NCSEA Structural Engineering Exam Review Course

Lateral Forces Review

Lateral General (Miscellaneous Topics) – August 2017

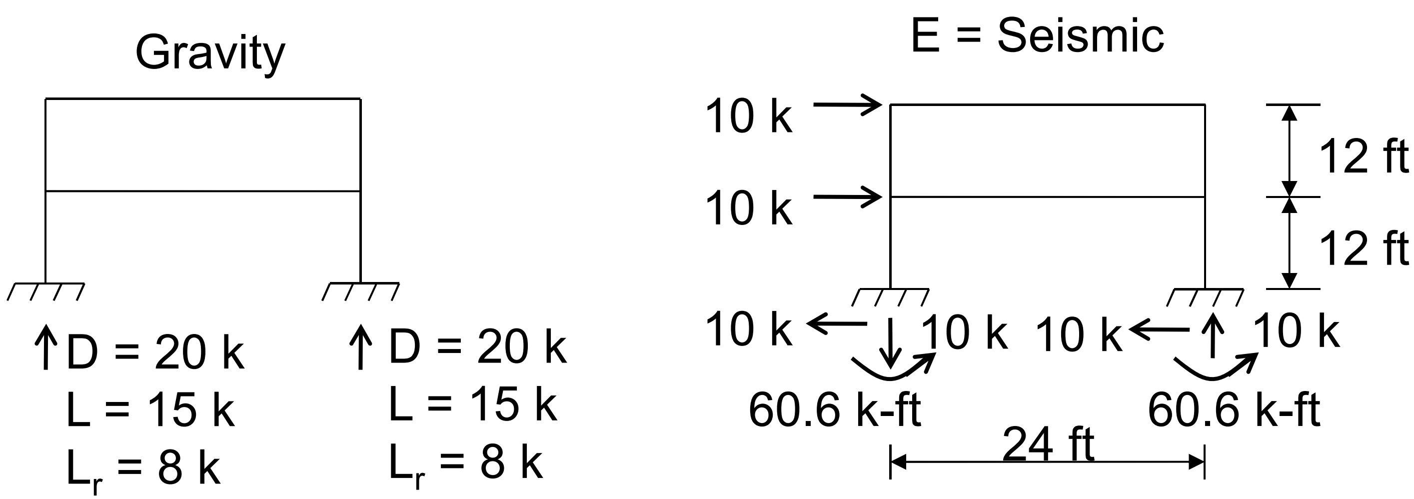
Presented by Timothy Mays

Topics

- Load Combinations
- Serviceability Requirements: Building Drift
- Anchorage to Resist Uplift and Sliding Forces
- Components, Attachments, and Cladding
- Redundancy Factors
- Overstrength
- Ductility Requirements
- Structural Systems to Resist Lateral Forces
- Strengthening Existing Systems: Seismic Retrofit

Load Combinations

Problem 1: For the building shown below, determine the maximum and minimum factored compressive force acting on the first story columns. ρ = 1.0, S_{DS} = 1.0, L_0 = 50 psf.

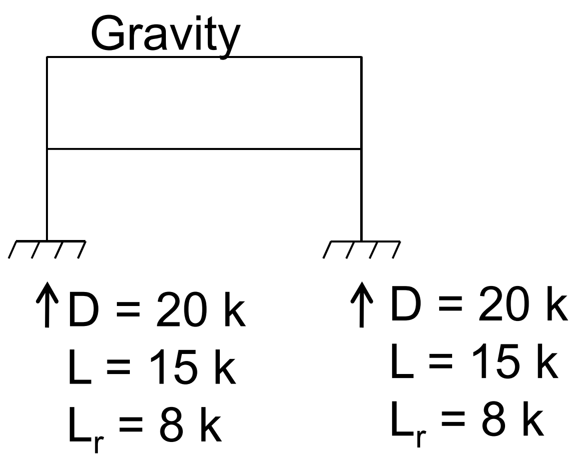


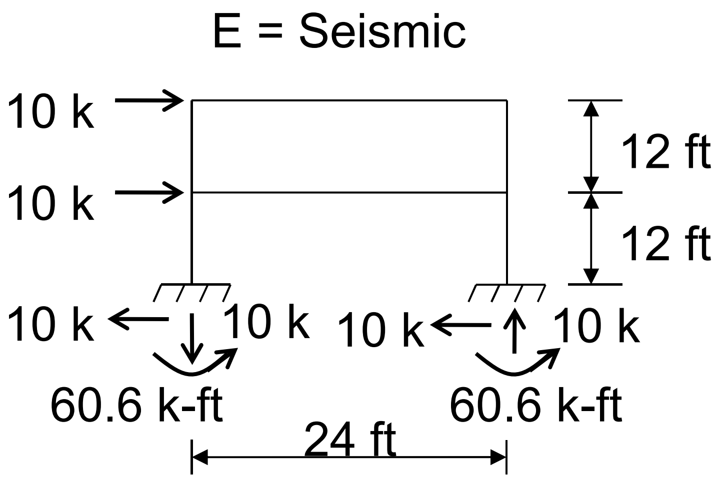
$$P_u = (1.2 + 0.2S_{DS})D + \rho Q_E + 0.5L + 0.2S \quad (Section \;\; 12.4.2.3)$$

$$P_u = [1.2 + 0.2(1.0)]20 + 1.0(10) + 0.5(15) + 0.2(0) = 45.5 \quad k$$

Load Combinations

Problem 1:





$$P_u = (0.9 - 0.2S_{DS})D + \rho Q_E \quad \text{(Section 12.4.2.3)}$$

$$P_u = [0.9 - 0.2(1.0)]20 + 1.0(-10) = 4 \quad k$$

$$P_u = 1.2D + 1.6L + 0.5L_r \quad \text{(Combination 2, Section 2.3.2)}$$

$$P_u = 1.2(20) + 1.6(15) + 0.5(8) = 52 \quad k$$

Building Drift

Problem 2: For the Special Steel Concentrically Braced Frame office building shown, elastic deflections for each floor's center of mass are provided. Determine the inelastic story drift of the top floor (i.e., roof) and compare it to the drift limit presented in Table 12.12-1 of ASCE 7-10. I_e = 1.0.

