NCSEA Structural Engineering Exam Review Course

Lateral Forces Review

Lateral Force Distribution – August 2017

Presented by Timothy Mays

Topics

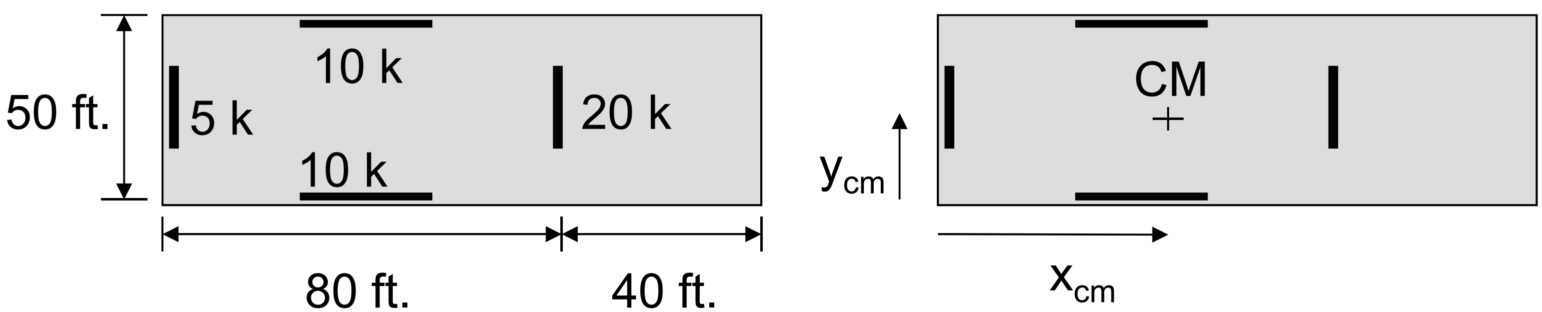
- Statics (Forces and Moments)
- Seismic Design Categories
- Seismic Static Force Procedures
- Seismic Dynamic Force Procedures
- Configuration of Structural Systems (Torsion)
- Relative Rigidity Force Distribution
- Horizontal and Vertical Irregularities
- Diaphragms, Chords, and Collectors

Statics (Forces and Moments)

Problem 1: For the building plan view shown below, determine the location of the center of mass CM at the given floor level. Assume the diaphragm weighs 100 psf except for the cantilevered portion which weights 38.5 psf. Wall weights shown in the figure are in kips and are considered tributary weights. Assume a rigid diaphragm. Total wall weights shown act at center of dimensions.

$$x_{cm} = \frac{\sum W_{i,y} x_i}{\sum W_{i,y}} = \frac{5(0) + 20(80) + 2(10)(40) + (0.1)(80)(50)(40) + 0.0385(40)(50)(100)}{5 + 20 + 2(10) + 0.1(80)(50) + 0.0385(40)(50)} = 50 \quad ft$$

$$y_{cm} = \frac{\sum W_{i,x} y_i}{\sum W_{i,x}} = \frac{5(25) + 20(25) + 10(0) + 10(50) + (0.1)(80)(50)(25) + 0.0385(40)(50)(25)}{5 + 20 + 2(10) + 0.1(80)(50) + 0.0385(40)(50)} = 25 \quad ft$$



Statics (Forces and Moments)

Problem 2: For the building plan view shown below, determine the location of the center of rigidity, CR, and the value of the torsional rigidity, J, for the lateral force resisting system configuration shown. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Assume a rigid diaphragm.

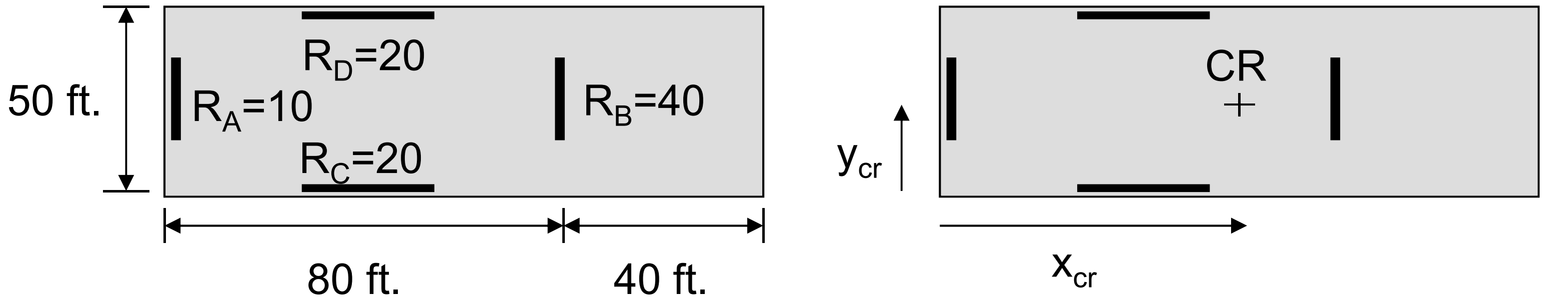
$$x_{cr} = \frac{\sum R_{i,y} x_i}{\sum R_{i,y}} = \frac{10(0) + 40(80)}{10 + 40} = 64 \quad ft$$

$$y_{cr} = \frac{\sum R_{i,x} y_i}{\sum R_{i,x}} = \frac{20(0) + 20(50)}{20 + 20} = 25 \quad ft$$

$$J = \sum R_{i,y} x_{cr,i}^2 + \sum R_{i,x} y_{cr,i}^2$$

$$J = 10(-64)^2 + 40(16)^2 + 20(-25)^2 + 20(25)^2$$

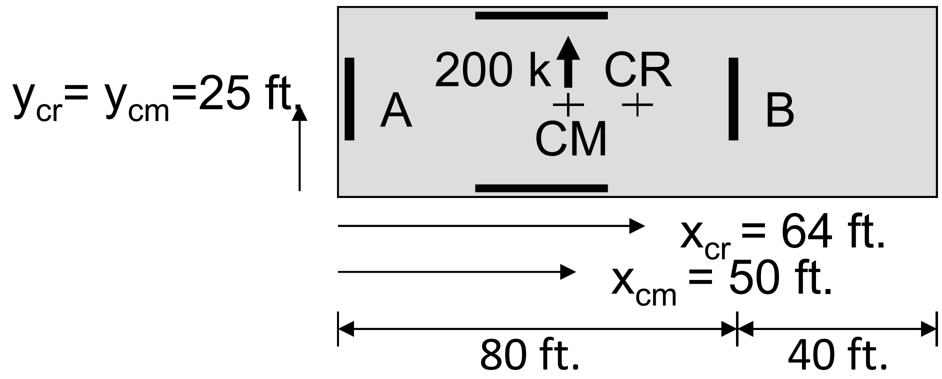
$$J = 76{,}200 \quad k-ft$$



Statics (Forces and Moments)

Problem 3: For the rigid diaphragm plan view shown below, determine where the seismic force V = 200 k must be placed on the model for determining the maximum shear in shear walls A and B.

According to Section 12.8.4.2 of ASCE 7-10, accidental eccentricity is considered by offsetting the CM shown below by 0.05(120) = 6 ft to the left and right. Hence, three locations are considered as follows: x_{cm}= 44 ft, x_{cm}= 50 ft, and x_{cm}= 56 ft



Seismic Design Categories

Problem 4: A hospital is to be located in Charleston, SC. Assume $S_S = 1.5$, $S_1 = 0.4$, and Site Class D. Determine the design spectral accelerations for the project.

Chapter 11 of ASCE 7-10 and Section 1613 of the 2012 IBC present the appropriate procedure for determining design spectral accelerations.

$$F_a = 1.0 \quad \text{(Table } 11.4-1)$$

$$S_{MS} = F_a S_s = 1.0(1.5) = 1.5 \quad \text{(Eq. } 11.4-1)$$

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3}(1.5) = 1.0 \quad \text{(Eq. } 11.4-3)$$

$$F_v = 1.6 \quad \text{(Table } 11.4-2)$$

$$S_{M1} = F_v S_1 = 1.6(0.4) = 0.64 \quad \text{(Eq. } 11.4-2)$$

$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3}(0.64) = 0.43 \quad \text{(Eq. } 11.4-4)$$

Seismic Design Categories

Problem 5: A hospital is to be located in Charleston, SC. Assume S_S = 1.5, S_1 = 0.4, and Site Class D. Determine the seismic design category (SDC) for the project.

Chapter 11 of ASCE 7-10 and Section 1613 of the 2012 IBC present the appropriate procedure for determining SDC.

$$S_{DS} = 1.0 \quad \text{(Previous problem)}$$

$$S_{D1} = 0.43 \quad \text{(Previous problem)}$$

$$\text{Risk Category IV (Table 1.5-1)}$$

$$SDC = MAX \left| \begin{array}{l} \text{SDC (Table 11.6-1)} \\ \text{SDC (Table 11.6-2)} \end{array} \right.$$

$$\text{SDC D (Table 11.6-1)}$$

$$\text{SDC D (Table 11.6-2)}$$

$$\text{SDC D}$$

Seismic Design Categories

- Additional comments
  - SDC E (OC I, II, or III and $S_1 \geq 0.75$)
  - SDC F (OC IV and $S_1 \geq 0.75$)
  - Can use S_{DS} only to determine SDC for short period structures meeting certain requirements presented in Section 11.6 of ASCE 7-10

Seismic Force Procedures

- ASCE 7-10 references
  - Table 12.6-1 Permitted Analytical Procedures
  - Equivalent Lateral Force Analysis (Section 12.8)
  - Modal Response Spectrum Analysis (Section 12.9)
  - Seismic Response History Procedures (Chapter 16)

Seismic Static Force Procedures

Problem 6: Determine the largest permitted fundamental period T of the structure for the special steel concentrically braced frame office building shown. A computer model has determined the natural period to be 0.3 s. S_{DS} = 1.0, S_{D1} = 0.43.

