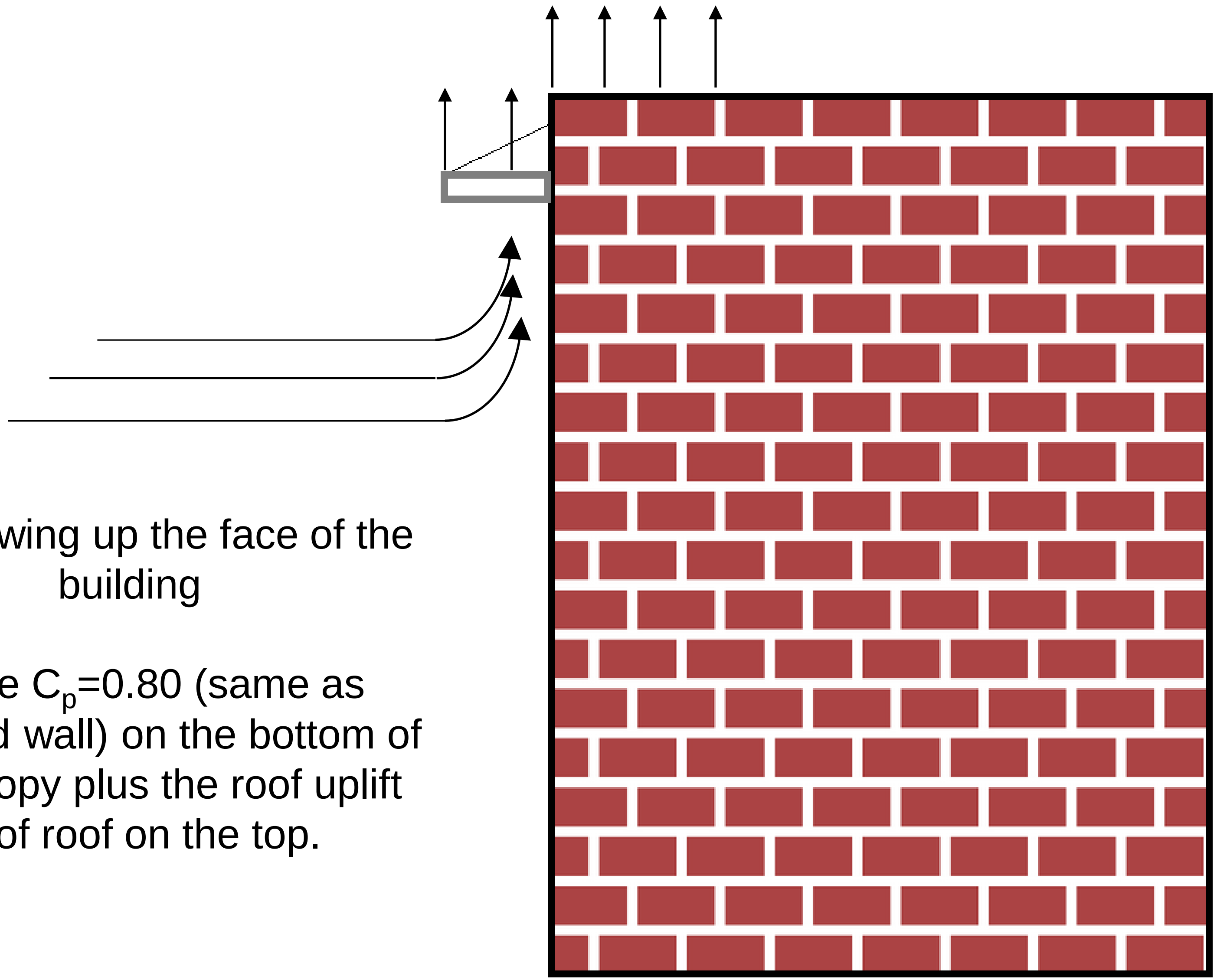
Canopies and Awnings

Down-draft effect of wind flowing down building

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



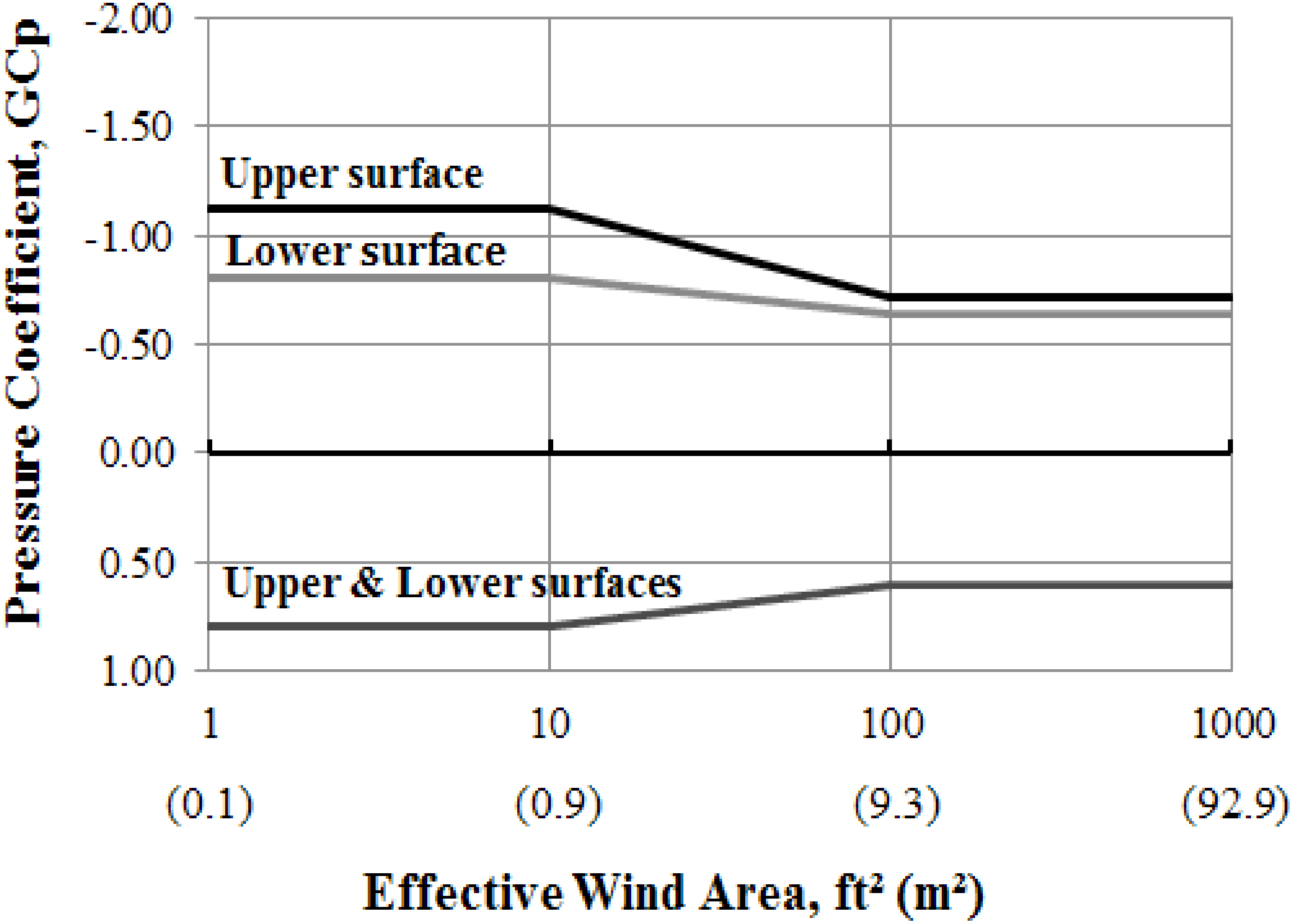
Canopies and Awnings



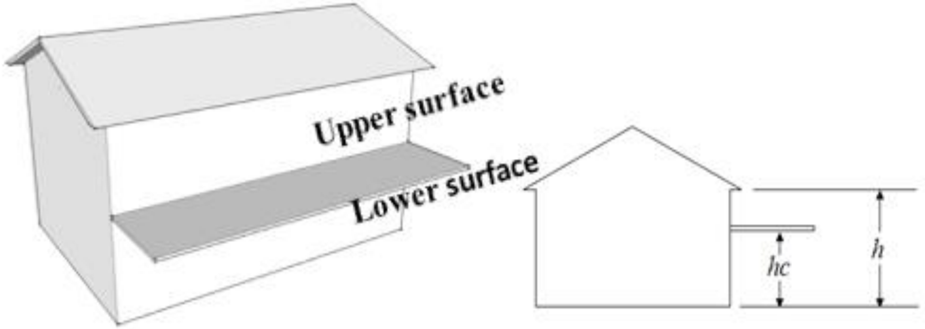
Wind flowing up the face of the building

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

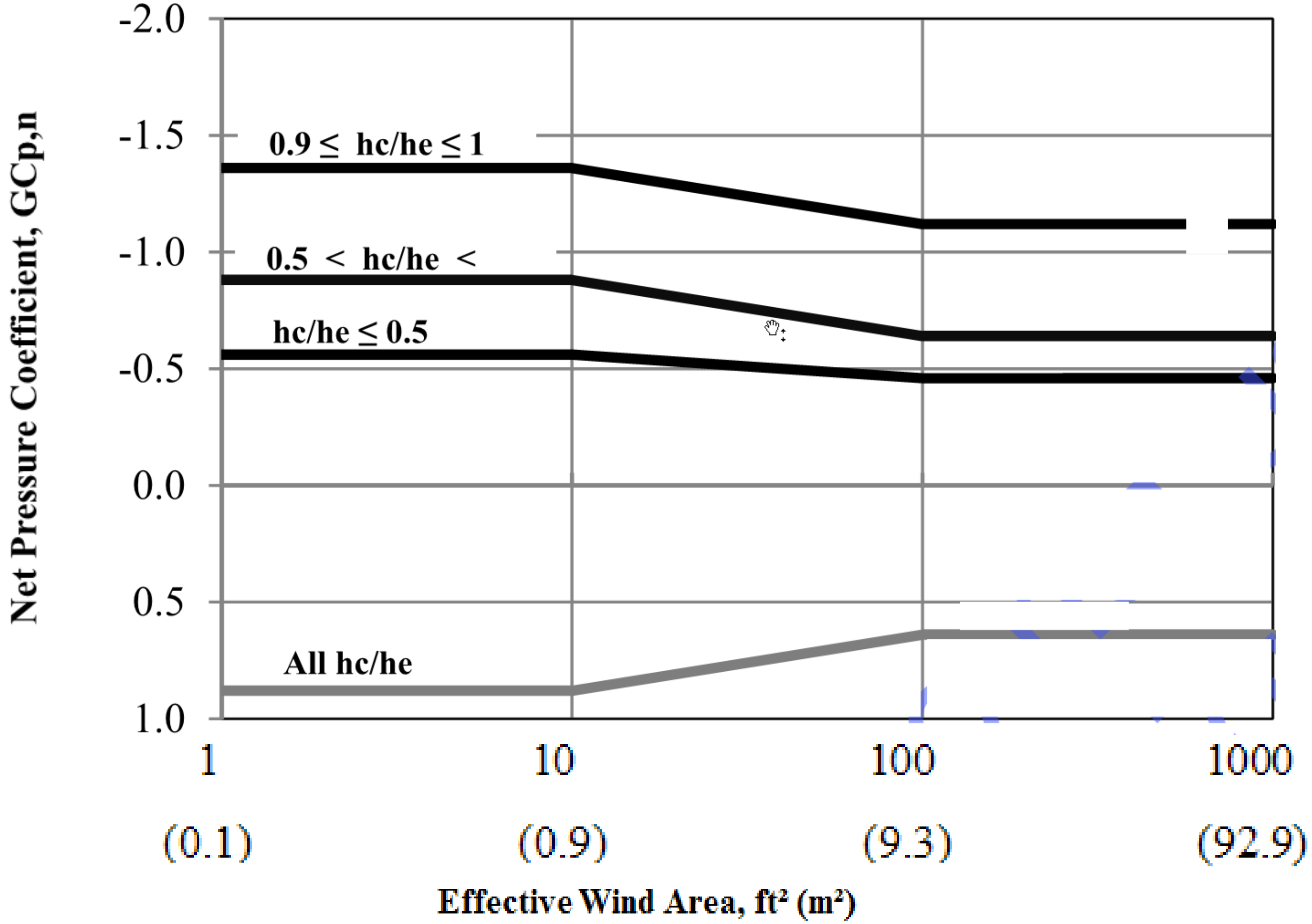
ASCE 7-16 – Attached Canopies



$p = q_h(GC_p)$ (lb/ft²) (N/m²)



ASCE 7-16 – Attached Canopies



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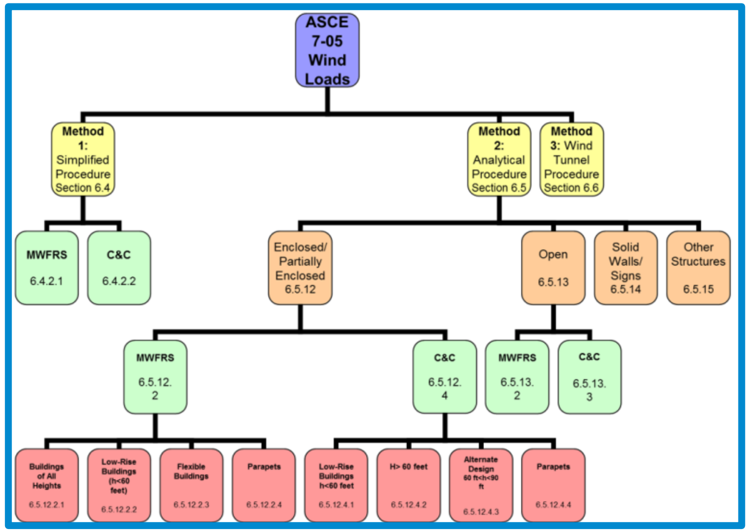
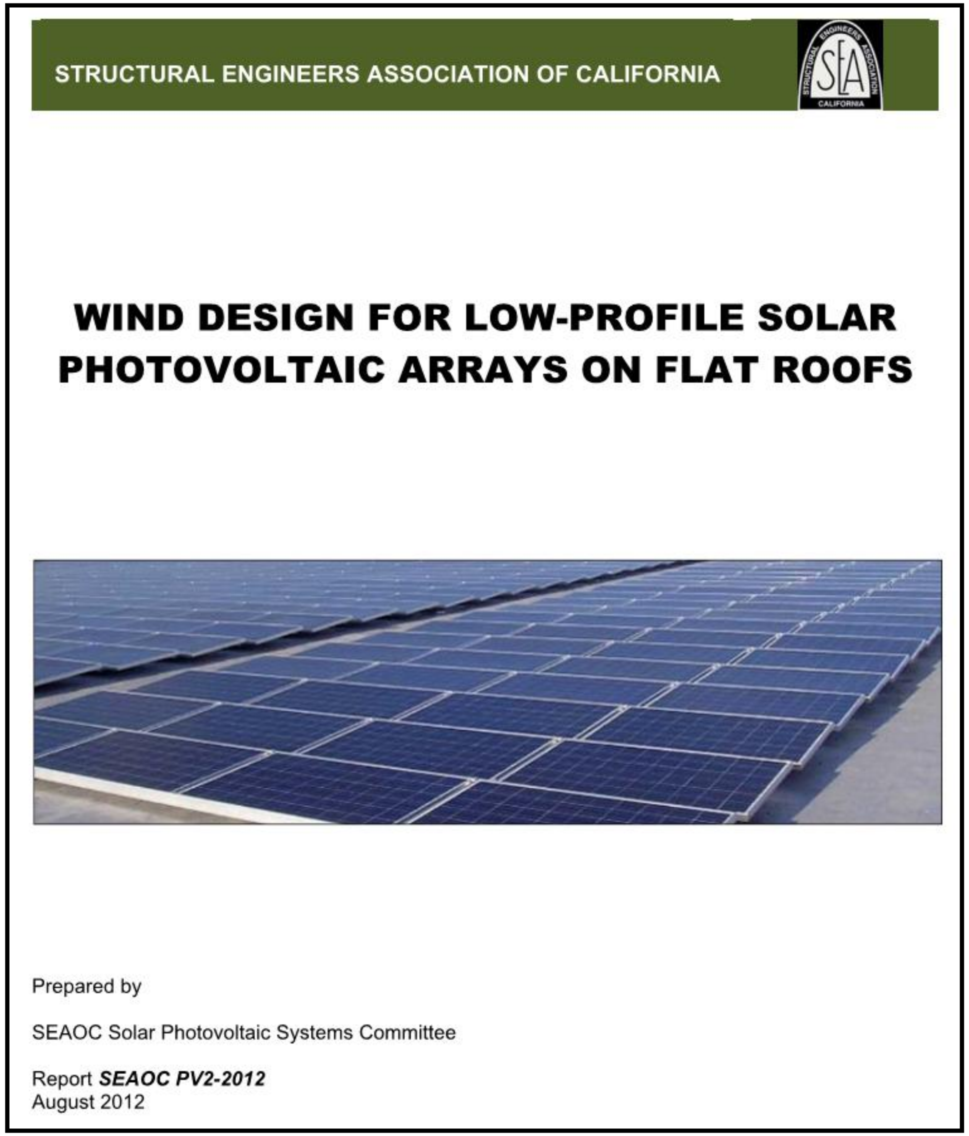


Solar PV


STRUCTURAL ENGINEERS ASSOCIATION OF CALIFORNIA

WIND DESIGN FOR LOW-PROFILE SOLAR PHOTOVOLTAIC ARRAYS ON FLAT ROOFS

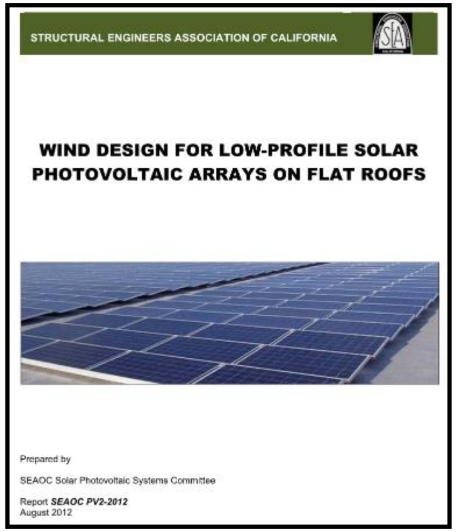
Prepared by

SEAOC Solar Photovoltaic Systems Committee

Report ***SEAOC PV2-2012***
August 2012

ASCE 7-16

Solar PV


STRUCTURAL ENGINEERS ASSOCIATION OF CALIFORNIA

WIND DESIGN FOR LOW-PROFILE SOLAR PHOTOVOLTAIC ARRAYS ON FLAT ROOFS

Prepared by

SEAOC Solar Photovoltaic Systems Committee

Report *SEAOC PV2-2012*
August 2012

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

<u>2012:</u>
- PV1-2012: Seismic Design
- PV2-2012: Wind Design → ASCE 7-16 incorporates and adopts PV2-2012

<u>2017:</u>
- PV2-2017: 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.

