DIAPHRAGMS

June 12, 2018

DESIGN AND DETAILING OF LOW-RISE REINFORCED CONCRETE BUILDINGS
Objectives

Analysis methods

Design and detailing requirements for shear, chord, and shear transfer reinforcement

Design and detailing of collectors
References

- Design and Detailing of Low-Rise Reinforced Concrete Buildings, CRSI, 2017
Chapters

1. Introduction
2. Reinforced Concrete Building Systems
3. Design and Detailing Requirements for SDC A and B
4. Design and Detailing Requirements for SDC C
5. Design and Detailing Requirements for SDC D, E, and F
Chapters

1. Introduction
2. Reinforced Concrete Building Systems
3. Design and Detailing Requirements for SDC A and B
4. Design and Detailing Requirements for SDC C
5. Design and Detailing Requirements for SDC D, E, and F
Appendices

A. Reinforcing Bar Data
B. Design Aids for Torsion
C. Cross-sectional Constant $C$ for Two-way Slab Systems and Edge Beams
D. Critical Section Properties for Square Columns
E. Design Strength Interaction Diagrams for Square Columns
F. Design Strength Interaction Diagrams for Reinforced Concrete Walls
References


www.crsi.org
References

• *Building Code Requirements for Structural Concrete, ACI 318-14, 2014*
Definition of Low-Rise Building

• No more than 6 stories above grade
• Height no more than 72 ft
• Fundamental period less than or equal to 0.5 sec
Analysis Methods
Diaphragms

- Diaphragm in-plane forces
- Diaphragm transfer forces
- Connection forces between diaphragm and vertical elements of the LFRS
- Forces from bracing vertical or sloped building elements
- Diaphragm out-of-plane forces
Diaphragms

• ACI 12.3

• Thickness
  • Must satisfy all applicable strength and serviceability requirements
Design Forces

- Wind
- ASCE/SEI Chapters 26 – 30

Figure 2.24 – Propagation of wind forces in a low-rise reinforced concrete building.
Design Forces

• Seismic
  • ASCE/SEI 12.10.1.1

\[ F_{px} = \left( \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} \right) w_{px} \]

\[ \geq 0.2 S_{DS} I_e w_{px} \]

\[ \leq 0.4 S_{DS} I_e w_{px} \]
Design Forces

• Transfer

Diaphragm force

Reinforced concrete shear wall (typ.)

Transfer force

Reinforced concrete basement wall (typ.)
Design Forces

- Connection

Diagram:
- Precast concrete wall panel
- Connector assembly
- Reinforced concrete slab
- C&C wind pressure
- Slab reinforcement not shown for clarity
- Wind connector force
Design Forces

• Soil
• Flood and tsunami
• Column bracing
Analysis Methods

- ACI 12.4.2.4

- Rigid diaphragm model
- Flexible diaphragm model
- Bounding analysis
- FEM
- Strut-and-tie model
Classifications

- Rigid
- Flexible
- Semi-rigid (-flexible)
Classifications

Rigid Diaphragm

Flexible Diaphragm
Diaphragm Rigidity

• Rigid diaphragms

• Wind loads
  • ASCE/SEI 26.2
  • Concrete slabs with span/depth \( \leq 2 \)

• Earthquake loads
  • ASCE/SEI 12.3.1.2
  • Concrete slabs with span/depth \( \leq 3 \) and no horizontal irregularities in accordance with ASCE/SEI 12.3.2.1
Diaphragm Rigidity

- Flexible diaphragms

**FIGURE 12.3-1 Flexible Diaphragm**

Note: Diaphragm is flexible if $MDD > 2(ADVE)$. 
Diaphragm Rigidity

- Reinforced concrete roof and floor systems
  - Rigid diaphragms
  - Lateral forces are transferred to the elements of the LFRS based on the stiffness of those elements
Force Distribution

Chord force (typ.)