$$h_n = 30 \text{ ft} \quad \text{(Highest level)}$$

$$C_t = 0.02 \quad \text{(Table 12.8-2, all other systems)}$$

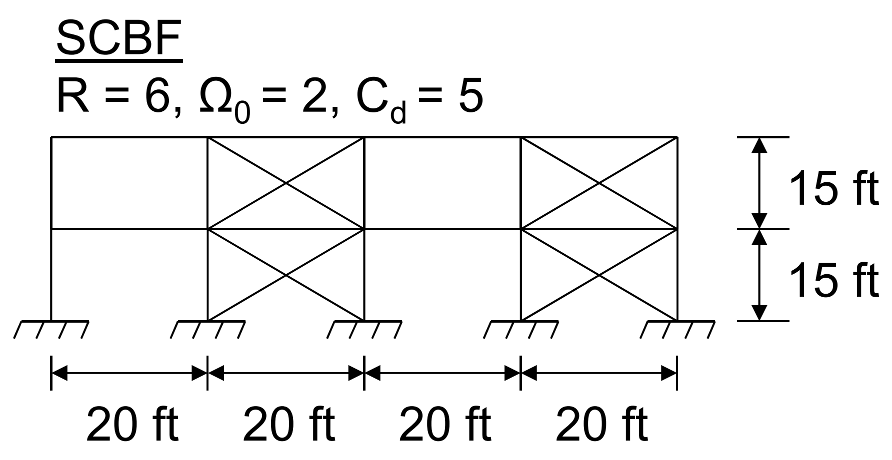
$$x = 0.75 \quad \text{(Table 12.8-2, all other systems)}$$

$$T_a = C_t h_n^x = 0.02(30^{0.75}) = 0.256 \text{ s}$$

$$C_u = 1.4 \quad \text{(Table 12.8-1, } S_{D1} > 0.4\text{)}$$

$$T = 0.3 \text{ s} \le C_u T_a = 1.4(0.256) = 0.358 \text{ s} \quad \text{(ok)}$$

$$T = 0.3 \text{ s}$$



Seismic Static Force Procedures

Problem 7: Using the equivalent lateral force method (Section 12.8 of ASCE 7-10), determine the seismic response coefficient C_S for the special steel concentrically braced frame office building shown. S_{DS} = 1.0, S_{D1} = 0.43, S_1 = 0.40. The structure is to be located in Charleston, SC.

$$T = 0.3 \text{ s} \quad \text{(Previous problem)}$$

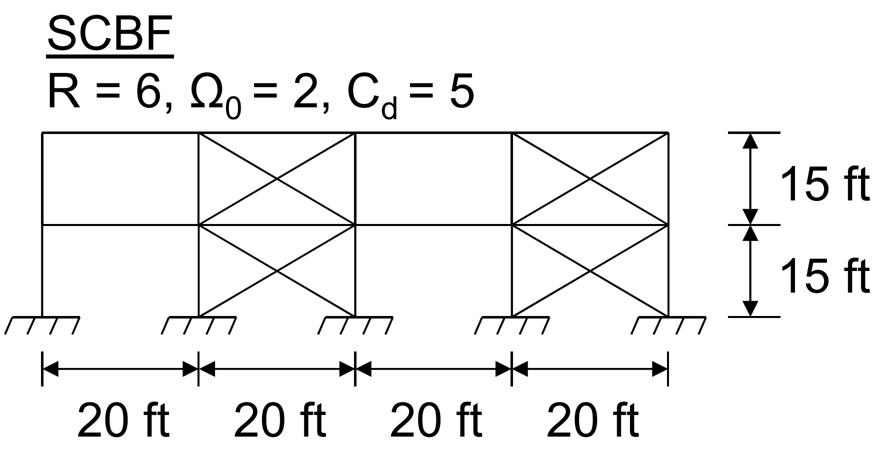
$$\text{Risk Category} = \text{II} \quad \text{(Table 1.5-1)}$$

$$I_e = 1.0 \quad \text{(Table 1.5-2)}$$

$$T_L = 8 \text{ s} \quad \text{(Figure 22-15)}$$

$$C_s = \frac{S_{DS}}{R/I_e} \leq \begin{vmatrix} \dfrac{S_{D1}}{T(R/I_e)} & \text{for } T \leq T_L \\ \dfrac{S_{D1}T_L}{T^2(R/I_e)} & \text{for } T > T_L \end{vmatrix}$$

$$C_s = \frac{1.0}{6/1} = 0.167 \leq \frac{S_{D1}}{T(R/I_e)} = \frac{0.43}{0.3(6/1)} = 0.239 \quad \text{(ok)}$$



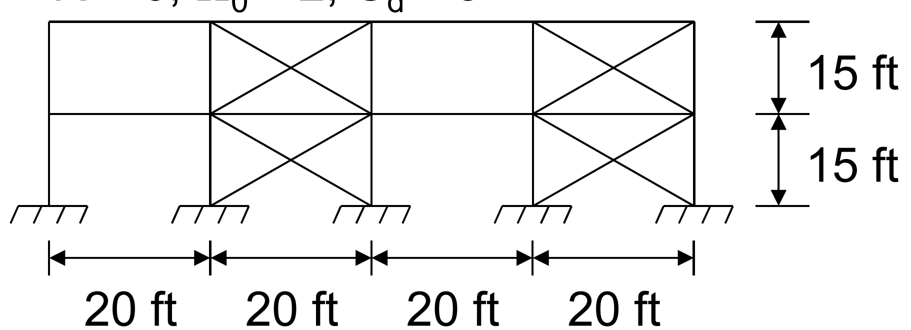
Seismic Static Force Procedures

Problem 7:

$$C_s \geq \begin{cases} 0.044 S_{DS} I_e \geq 0.01 \\ \dfrac{0.5 S_1}{(R/I_e)} \quad \text{for} \quad S_1 \geq 0.6 \end{cases}$$

$$C_s \geq \begin{cases} 0.044 S_{DS} I_e = 0.044 \geq 0.01 \quad \text{(ok)} \\ \text{NA} \end{cases}$$

$$C_s = 0.167$$



Seismic Static Force Procedures

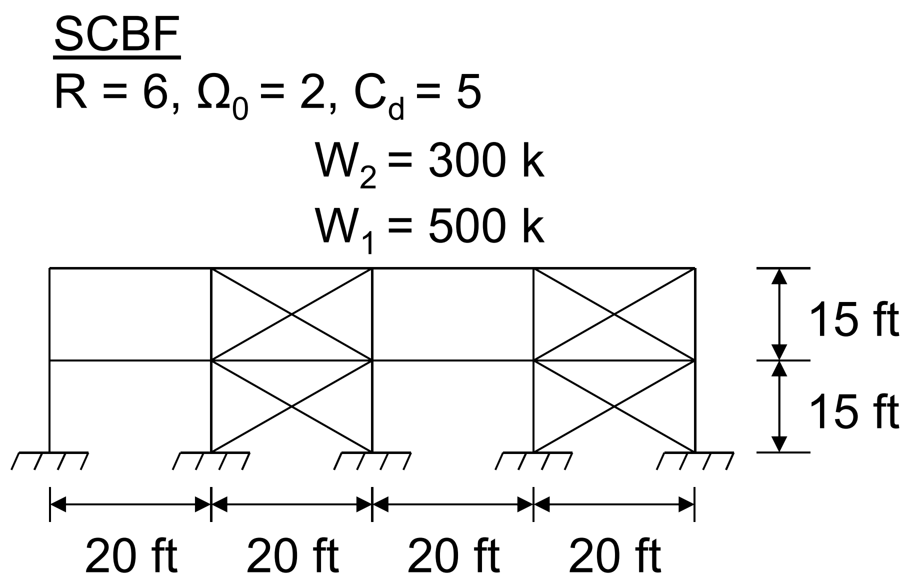
Problem 8: Using the equivalent lateral force method (Section 12.8 of ASCE 7-10), determine the base shear V for the special steel concentrically braced frame office building shown. $S_{DS} = 1.0$, $S_{D1} = 0.43$, $S_1 = 0.40$. The structure is to be located in Charleston, SC.

$$C_s = 0.167 \quad \text{(Previous problem)}$$

$$W = 300 + 500 = 800 \quad k$$

$$V = C_s W \quad (Eq.\ \ 12.8-1)$$

$$V = (0.167)(800) = 134 \quad k$$



Seismic Static Force Procedures

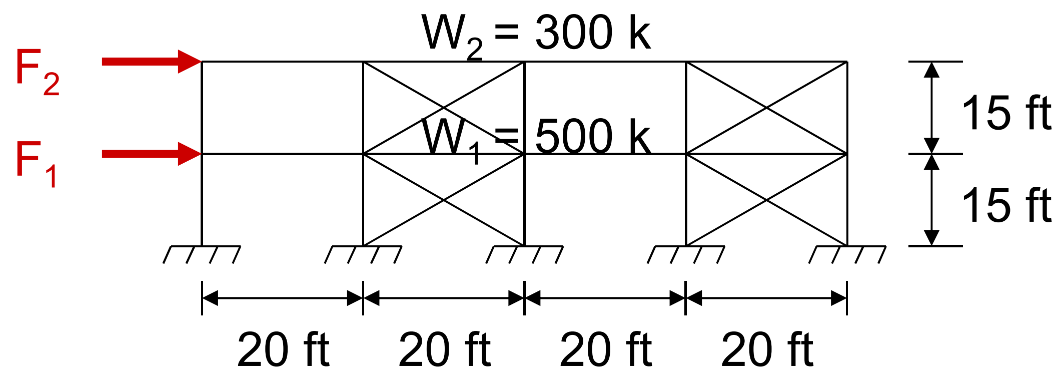
Problem 9: Using the Equivalent Lateral Force Method (Section 12.8 of ASCE 7-10), determine the vertical distribution of seismic forces for the Special Steel Concentrically Braced Frame office building shown. $S_{DS} = 1.0$, $S_{D1} = 0.43$, $S_1 = 0.40$. The structure is to be located in Charleston, SC.