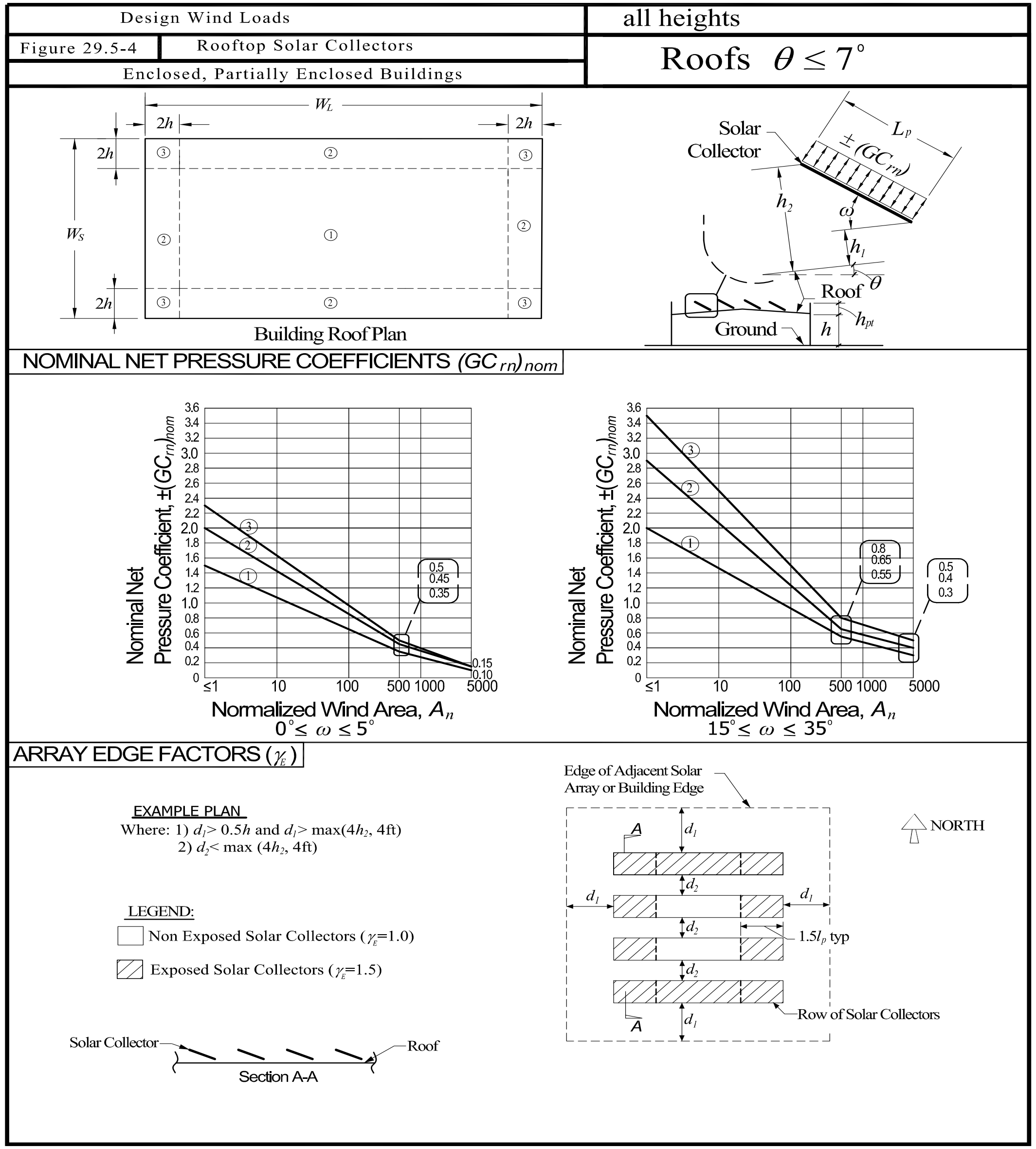
Guide DOES Cover:

- 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.)

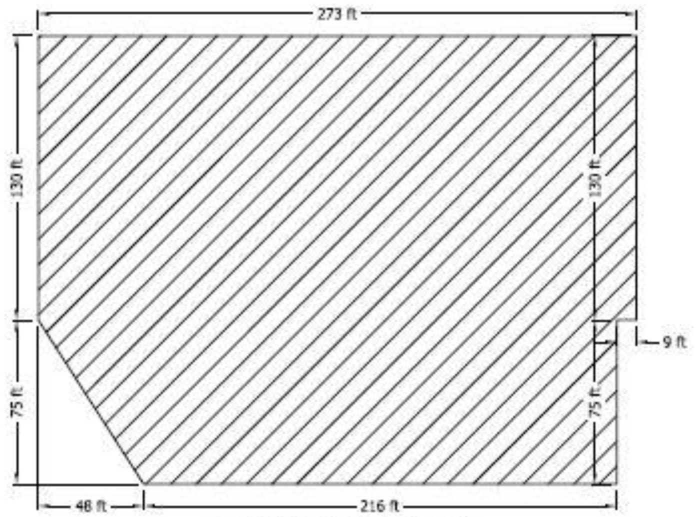
Solar PV


Design Wind Loads
all heights
Figure 29.5-4
Rooftop Solar Collectors
Enclosed, Partially Enclosed Buildings
Roofs θ ≤ 7°
Building Roof Plan
Solar Collector
Roof
Ground
NOMINAL NET PRESSURE COEFFICIENTS (GCrn)nom
Nominal Net Pressure Coefficient, ±(GCrn)nom
Normalized Wind Area, An
0° ≤ ω ≤ 5°
15° ≤ ω ≤ 35°
ARRAY EDGE FACTORS (γE)
EXAMPLE PLAN
Where: 1) d1 > 0.5h and d1 > max(4h2, 4ft)
2) d2 < max (4h2, 4ft)
LEGEND:
Non Exposed Solar Collectors (γE=1.0)
Exposed Solar Collectors (γE=1.5)
Solar Collector
Roof
Section A-A
Edge of Adjacent Solar Array or Building Edge
NORTH
1.5Lp typ
Row of Solar Collectors

SEAOC PV2-2017 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



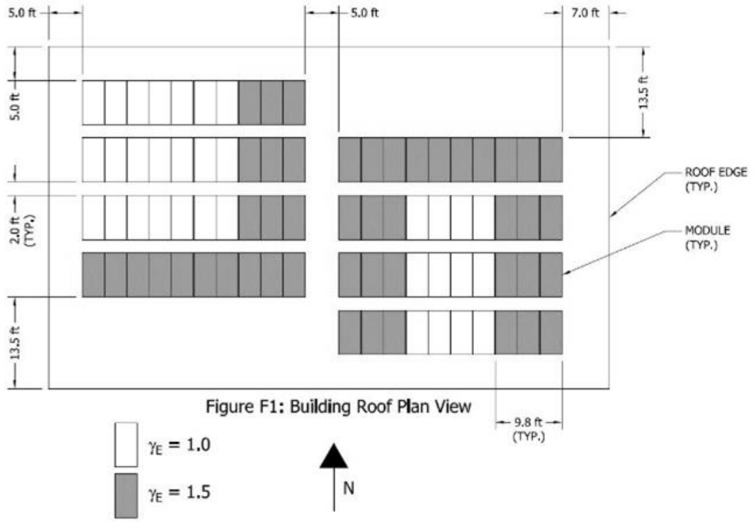
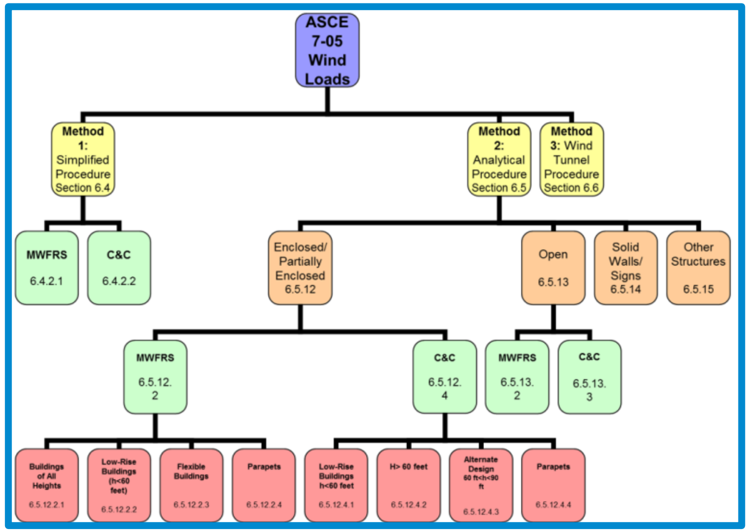


Figure F1: Building Roof Plan View

Frequently Misunderstood Wind Provisions

- Enclosure Classification
- Analysis Methods
- Canopies
- Rooftop Solar/ PV
- **Rooftop Screenwalls**



Rooftop Screenwalls

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

a) Rooftop Structures and Equipment?

29.5.1 ROOFTOP STRUCTURES AND EQUIPMENT FOR BUILDINGS WITH *h* ≤ 60 ft (18.3 m)

The lateral force F_h on rooftop structures and equipment located on buildings with a mean roof height $h \le$ 60 ft (18.3 m) shall be determined from Eq. 29.5-2.

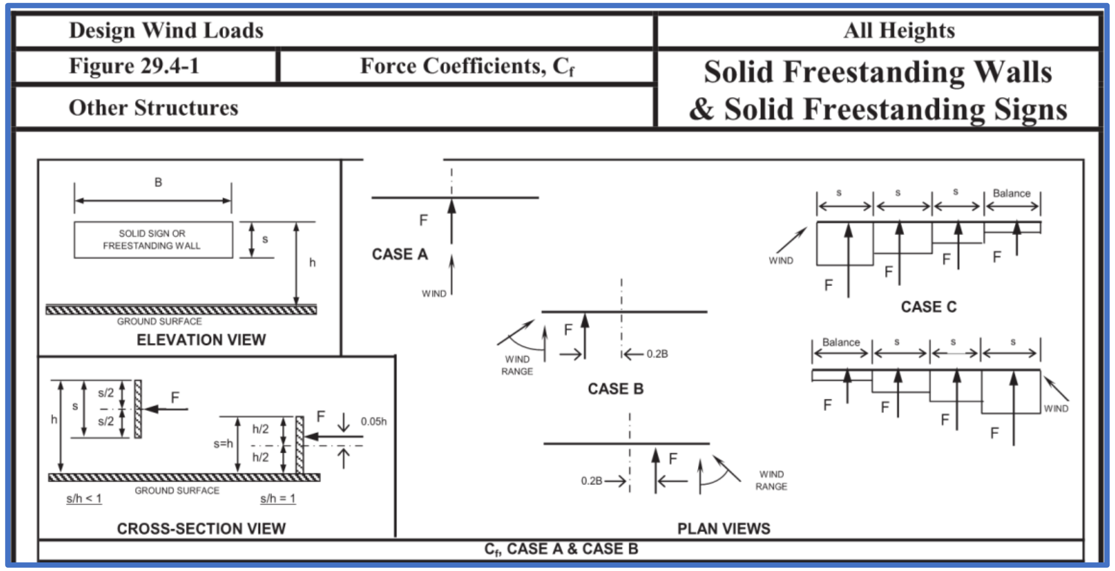
$$F_h = q_h(GC_r)A_f \text{ (lb) (N)} \qquad (29.5\text{-}2)$$

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)?



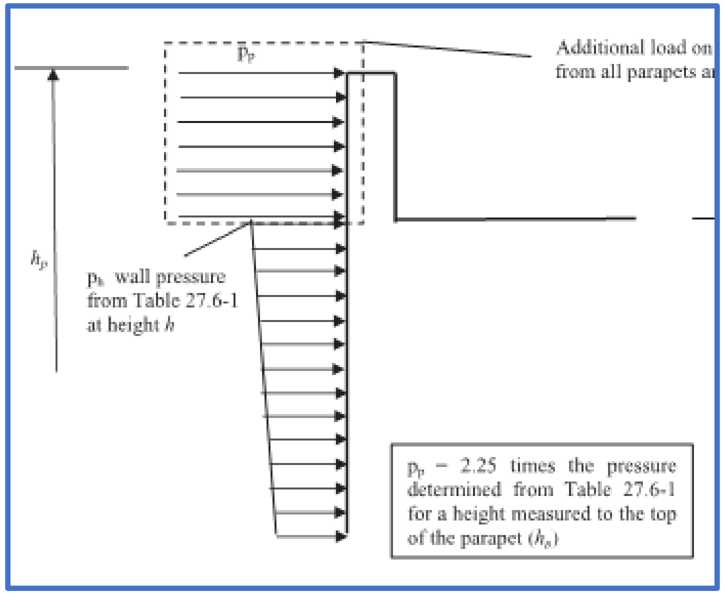
Rooftop Screenwalls

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?



Rooftop Screenwalls

ASCE 7-16: New Commentary

C29.5.1: Mechanical equipment screens commonly are used to conceal plumbing, electrical or mechanical equipment from view and are defined as rooftop structures.. located away from the edge of the building roof such that they are not considered parapets… little research is available to provide guidance for determining wind loads on screen walls and equipment behind screens. Accordingly, rooftop screens.. should be designed for the full wind load determined in accordance with Section 29.5.1. Where substantiating data have been obtained using the Wind Tunnel Procedure, design professionals may consider wind load reductions in the design of rooftop screens.

29.5.1 ROOFTOP STRUCTURES AND EQUIPMENT FOR BUILDINGS WITH $h \leq 60$ ft (18.3 m)

The lateral force F_h on rooftop structures and equipment located on buildings with a mean roof height $h \leq 60$ ft (18.3 m) shall be determined from Eq. 29.5-2.

$$F_h = q_h(GC_r)A_f \text{ (lb) (N)} \qquad (29.5\text{-}2)$$

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

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.

Phase 2 IBHS Research Center & ASHRAE Testing

- Evaluate wind loads on screenwalls themselves.