Structural wall
(collector elements not required)

Uniform shear distribution

Lateral force, $V$

Collector element

Structural wall

$V_1$

$V_2$

$T_u$

$C_u$
Rigid Diaphragm Model

\[ k_i = \frac{R_i}{\delta_i} \]
Rigid Diaphragm Model

- Reactions in Walls A, B, and C determined from analysis

\[ \delta_i = \delta_{Fi} + \delta_{Vi} \]
Rigid Diaphragm Model

- Equivalent distributed load

\[
\begin{align*}
\frac{(w_1 + w_2)(\ell_1 + \ell_2 + \ell_3)}{2} &= R_A + R_B + R_C = V \\
\frac{(w_1 + w_2)(\ell_1 + \ell_2 + \ell_3)^2}{3} &= R_A \ell_1 + R_B (\ell_1 + \ell_2) + R_C (\ell_1 + \ell_2 + \ell_3)
\end{align*}
\]
Rigid Diaphragm Model

- Shear and moment diagrams
Rigid Diaphragm Model

- Design shear strength of the diaphragm
- Connections of the diaphragm to the vertical elements of the LFRS
- Axial compressive and tensile forces in the collectors, if any
Rigid Diaphragm Model

- Moment diagram

Chord force (typ.)

\[ L \\
\]

\[ C_u = T_u = \frac{M_{u,max}}{0.95L} \]
Rigid Diaphragm Model

Uniformly distributed chord reinforcement developed outside of reinforcement zone

Zones for placement of chord reinforcement

Structural framing and other reinforcement not shown for clarity

Lateral force
Large Openings

Figure 3.100 – Force distribution in a diaphragm with an opening.
Large Openings

Figure 3.101 – Diaphragm in Figure 3.99 with a large opening.
Large Openings

• Seismic forces

\[ C_{u,1} = T_{u,1} = \frac{M_{u,t}}{0.95L_1} \]
Large Openings

• Seismic forces

\[ M_{u,b,\ell_4} = M_{u,b,L} - M_{u,b,R} \]

\[ w_{b,L} = \left( \frac{A_2}{A_1 + A_2} \right) w_L \]

\[ w_{b,R} = \left( \frac{A_2}{A_1 + A_2} \right) w_R \]

\[ C_{u,2} = T_{u,2} = \frac{M_{u,b}^+}{0.95L_2} \]
Large Openings

- Wind forces

\[
C_{u,1} = T_{u,1} = \frac{M_{u,t}}{0.95L_1}
\]
Large Openings

• Wind forces

\[ C_{u,2} = T_{u,2} = \frac{M_{u, b}^+}{0.95L_2} \]
Large Openings

• Total tensile chord force along edge of diaphragm

• Total tensile chord force is obtained by adding the secondary tensile chord force to the primary tensile chord force

• Primary tensile chord force at location of opening:

\[ T_u = \frac{M_u}{d} = \frac{M_u}{0.95L} \]

• Secondary tensile chord force:

\[ T_{u,1} = \frac{M_{u,t}}{d} = \frac{M_{u,t}}{0.95L_1} \]
Large Openings

- Total tensile chord force along edge of diaphragm

\[
T_{u,1} = \frac{M_{u,t}^+}{0.95L_1} \quad \text{and} \quad T_u = \frac{M_u}{0.95L}
\]
Large Openings

• Tensile chord reinforcement is to be provided based on the larger of the following:
  
  • Primary tensile chord force obtained from the maximum overall moment:
    \[ T_u = \frac{M_{u,max}}{0.95L} \]
  
  • Summation of the primary tensile chord force at the location of the opening plus the secondary tensile chord force at the opening:
    \[ T_u + T_{u,1} = \frac{M_u}{0.95L} + \frac{M_{u,t}}{0.95L_1} \]
Large Openings

- Tensile chord reinforcement

- For openings that are not centered in the diaphragm
  - Conservative to provide tensile chord reinforcement over the entire length of the diaphragm edge based on a total tensile chord force equal to the following:

\[
\frac{M_{u,\text{max}}}{0.95L} + \frac{M_{u,t}}{0.95L_1}
\]
Large Openings

- Tensile chord reinforcement
Large Openings

- Secondary tensile chord forces at corners of openings

\[ T_{u,2} = \frac{M_{u,b,R}^-}{(0.95L_2)} \]
Analysis Requirements

- Analysis must be performed for forces acting in the opposite direction as shown.
- Larger area of reinforcement determined from both analyses is provided along the edges of the diaphragm and openings, if any, for simpler detailing.
- Analyses required for forces acting in the perpendicular direction of analysis.
Shear, Chord, and Shear Transfer Reinforcement
Shear Strength Requirements

\[ \nu_{u,\text{max}} = \frac{V_{u,\text{max}}}{L} \]
\[ \phi V_n = \phi A_{cv} \left( 2\lambda \sqrt{f'_c} + \rho_t f_y \right) \]