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \quad (Eq.\ 12.8-15)$$

$$\delta_3 = \frac{5(1.5)}{1.0} = 7.5 \quad in.$$

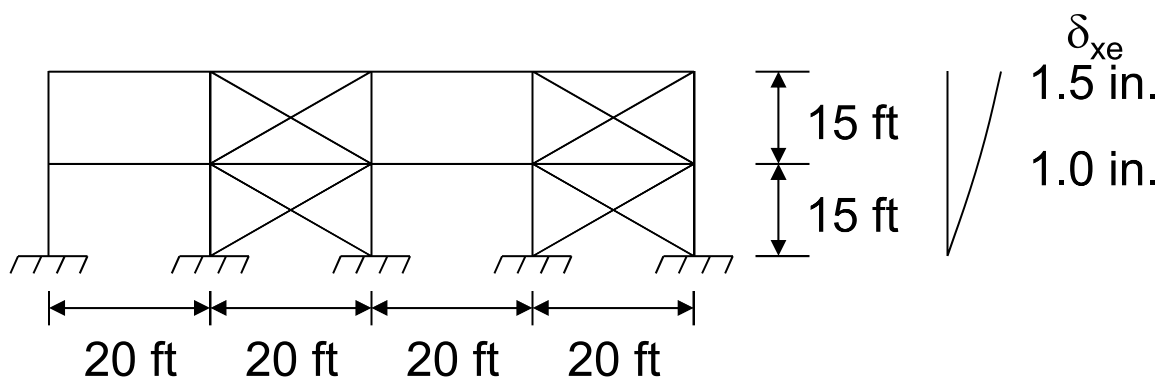
$$\delta_2 = \frac{5(1.0)}{1.0} = 5 \quad in.$$

$$\Delta = \delta_{x+1} - \delta_x$$

$$\Delta = 7.5 - 5 = 2.5 \quad in.$$

$$\Delta_a = 0.025 h_{sx} \quad (Table\ \ 12.12-1)$$

$$\Delta_a = 0.025 h_{sx} = 0.025(15)(12) = 4.5 \quad in. \quad (ok)$$



SCBF

R = 6, Ω_0 = 2, C_d = 5

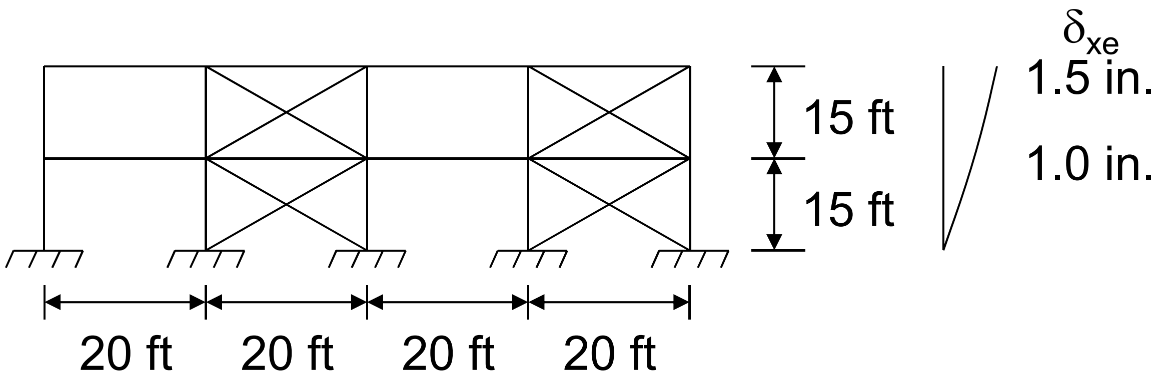
Building Drift

Problem 3: For the Special Steel Concentrically Braced Frame office building shown, elastic deflections for each floor's center of mass are provided. Determine the required separation distance between two identical structures based on requirements presented in Section 12.12.3 of ASCE 7-10.

$$\delta_x = \frac{C_d \delta_{xe}}{I} \quad (\text{Eq. } 12.8-15)$$

$$\delta_3 = \frac{5(1.5)}{1.0} = 7.5 \text{ in.}$$

$$\Delta_{separation} = \sqrt{7.5^2 + 7.5^2} = 10.6 \text{ in.}$$

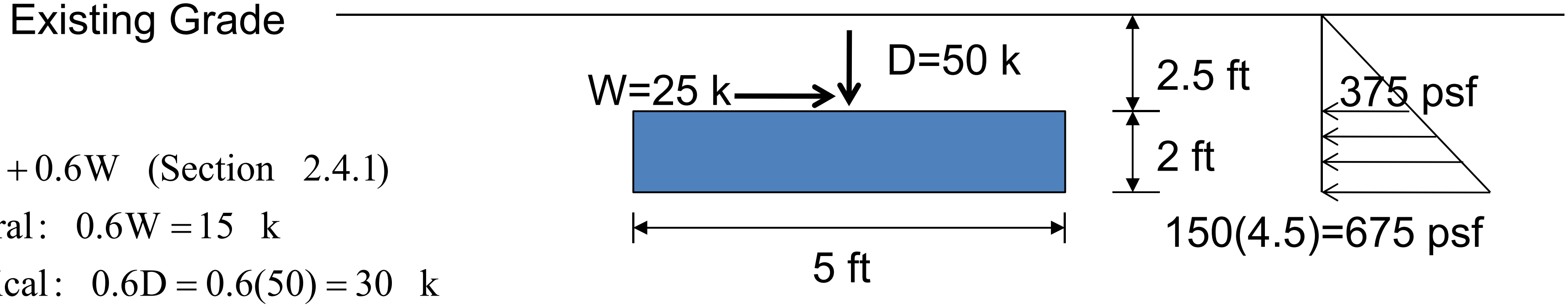


SCBF

$R = 6$, $\Omega_0 = 2$, $C_d = 5$

Anchorage to Resist Uplift/Sliding

Problem 4: For the footing and unfactored loads shown, determine if the system can resist sliding. The footing is 5 ft × 5 ft in plan. Soil is known to be sand.