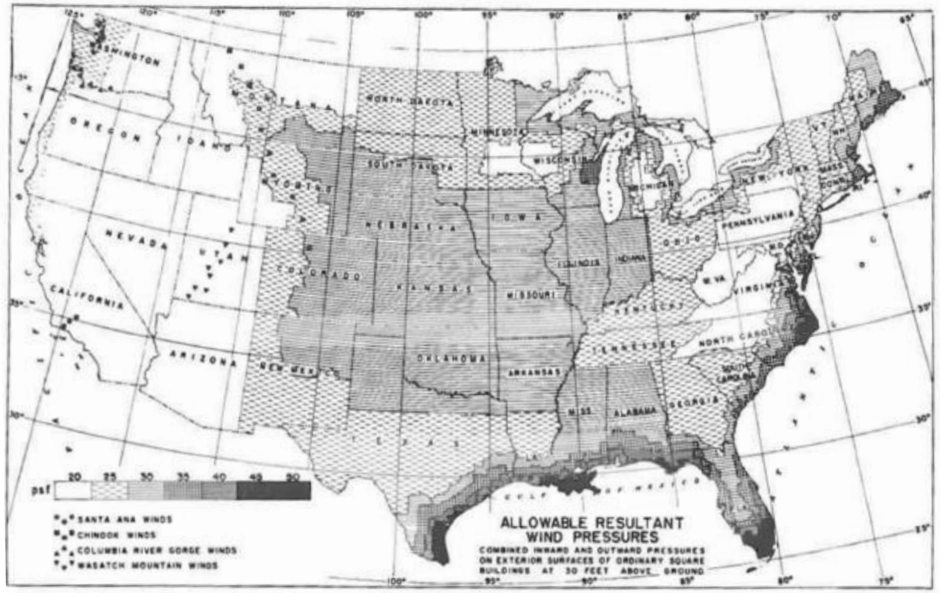


FIGURE NO. 4

1976 EDITION

23-4

1976 EDITION 23-F, 23-G, 23-H

TABLE NO. 23-F—WIND PRESSURES FOR VARIOUS HEIGHT ZONES ABOVE GROUND[1]

HEIGHT ZONES (in feet)	WIND-PRESSURE-MAP AREAS (pounds per square foot)						
	20	25	30	35	40	45	50
Less than 30	15	20	25	25	30	35	40
30 to 49	20	25	30	35	40	45	50
50 to 99	25	30	40	45	50	55	60
100 to 499	30	40	45	55	60	70	75
500 to 1199	35	45	55	60	70	80	90
1200 and over	40	50	60	70	80	90	100

Summary:

1) Consider intent of the code before applying provisions.
2) Does maintaining all Analysis Methods help or hurt?
3) There are attempts to simplify, address common situations.

Clarifying Frequently Misunderstood Wind and Seismic Provisions

Emily Guglielmo, SE
Martin/Martin, Inc.

Fundamentals of Earthquake Engineering, Newmark and Rosenblueth (1971):

"In dealing with earthquakes, we must contend with appreciable probabilities that ***failure*** will occur... Otherwise, all the ***wealth*** of the world would prove insufficient.. the most modest structures would be ***fortresses***. We must also face ***uncertainty*** on a large scale, for it is our task to design engineering systems – about whose pertinent ***properties we know little*** – to resist future earthquakes– whose characteristics we ***know even less***.. . ."

".. Earthquake engineering is a ***cartoon***. . . Earthquakes systematically bring out the ***mistakes*** made in design and construction."

Frequently Misunderstood Seismic Provisions

- R, C_d, Ω_o
- Redundancy, ρ
- Bearing Wall or Building Frame?
- Analysis Methods

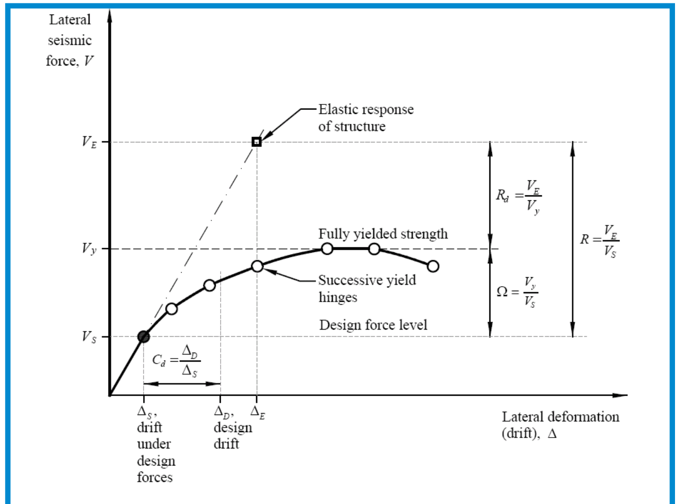
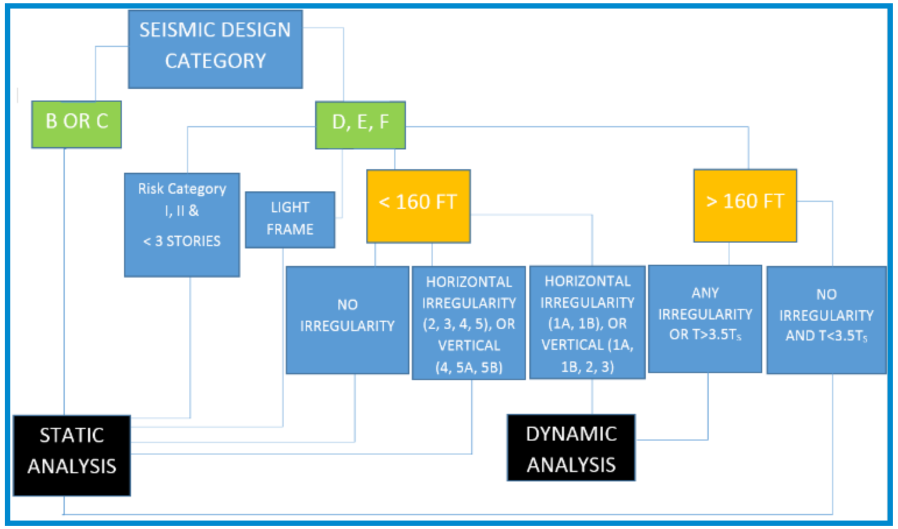


Figure C12.1-1 Inelastic force-deformation curve.



Frequently Misunderstood Seismic Provisions

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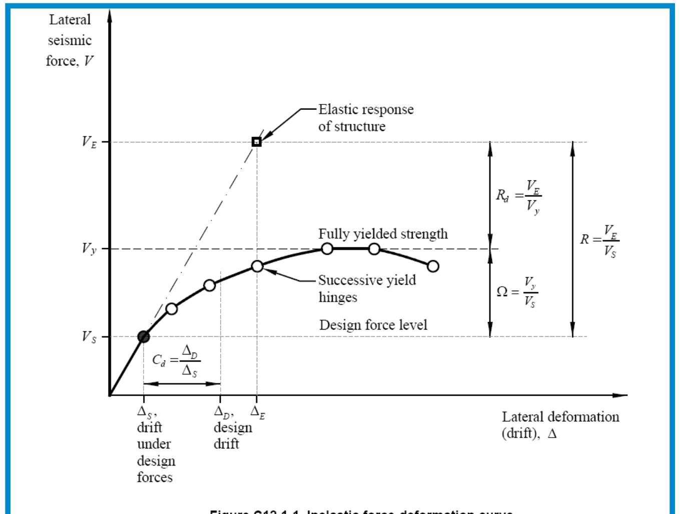
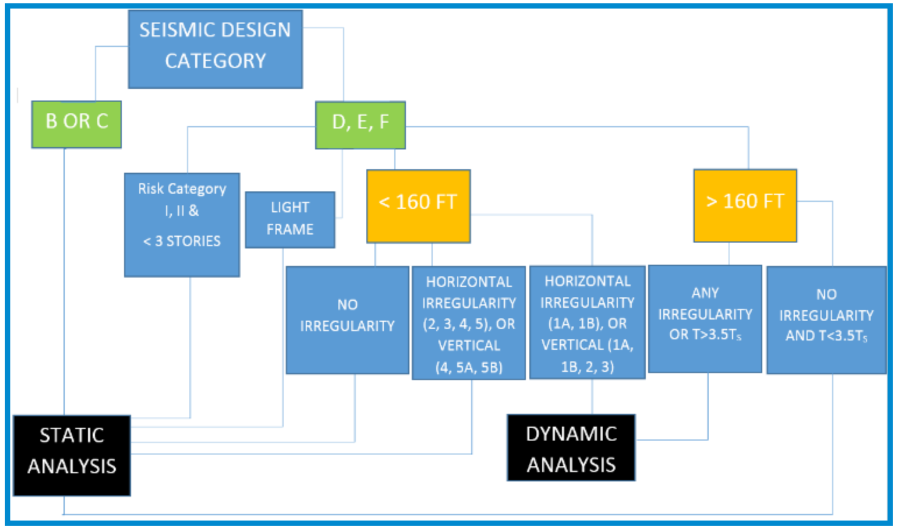


Figure C12.1-1 Inelastic force-deformation curve.



Elastic vs. Inelastic Response

- The red line is the force vs. displacement if the structure responded elastically.
- The green line is the actual force vs. displacement of the structure.
- The blue line is the code force per IBC/ ASCE 7.
- Illustrates the significance of design parameters contained in ASCE 7.
  - Response modification coefficient, *R*
  - Deflection amplification factor, C_d
  - System overstrength factor, Ω_o.

2009 *NEHRP Recommended Seismic Provisions*

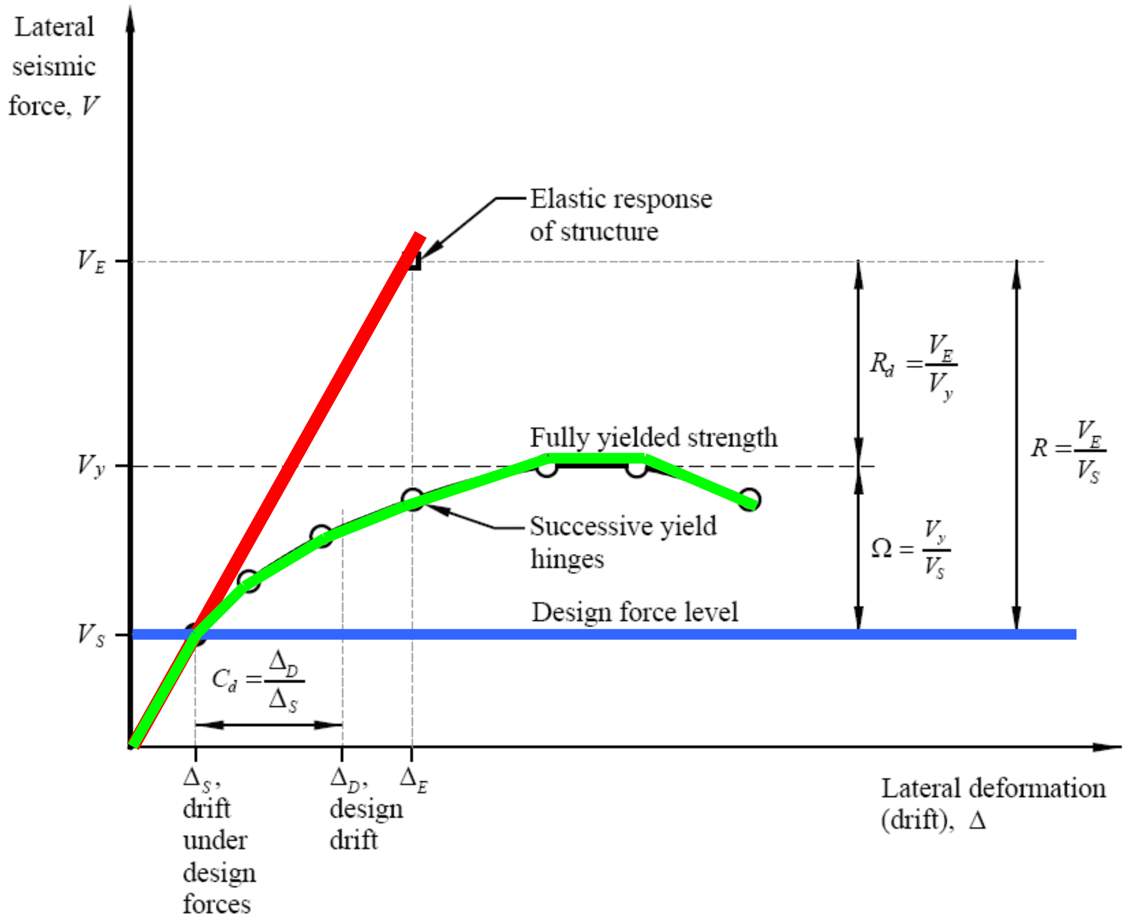
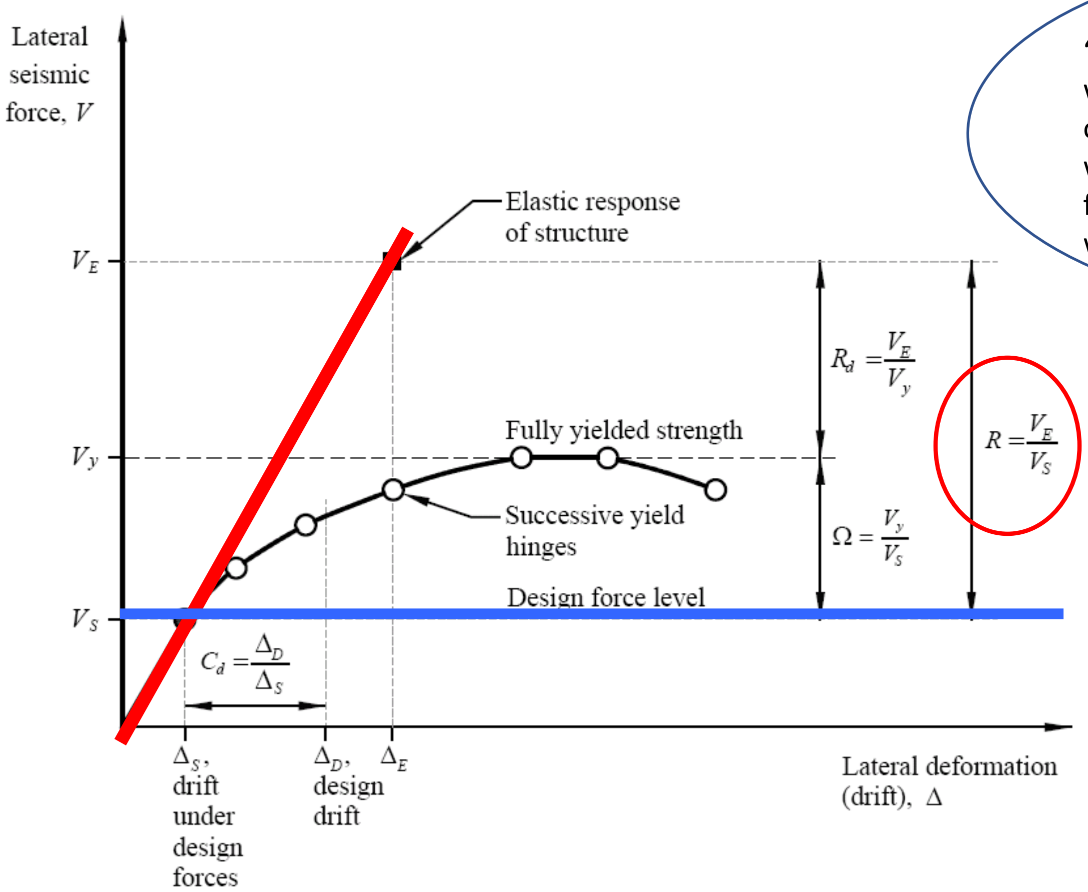


Figure C12.1-1 Inelastic force-deformation curve.

Response Modification Coefficient, *R*



"In dealing with earthquakes, we must contend with appreciable probabilities that failure will occur in the near future. Otherwise, all the wealth of the world would prove insufficient to fill our needs: the most modest structures would be fortresses."

In ASCE 7, seismic design forces are calculated by dividing the force from a linear response when subjected to the design ground motion by the response modification coefficient, *R*.

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_e}\right)}$$

R = 1

- Like wind (elastic)
- Used by Nuclear and Military Essential
- ASCE 7-16 Proposal…
  – No ductile detailing required?
  – Permitted in all SDCs?