- \( A_{cv} \) = gross area of diaphragm
- \( \rho_t \) = distributed reinforcement oriented in the direction of analysis
- \( \phi = 0.75 \) for buildings assigned to SDC A, B, or C that do not utilize special moment frames or special structural walls
Shear Strength Requirements

\[ \frac{V_{u, \text{max}}}{L} \leq \phi V_n \]

\[ \phi V_n \leq \phi 8 A_{cv} \sqrt{f_c'} \]

\[ \rho_t \geq \frac{(V_u / \phi) - 2 A_{cv} \lambda \sqrt{f_c'}}{f_y} \]
Chord Reinforcement

\[ T_u \leq \phi T_n = \phi A_s f_y \]

\[ \phi = 0.9 \]

\[ A_s \geq \frac{T_u}{\phi f_y} \]
Chord Reinforcement

- Placed perpendicular to the lateral force
- Provided in addition to any other required reinforcement
- In slabs without perimeter beams, typically concentrated near the edge of the slab and tied to either the top or bottom flexural reinforcement
- In slabs with perimeter beams, can be located within the slab outside of the beam cross-section
Chord Reinforcement
Shear Transfer Reinforcement

- Between the diaphragm and the vertical elements of the LFRS
- Between the diaphragm and the collector elements
Shear Transfer Reinforcement

- Shear-friction at joints

Figure 3.94 - Reinforcement details at slab-wall joints.
Shear Transfer Reinforcement

• Along Wall B

\[
\phi V_n = \phi \mu A_v f_y \geq V_u = R_B / L
\]
• Required area of dowel bars $A_{vf}$

$$A_{vf} \geq \frac{R_B}{L} \frac{R_B}{L} \phi f_y \mu$$

$\mu = 0.6$

$\phi = 0.75$
Shear Transfer Reinforcement

- Coefficient of friction $\mu$

### Table 22.9.4.2—Coefficients of friction

<table>
<thead>
<tr>
<th>Contact surface condition</th>
<th>Coefficient of friction $\mu$\textsuperscript{[1]}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete placed monolithically</td>
<td>$1.4\lambda$</td>
</tr>
<tr>
<td>Concrete placed against hardened concrete that is clean, free of laitance, and intentionally roughened to a full amplitude of approximately 1/4 in.</td>
<td>$1.0\lambda$</td>
</tr>
<tr>
<td>Concrete placed against hardened concrete that is clean, free of laitance, and not intentionally roughened</td>
<td>$0.6\lambda$</td>
</tr>
<tr>
<td>Concrete placed against as-rolled structural steel that is clean, free of paint, and with shear transferred across the contact surface by headed studs or by welded deformed bars or wires.</td>
<td>$0.7\lambda$</td>
</tr>
</tbody>
</table>

\textsuperscript{[1]}$\lambda = 1.0$ for normalweight concrete; $\lambda = 0.75$ for all lightweight concrete. Otherwise, $\lambda$ is calculated based on volumetric proportions of lightweight and normalweight aggregate as given in 19.2.4, but shall not exceed 0.85.
Shear transfer depends on width of collector

Figure 3.104 – Determination of dowel reinforcement in a diaphragm.
Shear Transfer Reinforcement

• Along Wall A

• Where width of collector = thickness of wall
  • All tension and compression forces from collector are transferred directly into the wall boundary

\[ A_{vf} \geq \frac{R_A/L_2}{\phi f_y \mu} \]

\[ \mu = 0.6 \]

\[ \phi = 0.75 \]
Shear Transfer Reinforcement

• Where width of collector > thickness of wall
  • $A_{vf}$ must be determined using the uniform shear along the wall length plus a portion of the total collector force
Shear Transfer Reinforcement

- Width of collector > thickness of wall
Shear Transfer Reinforcement

- Width of collector > thickness of wall
Shear Transfer Reinforcement

- Width of collector > thickness of wall

Fig. R12.5.4.1—Full-depth collector and shear-friction reinforcement required to transfer collector force into wall.
• Required area of dowel bars $A_{vf}$

$$A_{vf} \geq \frac{R_A}{\phi f_y \mu}$$

$\mu = 1.4$

$\phi = 0.75$
Tension Reinforcement

- Width of collector > thickness of wall

Other reinforcement not shown for clarity
Shear Transfer Reinforcement

- Alternate shear transfer
- Reinforcement in slab
Shear Transfer Reinforcement

- Alternate shear transfer
- Reinforcement in slab

Slab bottom reinforcement

Form saver assembly – deformed bar with a 90-deg hook
Dowel Bars

• Dowel bars must also be designed for any out-of-plane wind and seismic forces that act on the wall
Design and Detailing of Collectors
Collectors