$$0.6D + 0.6W \quad (\text{Section } 2.4.1)$$

$$\text{Lateral:} \quad 0.6W = 15 \text{ k}$$

$$\text{Vertical:} \quad 0.6D = 0.6(50) = 30 \text{ k}$$

$$\text{Resistance:} \quad \text{Sliding} + \text{Lateral Bearing} = 30(0.25) + 2(5)\frac{675+375}{2(1{,}000)} = 12.75 \text{ k}$$

$$12.75 \text{ k} < 15 \text{ k} \quad (\text{NG})$$

Per Table 1806.2 of the 2012 IBC, μ=0.25 and lateral bearing pressure = 150 psf/ft

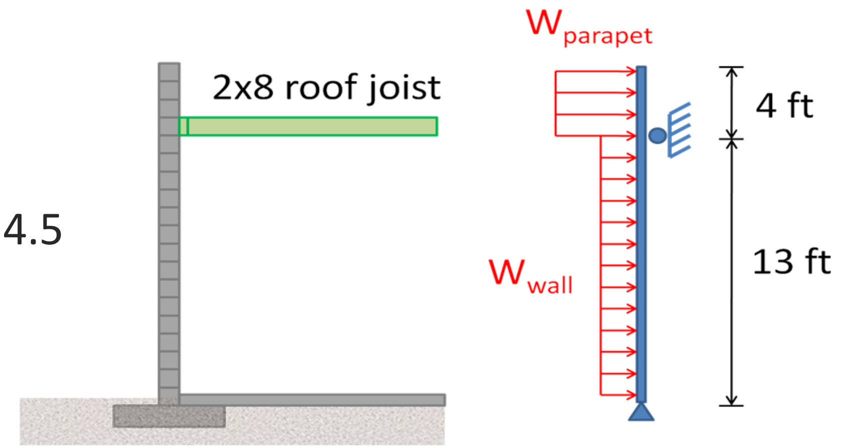
Components, Attachments, and Cladding

Problem 5: Determine the out-of-plane seismic load and the anchorage force at the roof diaphragm for the first story CMU load bearing shearwall shown. SDC A, S_{DS} = 0.10, h = 13 ft, I_e = 1.0, I_p = 1.0, rigid diaphragm, wall weight W_{wall} = 81 psf.

$$w_{wall} = w_{parapet} = 0.2(W_{wall}) = 0.2(81) = 16.2 \ \text{psf} > 5 \ \text{psf} \quad (\text{ok})$$

$$F_{anchorage} = 16.2(17)(17/2)/13 = 180 \ \text{lb/ft}$$

Anchorage force specified in ASCE 7-10 Section 1.4.5 (General Structural Stability)



Components, Attachments, and Cladding

Problem 6: Determine the out-of-plane seismic load on the cantilever parapet shown. SDC B, S_{DS} = 0.25, h = 13 ft, I_e = 1.0, I_p = 1.0, rigid diaphragm, wall weight W_{wall} = 81 psf.

$$w_{wall} = 0.4 S_{DS} I_e W_{wall} = 0.4(0.25)(1)(81) = 8.1 \text{ psf} \le 0.1 W_{wall} = 0.1(81) = 8.1 \text{ psf (ok)}$$

$$w_{wall} = 8.1 \text{ psf}$$

$$a_p = 2.5 \text{ (Table 13.5-1, cantilever parapet)}$$

$$R_p = 2.5 \text{ (Table 13.5-1, cantilever parapet)}$$

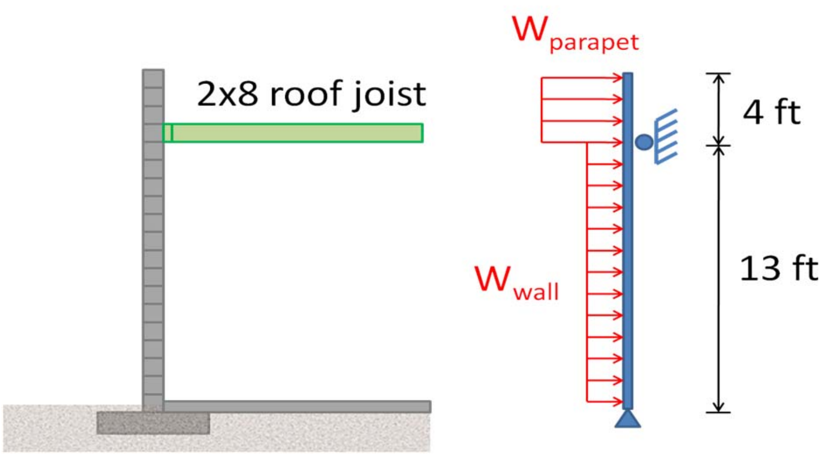
$$w_{parapet} = F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right)$$

$$w_{parapet} = F_p = \frac{0.4(2.5)(0.25)(81)}{(2.5)/(1.0)}\left(1 + 2\frac{13}{13}\right) = 24.3 \text{ psf}$$