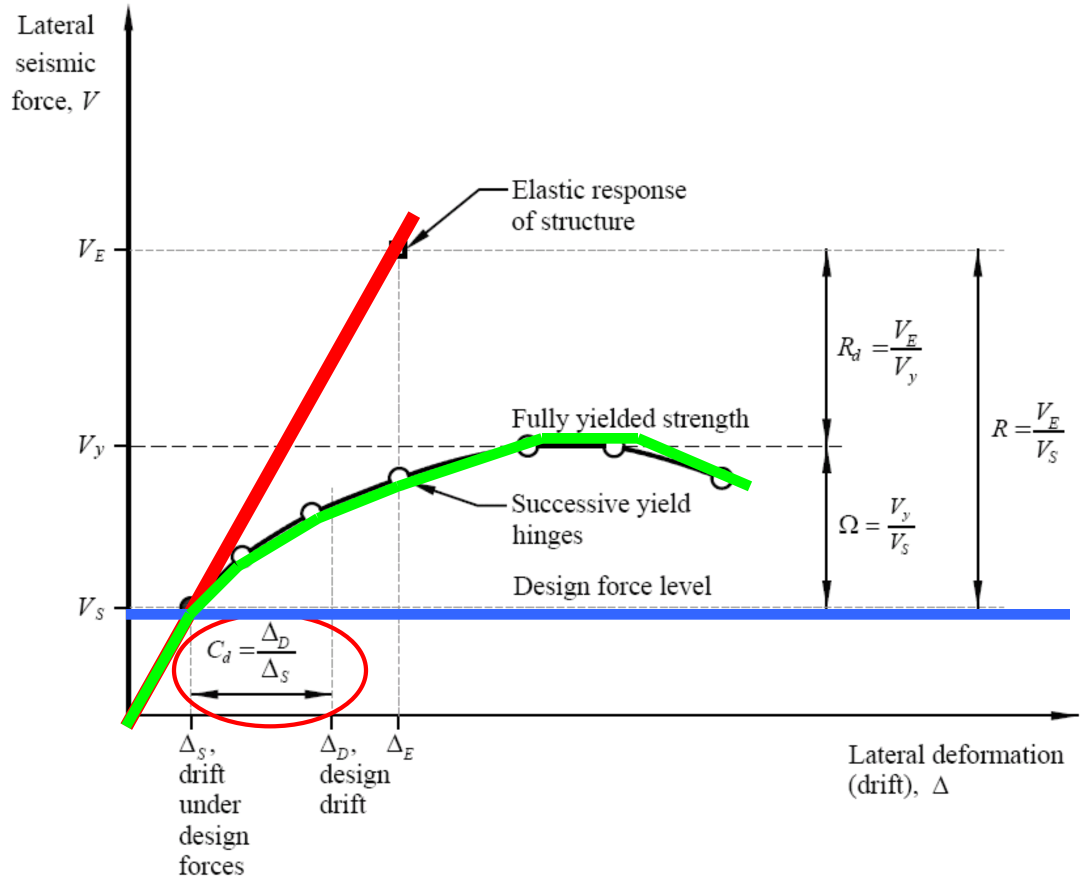
This proposal is an admission that it is too hard to design for seismic properly, so we will let lazy, uneducated engineers continue to be lazy and uneducated and design things stupidly. JUST VOTE NO!

If you accept the concept that the R factor reduces elastic seismic design forces because of system ductility, then by definition using an R of 1.0 should require no ductile detailing. Logically, this concept should apply to all buildings in all regions. Good chapter headed in the right direction.

Designers don't need another design approach. The profession wants ASCE 7 to simplify what is already in the standard.

It is impossible for me to express all of my concerns with regard to this proposal adequately. It will introduce into seismic design category D, E and F territory the design of building structures without the appropriate detailing. This is dangerous.

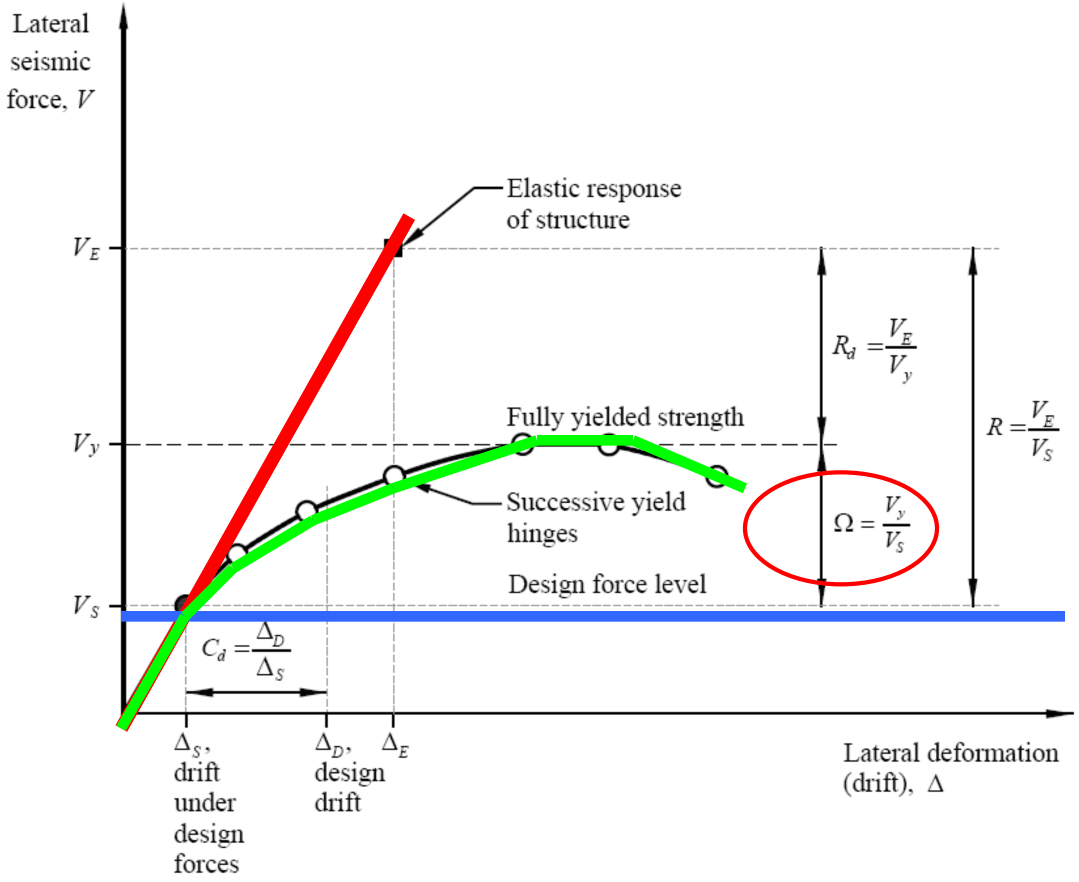
Deflection amplification factor, C_d



In ASCE 7, the elastic deformations (Δ_S) calculated under reduced forces are multiplied by C_d to estimate the actual inelastic deflections.

$$\delta_M = \frac{C_d \delta_{\max}}{I_e}$$

System Overstrength factor, Ω_o



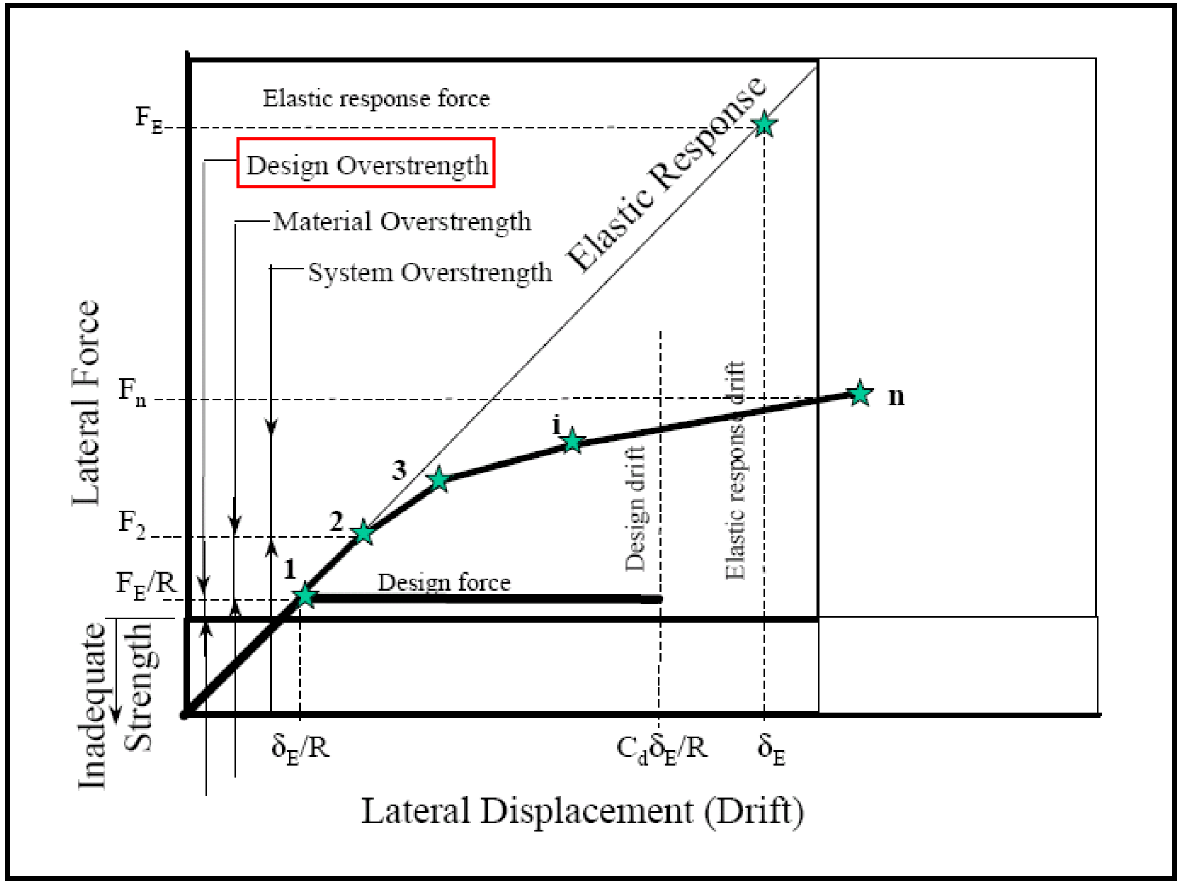
The Ω_o coefficient approximates the inherent overstrength and can be broken down into several components:

$$\Omega_o = \Omega_D \Omega_M \Omega_S$$

Ω_o

DESIGN OVERSTRENGTH

- Ω_D is the overstrength provided by the design engineer and/ or code.
- EXAMPLES:
- Load and resistance factors.
- Design controlled by stiffness.
- Architectural requirements.



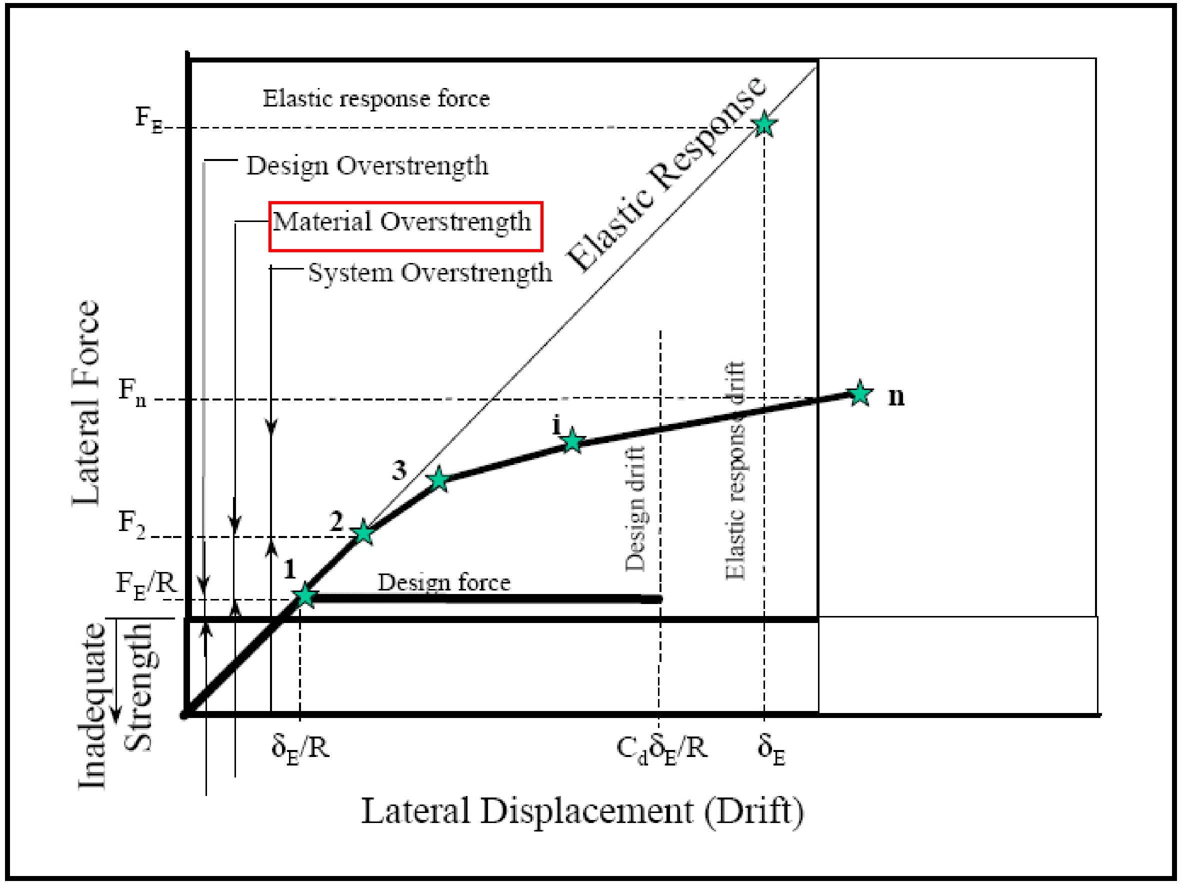
MATERIAL OVERSTRENGTH

•Ω_M represents material overstrength.

EXAMPLES:

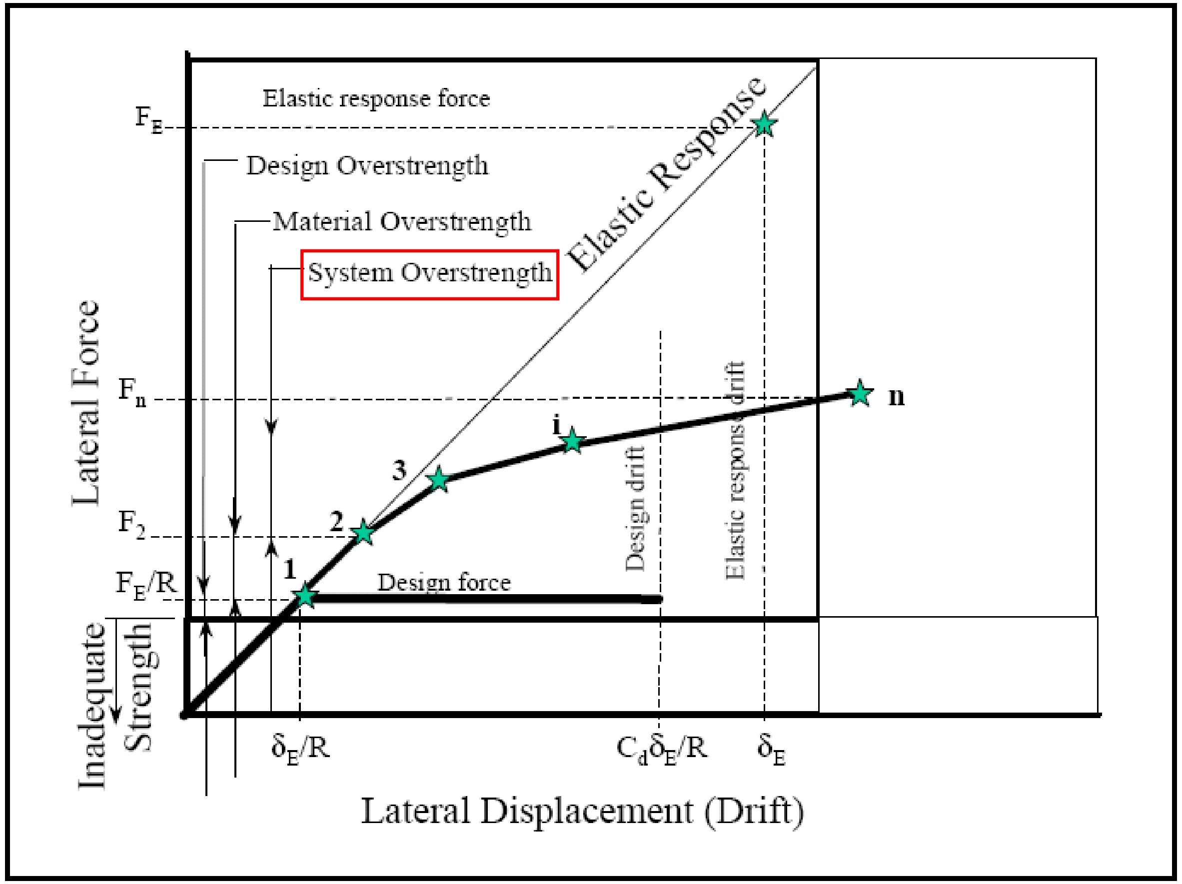
Reinforced masonry, concrete, and steel provisions have historically used a factor of ~1.25 to account for the ratio of mean to specified strengths.

- •A survey of WF steel: Ratios = 1.37 and 1.15 for A36 and A572 Gr. 50.



SYSTEM OVERSTRENGTH

- Ω_S represents the system overstrength.
- EXAMPLES:
- Redundancy.
- The degree to which non-LFRS elements provide resistance after LFRS has yielded.



