CHAPTER 12—DIAPHRAGMS

CODE

12.1—Scope

12.1.1 This chapter shall apply to the design of nonprestressed and prestressed diaphragms, including (a) through (d):

(a) Diaphragms that are cast-in-place slabs
(b) Diaphragms that comprise a cast-in-place topping slab on precast elements
(c) Diaphragms that comprise precast elements with end strips formed by either a cast-in-place concrete topping slab or edge beams
(d) Diaphragms of interconnected precast elements without cast-in-place concrete topping

COMMENTARY

R12.1—Scope

R12.1.1 Diaphragms typically are horizontal or nearly horizontal planar elements that serve to transfer lateral forces to vertical elements of the lateral-force-resisting system (Fig. R12.1.1). Diaphragms also tie the building elements together into a complete three-dimensional system and provide lateral support to those elements by connecting them to the lateral-force-resisting system. Typically, diaphragms also serve as floor and roof slabs, or as parking structure ramps and, therefore, support gravity loads. A diaphragm may include chords and collectors.

When subjected to lateral loads, such as the in-plane inertial loads acting on the roof diaphragm of Fig. R12.1.1, a diaphragm acts essentially as a beam spanning horizontally between vertical elements of the lateral-force-resisting system. The diaphragm thus develops in-plane bending moments, shears, and possibly other actions. Where vertical elements of the lateral-force-resisting system do not extend along the full depth of the diaphragm, collectors may be required to collect the diaphragm shear and transfer it to the vertical elements. The term "distributor" is sometimes used to describe a collector that transfers force from a vertical element of the lateral-force-resisting system into the diaphragm. This chapter describes minimum requirements for diaphragm and collector design and detailing, including configuration, analysis models, materials, and strength.

This chapter covers only the types of diaphragms listed in this provision. Other diaphragm types, such as horizontal trusses, are used successfully in buildings, but this chapter does not include prescriptive provisions for those other types.