$$F_{p,min} = 0.3 S_{DS} I_p W_p = 0.3(0.25)(1)(81) = 6.08 \text{ psf (ok)}$$

$$F_{p,max} = 1.6 S_{DS} I_p W_p = 1.6(0.25)(1)(81) = 32.4 \text{ psf (ok)}$$

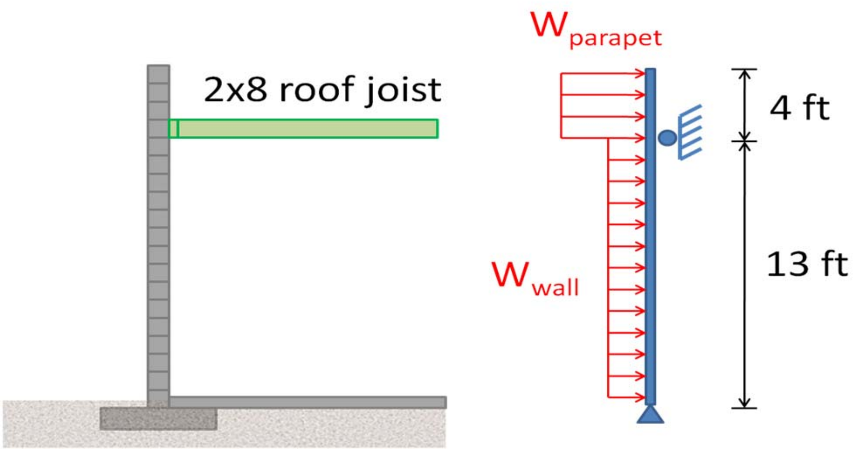
$$w_{parapet} = 24.3 \text{ psf}$$



Components, Attachments, and Cladding

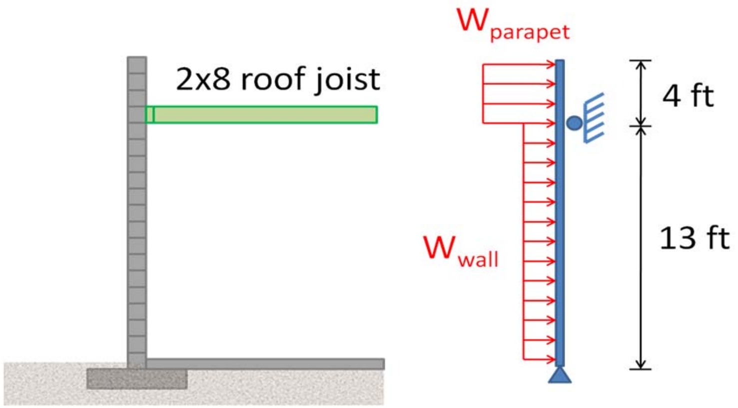
Problem 7: Determine the unfactored design wind pressure on the parapet shown. Given: V = 130 mph; h = 13 ft; building is enclosed and conforms to wind-borne debris provisions; building is regular-shaped; building is not subject to dynamic effects; building has a flat roof; K_{zt} = 1.0; Exposure C applies; overall building footprint = 50 ft × 100 ft; windward wall is 50 ft surface.

Section 30.9 (ASCE 7-10)
Two load cases are required for parapet walls:
Load Case A – positive wall pressure from front surface of parapet plus negative roof pressure (edge or corner as appropriate) on backside of parapet
Load Case B – positive wall pressure on the back surface of parapet plus negative wall pressure on the front surface



Components, Attachments, and Cladding

Problem 7:



$$A = \frac{4(4)}{3} = 5.33 \quad ft^2$$

$$q_z = 0.00256 K_z K_{zt} K_d V^2 \quad (Eq. \ 30.3-1)$$

$$K_z = 0.87 \quad (Table \ 30.3-1, \ z = 17 \ ft, \ Exposure \ C)$$

$$K_{zt} = 1.0 \quad (Given)$$

$$K_d = 0.85 \quad (Table \ 26.6-1, C \& C)$$

$$V = 130 \ mph \quad (Given)$$

$$I = 1.0 \quad (Given)$$

$$q_z = q_p = 0.00256(0.87)(1.0)(0.85)(130)^2 = 32.0 \quad psf$$

See Figure 30.9-1

Components, Attachments, and Cladding

Problem 7:

$p = q_p[GC_p - GC_{pi}]$

$GC_p = 1.0, \ -1.1$ (Figure 30.4-1, Zone 4)

$GC_p = 1.0, \ -1.4$ (Figure 30.4-1, Zone 5)

$GC_p = 0.30, \ -1.8$ (Figure 30.4-2A, Zone 2, Roof)

$GC_p = 0.30, \ -2.8$ (Figure 30.4-2A, Zone 3, Roof)

$GC_{pi} = \pm 0$ (Masonry Parapet)

Case A, $GC_p = 1.0 + 1.8 = 2.8$ (Zone 4), $GC_p = 1.0 + 2.8 = 3.8$ (Zone 5):

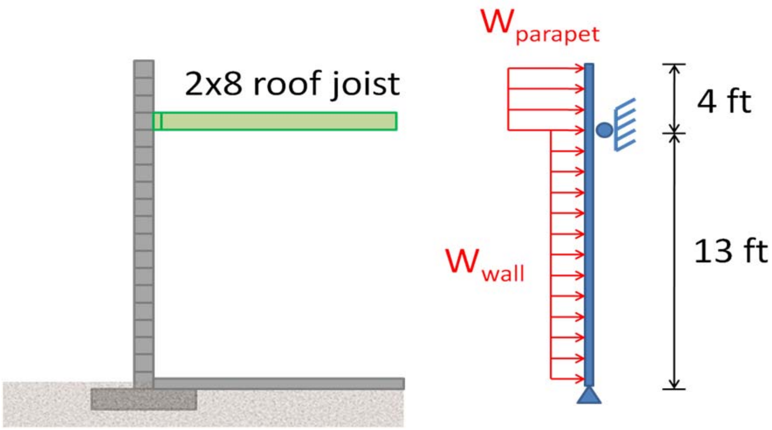
$p = W_{parapet} = 32.0[GC_p \mp 0] = 89.6$ psf (Zone 4)

$p = W_{parapet} = 32.0[GC_p \mp 0] = 122$ psf (Zone 5)

Case B, $GC_p = -1.0 - 1.1 = -2.1$ (Zone 4), $GC_p = -1.0 - 1.4 = -2.4$ (Zone 5):

$p = W_{parapet} = 32.0[GC_p \mp 0] = -67.2$ psf (Zone 4)

$p = W_{parapet} = 32.0[GC_p \mp 0] = -76.8$ psf (Zone 5)



GC_p for walls may be reduced 10%.
Roof zone 3 does not exist for tall parapet.