Structural System	Design Overstrength Ω_D	Material Overstrength Ω_M	System Overstrength Ω_S	$\Omega_o=\Omega_D\Omega_M\Omega_S$	ASCE 7 Ω_o
Special Moment Frames (Concrete and Steel)	1.5-2.5	1.2-1.6	1.0-1.5	2.0-3.5	3.0
Intermediate Moment Frames (Concrete and Steel)	1.0-2.0	1.2-1.6	1.0-2.0	2.0-3.5	3.0
Ordinary Moment Frames (Concrete and Steel)	1.0-1.5	1.2-1.6	1.5-2.5	2.0-3.5	3.0
Braced Frames	1.5-2.0	1.2-1.6	1.0-1.5	1.5-2.0	2.0
Reinforced Bearing Wall	1.0-1.5	1.2-1.6	1.0-1.5	1.5-2.5	2.5
Unreinforced Bearing Wall	1.0-2.0	0.8-2.0	1.0-2.0	2.0-3.0	2.5
Dual System (Bracing and Frame)	1.1-1.75	1.2-1.6	1.0-1.5	1.5-2.5	2.5

Table 12.2-1 *(Continued)*

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category: B	C	D^d	E^d	F^e
7. Steel and concrete composite plate shear walls	14.3	7½	2½	6	NL	NL	NL	NL	NL
8. Steel and concrete composite special shear walls	14.3	7	2½	6	NL	NL	NL	NL	NL
9. Steel and concrete composite ordinary shear walls	14.3	6	2½	5	NL	NL	NP	NP	NP
10. Special reinforced masonry shear walls	14.4	5½	3	5	NL	NL	NL	NL	NL
11. Intermediate reinforced masonry shear walls	14.4	4	3	3½	NL	NL	NP	NP	NP

[a]Response modification coefficient, R, for use throughout the standard. Note R reduces forces to a strength level, not an allowable stress level.
[b]Deflection amplification factor, C_d, for use in Sections 12.8.6, 12.8.7, and 12.9.2.
[c]NL = Not Limited and NP = Not Permitted. For metric units use 30.5 m for 100 ft and use 48.8 m for 160 ft.
[d]See Section 12.2.5.4 for a description of seismic force-resisting systems limited to buildings with a structural height, h_n, of 240 ft (73.2 m) or less.
[e]See Section 12.2.5.4 for seismic force-resisting systems limited to buildings with a structural height, h_n, of 160 ft (48.8 m) or less.
[f]Ordinary moment frame is permitted to be used in lieu of intermediate moment frame for Seismic Design Categories B or C.
[g]Where the tabulated value of the overstrength factor, Ω_0, is greater than or equal to 2½, Ω_0 is permitted to be reduced by subtracting the value of 1/2 for structures with flexible diaphragms.
[h]See Section 12.2.5.7 for limitations in structures assigned to Seismic Design Categories D, E, or F.

Where the tabulated value of the overstrength factor, Ω_o, is greater than or equal to 2½, Ω_0 is permitted to be reduced by subtracting the value of 1/2 for structures with flexible diaphragms.

ASCE 7 Section 12.4.3.2

Basic Combinations for Strength Design with Overstrength Factor (see Sections 2.3.2 and 2.2 for notation).

5. $(1.2 + 0.2S_{DS})D + \Omega_o Q_E + L + 0.2S$
7. $(0.9 - 0.2S_{DS})D + \Omega_o Q_E + 1.6H$

Load Combinations with Overstrength Factor

Question:
When do I need to design with load combinations with overstrength factors, Ω_o?

Answer:
IBC 1605.1 "Buildings shall be designed to resist the load combinations with overstrength factor specified in Section 12.4.3.2 of ASCE 7 where required by Section 12.2.5.2, 12.3.3.3, or 12.10.2.1…"

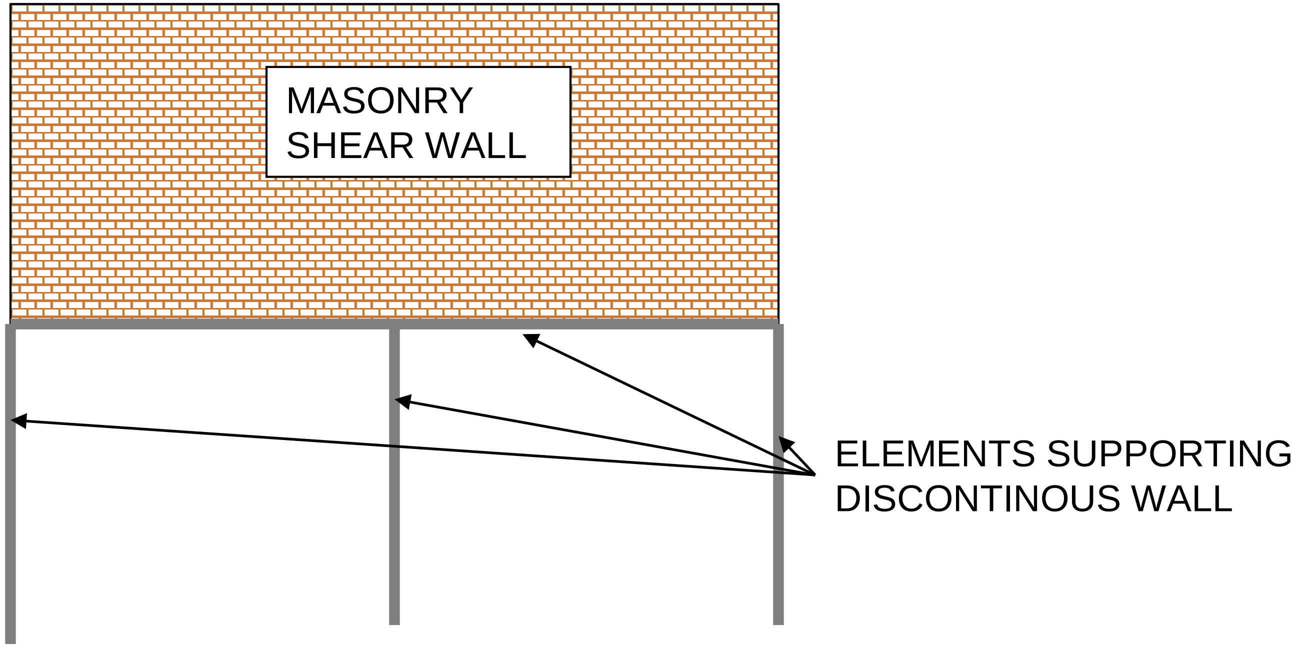
12.2.5.2: Cantilever Column Systems

SDC B-F

Foundations and other elements used to provide overturning resistance at the base of cantilever column elements shall have the strength to resist the load combinations with overstrength factors of Section 12.4.3.2.

12.3.3.3: Elements Supporting Discontinuous Walls or Frames
SDC B-F

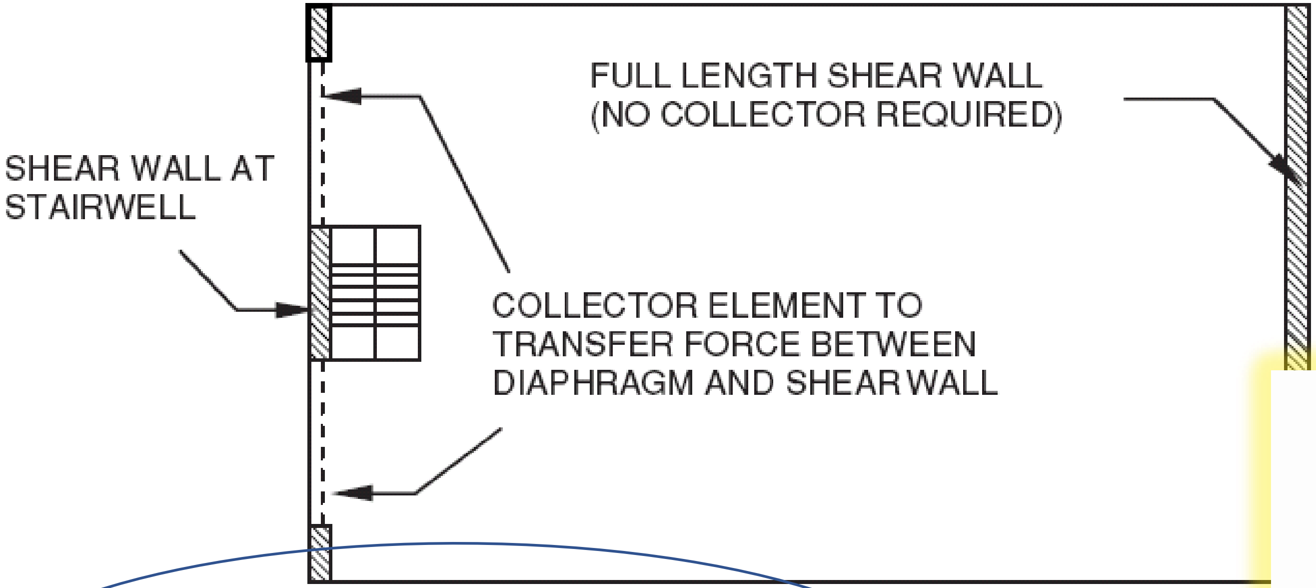
Columns, beams, trusses, or slabs supporting discontinuous walls or frames shall have the strength to resist the maximum axial force that can develop in accordance with the load combinations with overstrength factors of Section 12.4.3.2.



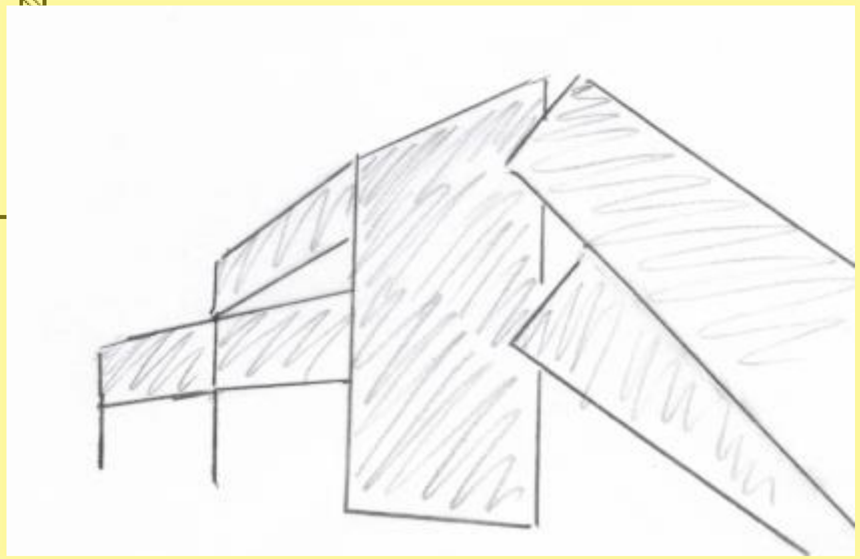
12.10.2.1: Collector Elements

SDC C-F

Collector elements, splices, and their connections to resisting elements shall resist the load combinations of Section 12.4.3.2.

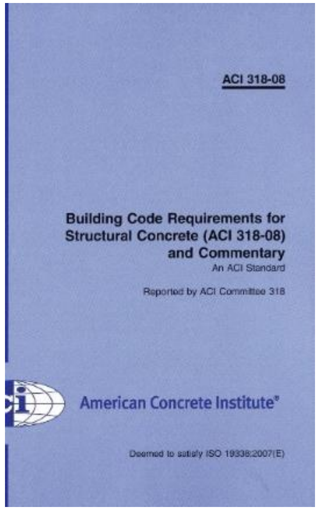


"In a way, earthquake engineering is a cartoon . . . Earthquake effects on structures systematically bring out the mistakes made in design and construction, even the minutest mistakes."



Ω_o Triggers Summary

- 12.2.5.2 Cantilever Columns SDC B,C,D,E,F
- 12.10.2.1 Collectors – (Light Frame, Wood excepted) SDC C,D,E,F
- 12.3.3.3 Columns, Beams Supporting Discontinuous Walls or Frames SDC B,C,D,E,F
- 12.13.6.5 Pile Anchorage SDC D,E,F
- Material Specifications: SDC B,C,D,E,F
  - AISC where R>3
  - ACI Chapter 21, Appendix D, Etc.



Frequently Misunderstood Seismic Provisions

- R, C_d, Ω_o
- Redundancy, ρ
- Bearing Wall or Building Frame?
- Analysis Methods

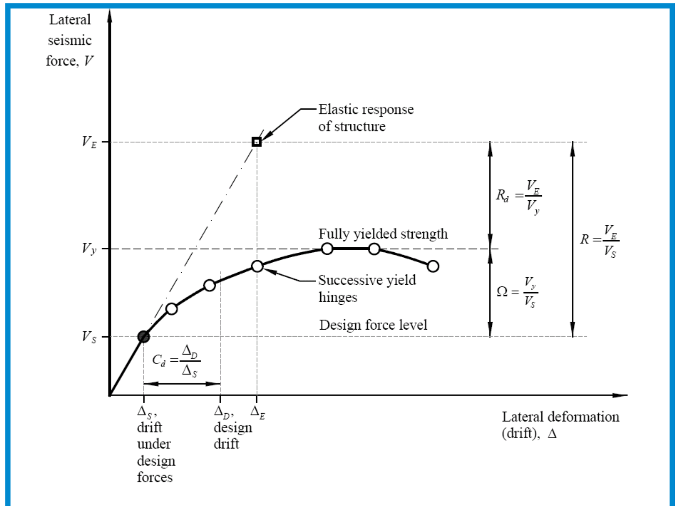
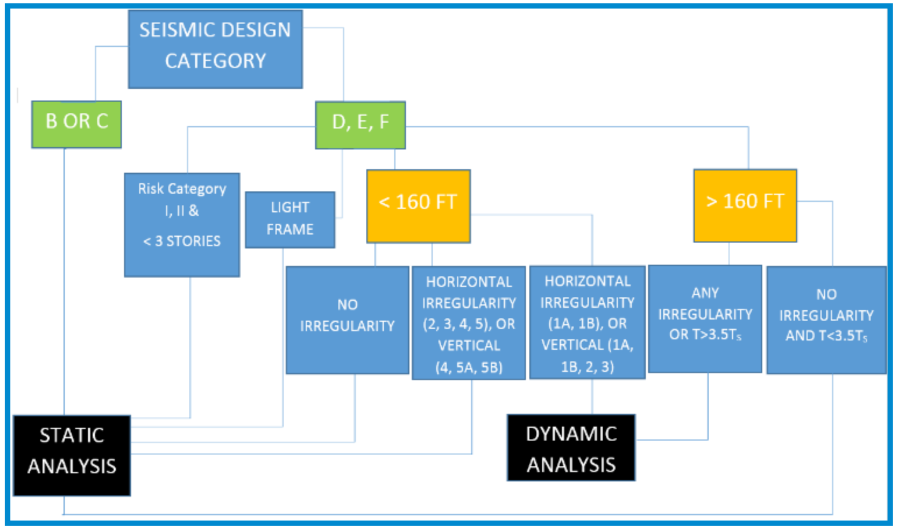


Figure C12.1-1 Inelastic force-deformation curve.



REDUNDANCY FACTOR, ρ

- Damage from the 1994 Northridge earthquake was concentrated in buildings with low redundancy.
- The code was modified to increase redundancy for structures in Seismic Design Categories D, E and F.
- For structures with low inherent redundancy, the required design forces are (arbitrarily?) amplified to increase strength and resistance to damage.

ASCE 7 SECTION

12.3.4.1: Conditions Where the Value of ρ is 1.0.

- 10 conditions

12.3.4.2: Redundancy Factor, ρ, for SDC D, E, F

- Either ρ = 1.0 or 1.3

REDUNDANCY FACTOR, ρ=1.0

1. Structures assigned to Seismic Design Category B or C.
2. Drift calculation and P-delta effects.
3. Design of nonstructural components (Chapter 13).

Examples: Mechanical/ electrical components, ceilings, cabinets.

4. Design of non-building structures that are *not* similar to buildings (Chapter 15).

Examples: Tanks, amusement structures/ monuments, signs and billboards, cooling towers.

"THE BOBS"—RIVERVIEW PARK, CHICAGO—*Photo by Frank Fournier*

REDUNDANCY FACTOR, ρ=1.0

5. Design of collector elements, splices and their connections for which the load combinations with overstrength factor of 12.4.3.2 are used.

6. Design of members or connections where the load combinations with overstrength of 12.4.3.2 are required for design.

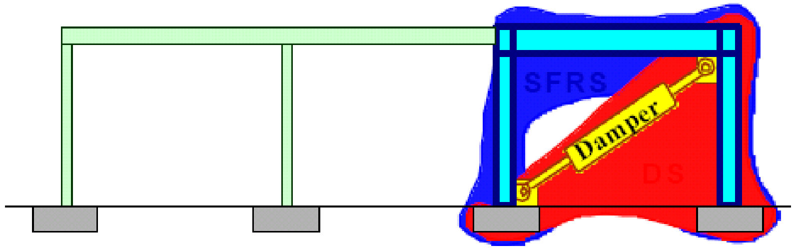
Basic Combinations for Strength Design with Overstrength Factor (see Sections 2.3.2 and 2.2 for notation).