$$V = 134 \quad k \quad \text{(Previous problem)}$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \quad (Eq. \ 12.8-12)$$

$$F_x = C_{vx} V \quad (Eq. \ 12.8-11)$$

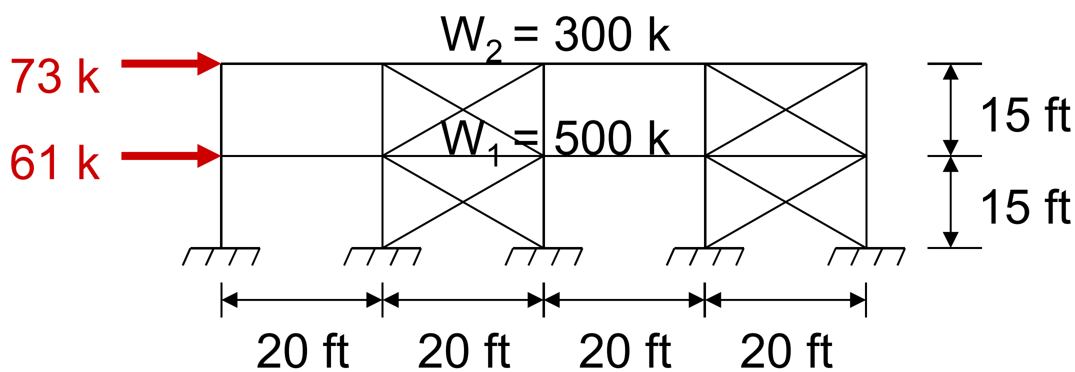
$$k = 1 \quad (T = 0.3 \ s \leq 0.5 \ s)$$



Level x	h_x (ft)	h_x^k (ft)	w_x (k)	$w_x h_x^k$ (k-ft)	C_{vx}	F_x (k)
2	30	30	300	9,000	0.545	73
1	15	15	500	7,500	0.455	61
				Σ=16,500	**1.00**	**134**

Seismic Static Force Procedures

Problem 10: Using the equivalent lateral force method (Section 12.8 of ASCE 7-10), determine the first story shear for the special steel concentrically braced frame office building shown. S_{DS} = 1.0, S_{D1} = 0.43, S_1 = 0.40. The structure is to be located in Charleston, SC.



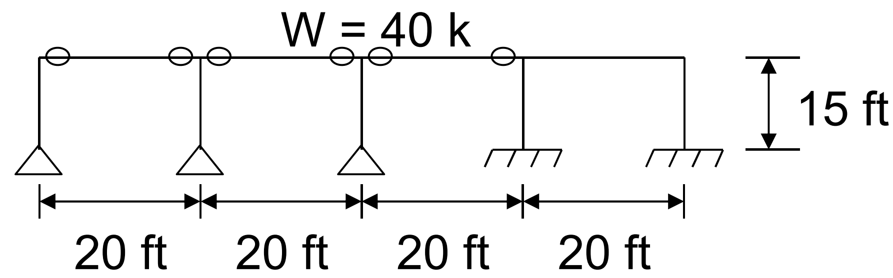
$$V = 134 \quad k \quad \text{(Previous problem)}$$

$$V_x = \sum_{i=x}^{n} F_i \quad (Eq.\ \ 12.8-13)$$

$$V_{1st\ \ floor} = 73 + 61 = 134 \quad k$$

Seismic Dynamic Force Procedures

Problem 11: Using principles of dynamics, determine the natural period of the structure shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beam is infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.



$$m_1 = \frac{W_1}{g} = \frac{40{,}000}{32.2} = 1{,}242 \quad \text{slugs}$$

$$I_{W10x45} = 248 \quad \text{in}^4$$

$$K_{free} = \frac{3EI}{h^3}; K_{fixed} = \frac{12EI}{h^3}$$

$$K_{fixed} = \frac{12(29{,}000)(248)}{(15x12)^3} = 14.8 \quad \text{k/in} \quad (\text{per column})$$

$$K_{system} = 2(14.8) = 29.6 \quad \text{k/in} = 355{,}160 \quad \text{lb/ft}$$

$$\omega_1 = \sqrt{K_{system}/m_1} = \sqrt{355{,}160/1{,}242} = 16.9 \quad \text{rad/s}$$

$$T_1 = \frac{2\pi}{\omega_1} = \frac{2\pi}{16.9} = 0.372 \quad \text{s}$$

Seismic Dynamic Force Procedures

Problem 12: Determine the stiffness matrix for the structure shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

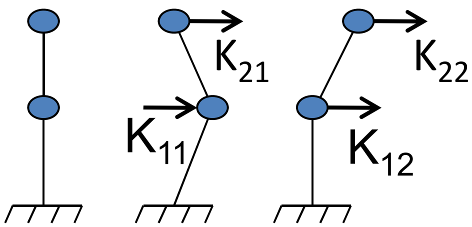
$$K_{fixed} = 14.8 \text{ k/in (per column, previous problem)}$$

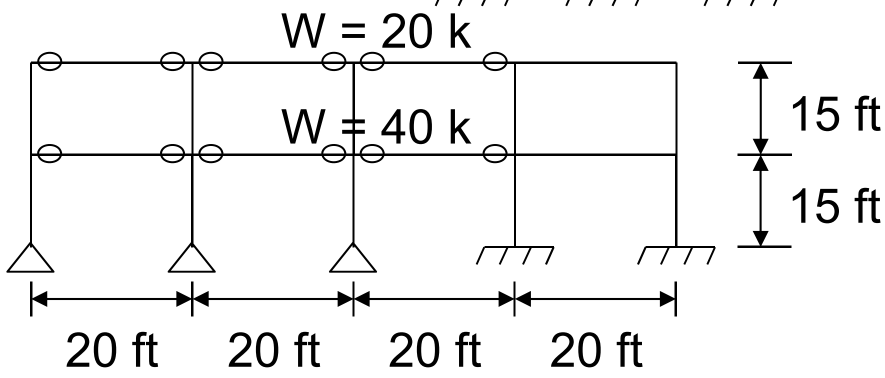
$$K_{11} = 4(14.8) = 59.2 \text{ k/in} = 710{,}400 \text{ lb/ft}$$

$$K_{22} = 2(14.8) = 29.6 \text{ k/in} = 355{,}200 \text{ lb/ft}$$

$$K_{12} = K_{21} = -355{,}200 \text{ lb/ft}$$

$$[K] = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} = \begin{bmatrix} 710{,}400 & -355{,}200 \\ -355{,}200 & 355{,}200 \end{bmatrix}$$





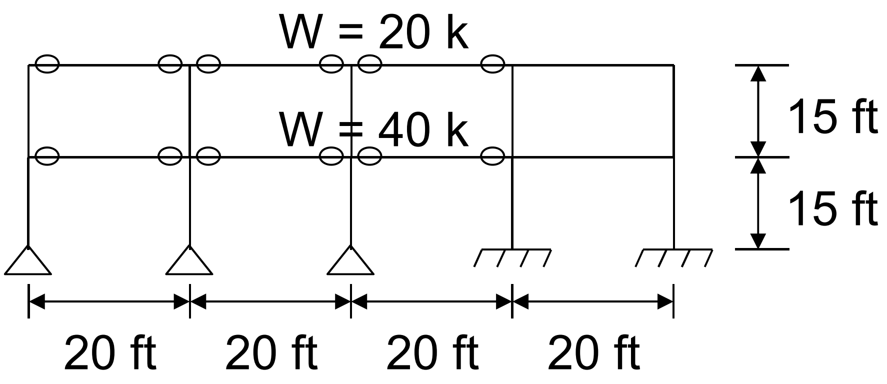
Seismic Dynamic Force Procedures

Problem 13: Determine the mass matrix for the structure shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

$$m_1 = \frac{W_1}{g} = \frac{40{,}000}{32.2} = 1{,}242 \quad \text{slugs}$$

$$m_2 = \frac{W_2}{g} = \frac{20{,}000}{32.2} = 621 \quad \text{slugs}$$

$$[M] = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} = \begin{bmatrix} 1{,}242 & 0 \\ 0 & 621 \end{bmatrix}$$



Seismic Dynamic Force Procedures

Problem 14: Determine the eigenvalue equation for the system shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

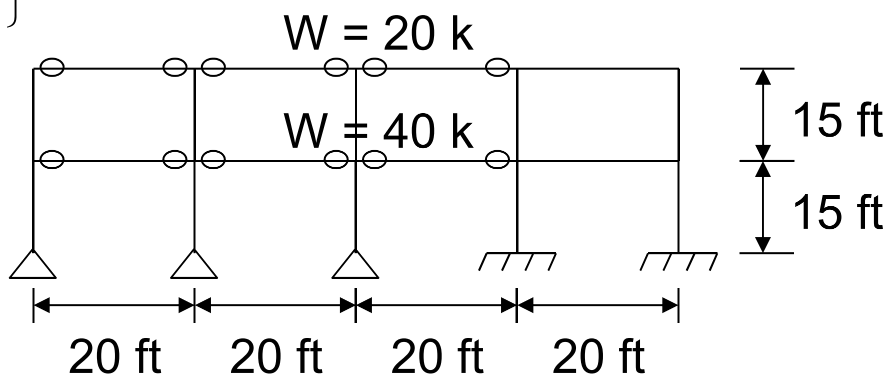
$$\{0\} = [M]\{\ddot{x}\} + [K]\{x\}$$

$$\{0\} = ([K] - \omega^2[M])\{\phi\}$$

$$\{0\} = \left(\begin{bmatrix} 710{,}400 & -355{,}200 \\ -355{,}200 & 355{,}200 \end{bmatrix} - \omega^2 \begin{bmatrix} 1{,}242 & 0 \\ 0 & 621 \end{bmatrix} \right) \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix}$$

$$[K] = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} = \begin{bmatrix} 710{,}400 & -355{,}200 \\ -355{,}200 & 355{,}200 \end{bmatrix}$$

$$[M] = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} = \begin{bmatrix} 1{,}242 & 0 \\ 0 & 621 \end{bmatrix}$$



Seismic Dynamic Force Procedures

Problem 15: Determine the natural periods for the system shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