Redundancy Factors

- ASCE 7-10 (Section 12.3.4)
  - Two orthogonal directions
  - ρ = 1.0 or 1.3
  - ρ = 1.0 for SDC C or lower
  - ρ = 1.0 always true for drift calculations, P-delta effects, nonstructural components, nonbuilding structures not similar to buildings, designs with Ω_0, diaphragm loads (Eq. 12.10-1), Chapter 18, and design of structural walls for out-of-plane forces/anchorage.

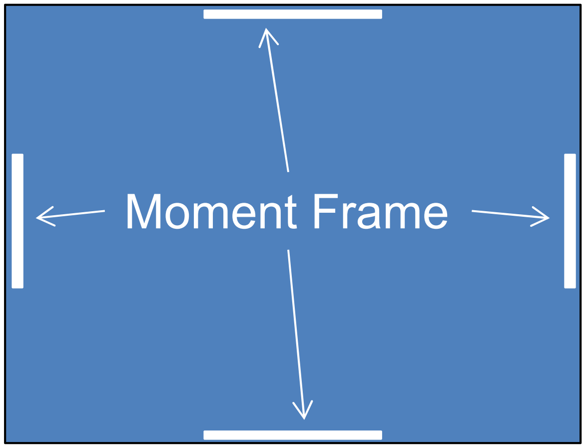
Redundancy Factors

- ASCE 7-10 (Section 12.3.4.2)
  - ρ = 1.3 for SDC D, E, or F unless one of the following conditions is met:
    1. Each story resisting more than 35% of base shear complies with Table 12.3-3
    2. Regular structure in plan at all levels with at least two bays of seismic resisting perimeter framing on each side of the structure at each story resisting more than 35% of the base shear. The number of bays for a shear wall is L_{wall}/h_{story}. Use $2L_{wall}/h_{story}$ for light frame construction.

Redundancy Factors

Problem 8: Determine the redundancy factor for the system shown. SDC D and story shown resists at least 35% of base shear. Assume all frames have same strength and stiffness.

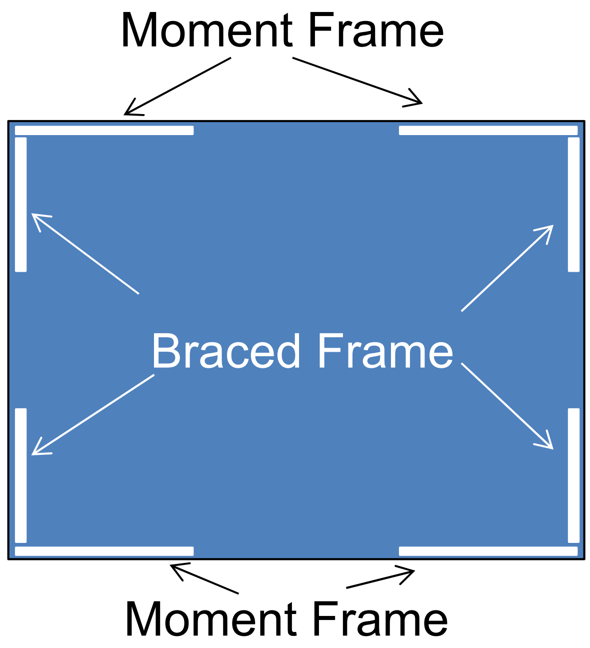
ρ = 1.3 since loss of moment frame results in at least 50% (>33%) reduction in story strength. Although not checked, extreme torsional irregularity may also result from loss of moment resistance at any location.



Redundancy Factors

Problem 9: Determine the redundancy factor for the system shown. SDC D and story shown resists at least 35% of base shear.

ρ = 1.0 since system meets requirement of two bays of seismic resisting perimeter framing on each side of the building.



Overstrength

- ASCE 7-10 requirements
  - Ω_0 —intent is to design for maximum force that may be resisted by the element
  - Collectors (Section 12.10.2.1)
  - Discontinuous shear walls (Section 12.3.3.3)
  - Batter piles (Section 1810.3.11.2, 2012 IBC)
  - Weak story design using Ω_0 to avoid two story (30 ft) height limit for vertical irregularity type 5b (extreme weak story) (Section 12.3.3.2)
  - See material specific presentations for other cases

Ductility Requirements

Problem 10: Explain seismic force-resisting system B.3 from Table 12.2-1 of ASCE 7-10.

Seismic Force Resisting System	R	Ω_0	C_d	Structural System Limitations and Building Height (ft) Limits for Different Seismic Design Categories				
				B	C	D	E	F
3. Steel ordinary concentrically braced frames	3 ¼	2	3 ¼	NL	NL	35[j]	35[j]	NP[j]

[j] permitted up to 60 ft for single story structures with roof dead load less than 20 psf and for penthouse structures.