5. $(1.2 + 0.2S_{DS})D + \Omega_o Q_E + L + 0.2S$

7. $(0.9 - 0.2S_{DS})D + \Omega_o Q_E + 1.6H$

7. Diaphragm loads determined using Eq. 12.10-1.

$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px} \qquad (12.10\text{-}1)$$



8. Structures with damping systems designed in accordance with Chapter 18.

9. Out-of-plane wall anchorage (including connections).

$$F_p = 0.4 S_{DS} k_a I_e W_p \qquad (12.11\text{-}1)$$

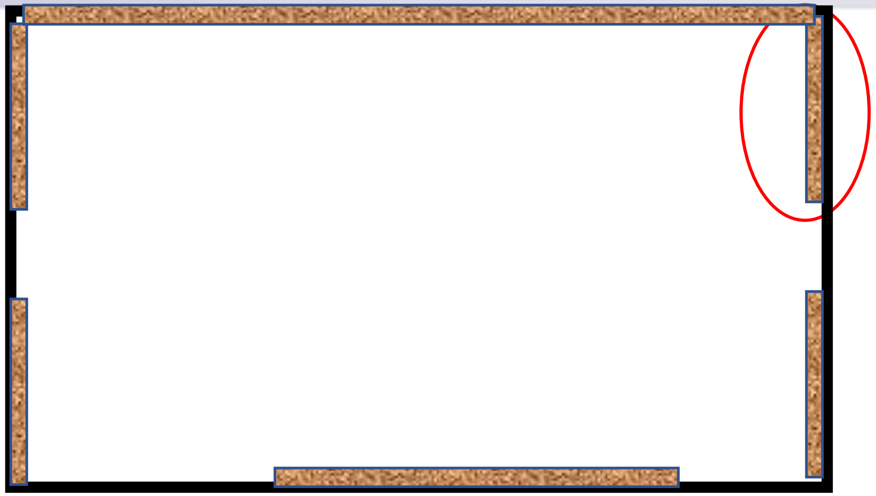
ASCE 7-10 12.3.4.2

ρ = 1.0 or 1.3
ρ = 1.3 unless ONE of the following conditions is met:

Condition 1: Can an individual element be removed from the lateral force resisting system without:

- Causing the remaining structure to suffer a reduction in story strength > 33%, or
- Creating an extreme torsional irregularity?

Condition 1: Requires Calculations!



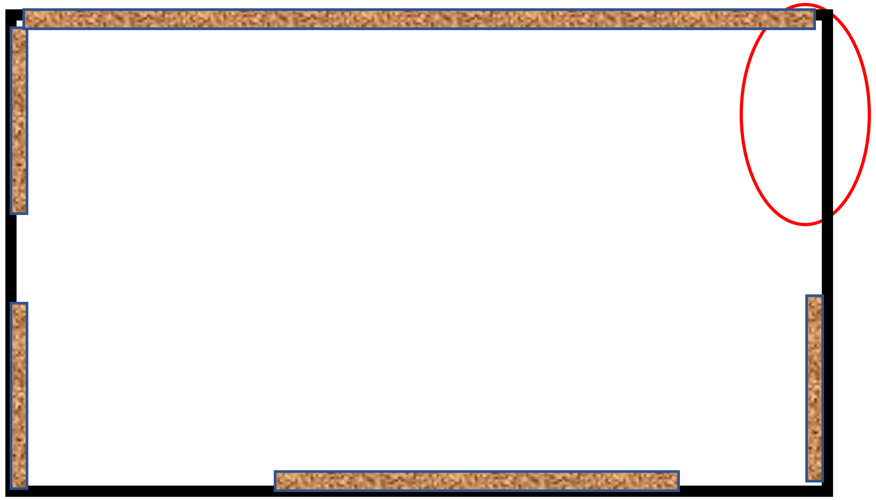


TABLE 12.3-3 REQUIREMENTS FOR EACH STORY RESISTING MORE THAN 35% OF THE BASE SHEAR

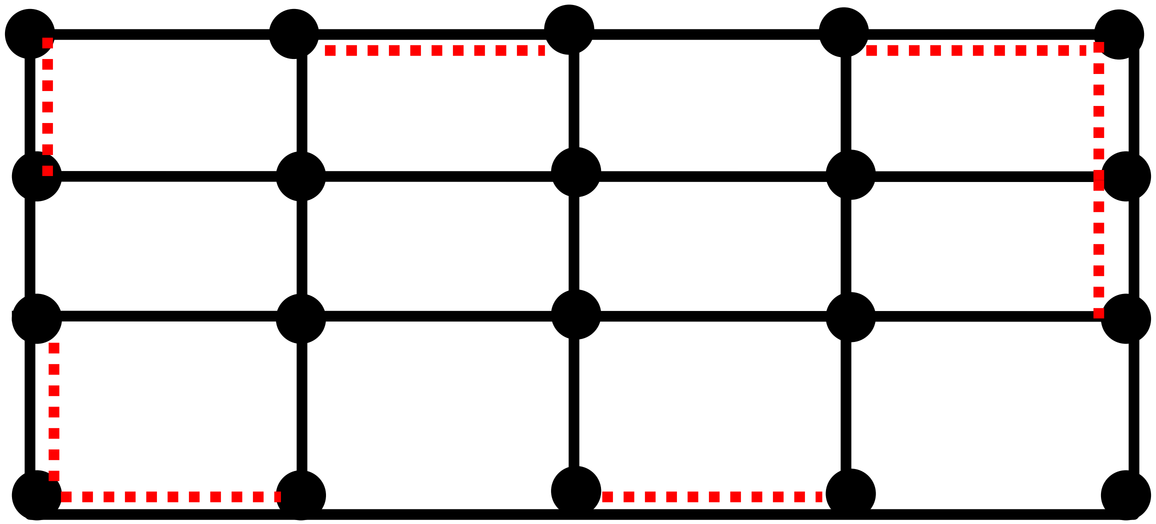
Lateral Force-Resisting Element	Requirement
Braced Frames	Removal of an individual brace, or connection thereto, would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Moment Frames	Loss of moment resistance at the beam-to-column connections at both ends of a single beam would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Shear Walls or Wall Pier with a height-to-length ratio of greater than 1.0	Removal of a shear wall or wall pier with a height-to-length ratio greater than 1.0 within any story, or collector connections thereto, would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Cantilever Columns	Loss of moment resistance at the base connections of any single cantilever column would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Other	No requirements

ASCE 7-10 12.3.4.2

ρ = 1.0 or 1.3

ρ = 1.3 unless ONE of the following conditions is met:

Condition 2: If a structure is *regular in plan* and there are at least *2 bays* of seismic force resisting *perimeter framing on each side* of the structure in *each orthogonal direction* at each *story resisting > 35%* of the base shear.

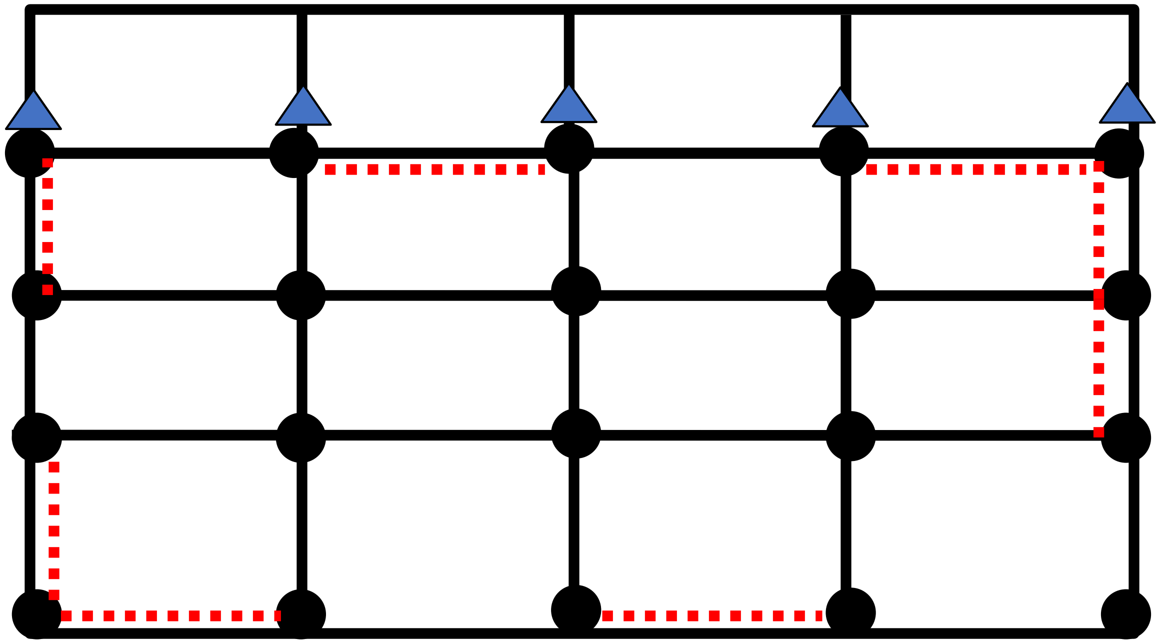


ASCE 7-10 12.3.4.2

ρ = 1.0 or 1.3

ρ = 1.3 unless ONE of the following conditions is met:

Condition 2: If a structure is *regular in plan* and there are at least *2 bays* of seismic force resisting *perimeter framing on each side* of the structure in *each orthogonal direction* at each *story resisting > 35%* of the base shear.



Frequently Misunderstood Seismic Provisions

- R, C_d, Ω_o
- Redundancy, ρ
- **Bearing Wall or Building Frame?**
- Analysis Methods

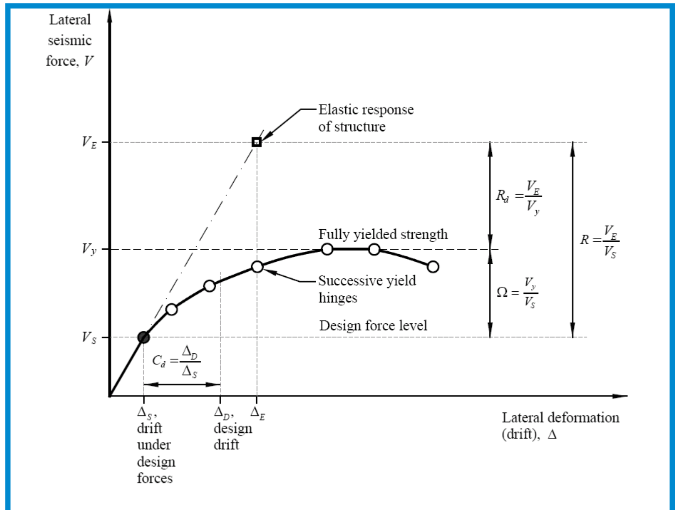
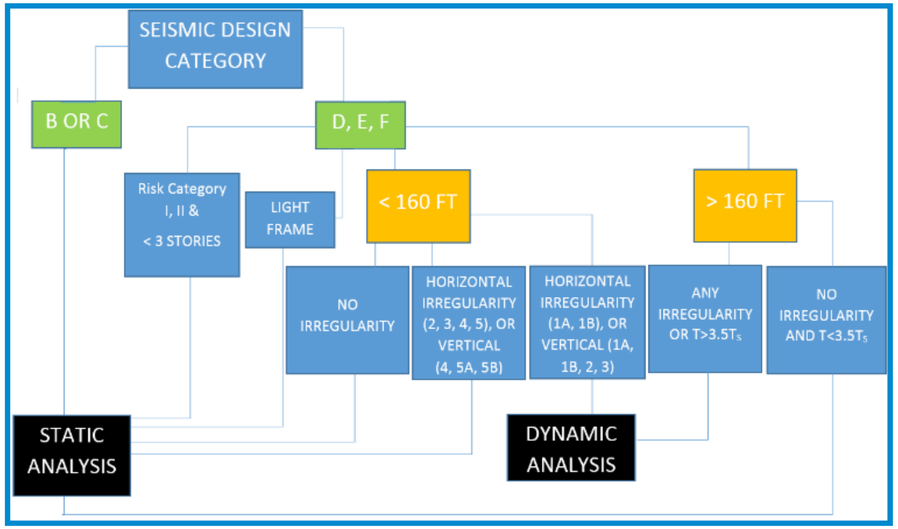


Figure C12.1-1 Inelastic force-deformation curve.



Bearing Wall v. Building Frame

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category B	C	D^d	E^d	F^e
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls[l, m]	14.2	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls[l]	14.2	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls[l]	14.2	2	2½	2	NL	NP	NP	NP	NP

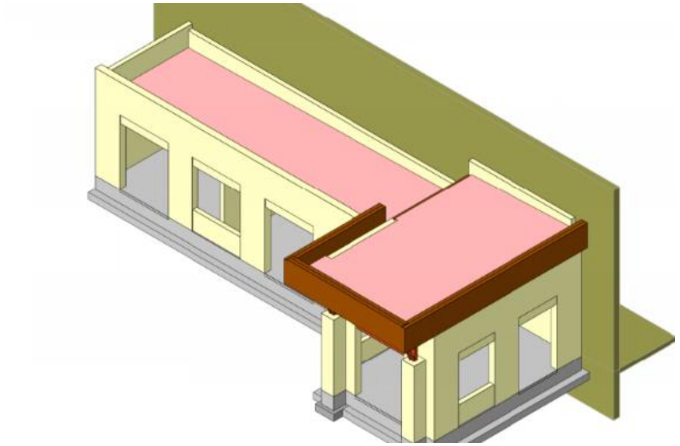
B. BUILDING FRAME SYSTEMS

Table 12.2-1 *(Continued)*

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category B	C	D^d	E^d	F^e
4. Special reinforced concrete shear walls[l,m]	14.2	6	2½	5	NL	NL	160	160	100
5. Ordinary reinforced concrete shear walls[l]	14.2	5	2½	4½	NL	NL	NP	NP	NP
6. Detailed plain concrete shear walls[l]	14.2 and	2	2½	2	NL	NP	NP	NP	NP

Bearing Wall v. Building Frame

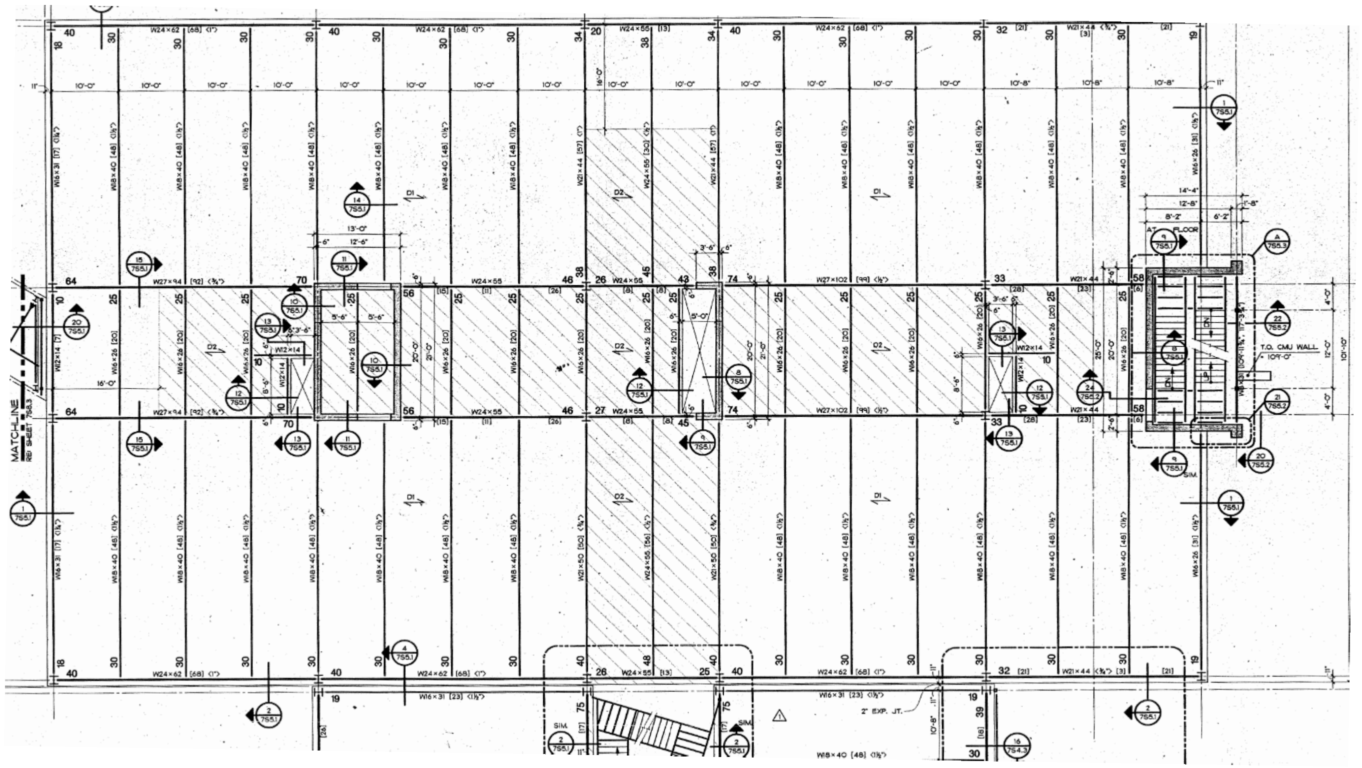
WALL SYSTEM, BEARING: A structural system with bearing walls providing support for all or major portions of the vertical loads. Shear walls or braced frames provide seismic force resistance.