CODE | COMMENTARY

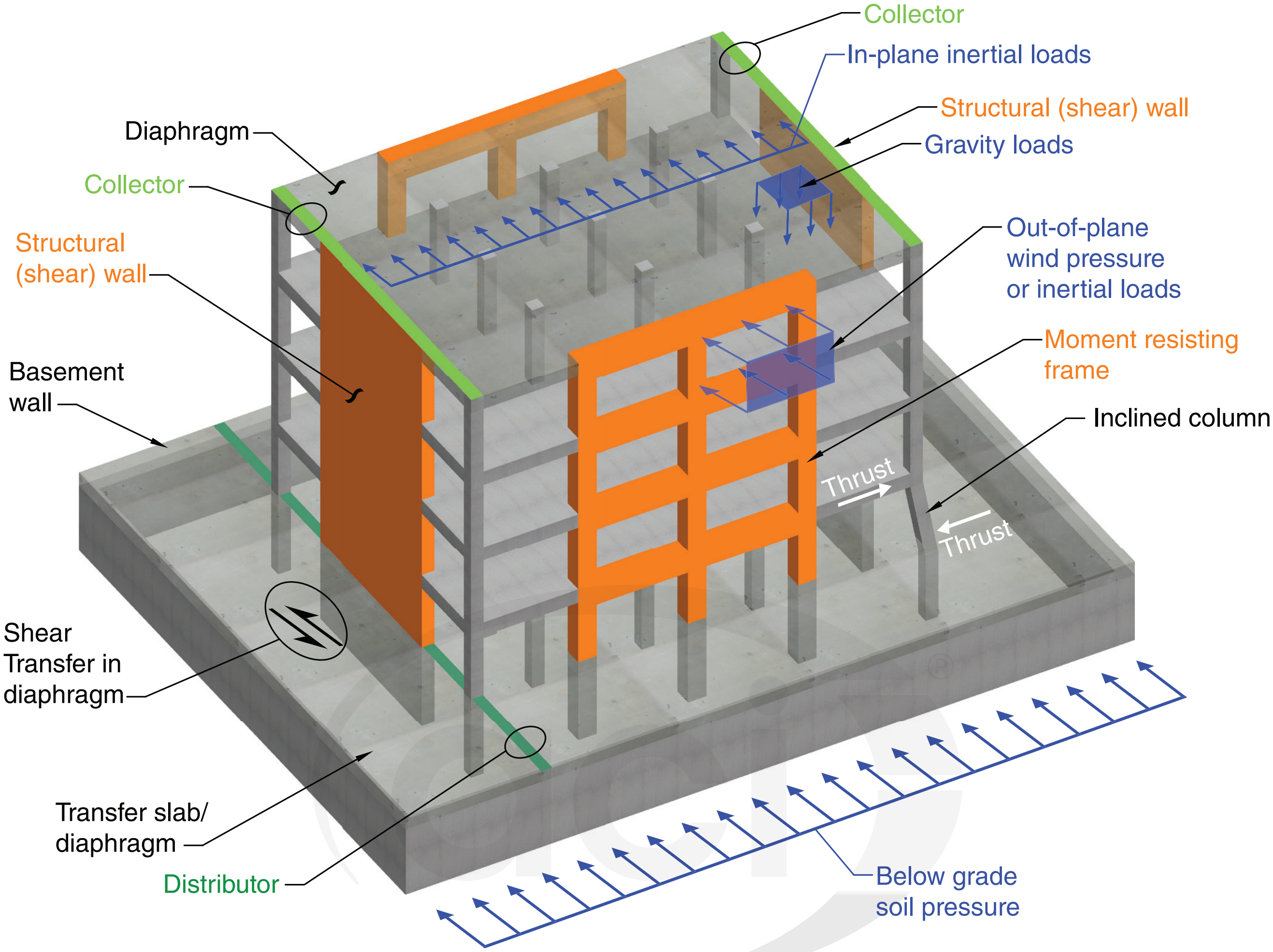

Fig. R12.1.1—Typical diaphragm actions.

12.1.2 Diaphragm types defined in 12.1.1 that form part of the seismic-force resisting system shall also satisfy requirements of 18.12 where applicable.

12.2—General

12.2.1 Design shall consider forces (a) through (e):

(a) Diaphragm in-plane forces due to lateral loads acting on the building
(b) Diaphragm transfer forces
(c) Connection forces between the diaphragm and vertical framing or nonstructural elements
(d) Forces resulting from bracing vertical or sloped building elements
(e) Diaphragm out-of-plane forces due to gravity and other loads applied to the diaphragm surface

R12.2—General

R12.2.1 As partially illustrated in Fig. R12.1.1, diaphragms resist forces from several types of actions (Moehle et al. 2010):

(a) **Diaphragm in-plane forces**—Lateral forces from load combinations including wind, earthquake, and horizontal fluid or soil pressure generate in-plane shear, axial, and bending actions in diaphragms as they span between, and transfer forces to, vertical elements of the lateral-force-resisting system. For wind loading, lateral force is generated by wind pressure acting on building cladding that is transferred by diaphragms to the vertical elements. For earthquake loading, inertial forces are generated within the diaphragm and tributary portions of walls, columns, and other elements, and then transferred by diaphragms to the vertical elements. For buildings with subterranean levels, lateral forces are generated by soil pressure bearing against the basement walls; in a typical system, the base-

CODE | COMMENTARY

ment walls span vertically between floors also serving as diaphragms, which in turn distribute the lateral soil forces to other force-resisting elements.

(b) **Diaphragm transfer forces**—Vertical elements of the lateral-force-resisting system may have different properties over their height, or their planes of resistance may change from one story to another, creating force transfers between vertical elements. A common location where planes of resistance change is at grade level of a building with an enlarged subterranean plan; at this location, forces may transfer from the narrower tower into the basement walls through a podium diaphragm (refer to Fig. R12.1.1).

(c) **Connection forces**—Wind pressure acting on exposed building surfaces generates out-of-plane forces on those surfaces. Similarly, earthquake shaking can produce inertial forces in vertical framing and nonstructural elements such as cladding. These forces are transferred from the elements where the forces are developed to the diaphragm through connections.