Structural Systems to Resist Lateral Forces

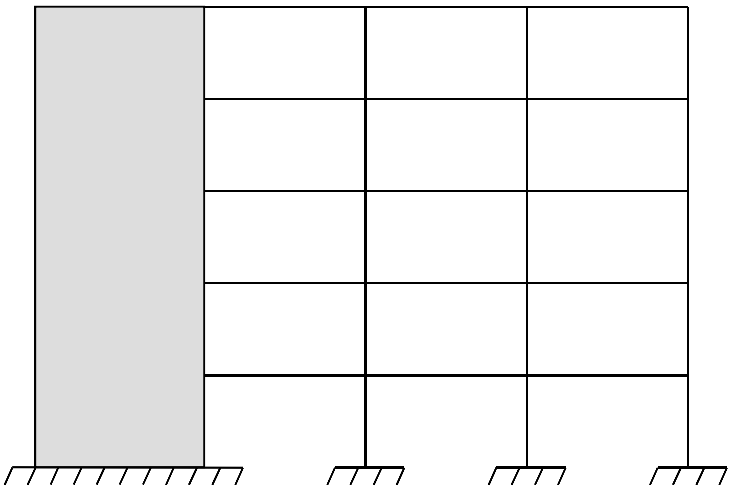
- ASCE 7-10 (Section 12.2.2 and 12.2.3)
  - Different lateral force resisting systems are permitted in orthogonal directions
  - Where different lateral force resisting systems are used in the same direction (other than dual systems), the more stringent system limitations shall apply
  - Where different lateral force resisting systems are used in the same direction (other than dual systems), the minimum R value (and associated values of C_d and Ω_0) shall apply

Structural Systems to Resist Lateral Forces

- ASCE 7-10 (Section 12.2.2 and 12.2.3)
  - For $R_{upper}>R_{lower}$, use R, C_d, and Ω_0 for each system but forces for the lower section are determined as the upper force times R_{upper}/R_{lower}
  - For $R_{upper}<R_{lower}$, use R, C_d, and Ω_0 for the upper system for the design of everything

Structural Systems to Resist Lateral Forces

Problem 11: Determine the appropriate seismic design coefficients and factors for the five story building shown. A rigid diaphragm is assumed and both Special Steel Moment Frames (SMF) and Special Reinforced Concrete Shear Wall (SRCSW) building frame systems are used for lateral load resistance in the same direction.



SMF

$R = 8$, $\Omega_0 = 3$, $C_d = 5\ ½$

SRCSW

$R = 6$, $\Omega_0 = 2\ ½$, $C_d = 5$

Answers (12.2.3.2, ASCE 7-10)

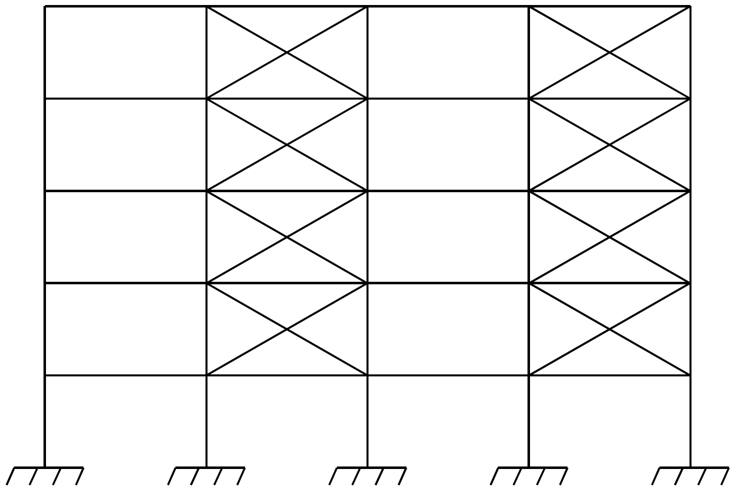
$R = 6$, $\Omega_0 = 2\ ½$, $C_d = 5$

$R = 7$, $\Omega_0 = 2\ ½$, $C_d = 5\ ½$ (Dual System)

Structural Systems to Resist Lateral Forces

Problem 12: Determine the appropriate seismic design coefficients and factors for the bottom floor of the five story building shown. The top four floors are Special Steel Concentrically Braced Frames (SCBF) and the bottom floor is constructed as a Special Steel Moment Frame (SMF) system.

Section 12.2.3.1 of ASCE 7-10 states that R values for any story shall not exceed the lowest R value on any floor above. C_d and Ω_0 shall not be less than the highest values on any floor above.



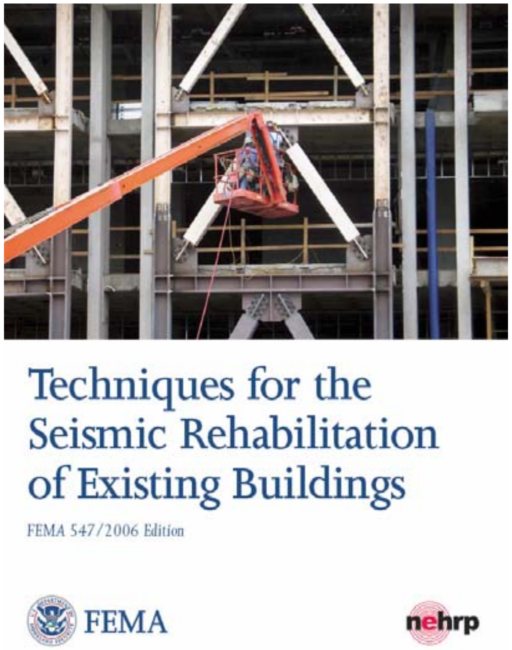
<u>SCBF</u>
$R = 6$, $\Omega_0 = 2$, $C_d = 5$