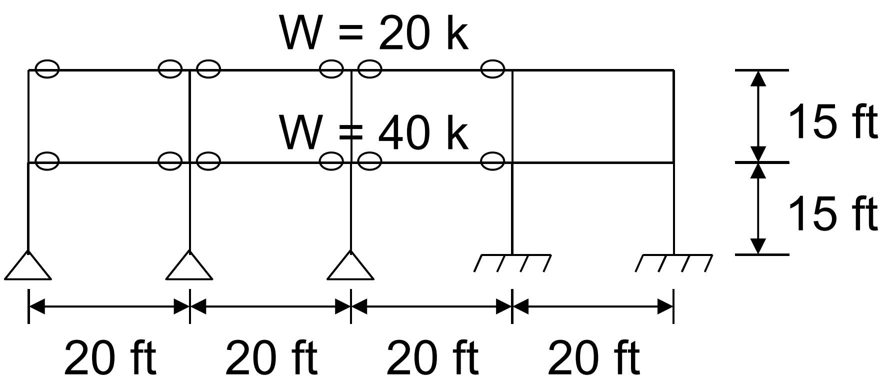
$$\{0\} = \left(\begin{bmatrix} 710{,}400 & -355{,}200 \\ -355{,}200 & 355{,}200 \end{bmatrix} - \omega^2 \begin{bmatrix} 1{,}242 & 0 \\ 0 & 621 \end{bmatrix} \right) \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix}$$

$$\begin{vmatrix} 710{,}400 - 1{,}242\omega^2 & -355{,}200 \\ -355{,}200 & 355{,}200 - 621\omega^2 \end{vmatrix} = 0$$

$$771{,}282\omega^4 - 882{,}316{,}000\omega^2 + 126{,}167{,}000{,}000 = 0$$

$$\omega_1 = 12.94 \ \text{rad/s}, \quad T_1 = \frac{2\pi}{\omega_1} = \frac{2\pi}{12.94} = 0.486 \ \text{s}$$

$$\omega_2 = 31.25 \ \text{rad/s}, \quad T_2 = \frac{2\pi}{\omega_2} = \frac{2\pi}{31.25} = 0.201 \ \text{s}$$



Seismic Dynamic Force Procedures

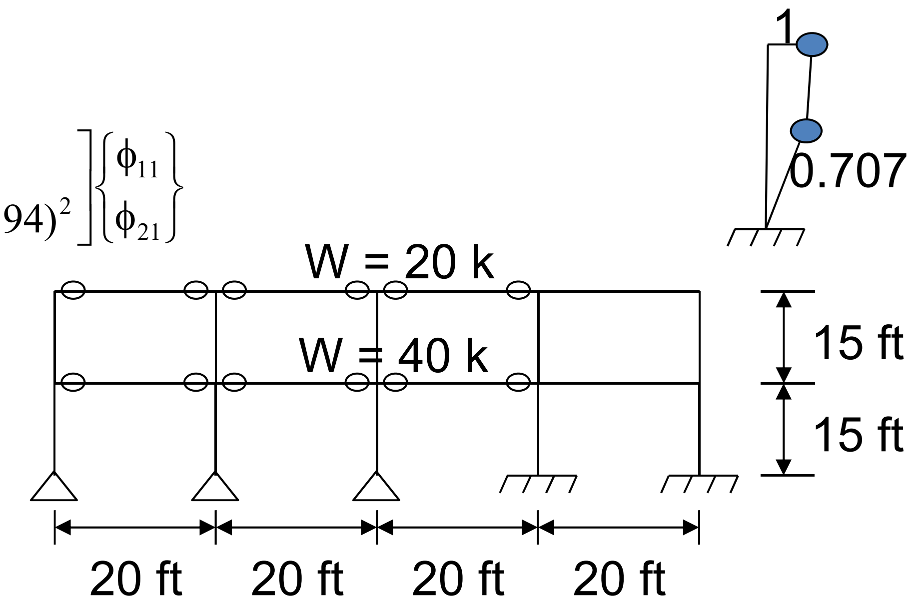
Problem 16: Determine the first mode shape for the system shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

$$\omega_1 = 12.94 \quad \text{rad/s}$$

$$\{0\} = \begin{bmatrix} 710{,}400 - 1{,}242(12.94)^2 & -355{,}200 \\ -355{,}200 & 355{,}200 - 621(12.94)^2 \end{bmatrix} \begin{Bmatrix} \phi_{11} \\ \phi_{21} \end{Bmatrix}$$

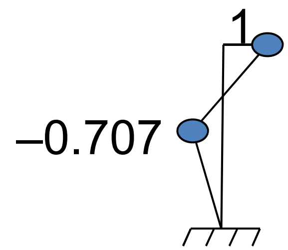
$$\{0\} = \begin{bmatrix} 502{,}440 & -355{,}200 \\ -355{,}200 & 251{,}200 \end{bmatrix} \begin{Bmatrix} \phi_{11} \\ \phi_{21} \end{Bmatrix}$$

$$\phi_{11} = 0.707\phi_{21}$$



Seismic Dynamic Force Procedures

Problem 17: Determine the second mode shape for the system shown. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

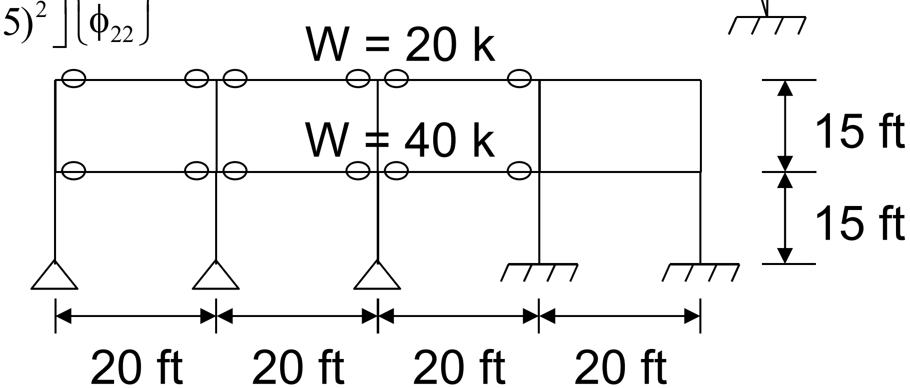


$$\omega_2 = 31.25 \quad \text{rad/s}$$

$$\{0\} = \begin{bmatrix} 710{,}400 - 1{,}242(31.25)^2 & -355{,}200 \\ -355{,}200 & 355{,}200 - 621(31.25)^2 \end{bmatrix} \begin{Bmatrix} \phi_{12} \\ \phi_{22} \end{Bmatrix}$$

$$\{0\} = \begin{bmatrix} -502{,}500 & -355{,}200 \\ -355{,}200 & -251{,}200 \end{bmatrix} \begin{Bmatrix} \phi_{12} \\ \phi_{22} \end{Bmatrix}$$

$$\phi_{12} = -0.707\phi_{22}$$

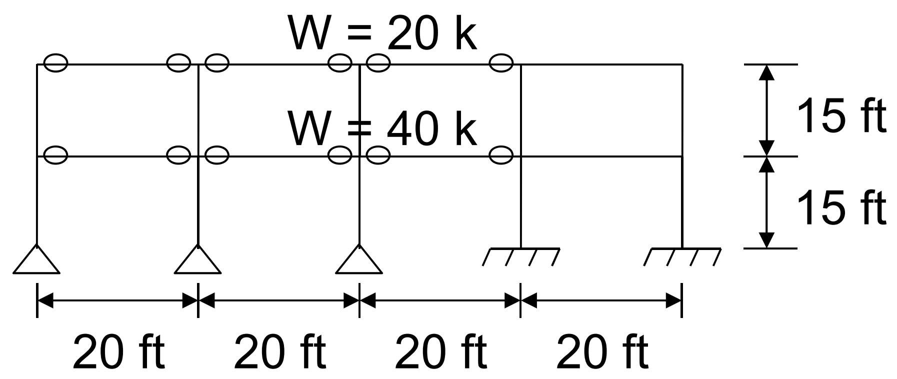


Seismic Dynamic Force Procedures

Problem 18: Determine the percent mass participation for the first two modes of response. All columns are W10×45. All beams and columns are oriented for strong axis bending in the plane of the figure. Also, assume that the moment frame beams are infinitely stiff (i.e., $I_x = \infty$) so that columns respond as fixed-fixed columns.

$$\omega_1 = 12.94 \quad rad/s, \quad \varphi_{11} = 0.707\varphi_{21}$$

$$\omega_2 = 31.25 \quad rad/s, \quad \varphi_{12} = -0.707\varphi_{22}$$



Seismic Dynamic Force Procedures

Problem 18:

$$P_1 = \frac{\sum w_{i1}\phi_{i1}}{\sum w_{i1}\phi_{i1}^2} = \frac{(20)(1)+(40)(0.707)}{(20)(1)^2+(40)(0.707)^2} = 1.207$$

$$W_1 = P_1 \sum w_{i1}\phi_{i1} = 1.207[(20)(1)+(40)(0.707)] = 58.27 \quad \text{k}$$

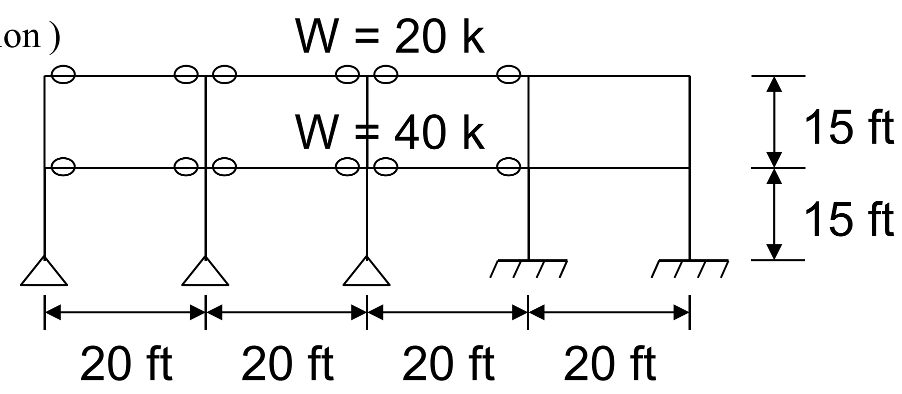
$$P_2 = \frac{\sum w_{i2}\phi_{i2}}{\sum w_{i2}\phi_{i2}^2} = \frac{(20)(1)+(40)(-0.707)}{(20)(1)^2+(40)(-0.707)^2} = -0.207$$

$$W_2 = P_2 \sum w_{i2}\phi_{i2} = -0.207[(20)(1)+(40)(-0.707)] = 1.71 \quad \text{k}$$

$$W_1 + W_2 = 58.27 + 1.71 \approx 60 \quad \text{k} \quad (\approx 100\% \quad \text{participation})$$