(d) **Column bracing forces**—Architectural configurations sometimes require inclined columns, which can result in large horizontal thrusts acting within the plane of the diaphragms due to gravity and overturning actions. The thrusts can act in different directions depending on orientation of the column and whether it is in compression or tension. Where these thrusts are not balanced locally by other elements, the forces have to be transferred into the diaphragm so they can be transmitted to other suitable elements of the lateral-force-resisting system. Such forces are common and may be significant with eccentrically loaded precast concrete columns that are not monolithic with adjacent framing. The diaphragm also provides lateral support to columns not designed as part of the lateral-force-resisting system by connecting them to other elements that provide lateral stability for the structure.

(e) **Diaphragm out-of-plane forces**—Most diaphragms are part of floor and roof framing and, therefore, support gravity loads. The general building code may also require consideration of out-of-plane forces due to wind uplift pressure on a roof slab and vertical acceleration due to earthquake effects.

12.2.2 The effects of slab openings and slab voids shall be considered in design.

R12.2.2 Refer to R7.2.1.

12.2.3 *Materials*

12.2.3.1 Design properties for concrete shall be selected to be in accordance with Chapter 19.

12.2.3.2 Design properties for steel reinforcement shall be selected to be in accordance with Chapter 20.

CODE

12.3—Design limits

12.3.1 *Minimum diaphragm thickness*

12.3.1.1 Diaphragms shall have thickness as required for stability, strength, and stiffness under factored load combinations.

12.3.1.2 Floor and roof diaphragms shall have a thickness not less than that required for floor and roof elements in other parts of this Code.

12.4—Required strength

12.4.1 *General*

12.4.1.1 Required strength of diaphragms, collectors, and their connections shall be calculated in accordance with the factored load combinations in Chapter 5.

12.4.1.2 Required strength of diaphragms that are part of floor or roof construction shall include effects of out-of-plane loads simultaneous with other applicable loads.

12.4.2 *Diaphragm modeling and analysis*

12.4.2.1 Diaphragm modeling and analysis requirements of the general building code shall govern where applicable. Otherwise, diaphragm modeling and analysis shall be in accordance with 12.4.2.2 through 12.4.2.4.

12.4.2.2 Modeling and analysis procedures shall satisfy requirements of Chapter 6.

COMMENTARY

R12.3—Design limits

R12.3.1 *Minimum diaphragm thickness*

R12.3.1.1 Diaphragms may be required to resist in-plane moment, shear, and axial force. For diaphragms that are entirely cast-in-place or comprise topping slabs composite with precast members, thickness of the entire diaphragm must be sufficient to resist these actions. For noncomposite topping slabs, thickness of the cast-in-place topping alone must be sufficient to resist these actions. Section 18.12 contains specific requirements for diaphragms in buildings assigned to Seismic Design Categories D, E, and F.

In addition to requirements for in-plane force resistance, diaphragms that are part of floor or roof construction must satisfy applicable requirements for slab or flange thickness.

R12.4—Required strength

R12.4.1 Factored load combinations generally require consideration of out-of-plane loads that act simultaneously with diaphragm in-plane forces. For example, this is required where a floor beam also serves as a collector, in which case the beam is to be designed to resist axial forces acting as a collector and bending moments acting as a floor beam supporting gravity loads.

R12.4.2 *Diaphragm modeling and analysis*

R12.4.2.1 ASCE/SEI 7 includes diaphragm modeling requirements for some design conditions, such as design to resist wind and earthquake loads. Where ASCE/SEI 7 is adopted as part of the general building code, those requirements govern over provisions of ACI CODE-318.

R12.4.2.2 Chapter 6 contains general requirements for analysis that are applicable to diaphragms. Diaphragms are usually designed to remain elastic or nearly elastic for forces acting within their plane under factored load combinations. Therefore, analysis methods satisfying theory of elastic analysis are generally acceptable. The provisions for elastic analysis in 6.6.1 through 6.6.3 can be applied.