• Must be provided where elements of the LFRS do not extend the full depth of the diaphragm
Collectors

- Portion of the slab or a reinforced concrete beam
- Slab or beam has the same width as the member of the LFRS

Figure 3.104
Collectors

Figure 3.105 - Unit shear forces, net shear forces, and collector forces in a diaphragm.
Collectors

- Design and detailing requirements

- Collectors must be designed for the combined factored load effects due to
  - Axial tension forces due to lateral loads and flexure and shear forces due to gravity loads
  - Axial compression forces due to lateral loads and flexure and shear forces due to gravity loads

- Design strength interaction diagram
  - Must include both axial compression and tensile segments
Collectors

- Design and detailing requirements
**Design Procedure**

- **Figure 3.106**
- **Examples**
  - **Section 3.8.7**

<table>
<thead>
<tr>
<th>Step</th>
<th>Task</th>
</tr>
</thead>
</table>
| Step 1 | **Determine diaphragm thickness** — Sections 3.8.1 and 3.8.3  
Based on strength and serviceability requirements for gravity loads  
*Section 3.4.2 for one-way slabs*  
*Section 3.5.1 for two-way slabs*  
Based on in-plane shear strength requirements in ACI 12.5.3.4 |
| Step 2 | **Determine chord forces at edges of diaphragm and at openings**  
*Section 3.8.2*  
Diaphragms without openings — Figure 2.32  
Diaphragms with openings — Figure 3.100 |
| Step 3 | **Check shear strength requirements in the diaphragm**  
*Section 3.8.3*  
Equation (3.58)  
Table 3.65 |
| Step 4 | **Design and detail the reinforcement in the diaphragm**  
*Section 3.8.4*  
Chord reinforcement  
Dowel reinforcement |
| Step 5 | **Design and detail the collectors**  
*Section 3.8.5*  
Determine axial forces in the collectors — Figure 3.105  
Design and detail collectors for combined axial force (tension and compression) and flexure |
Design and Detailing Requirements

SDC C
• Design and detailing requirements of ACI Chapter 12 are applicable
Collector Design

- Maximum of the three forces in ASCE/SEI 12.10.2.1
  - Forces calculated using seismic load effects including overstrength factor $\Omega_o$ with seismic forces determined by the Equivalent Lateral Force Procedure of ASCE/SEI 12.8 or the Modal Response Spectrum Analysis of ASCE/SEI 12.9
  - Forces calculated using seismic load effects including overstrength factor $\Omega_o$ with seismic forces determined by ASCE/SEI Equation 12.10-1
  - Forces calculated using the load combinations of ASCE/SEI 12.4.2.3 with seismic forces determined by ASCE/SEI Equation 12.10-2
Design and Detailing Requirements

SDC D, E, AND F
### Table R18.2—Sections of Chapter 18 to be satisfied in typical applications

<table>
<thead>
<tr>
<th>Component resisting earthquake effect, unless otherwise noted</th>
<th>SDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (None)</td>
</tr>
<tr>
<td>Analysis and design requirements</td>
<td>18.2.2</td>
</tr>
<tr>
<td>Materials</td>
<td>None</td>
</tr>
<tr>
<td>Frame members</td>
<td>18.3</td>
</tr>
<tr>
<td>Structural walls and coupling beams</td>
<td>None</td>
</tr>
<tr>
<td>Precast structural walls</td>
<td>None</td>
</tr>
<tr>
<td>Diaphragms and trusses</td>
<td>None</td>
</tr>
<tr>
<td>Foundations</td>
<td>None</td>
</tr>
<tr>
<td>Frame members not designated as part of the seismic-force-resisting system</td>
<td>None</td>
</tr>
<tr>
<td>Anchors</td>
<td>None</td>
</tr>
</tbody>
</table>

[1] In addition to requirements of Chapters 1 through 17, 19 through 26, and ACI 318.2, except as modified by Chapter 18. Section 14.1.4 also applies in SDC D, E, and F.