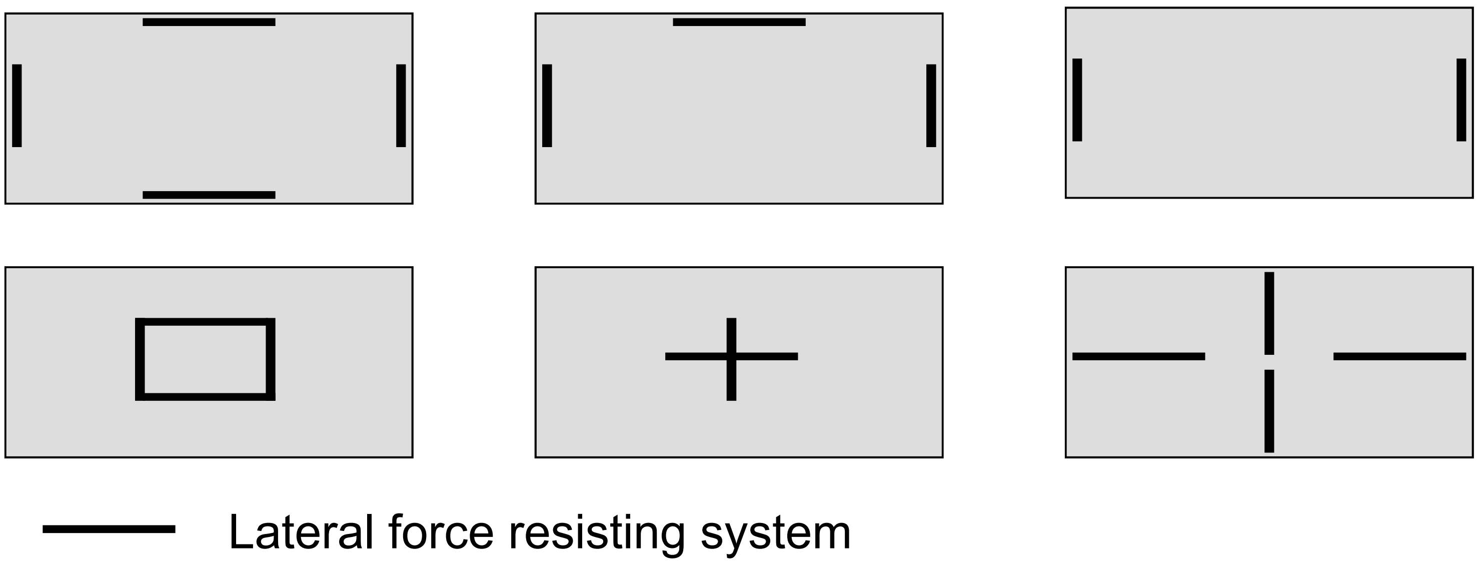
$$\omega_1 = 12.94 \quad \text{rad/s}, \quad \phi_{11} = 0.707\,\phi_{21}$$

$$\omega_2 = 31.25 \quad \text{rad/s}, \quad \phi_{12} = -0.707\phi_{22}$$



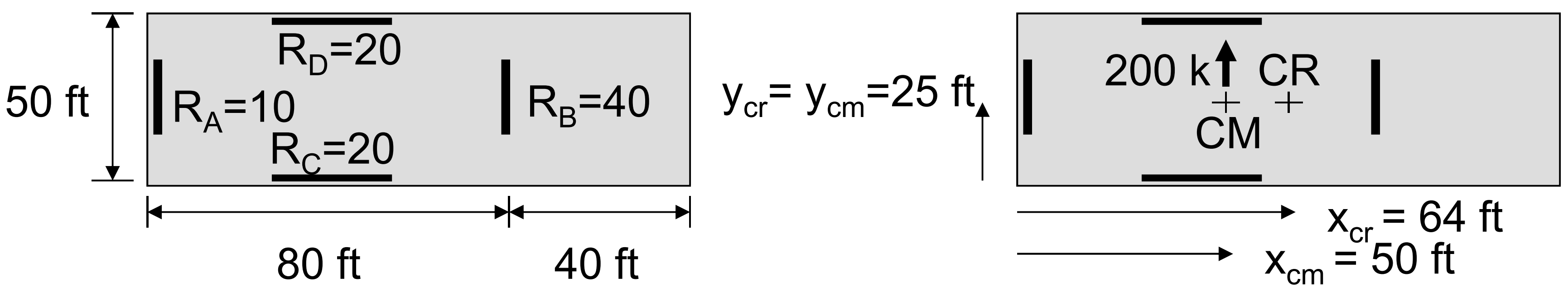
Configuration of Structural Systems

Problem 19: For the various plan view layouts of lateral force resisting systems shown, discuss the pros and cons as related to their ability to resist horizontal torsional moments. Assume rigid diaphragms.



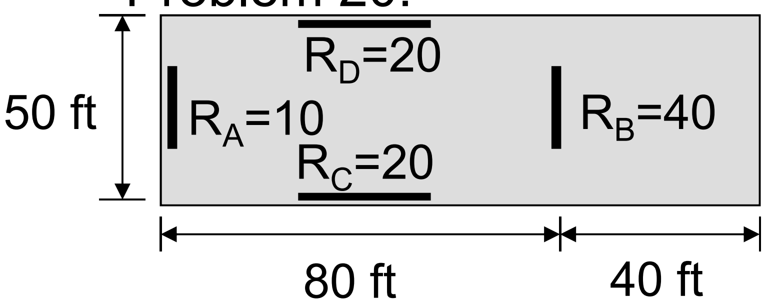
Relative Rigidity Force Distribution

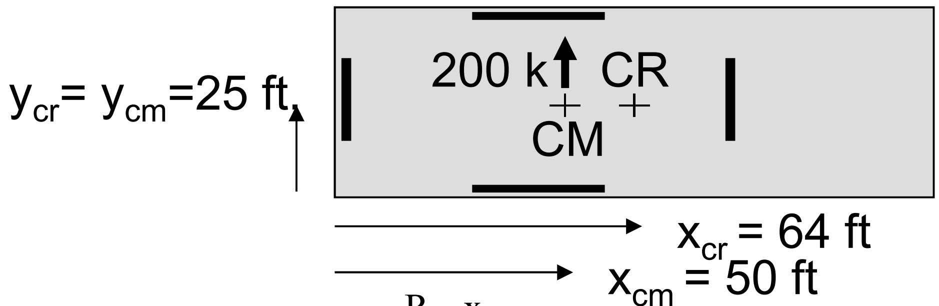
Problem 20: For the building plan view shown below and a total seismic force, V = 200 kips, applied at the center of mass CM, determine the shear force in walls A and B. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Neglect accidental eccentricity. Assume a rigid diaphragm.



Relative Rigidity Force Distribution

Problem 20:





$$J = 76{,}200 \quad k-ft \quad \text{(Previous problem)}$$

$$e_x = 64 - 50 = 14 \quad ft$$

$$V_{D,i,y} = V_y \frac{R_{i,y}}{\sum R_{i,y}}$$

$$V_{D,A} = 200 \frac{10}{10+40} = 40 \quad k \quad \downarrow$$

$$V_{D,B} = 200 \frac{40}{10+40} = 160 \quad k \quad \downarrow$$

$$V_{T,i,y} = Ve \frac{R_{i,y} x_{cr,i}}{J}$$

$$V_{T,A} = 200(14)\frac{10(-64)}{76{,}200} = -23.5 \quad \text{or} \quad 23.5 \quad k \quad \downarrow$$

$$V_{T,B} = 200(14)\frac{40(16)}{76{,}200} = 23.5 \quad k \quad \uparrow$$

$$V_A = 40 + 23.5 = 63.5 \quad k \quad \downarrow$$

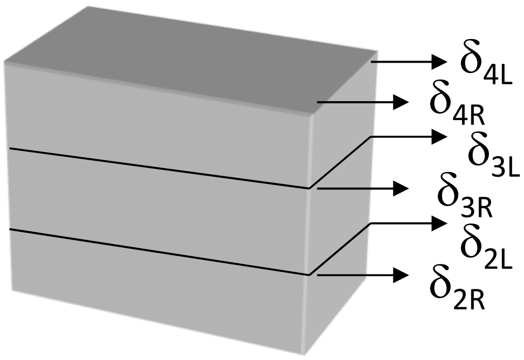
$$V_B = 160 - 23.5 = 136.5 \quad k \quad \downarrow$$

Horizontal and Vertical Irregularities

Problem 21: Define horizontal irregularity Type 1a and 1b and discuss the implications of these irregularities on analysis and design provisions.

1a: maximum story drift (including accidental torsion) at one end of the structure exceeds 1.2 (or 1.4 for 1b) times the average of the story drift at both ends of the structure

- Analysis and design implications (see Table 12.3-1 of ASCE 7-10):
  - Increase forces 25% (connections to diaphragms, collectors)
  - 1b not permitted for SDC E or F
  - 3D model required
  - A_x required to amplify M_{ta}
  - Story drift measured at edge with max displacement
  - Dynamic analysis may be required

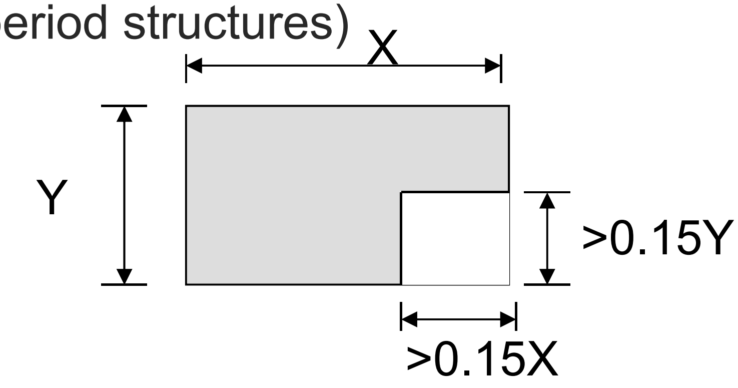


Horizontal and Vertical Irregularities

Problem 22: Define horizontal irregularity Type 2 and discuss the implications of this irregularity on analysis and design provisions.