Diaphragm in-plane stiffness affects not only the distribution of forces within the diaphragm, but also the distribution of displacements and forces among the vertical

CODE

COMMENTARY

elements. Thus, the diaphragm stiffness model should be consistent with characteristics of the building. Where the diaphragm is very stiff compared to the vertical elements, as in a low aspect ratio, cast-in-place diaphragm supported by moment frames, it is acceptable to model the diaphragm as a completely rigid element. Where the diaphragm is flexible compared with the vertical elements, as in some jointed precast systems supported by structural walls, it may be acceptable to model the diaphragm as a flexible beam spanning between rigid supports. In other cases, it may be advisable to adopt a more detailed analytical model to account for the effects of diaphragm flexibility on the distribution of displacements and forces. Examples include buildings in which diaphragm and vertical element stiffnesses have approximately the same value, buildings with large force transfers, and parking structures in which ramps connect between floors and act essentially as bracing elements within the building.

For diaphragms constructed of concrete slabs, ASCE/SEI 7 permits the assumption of a rigid diaphragm if the diaphragm aspect ratio falls within a prescribed limit, which is different for wind and earthquake loads, and if the structure has no horizontal irregularities. ASCE/SEI 7 provisions do not prohibit the rigid diaphragm assumption for other conditions, provided the rigid diaphragm assumption is reasonably consistent with anticipated behavior. Cast-in-place concrete diaphragms designed with the rigid-diaphragm assumption have a long history of satisfactory performance even though they may fall outside the ASCE/SEI 7 index values.

12.4.2.3 Any set of reasonable and consistent assumptions for diaphragm stiffness shall be permitted.

R12.4.2.3 For low-aspect-ratio diaphragms that are entirely cast-in-place or comprise a cast-in-place topping slab on precast elements, the diaphragm is often modeled as a rigid element supported by flexible vertical elements. However, effects of diaphragm flexibility should be considered where such effects will materially affect calculated design actions. Such effects should be considered for diaphragms that use precast elements, with or without a cast-in-place topping. Where large transfer forces occur, as outlined in R12.2.1(b), more realistic design forces can be obtained by modeling diaphragm in-plane stiffness. Diaphragms with long spans, large cutout areas, or other irregularities may develop in-plane deformations that should be considered in design (refer to Fig. R12.4.2.3a).

For a diaphragm considered rigid in its own plane, and for semi-rigid diaphragms, the diaphragm internal force distribution can be obtained by modeling it as a horizontal rigid beam supported on springs representing lateral stiffnesses of the vertical elements (refer to Fig. R12.4.2.3b). Effects of in-plane eccentricity between applied forces and vertical element resistances, resulting in overall building torsion, should be included in the analysis. Elements of the lateral-force-resisting system aligned in the orthogonal direction can participate in resisting diaphragm plan rotation (Moehle et al. 2010).

CODE

COMMENTARY

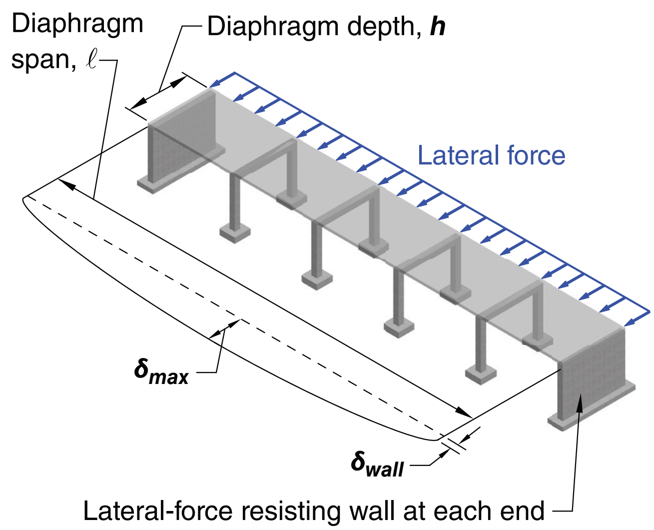

Fig. R12.4.2.3a—Example of diaphragm that might not be considered rigid in its plane.