<u>SMF</u>
$R = 8$, $\Omega_0 = 3$, $C_d = 5\frac{1}{2}$

<u>Answer</u>
$R = 6$, $\Omega_0 = 2$, $C_d = 5$

Strengthening Existing Systems: Seismic Retrofit

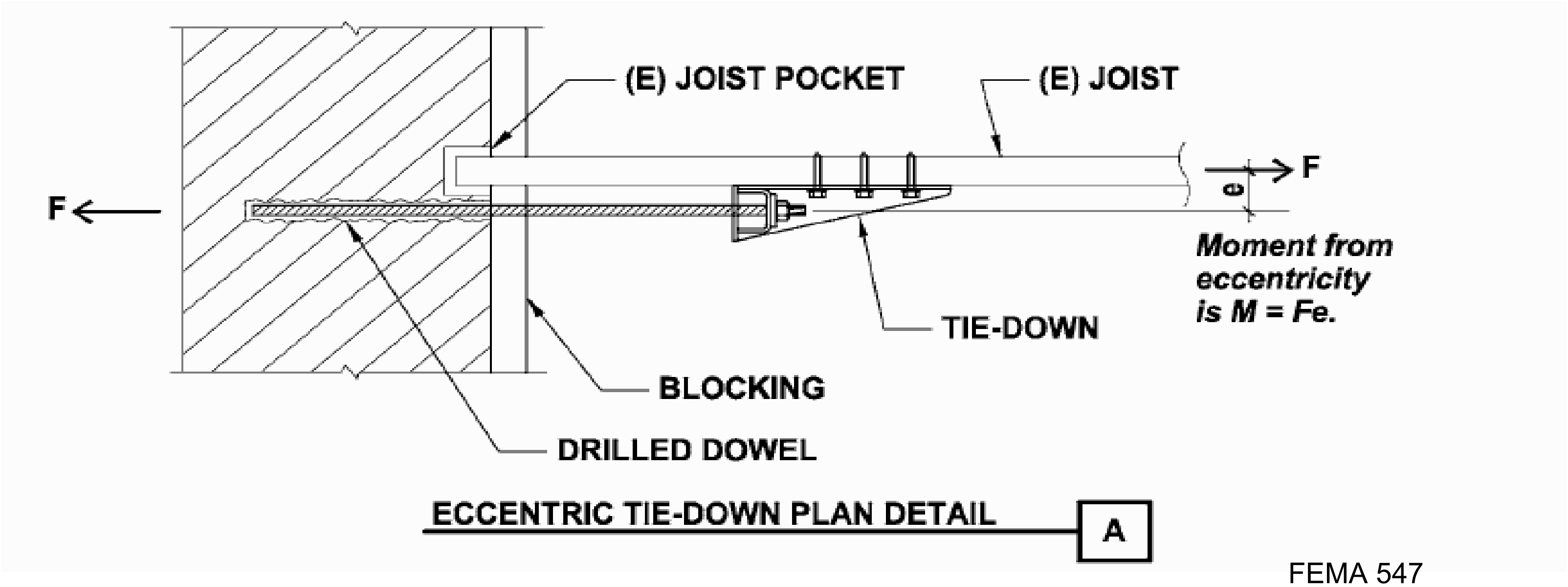
- Key references
  - FEMA 547
  - ASCE 31-03
  - ASCE 41-13
  - Other FEMA publications