2: both plan projections of the reentrant corner exceed 15% of total plan dimension of the structure in the given direction

- Analysis and design implications (see Table 12.3-1 of ASCE 7-10):
  - Increase forces 25% (connections to diaphragms, collectors)
  - Dynamic analysis may be required (longer period structures)

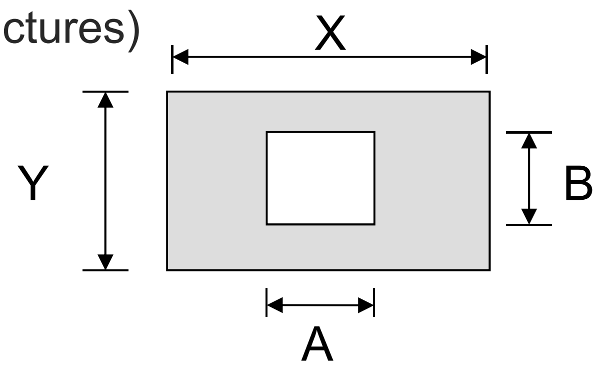


Horizontal and Vertical Irregularities

Problem 23: Define horizontal irregularity Type 3 and discuss the implications of this irregularity on analysis and design provisions.

3: the diaphragm is discontinuous as defined by an opening exceeding 50% of the gross diaphragm area or changes in diaphragm stiffness by more than 50% as compared to adjacent diaphragms

- Analysis and design implications (see Table 12.3-1 of ASCE 7-10):
  - Increase forces 25% (connections to diaphragms, collectors)
  - Dynamic analysis may be required (longer period structures)

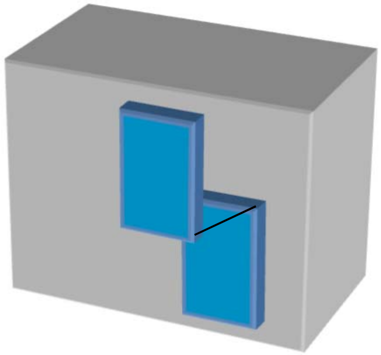


Horizontal and Vertical Irregularities

Problem 24: Define horizontal irregularity Type 4 and discuss the implications of this irregularity on analysis and design provisions.

4: the lateral force resisting system's vertical elements have out-of-plane offsets

- Analysis and design implications (see Table 12.3-1 of ASCE 7-10):
  - Increase forces 25% (connections to diaphragms, collectors)
  - Elements supporting discontinuous system designed with Ω_0
  - 3D model required
  - Dynamic analysis may be required (longer period structures)

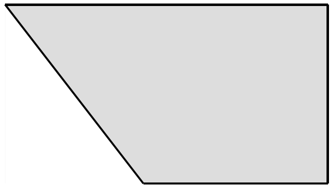


Horizontal and Vertical Irregularities

Problem 25: Define horizontal irregularity Type 5 and discuss the implications of this irregularity on analysis and design provisions.

5: the lateral force resisting system's vertical elements are not parallel to the major orthogonal axes

- Analysis and design implications (see Table 12.3-1 of ASCE 7-10):
  - Orthogonal combination required
  - 3D model required
  - Dynamic analysis may be required (longer period structures)



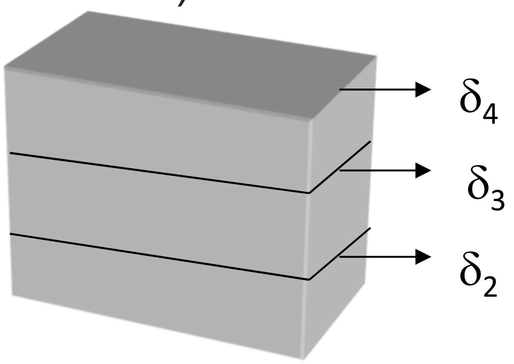
Horizontal and Vertical Irregularities

Problem 26: Define vertical irregularity Type 1a and 1b and discuss the implications of these irregularities on analysis and design provisions.

1a: story stiffness is less than 70% of the story above or 80% of the average of three stories above

1b: story stiffness is less than 60% of the story above or 70% of the average of three stories above

- Analysis and design implications (see Table 12.3-2 of ASCE 7-10):
  - 1b not permitted for SDC E or F
  - Dynamic analysis may be required
  - Does not apply to one story buildings
  - Does not apply to two story buildings (SDC B, C, D)

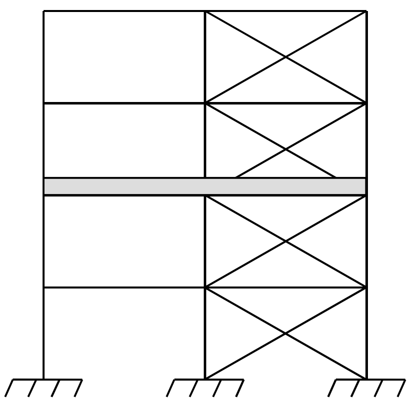


Horizontal and Vertical Irregularities

Problem 27: Define vertical irregularity Type 2 and discuss the implications of this irregularity on analysis and design provisions.

2: excluding lighter roofs, the effective mass of a story exceeds 150% of the effective mass of an adjacent story

- Analysis and design implications (see Table 12.3-2 of ASCE 7-10):
  - Dynamic analysis may be required
  - Does not apply to one story buildings
  - Does not apply to two story buildings (SDC B, C, D)

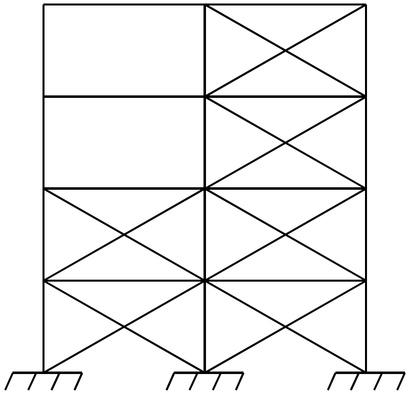


Horizontal and Vertical Irregularities

Problem 28: Define vertical irregularity Type 3 and discuss the implications of this irregularity on analysis and design provisions.

3: horizontal dimension of the lateral force resisting system in any story is more than 130% of that in an adjacent story

- Analysis and design implications (see Table 12.3-2 of ASCE 7-10):
  - Dynamic analysis may be required

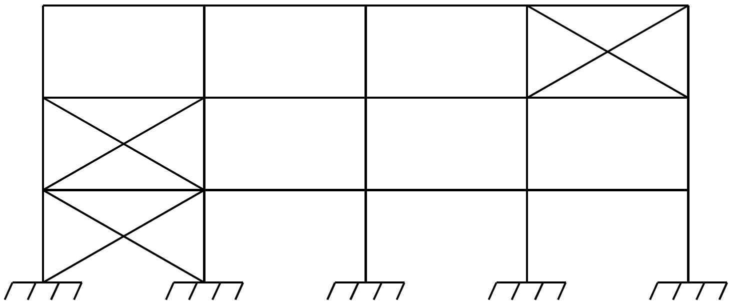


Horizontal and Vertical Irregularities

Problem 29: Define vertical irregularity Type 4 and discuss the implications of this irregularity on analysis and design provisions.

4: the in-plane offset of the lateral force resisting system exceeds the length of the elements

- Analysis and design implications (see Table 12.3-2 of ASCE 7-10):
  - Increase forces 25% (connections to diaphragms, collectors)
  - Elements supporting discontinuous system designed with Ω_0
  - Dynamic analysis may be required (longer period structures)

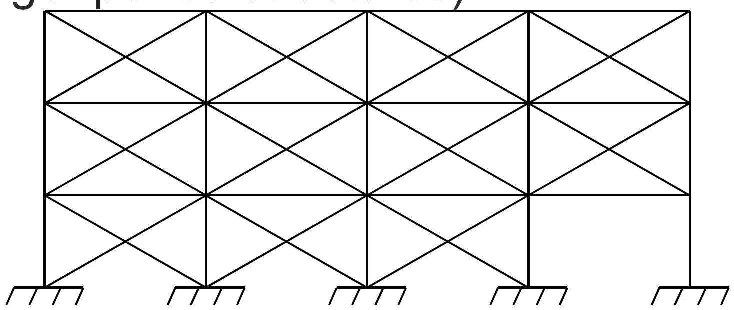


Horizontal and Vertical Irregularities

Problem 30: Define vertical irregularities Type 5a and 5b and discuss the implications of these irregularities on analysis and design provisions.

5a: the lateral strength of any story is less than 80 percent (65 percent for 5b) of the strength above

- Analysis and design implications (see Table 12.3-2 of ASCE 7-10):
  - 5a not permitted for SDC E or F, 5b not permitted for SDC D, E, or F
  - 5b has a two story and 30-foot height limit unless designed with Ω_0
  - Dynamic analysis may be required (longer period structures)



Diaphragms, Chords, and Collectors

- ASCE 7-10 references
  - Section 12.3.1 – Semirigid unless below conditions apply
  - Section 12.3.1.1 – Flexible diaphragm: Untopped steel deck or wood panel diaphragms with vertical elements consisting of steel or composite steel and concrete braced frames, or concrete, masonry, steel, or composite shear walls.
  - Section 12.3.1.2 – Rigid diaphragm: Concrete slabs or concrete slabs on metal decking with span-to-depth ratios of three or less in structures with no horizontal irregularities.
  - Section 12.3.1.3 – Calculated flexible diaphragm: Computed maximum in-plane deflection of the diaphragm is more than two times the average story drift of adjoining vertical elements of the seismic-force-resisting system. Loads shall be from the equivalent lateral force method of Section 12.8.