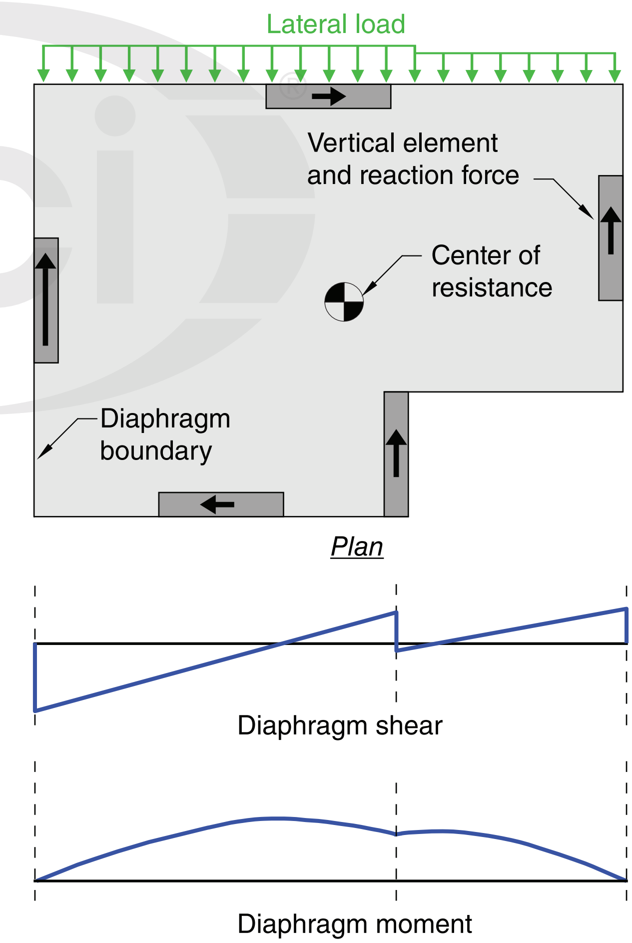

Fig. R12.4.2.3b—Diaphragm in-plane actions obtained by modeling the diaphragm as a horizontal rigid beam on flexible supports.

12.4.2.4 Calculation of diaphragm in-plane design moments, shears, and axial forces shall be consistent with requirements of equilibrium and with design boundary

R12.4.2.4 The rigid diaphragm model is widely used for diaphragms that are entirely cast-in-place and for diaphragms that comprise a cast-in-place topping slab on precast

CODE

conditions. It shall be permitted to calculate design moments, shears, and axial forces in accordance with one of (a) through (e):

(a) A rigid diaphragm model if the diaphragm can be idealized as rigid
(b) A flexible diaphragm model if the diaphragm can be idealized as flexible
(c) A bounding analysis in which the design values are the envelope of values obtained by assuming upper bound and lower bound in-plane stiffnesses for the diaphragm in two or more separate analyses
(d) A finite element model considering diaphragm flexibility
(e) A strut-and-tie model in accordance with 23.2

COMMENTARY

elements, provided flexible conditions are not created by a long span, by a large aspect ratio, or by diaphragm irregularity. For more flexible diaphragms, a bounding analysis is sometimes done in which the diaphragm is analyzed as a stiff or rigid element on flexible supports and as a flexible diaphragm on rigid supports, with the design values taken as the envelope of values from the two analyses. Finite element models can be suitable for any diaphragm, but are especially useful for irregularly shaped diaphragms and diaphragms resisting large transfer forces. Stiffness should be adjusted to account for expected concrete cracking under design loads. For jointed precast concrete diaphragms that rely on mechanical connectors, it may be necessary to include the joints and connectors in the finite element model. Strut-and-tie models may be used for diaphragm design. The strut-and-tie models should include considerations of force reversals that may occur under design load combinations.

12.5—Design strength

12.5.1 *General*

12.5.1.1 For each applicable factored load combination, design strengths of diaphragms and connections shall satisfy $\phi S_n \geq U$. Interaction between load effects shall be considered.

R12.5—Design strength

R12.5.1 *General*

R12.5.1.1 Design actions commonly include in-plane moment, with or without axial force; in-plane shear; and axial compression and tension in collectors and other elements acting as struts or ties. Some diaphragm configurations may result in additional types of design actions. For example, a diaphragm vertical step can result in out-of-plane bending, torsion, or both. The diaphragm is required to be designed for such actions where they occur in elements that are part of the load path.