FEMA 547

Strengthening Existing Systems: Seismic Retrofit

FEMA 547



FEMA 547

Strengthening Existing Systems: Seismic Retrofit

FEMA 547

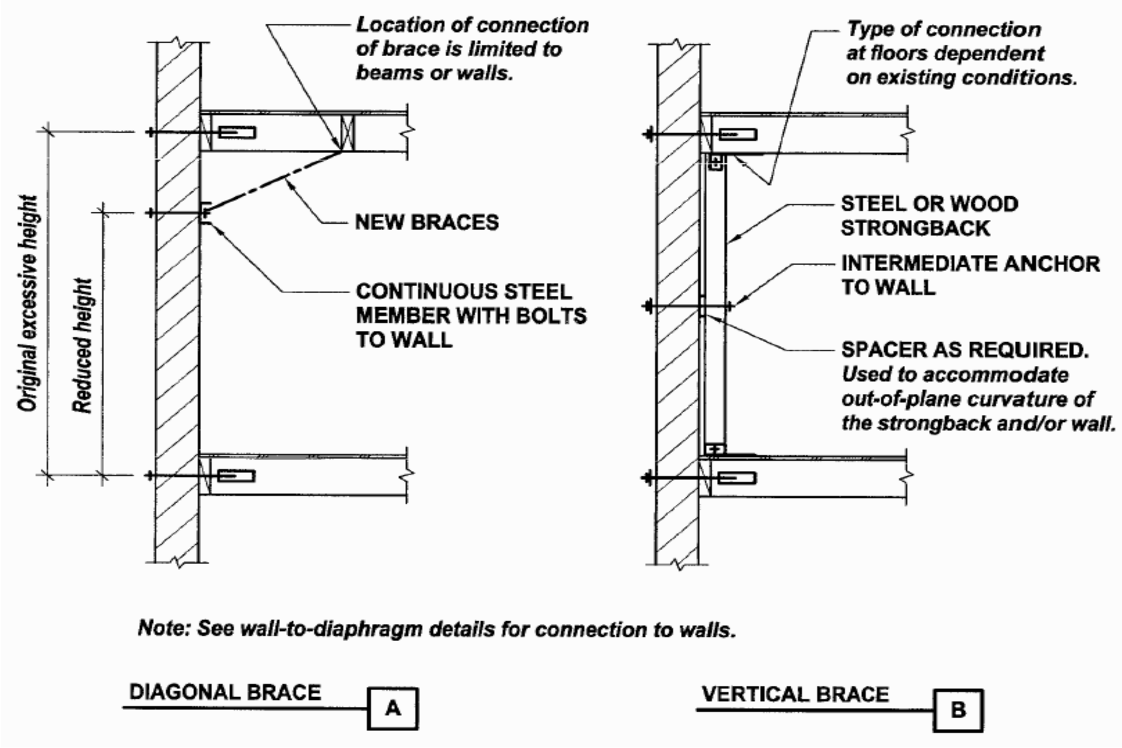


Figure 21.4.3-1: Exposed Out-of-Plane Wall Bracing

FEMA 547

Strengthening Existing Systems: Seismic Retrofit

FEMA 547

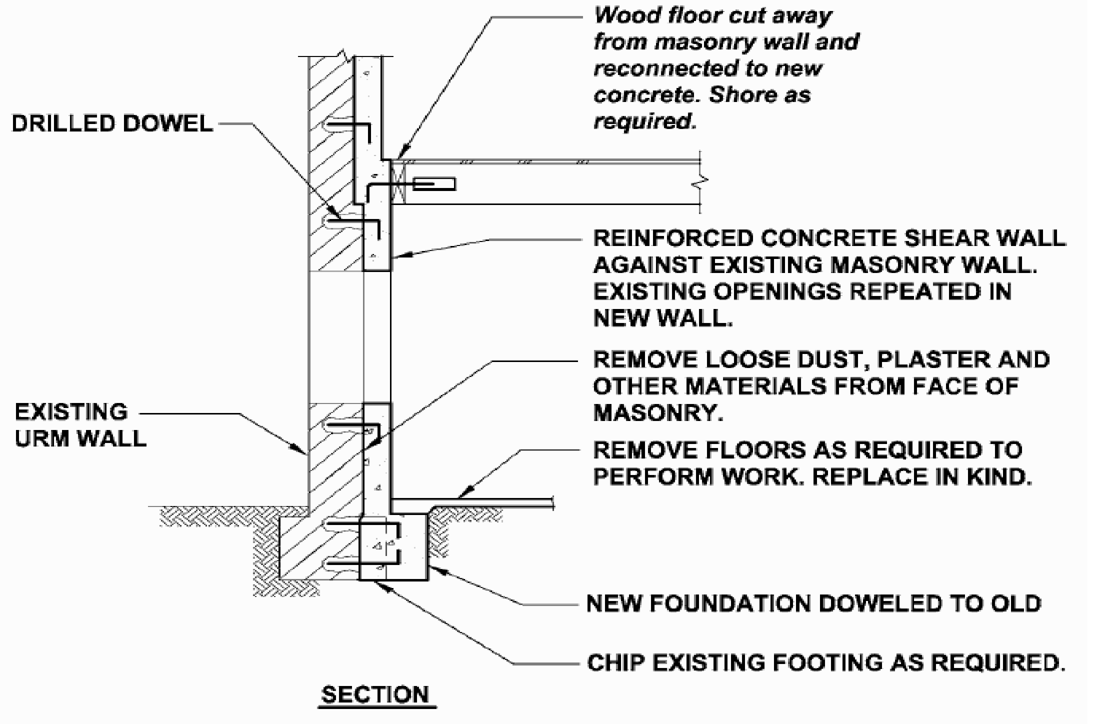


Figure 21.4.5-1: Concrete or Shotcrete Wall Overlay

Strengthening Existing Systems: Seismic Retrofit

FEMA 547

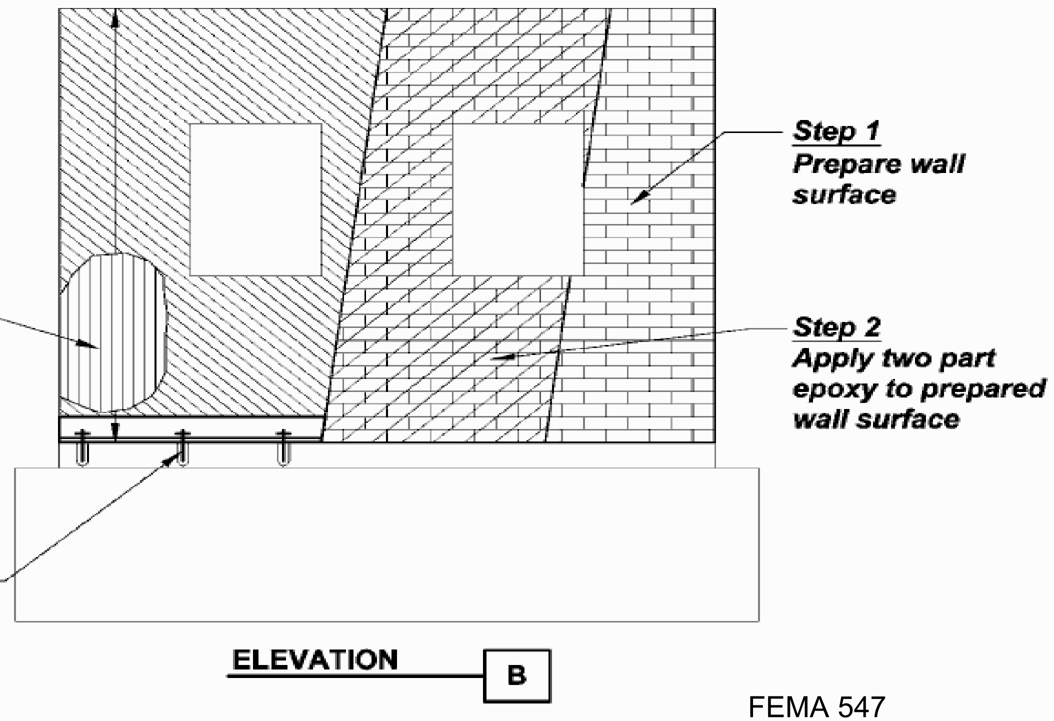


Figure 21.4.6-1: Fiber Composite Wall Overlay on URM Wall

Structural Design Standards Relevant for Lateral Forces

- In order of precedence
  - International Building Code (2012 Edition)
  - Minimum Design Loads for Buildings and Other Structures (ASCE 7-10)

or

  - AASHTO LRFD Bridge Design Specifications (7th Edition, 2014)

Recommended References and Additional Study Materials

- Structural: Sample Questions + Solutions (NCEES, 2014)
- Seismic and Wind Forces: Structural Design Examples (Williams, ICC, 2013)
- 2012 IBC Structural/Seismic Design Manual: Code Application Examples (Volume 1, ICC, 2013)
- Guide to the Design of Out-of-Plane Wall Anchorage (Mays, ICC, 2010)