[1] As permitted by the general building code.
Analysis Model

• Rigid diaphragm model can be used to determine in-plane design bending moments, shear forces, and axial forces

• Chord reinforcement and shear transfer reinforcement can be determined using methods outlined previously
Diaphragm Forces

• Connections of diaphragms to vertical elements of the SFRS and to collectors
• Collectors and their connections to the vertical elements of the LFRS

Design forces determined in accordance with ASCE/SEI 12.10.1.1 must be increased by 25% for structures with the following irregularities

• Horizontal structural irregularities
  • Type 1a, 1b, 2, 3, or 4
  • Vertical structural irregularity Type 4
Horizontal Structural Irregularities

- Types 1a and 1b

\[ \Delta_{avg} = \frac{\Delta_{max} + \Delta_{min}}{2} \]

Torsional irregularity: \( \Delta_{max} > 1.2\Delta_{avg} \)

Extreme torsional irregularity: \( \Delta_{max} > 1.4\Delta_{avg} \)
Horizontal Structural Irregularities

• Type 2

Reentrant corner irregularity: $b > 0.15a$ and $d > 0.15c$
Horizontal Structural Irregularities

• Type 3

Diaphragm discontinuity irregularity: \( a_1 b_1 > 0.5ab \)
Horizontal Structural Irregularities

- Type 4
Vertical Structural Irregularity

• Type 4

In-plane discontinuity irregularity:
Offset > $L_1$ or Offset > $L_2$
Minimum Reinforcement

- ACI 18.12.7.1
- ACI 24.4

• \( A_{s,min} = 0.0018A_g \)
• Maximum spacing = 18 in.
\[ \phi V_n = \phi A_{cv} \left( 2\lambda \sqrt{f'_c} + \rho_t f_y \right) \]

\( A_{cv} \) = gross area of diaphragm

\( \rho_t \) = distributed reinforcement oriented in the direction of analysis

\( \phi \) must not exceed the least value of \( \phi \) for shear used for the vertical elements of the SFRS
• Maximum of the three forces in ASCE/SEI 12.10.2.1
  • Forces calculated using seismic load effects including overstrength factor $\Omega_o$ with seismic forces determined by the Equivalent Lateral Force Procedure of ASCE/SEI 12.8 or the Modal Response Spectrum Analysis of ASCE/SEI 12.9
  • Forces calculated using seismic load effects including overstrength factor $\Omega_o$ with seismic forces determined by ASCE/SEI Equation 12.10-1
  • Forces calculated using the load combinations of ASCE/SEI 12.4.2.3 with seismic forces determined by ASCE/SEI Equation 12.10-2
Collectors

• Design and detailing requirements

- At sections where combined compressive stress > 0.2$f_c'$
- Provide transverse reinforcement conforming to ACI 18.7.5.2(a) through (e) and ACI 18.7.5.3 for columns of special moment frames
- Transverse reinforcement conforming to above requirements need not be provided at sections where combined compressive stress < 0.15$f_c'$
- Limits of 0.2$f_c'$ and 0.15$f_c'$ are to be increased to 0.5$f_c'$ and 0.4$f_c'$, respectively, in cases where forces have been amplified by the overstrength factor $\Omega_o$
Collectors

- Design and detailing requirements

- For collectors that are part of the slab
  - Required longitudinal reinforcement must be in addition to any of the other required reinforcement for flexure
  - Longitudinal reinforcement should be located near the mid-depth of the slab
  - Maximum bar spacing = 18 in.
Collectors

• Design and detailing requirements

• For collectors that are reinforced concrete beams
  • All applicable design and detailing requirements for beams must be satisfied
  • Longitudinal reinforcement in the beam is determined for combined flexure and axial tension and combined flexure and axial compression
  • Transverse reinforcement is determined for shear and/or torsion
Collectors

- Design and detailing requirements

- Longitudinal reinforcement must extend into the attached element of the LFRS a distance equal to at least $\ell_d$
  - It is recommended to extend the longitudinal bars through the entire length of the member of the LFRS that is in-plane with the collector
  - Provide tension splices in accordance with ACI 25.5 where required
Detailing Requirements

Figure 5.60
Detailing Requirements

Figure 5.60

**Compressive stress** $f'c$  |  **Transverse reinforcement, $A_{sh}$**  |  **Spacing, $s$**
--- | --- | ---
$> 0.2f'c$  |  $A_{sh} \geq 0.09s_t \frac{f'c}{f_{yf}}$  |  $s \leq \left\{ \begin{array}{l} 0.25 \times (\text{smaller of } h \text{ and } b_w) \\ 6\frac{d_b}{s_0} \end{array} \right.$