Diaphragms, Chords, and Collectors

- ASCE 7-10 references
  - Section 12.10.1 – Design diaphragms for shear and bending stresses resulting from design forces. For openings and reentrant corners, design localized chord forces in combination with other diaphragm forces.
  - Section 12.10.1.1 – Design diaphragms for seismic forces from structural model, but not less than:

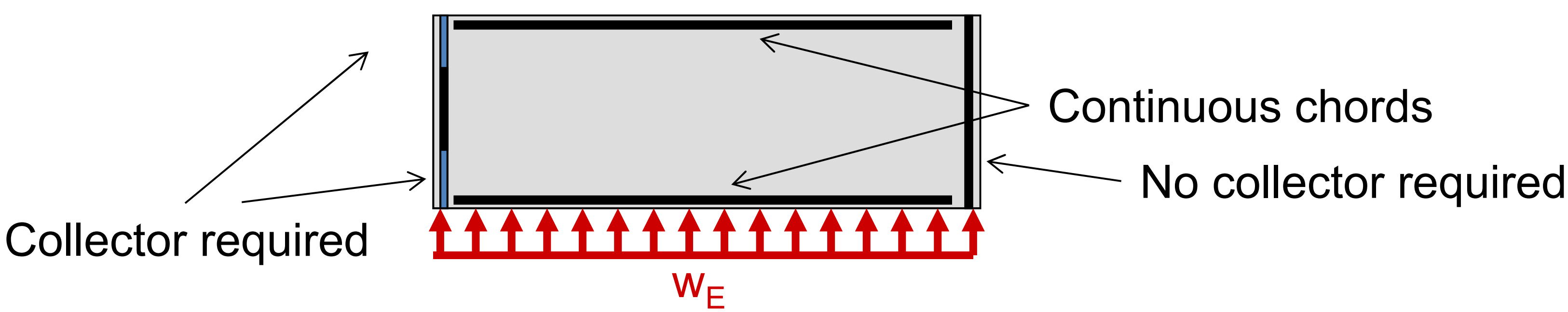
$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px} \quad (Eq.\ \ 12.10-1)$$

$$F_{px,\min} = 0.2 S_{DS} I w_{px}, \quad F_{px,\max} = 0.4 S_{DS} I w_{px}$$

  - Out-of-plane offset – add forces to force determined above

Diaphragms, Chords, and Collectors

- ASCE 7-10 references
  - Section 12.10.2 – Collectors are required.
  - Section 12.10.2.1 – In SDCs C, D, E, and F, design collectors, splices, and their connections to resisting elements to account for maximum expected (and realistic) forces => includes Ω_0 but limited by $F_{px,max}$ without Ω_0



Diaphragms, Chords, and Collectors

- ASCE 7-10 references
  - Section 12.12.2 – Deflection of the diaphragm must not exceed the allowable deflection of the elements attached to the diaphragm.
  - Section 12.3.3.4 – Design forces must be increased by 25% for the design of diaphragm connections to the vertical LLRS and to collectors and the connection between collectors and vertical elements if the structure has horizontal irregularities Type 1a, 1b, 2, 3 or 4 as listed in Table 12.3-1 or vertical irregularity Type 4 in Table 12.3-2. (SDCs D, E, and F only)
  - Section 12.11.2.2.1 – Requires continuous ties or struts between diaphragm chords in order to distribute anchorage forces into the diaphragm. (SDCs C, D, E, and F only)

Diaphragms, Chords, and Collectors

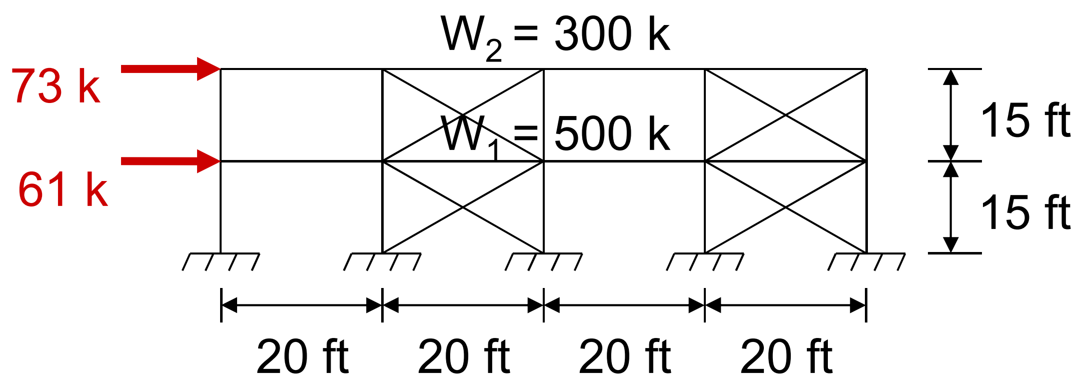
Problem 31: Determine the diaphragm design forces (seismic) for the building shown. Lateral forces shown were determined using the equivalent lateral force method. S_{DS} = 1.0, I = 1.0, and V = 134 k.

$$V = 73 + 61 = 134 \text{ k (Given)}$$

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

$$F_{px,min} = 0.2 S_{DS} I w_{px}$$

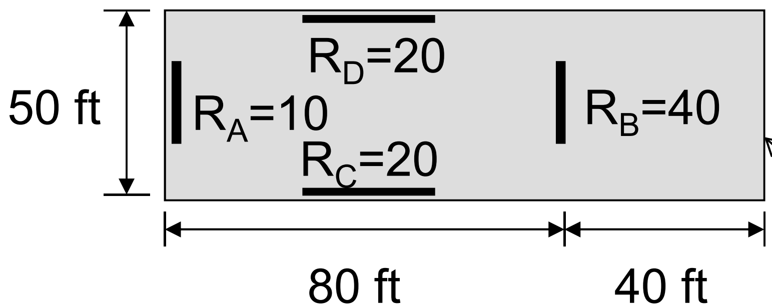
$$F_{px,max} = 0.4 S_{DS} I w_{px}$$

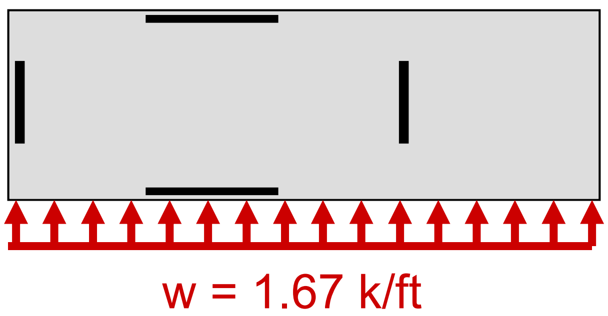


Level x	h_x (ft.)	w_x (k)	F_x (k) (Given)	F_{px} (k)	$F_{px,min}$ (k)	$F_{px,max}$ (k)
2	30	300	73	73	60	120
1	15	500	61	84	100	200
			134			

Diaphragms, Chords, and Collectors

Problem 32: For the building plan view shown below and a total lateral force V = 200 kips distributed across the building as shown, determine the shear force in walls A and B. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Assume a flexible diaphragm.





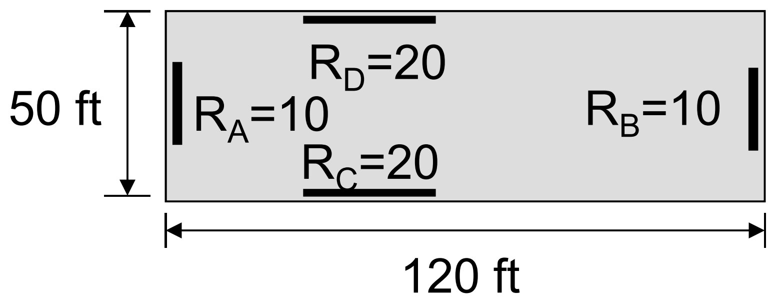
$$V_A = 1.67(40) = 66.7 \quad k \downarrow$$

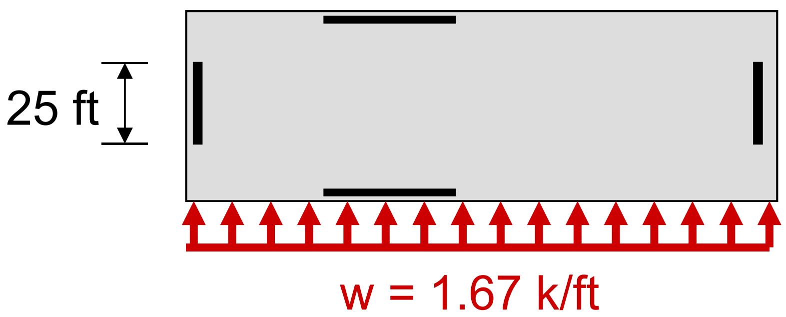
Moment frame?

$$V_B = 1.67(80) = 133 \quad k \downarrow$$

Diaphragms, Chords, and Collectors

Problem 33: For the building plan view shown below and a total force V = 200 kips distributed across the building as shown, determine the shear force (k/ft) in the diaphragm at wall A. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Assume a flexible diaphragm.