Nominal strengths are prescribed in Chapter 22 for a diaphragm idealized as a beam or solid element resisting in-plane moment, axial force, and shear; and in Chapter 23 for a diaphragm or diaphragm segment idealized as a strut-and-tie system. Collectors and struts around openings can be designed as compression members subjected to axial force using provisions of 10.5.2 with the strength reduction factor for compression-controlled members in 21.2.2. For axial tension in such members, nominal tensile strength is $A_s f_y$, and the strength reduction factor is 0.90 as required for tension-controlled members in 21.2.2.

Diaphragms are designed under load combinations of 5.3. Where a diaphragm or part of a diaphragm is subjected to multiple load effects, the interaction of the load effects is to be considered. A common example is where a collector is built within a beam or slab that also resists gravity loads, in which case the element is designed for combined moment and axial force. Another example is where a connection is subjected to simultaneous tension and shear.

12.5.1.2 ϕ shall be determined in accordance with 21.2.

12.5.1.3 Design strengths shall be in accordance with (a), (b), (c), or (d):

R12.5.1.3 Different design strength requirements apply depending on how the diaphragm load-path is idealized.

CODE

(a) For a diaphragm idealized as a beam whose depth is equal to the full diaphragm depth, with moment resisted by boundary reinforcement concentrated at the diaphragm edges, design strengths shall be in accordance with 12.5.2 through 12.5.4.

(b) For a diaphragm or a diaphragm segment modeled as a strut-and-tie system, design strengths shall be in accordance with 23.3.

(c) For a diaphragm idealized with a finite-element model, design strengths shall be in accordance with Chapter 22. Nonuniform shear distributions shall be considered in design for shear. Collectors, where needed to transfer diaphragm shears to thevertical elements of the lateral-force-resisting system, shall be designed inaccordance with 12.5.4.

(d) For a diaphragm designed by alternative methods, such methods shall satisfy the requirements of equilibrium and shall provide design strengths at least equal to required strengths for all elements in the load path.

COMMENTARY

Section 12.5.1.3(a) addresses requirements for the common case where a diaphragm is idealized as a beam spanning between supports and resisting forces within its plane, with chord reinforcement at the boundaries to resist in-plane moment and axial force. If diaphragms are designed according to this model, then it is appropriate to assume that shear flow is uniform through the diaphragm depth. Diaphragm depth refers to the dimension measured in the direction of lateral forces within the plane of the diaphragm (refer to Fig. R12.4.2.3a). If vertical elements of the lateral-force-resisting system do not extend the full depth of the diaphragm, then collectors are required to transfer shear acting along the remaining portions of the diaphragm depth to the vertical elements. Sections 12.5.2 through 12.5.4 are based on this model. This design approach is acceptable even if some of the moment is resisted by precompression as provided by 12.5.1.4.

Sections 12.5.1.3(b) through (d) permit alternative methods for design of diaphragms. If diaphragms are designed to resist moment through distributed chords, or if diaphragms are designed according to stress fields determined by finite-element analysis, then non-uniform shear flow should be taken into account.

12.5.1.4 It shall be permitted to use precompression from prestressed reinforcement to resist diaphragm forces.

R12.5.1.4 In the typical case of a prestressed floor slab, prestressing is required, at a minimum, to resist the factored load combination $1.2D + 1.6L$, where L may have been reduced as permitted by the general building code. For wind or earthquake design, however, the gravity load to be resisted by prestressing is reduced because the governing load combination is $1.2D + f_1L + (W \text{ or } E)$, where f_1 is either 1.0 or 0.5 depending on the nature of L. Thus, only a portion of the effective prestress is required to resist the reduced gravity loads. The remainder of the effective prestress can be used to resist in-plane diaphragm moments. Additional moment, if any, is resisted by added reinforcement.

12.5.1.5 If nonprestressed, bonded prestressing reinforcement is designed to resist collector forces, diaphragm shear, or tension due to in-plane moment, the value of steel stress used to calculate resistance shall not exceed the lesser of the specified yield strength and 60,000 psi.

R12.5.1.5 Nonprestressed bonded prestressing reinforcement, either strand or bars, is sometimes used to resist diaphragm design forces. The imposed limit on assumed yield strength is to control crack width and joint opening. The Code does not include provisions for developing nonprestressed, bonded prestressing reinforcement. Stress limits for other provided reinforcement are prescribed in Chapter 20.