$4'' \leq s_0 = 4 + \left\lceil (14 - h_s)/3 \right\rceil \leq 6''$

$h_s = \text{maximum of } x_1 \leq 14''$

$< 0.15f'c$  |  $A_{sh} \geq \left\{ \begin{array}{l} 0.75\sqrt{f'c} \frac{b_w s}{f_{yf}} \\ 50 b_w s / f_{yf} \end{array} \right.$  |  Spacing $s$ determined in accordance with ACI 22.5

Maximum spacing in ACI Table 9.7.6.2.2

* Where design forces have been amplified by $\Omega_p$, limits of $0.2f'c$ and $0.15f'c$ are increased to $0.5f'c$ and $0.4f'c$, respectively.
Example
Example 5.19

- SDC D
- $S_{DS} = 1.00$
- SIDL = 10 psf
- $L_r = 20$ psf
- $f_c' = 4,000$ psi
- Grade 60 reinforcement
- Design roof diaphragm for seismic forces in N-S direction

4-story building
Example 5.19

\[ F_{px} = \left( \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} \right) w_{px} \]

\[ \geq 0.2 S_{DS} l_e w_{px} = 0.2 \times 1.00 \times 1.0 \times w_{px} = 0.200 w_{px} \]

\[ \leq 0.4 S_{DS} l_e w_{px} = 0.4 \times 1.00 \times 1.0 \times w_{px} = 0.400 w_{px} \]
Example 5.19

• Redundancy factor $\rho = 1.0$
  • Example 5.16
Example 5.19

• CM and CR

Figure 5.66

\[ e = 0.05 \times 102.33 = 5.1' \]
Example 5.19

1. \( (w_1 \times 100) + \left[ \frac{1}{2} (w_2 - w_1) \times 100 \right] = 333 \)

2. \( \left( w_1 \times \frac{100^2}{2} \right) + \left[ \frac{1}{2} (w_2 - w_1) \times 100 \times \left( \frac{2}{3} \times 100 \right) \right] = (150 \times 40) + (183 \times 60) \)

\[ w_1 = 3.13 \text{ kips/ft and } w_2 = 3.53 \text{ kips/ft} \]
Example 5.19

Figure 5.66
Example 5.19

- Chord reinforcement

\[ C_u = T_u = \frac{M_{u,\text{max}}}{d} = \frac{2,778}{0.95 \times 80} = 36.6 \text{ kips} \]

\[ A_s = \frac{T_u}{\phi f_y} = \frac{36.6}{0.9 \times 60} = 0.68 \text{ in.}^2 \]

Provide 2-#6 chord bars along the north and side edges of the slab.
Example 5.19

- Shear strength

Maximum shear force in diaphragm:

\[ V_{u,\text{max}} = \frac{138.0}{80} = 1.7 \text{ kips/ft} \]

Conservatively assuming \( \rho_t = 0 \):

\[ \phi V_n = \phi A_{cv} 2 \lambda \sqrt{f'_c} = 0.6 \times (8.0 \times 12) \times \sqrt{4000/1000} \]
\[ = 7.3 \text{ kips/ft} > 1.7 \text{ kips/ft} \]
Example 5.19

- Shear transfer reinforcement – East wall and diaphragm

\[ A_{vf} = \frac{R_E}{L \phi f_y \mu} = \frac{9.2}{0.6 \times 60 \times 0.6} \]

\[ = 0.42 \text{ in.}^2/\text{ft} \]

Use #5 dowel bars spaced at 8 in. on center

Figure 5.67 – Unit shear forces, net shear forces, and collector forces in the diaphragm in Example 5.19.
Example 5.19

- Shear transfer reinforcement – Diaphragm and collectors

Shear force in diaphragm = 2.5 × (1.7 + 0.6) = 5.8 kips/ft
Example 5.19

- Shear transfer reinforcement – Diaphragm and collectors

\[
A_{vf} = \frac{R_E/L}{\phi f_y \mu} = \frac{5.8}{0.6 \times 60 \times 1.4} = \frac{5.8}{84} = 0.12 \text{ in.}^2/\text{ft}
\]

Provide #4 bars spaced at 14 in. on center
Example 5.19

1. Forces calculated using the seismic load effects including overstrength of ASCE/SEI 12.4.3 with seismic forces determined using the Equivalent Lateral Force Procedure of ASCE/SEI 12.8 or the modal response spectrum analysis procedure of ASCE/SEI 12.9