BUILDING FRAME SYSTEM: A structural system with an essentially complete space frame providing support for vertical loads. Seismic force resistance is provided by shear walls or braced frames.

Bearing Wall v. Building Frame

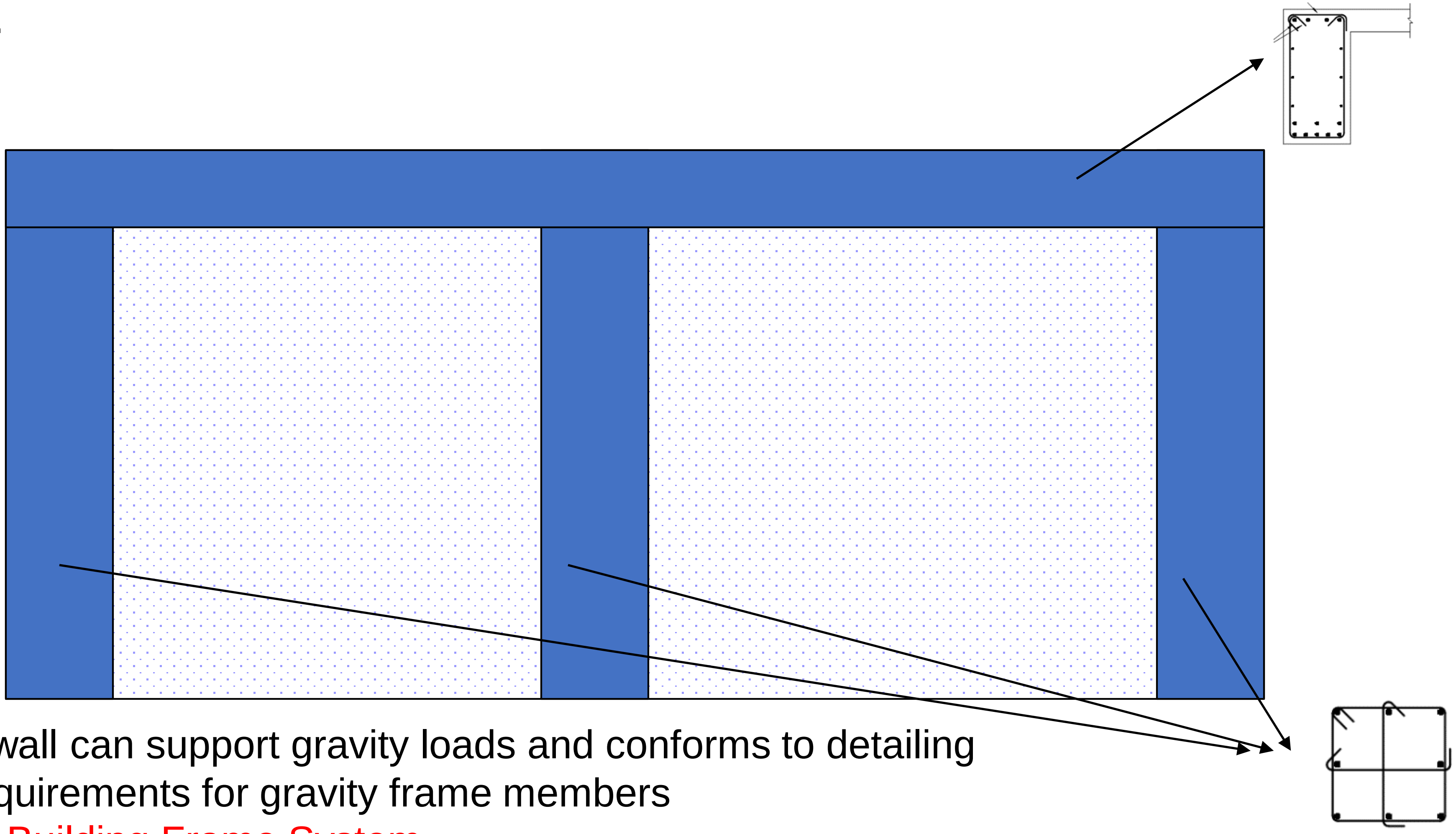
Question: If some of the gravity loads are resisted by shear walls, is it possible to classify the system as a building frame system?



Bearing Wall v. Building Frame

SEAOC:

Assume all portions of the walls not reinforced as columns or beams are removed, but the self-weight of the wall is still present.

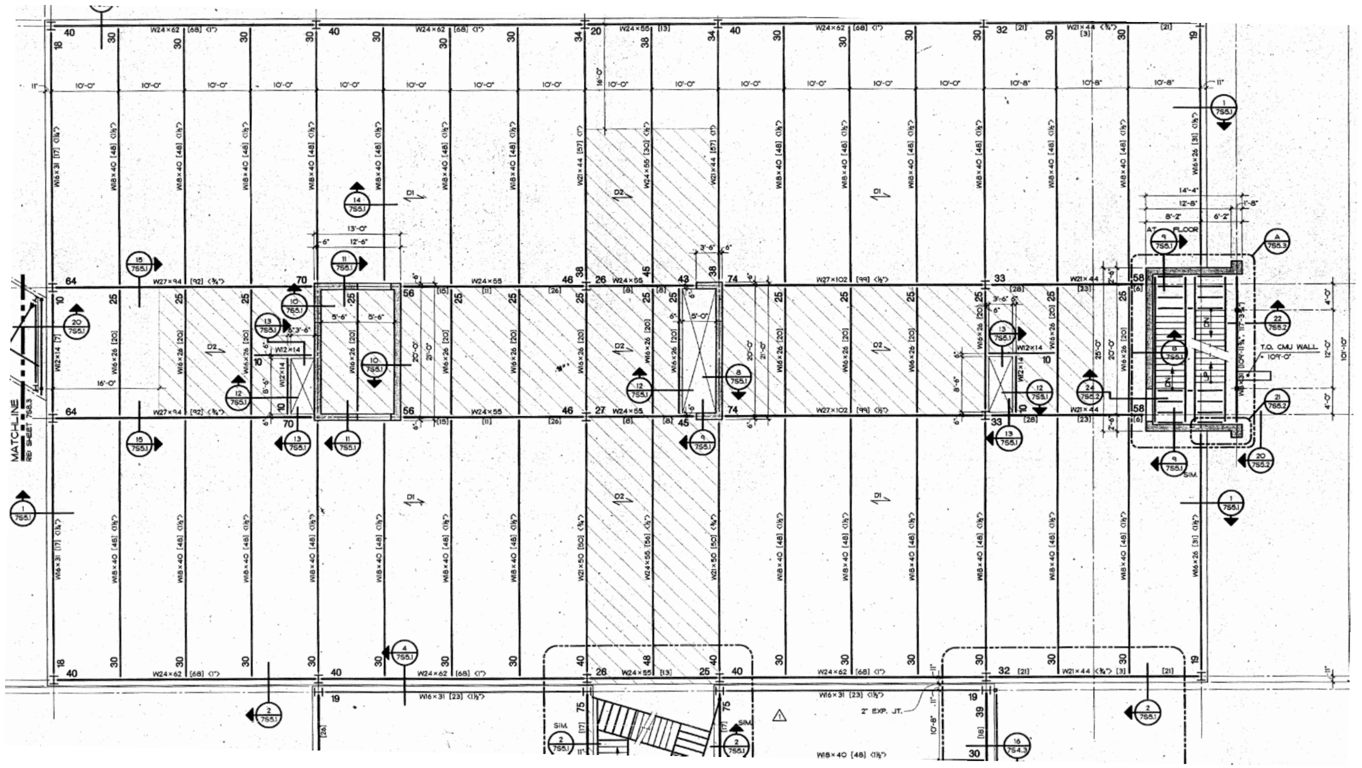


If wall can support gravity loads and conforms to detailing requirements for gravity frame members

→ Building Frame System

Bearing Wall v. Building Frame

NEHRP:
"A building frame system is when gravity loads are carried *primarily* by a frame supported on columns rather than by bearing walls. Some *minor portions* of the gravity load may be carried on bearing walls, but the amount.. should not represent more than *a few percent* of the building area."



Frequently Misunderstood Seismic Provisions

- R, C_d, Ω_o
- Redundancy, ρ
- Bearing Wall or Building Frame?
- Analysis Methods

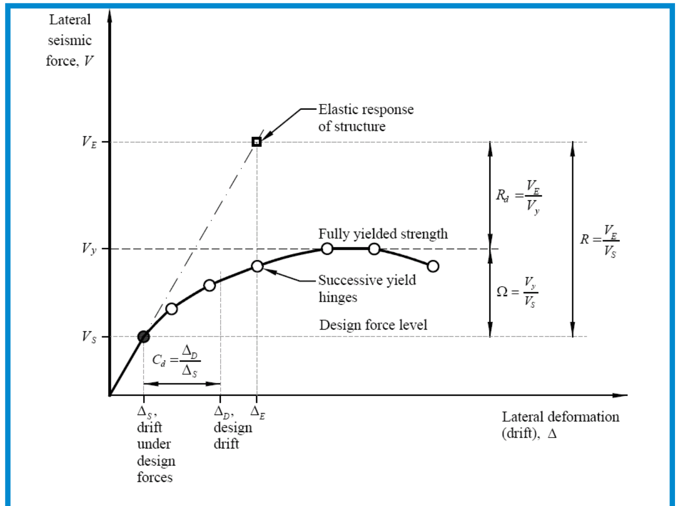


Figure C12.1-1 Inelastic force-deformation curve.

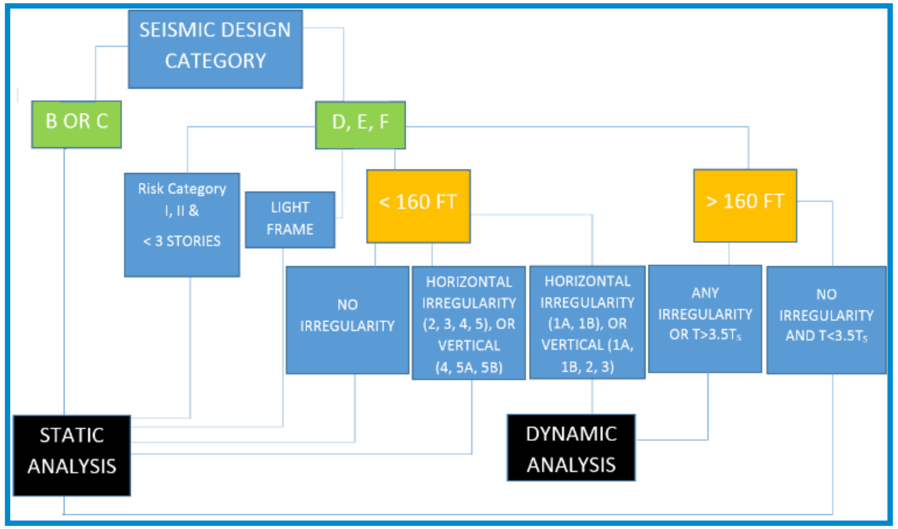
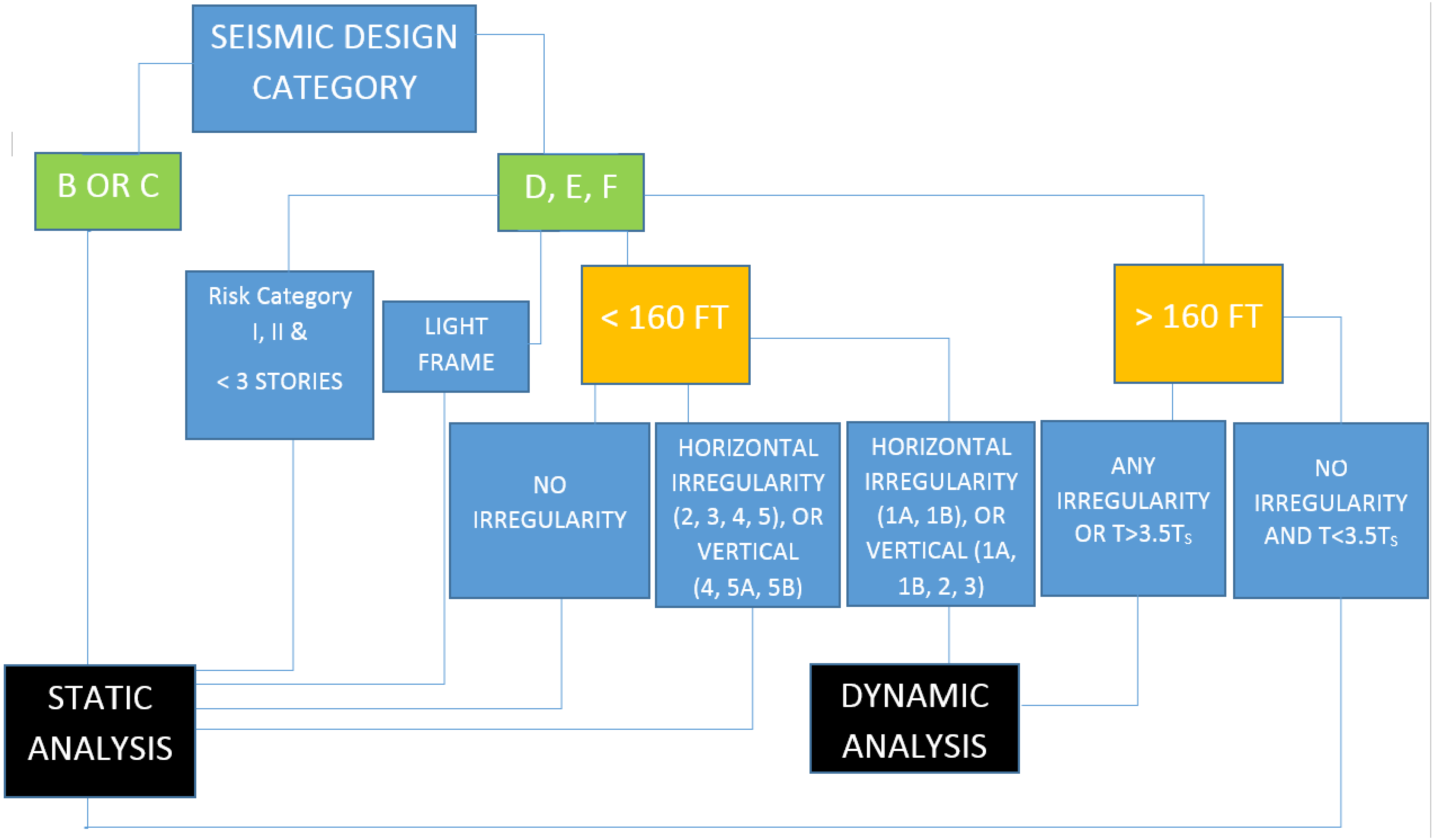


Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9[a]	Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 stories above the base	P	P	P
	Structures of light frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

Permitted Analysis Procedures



Height Threshold for Dynamic Analysis

<u>UBC</u>→ Dynamic for Ht >240’

≈ 24 stories

<u>IBC 2003</u> → $T>3.5\ T_s$

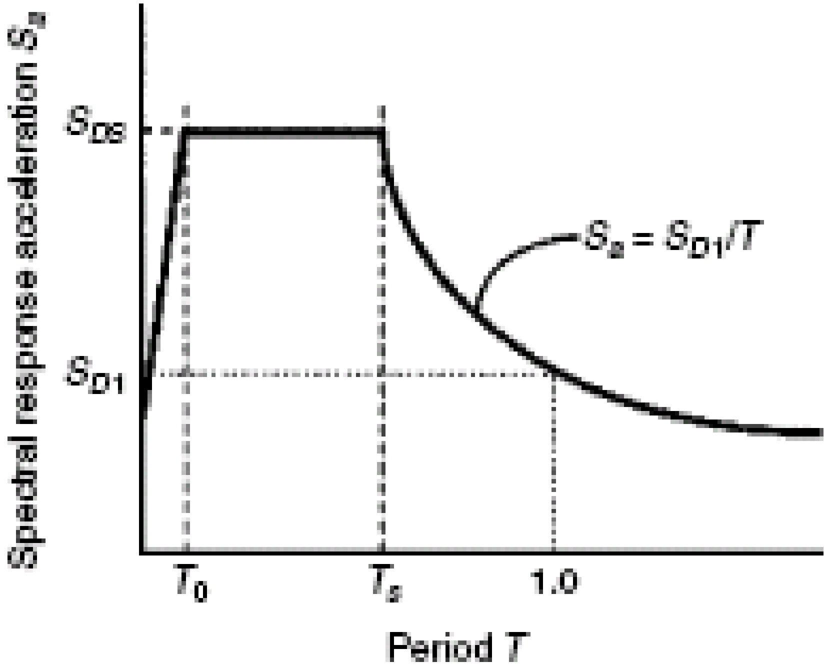
$T_s=S_{D1}/S_{DS}\approx 1/2$ sec

$T>3.5*1/2=1.75s$

≈17-18 stories

<u>IBC 2012</u> → $T>3.5T_s$ AND Ht >160’