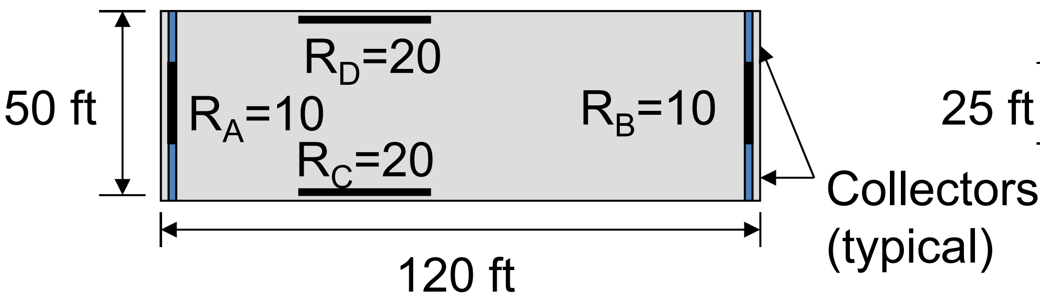


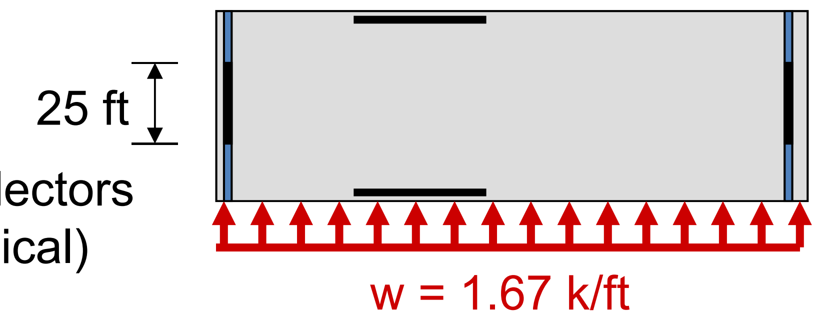


$$V_A = \frac{1.67(120)}{(2)25} = 4 \quad k/ft$$

Diaphragms, Chords, and Collectors

Problem 34: For the building plan view shown below and a total force V = 200 kips distributed across the building as shown, determine the shear force (k/ft) in the diaphragm at wall A. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Assume a flexible diaphragm.

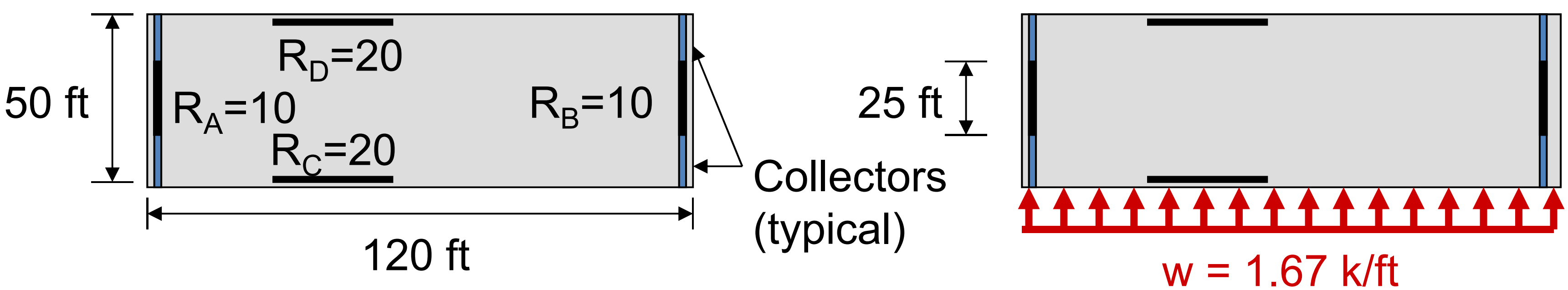




$$V_A = \frac{1.67(120)}{(2)50} = 2 \quad k/ft$$

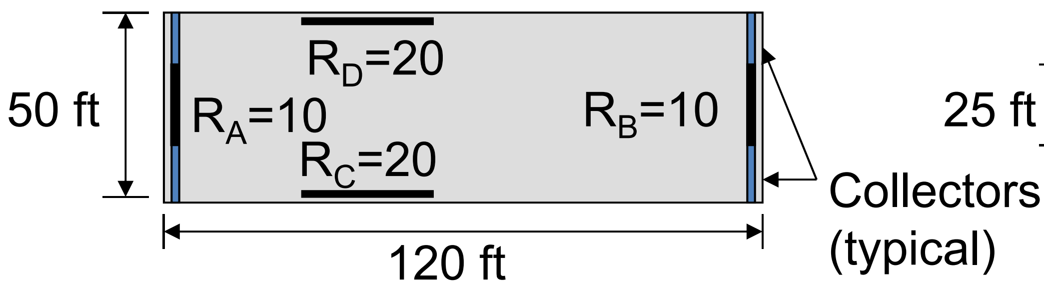
Diaphragms, Chords, and Collectors

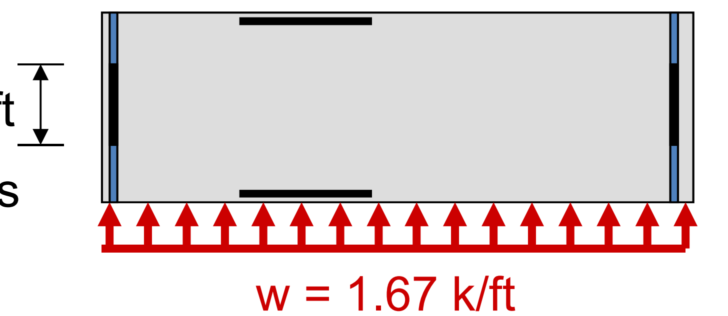
Problem 35: For the building plan view shown below and a total force V = 200 kips distributed across the building as shown, determine the maximum axial force (k) in the collector associated with wall A. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Assume a flexible diaphragm.



Diaphragms, Chords, and Collectors

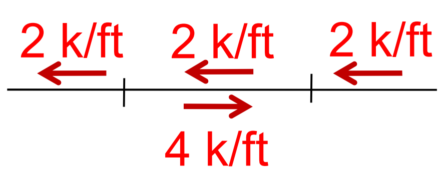
Problem 35:

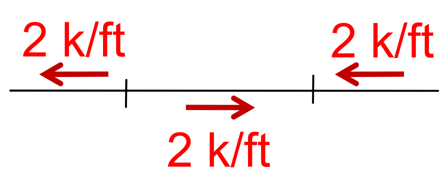


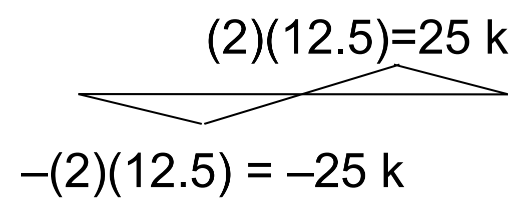


$$V_{A,diaphragm} = 2 \ \ k/ft \ \ \text{(previous problem)}$$

$$V_{A,wall} = 4 \ \ k/ft \ \ \text{(previous problem)}$$

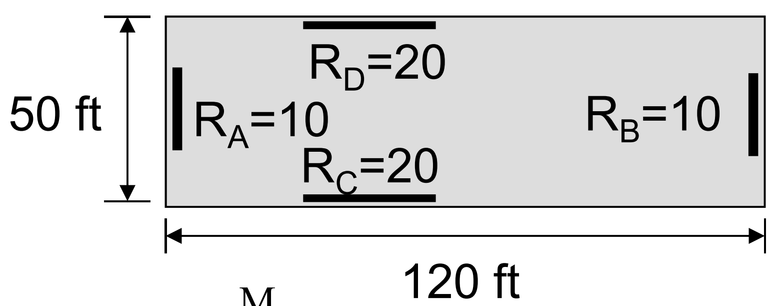


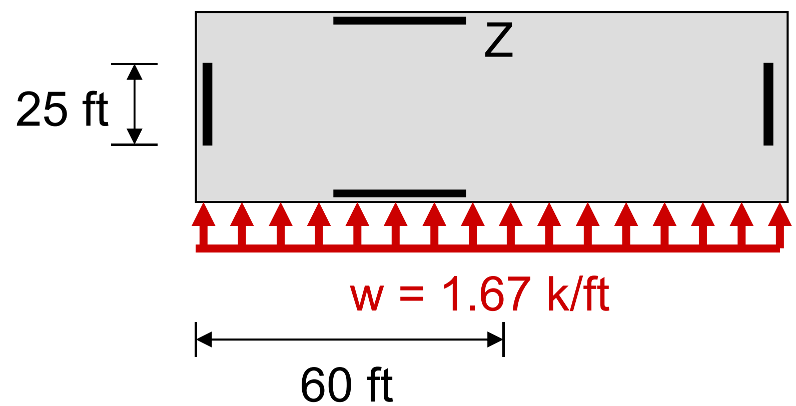




Diaphragms, Chords, and Collectors

Problem 36: For the building plan view shown below and a total force V = 200 kips distributed across the building as shown, determine the maximum chord force (k) in the diaphragm at Z. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Assume a flexible diaphragm.





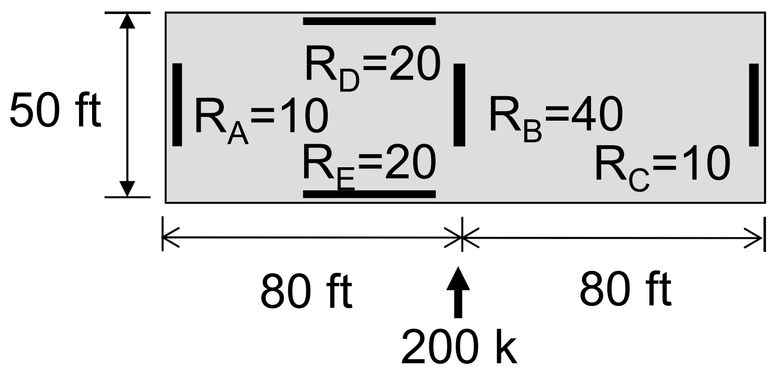
$$F_{chord} = \frac{M_{diaphragm}}{d_{diaphragm}}$$

$$M_{diaphragm} = \frac{1.67(120^2)}{8} = 3{,}000 \quad k-ft$$

$$F_{chord} = \frac{3{,}000}{50} = 60 \quad k \quad (tension)$$

Diaphragms, Chords, and Collectors

Problem 37: For the building plan view shown below and a total force V = 200 kips applied at the center of mass, determine the shear force (k) in walls A and B. Wall rigidities (stiffnesses) shown in the figure are in kips/ft. Neglect accidental eccentricity. Assume a rigid diaphragm.



$$V_A = \frac{200(10)}{(10+40+10)} = 33.3 \quad k$$

$$V_B = \frac{200(40)}{(10+40+10)} = 133.3 \quad k$$

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)

<u>or</u>

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

Recommended References and Additional Study Materials

- Structural: Sample Questions and 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 Diaphragms, Chords, and Collectors (Prasad et al., ICC, 2009)
- Structural Engineering: PE License Review Problems and Solutions (Williams, ICC, 2008)