12.5.2 *Moment and axial force*

R12.5.2 *Moment and axial force*

12.5.2.1 It shall be permitted to design a diaphragm to resist in-plane moment and axial force in accordance with 22.3 and 22.4.

R12.5.2.1 This section permits design for moment and axial force in accordance with the usual assumptions of 22.3 and 22.4, including the assumption that strains vary linearly through the depth of the diaphragm. In most cases, design for moment and axial force can be accomplished satisfactorily using an approximate tension-compression couple with the strength reduction factor equal to 0.90.

CODE

12.5.2.2 It shall be permitted to resist tension due to moment by (a), (b), (c), or (d), or those methods in combination:

(a) Deformed bars conforming to 20.2.1
(b) Strands or bars conforming to 20.3.1, either prestressed or nonprestressed
(c) Mechanical connectors crossing joints between precast elements
(d) Precompression from prestressed reinforcement

12.5.2.3 Nonprestressed reinforcement and mechanical connectors resisting tension due to moment shall be located within $h/4$ of the tension edge of the diaphragm, where h is diaphragm depth measured in the plane of the diaphragm at that location. Where diaphragm depth changes along the span, it shall be permitted to develop reinforcement into adjacent diaphragm segments that are not within the $h/4$ limit.

COMMENTARY

R12.5.2.2 Bonded prestressing reinforcement used to resist in-plane moment and axial force can be either prestressed or nonprestressed. Mechanical connectors crossing joints between precast concrete elements are provided to complete a continuous load path for reinforcement embedded in those elements. The use of precompression from prestressed reinforcement is discussed in R12.5.1.4

R12.5.2.3 Figure R12.5.2.3 illustrates permitted locations of nonprestressed reinforcement resisting tension due to moment and axial force. Where diaphragm depth changes along the span, it is permitted to develop tension reinforcement in adjacent sections even if the reinforcement falls outside the $h/4$ limit of the adjacent section. In such cases, the strut-and-tie method or elastic plane stress analysis can be used to determine bar extensions and other reinforcement requirements to provide continuity across the step. The restriction on location of nonprestressed reinforcement and mechanical connectors is intended to control cracking and excessive joint opening that might occur near the edges if reinforcement or mechanical connectors were distributed throughout the diaphragm depth. The concentration of flexural tension reinforcement near the edge of the diaphragm also results in more uniform shear flow through the depth of the diaphragm.

There are no restrictions on placement of prestressed reinforcement provided to resist moment through precompression. In effect, the precompression determines a moment that the prestressed reinforcement can resist, with the remainder of the moment resisted by reinforcement or mechanical connectors placed in accordance with 12.5.2.3.

The Code does not require that diaphragm boundary elements resisting design flexural compression forces be detailed as columns. However, where a boundary element resists a large compressive force compared with axial strength, or is designed as a strut adjacent to an edge or opening, detailing with transverse reinforcement similar to column hoops should be considered.