≈16 stories

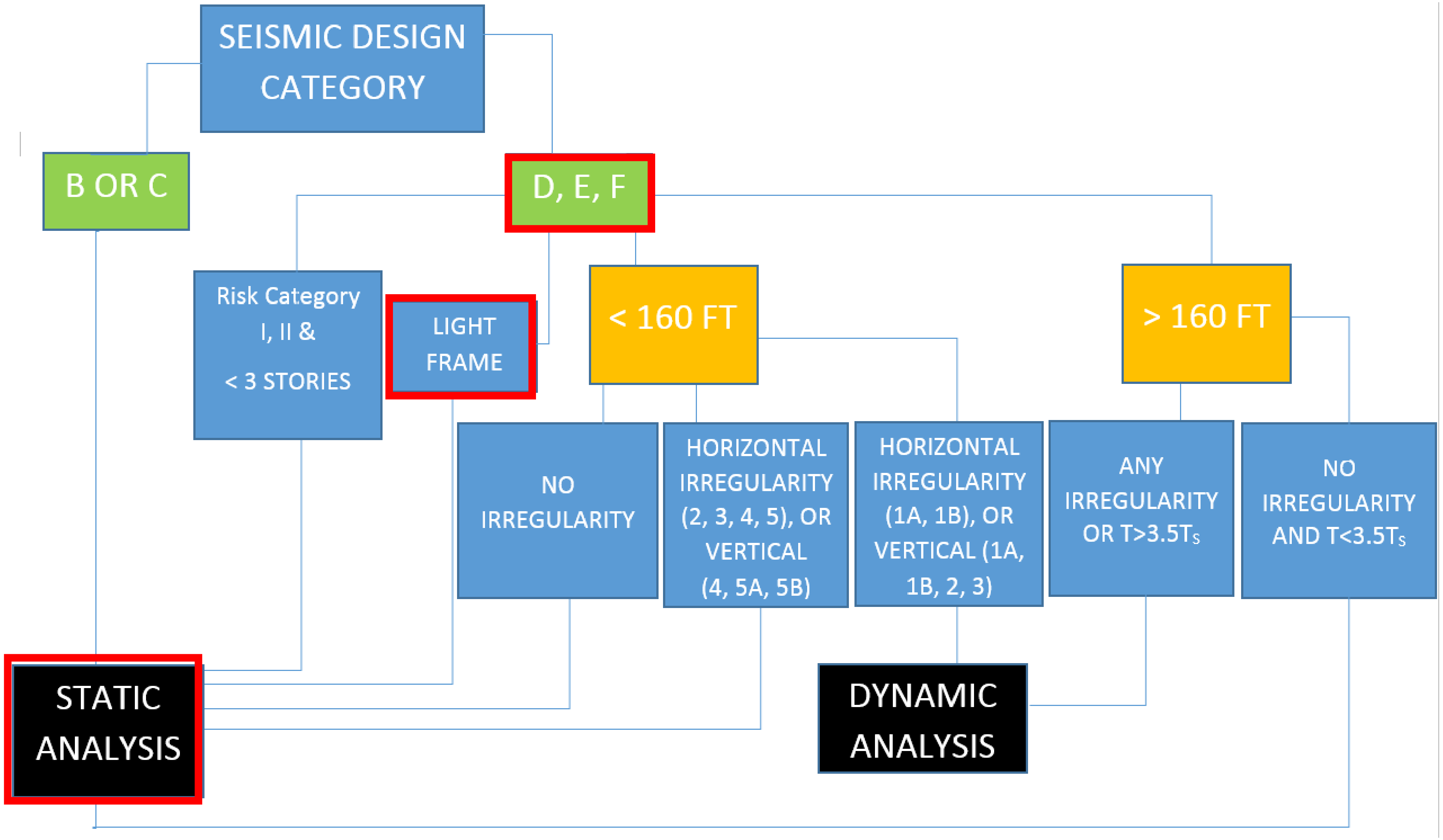


Permitted Analysis Procedures

Question: Can I use static (equivalent lateral force procedure) analysis for the following building:

- SDC F
- Type 1a (torsional) horizontal irregularities
- 5-story hotel ballroom (Occupancy III)
- Load bearing metal studs

Permitted Analysis Procedures

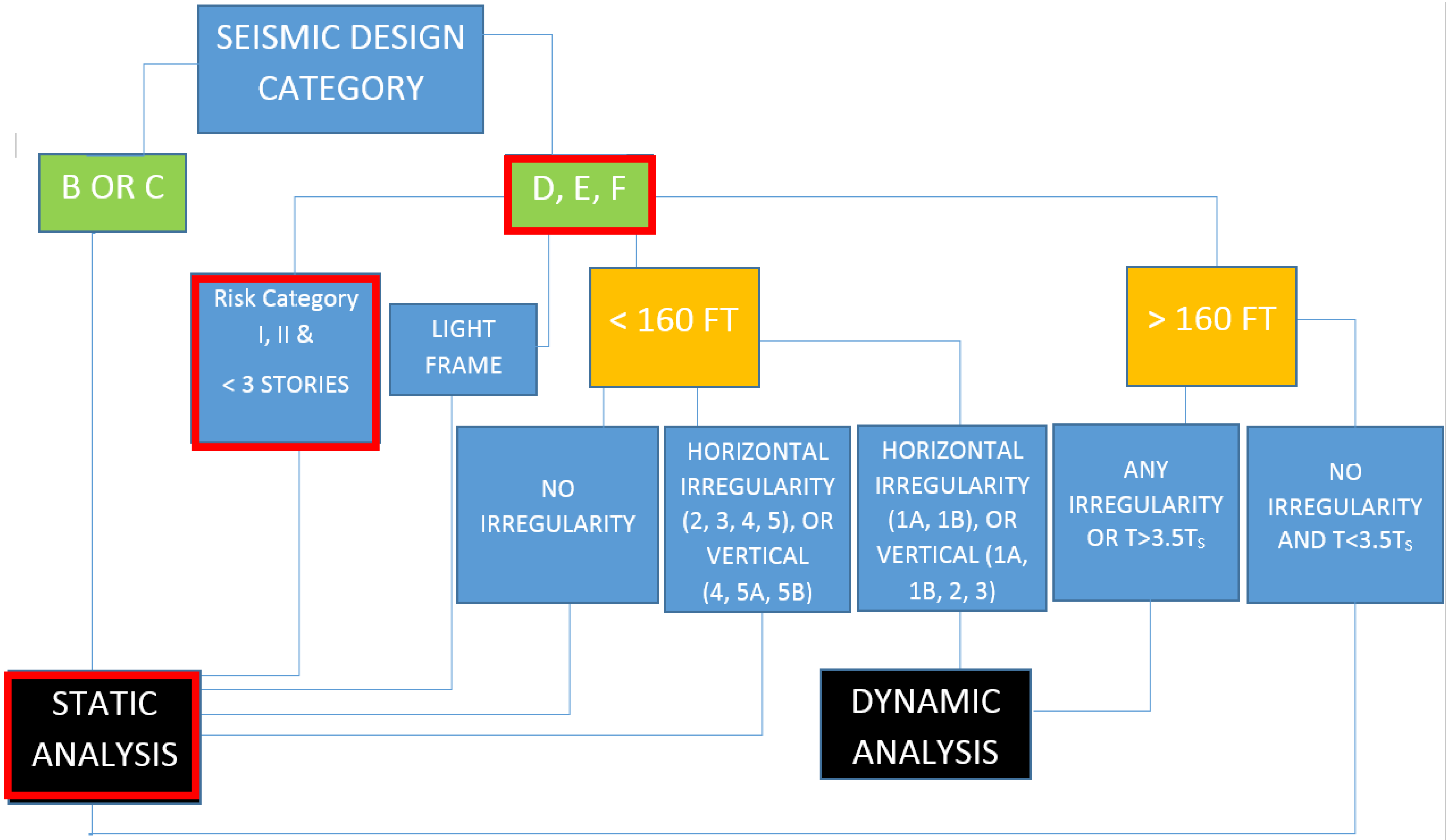


Permitted Analysis Procedures

Question: Can I use static (equivalent lateral force procedure) analysis for the following building:

- SDC E
- Type 2 (reentrant corner) vertical irregularities
- 2-story office building (Occupancy II)
- Concrete shear walls with steel floor/ roof framing

Permitted Analysis Procedures

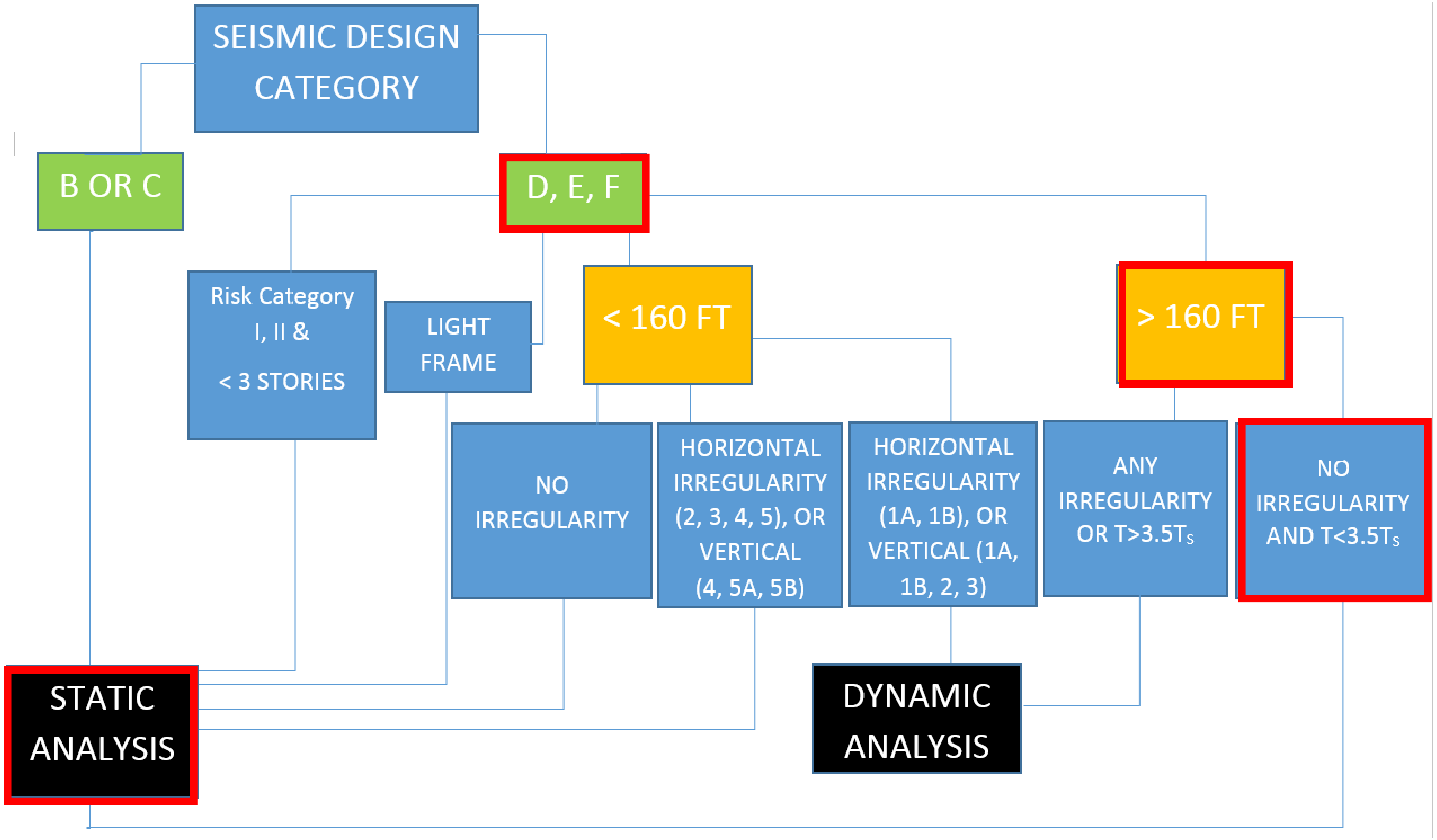


Permitted Analysis Procedures

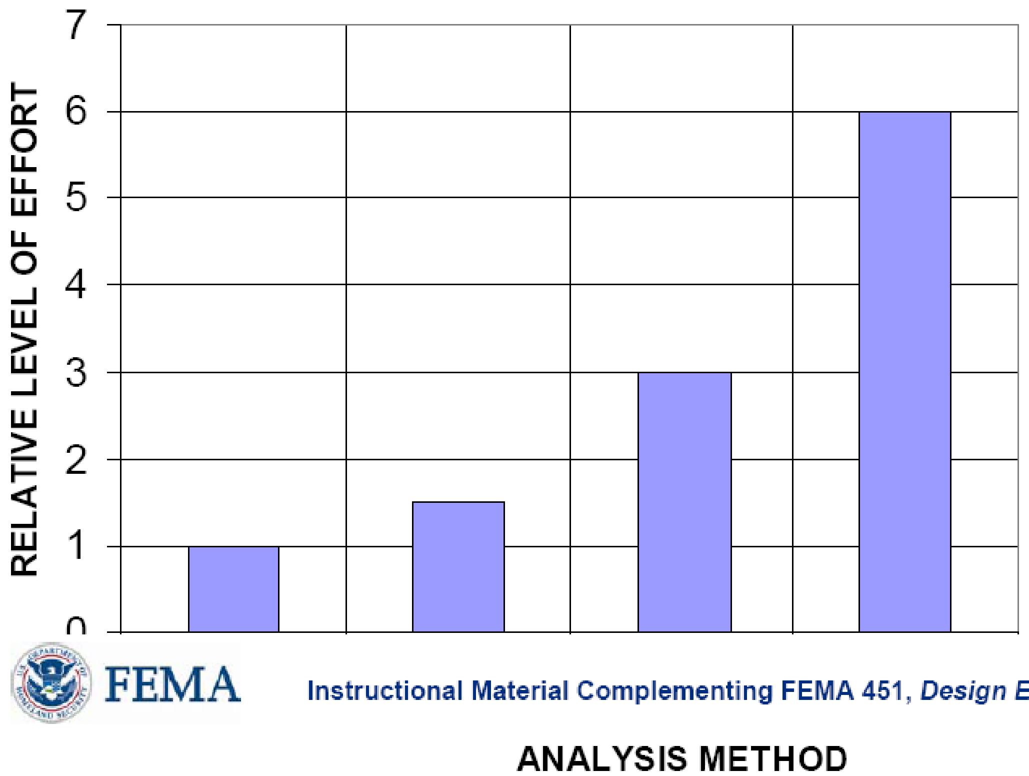
Question: Can I use static (equivalent lateral force procedure) analysis for the following building:

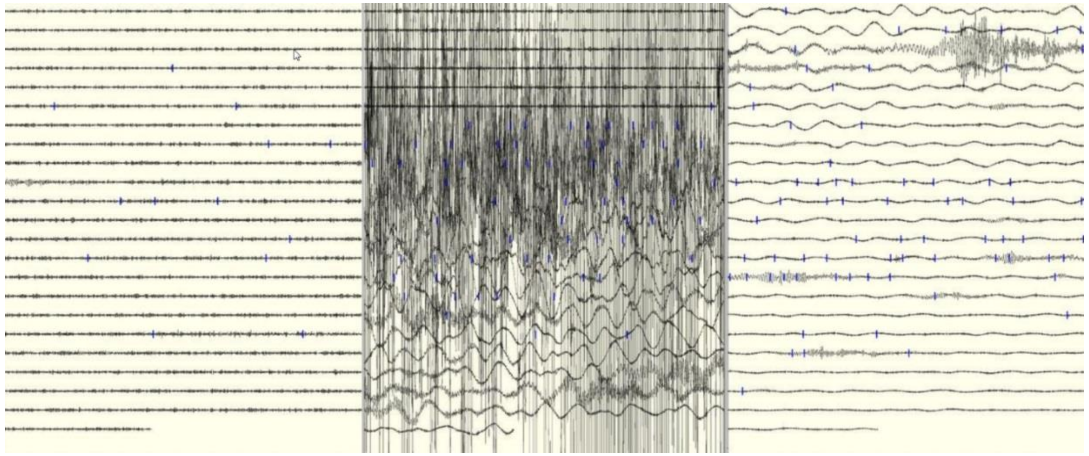
- SDC D
- 175 ft. tall
- No irregularities
- $T<3.5T_s$

Permitted Analysis Procedures



ELF: Equivalent Lateral Force (Simplified Design Procedure)	12.8 (12.14)
MRS: Modal Response Spectrum	12.9
LTH: Linear Time History	16.1
NTH: Nonlinear Dynamic Time History	16.2





Summary:

1) Understand the methodology built into code-values of R, C_d, Ω_o.
2) The code attempts to steer engineers into redundant, ductile designs with regular load path.

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