Building frame system: $\Omega_0 = 2.5$

Diaphragm force = 333 kips (see Table 5.17)

$\Rightarrow$ Axial force in collector = $2.5 \times 92 = 230$ kips

• Collector design
  • Collectors and their connections must be designed for the maximum of the three forces in ASCE/SEI 12.10.2.1
Example 5.19

• Collector design
• Collectors and their connections must be designed for the maximum of the three forces in ASCE/SEI 12.10.2.1

2. Forces calculated using the seismic load effects including overstrength of ASCE/SEI 12.4.3 with seismic forces determined by ASCE/SEI Equation (12.10-1)

Diaphragm force = 333 kips (see Table 5.17)

⇒ Axial force in collector = 2.5 × 92 = 230 kips
Example 5.19

• Collector design
  • Collectors and their connections must be designed for the maximum of the three forces in ASCE/SEI 12.10.2.1

3. Forces calculated using the load combinations of ASCE/SEI 2.3.6 with seismic forces determined by ASCE/SEI Equation (12.10-2)

\[
\text{Minimum } F_{px} = 0.2 S_{DS} I_e w_{px} = 0.2 \times 1.00 \times 1.0 \times 1,222 = 244 \text{ kips} < 333 \text{ kips}
\]

⇒ Axial force in collector will be less than that from Methods 1 and 2

Collector axial force = ±230 kips
Example 5.19

- Collector design

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Axial Force (kips)</th>
<th>Bending Moment (ft-kips)</th>
<th>Shear Force (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Negative</td>
<td>Positive</td>
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<tr>
<td>Dead ($D$)</td>
<td>0</td>
<td>67.2</td>
<td>46.2</td>
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<tr>
<td>Roof Live ($L_r$)</td>
<td>0</td>
<td>12.2</td>
<td>8.4</td>
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<tr>
<td>Seismic ($2.5Q_E$)</td>
<td>±230</td>
<td>0</td>
<td>0</td>
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<tr>
<th>Load Combination</th>
<th>Axial Force (kips)</th>
<th>Bending Moment (ft-kips)</th>
<th>Shear Force (kips)</th>
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<td>1</td>
<td>1.4$D$</td>
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<td>94.1</td>
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<tr>
<td>2</td>
<td>1.2$D + 1.6L_r$</td>
<td>0</td>
<td>100.2</td>
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<tr>
<td>3</td>
<td>1.4$D + 2.5Q_E$</td>
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<td>94.1</td>
</tr>
<tr>
<td>4</td>
<td>0.7$D + 2.5Q_E$</td>
<td>±230</td>
<td>47.0</td>
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</table>
Example 5.19

• Collector design
  • 3-#8 top bars
  • 2-#8 side bars
  • 3-#8 bottom bars

Figure 5.68 – Design strength interaction diagram for the collector in Example 5.19.
Example 5.19

- Confinement reinforcement per ACI 18.12.7.5

\[
fcu = \frac{230,000}{20 \times 28} = 411 \text{ psi} < 0.5f'_c = 2,000 \text{ psi}
\]

Transverse reinforcement satisfying ACI 18.12.7.5 need not be provided.
Example 5.19

- Transverse reinforcement

\[ s = \frac{A_v f_{yt} d}{V_u \frac{\phi}{\phi} - V_c} = \frac{(2 \times 0.11) \times 60 \times 25.5}{28.3 - 0} = 7.1 \text{ in.} < \frac{d}{2} = 12.8 \text{ in.} \]

Collector subjected to significant axial tension

\[ \leq \frac{A_v f_{yt}}{0.75 \sqrt{f'_c b_w}} = \frac{(2 \times 0.11) \times 60,000}{0.75 \times \sqrt{4,000 \times 20}} = 13.9 \text{ in.} \]

\[ \leq \frac{A_v f_{yt}}{50 b_w} = \frac{(2 \times 0.11) \times 60,000}{50 \times 20} = 13.2 \text{ in.} \]

Provide #3 ties spaced at 7 in. on center over the entire length of the collectors
Example 5.19

- Reinforcement details

Figure 5.69 – Reinforcement details for the collector in Example 5.19.
Example 5.20

- Diaphragm with large opening
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- Project completed between January 1, 2015 and June 1, 2018
- Enter online or by mail
- No limit to the number of submittals. Entry fees:
  - Corporate and Professional Members: FREE
  - Non-Members: $150 per submission

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<td>Federal/State/Municipal</td>
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