CODE | COMMENTARY

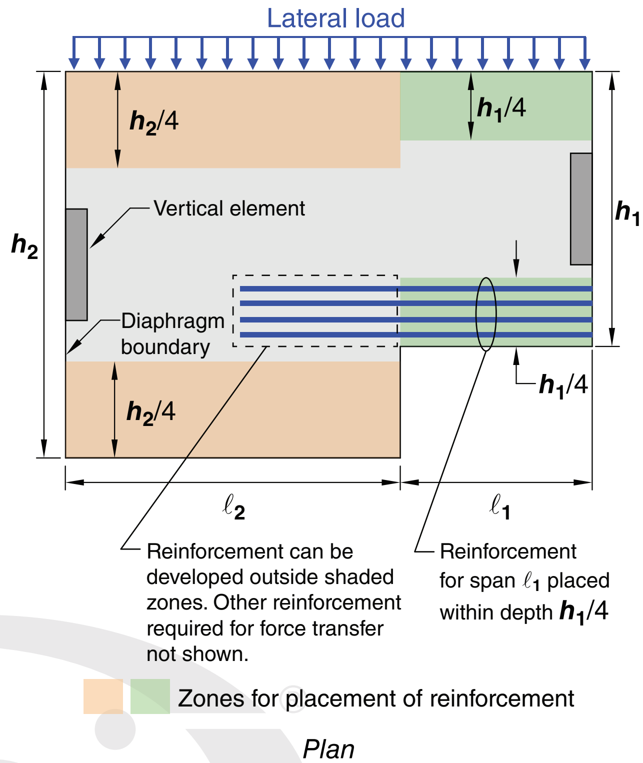

Fig. R12.5.2.3—Locations of nonprestressed reinforcement resisting tension due to moment and axial force according to 12.5.2.3.

12.5.2.4 Mechanical connectors crossing joints between precast elements shall be designed to resist required tension under the anticipated joint opening.

R12.5.2.4 In an untopped precast diaphragm resisting in-plane forces and responding in the linear range, some joint opening (on the order of 0.1 in. or less) should be anticipated. A larger joint opening may occur under earthquake motions exceeding the design level. Mechanical connectors should be capable of maintaining design strength under the anticipated joint opening.

12.5.3 *Shear*

R12.5.3 *Shear*

12.5.3.1 This section shall apply to diaphragm in-plane shear strength.

R12.5.3.1 These provisions assume that diaphragm shear flow is approximately uniform over the diaphragm depth, as is the case where design is in accordance with 12.5.1.3(a). Where alternative approaches are used, local variations of in-plane shear through the diaphragm depth should be considered.

12.5.3.2 ϕ shall be 0.75, unless a lesser value is required by 21.2.4.

R12.5.3.2 A lower strength reduction factor may be required in Seismic Design Categories D, E, or F, or where special systems for earthquake resistance are used.

12.5.3.3 For a diaphragm that is entirely cast-in-place, V_n shall be calculated by Eq. (12.5.3.3).

$$V_n = A_{cv}\left(2\lambda\sqrt{f_c'} + \rho_t f_y\right) \qquad (12.5.3.3)$$

R12.5.3.3 This provision was adapted from the earthquake-resistant design provisions of 18.12.9. The term A_{cv} refers to the cross-sectional area of the effective deep beam that forms the diaphragm.

CODE

where A_{cv} is the gross area of concrete bounded by diaphragm web thickness and depth, reduced by void areas if present; the value of $\sqrt{f_c'}$ used to calculate V_n shall not exceed 100 psi; and ρ_t refers to the distributed reinforcement oriented parallel to the in-plane shear.

12.5.3.4 For a diaphragm that is entirely cast-in-place, cross-sectional dimensions shall be selected to satisfy Eq. (12.5.3.4).

$$V_u \leq \phi 8 A_{cv}\sqrt{f_c'} \qquad (12.5.3.4)$$

where the value of $\sqrt{f_c'}$ used to calculate V_n shall not exceed 100 psi.

12.5.3.5 For diaphragms that are cast-in-place concrete topping slabs on precast elements, (a) and (b) shall be satisfied:

(a) V_n shall be calculated in accordance with Eq. (12.5.3.3), and cross-sectional dimensions shall be selected to satisfy Eq. (12.5.3.4). A_{cv} shall be calculated using the thickness of the topping slab for noncomposite topping slab diaphragms and the combined thickness of cast-in-place and precast elements for composite topping slab diaphragms. For composite topping slab diaphragms, the value of f_c' in Eq. (12.5.3.3) and (12.5.3.4) shall not exceed the lesser of f_c' for the precast members and f_c' for the topping slab.
(b) V_n shall not exceed the value calculated in accordance with the shear-friction provisions of 22.9 considering the thickness of the topping slab above joints between precast elements in noncomposite and composite topping slab diaphragms and the reinforcement crossing the joints between the precast members.

12.5.3.6 For diaphragms that are interconnected precast elements without a concrete topping, and for diaphragms that are precast elements with end strips formed by either a cast-in-place concrete topping slab or edge beams, it shall be permitted to design for shear in accordance with (a), (b), or both.

(a) The nominal strength of grouted joints shall not exceed 80 psi. Reinforcement shall be designed to resist shear through shear-friction in accordance with 22.9. Shear-friction reinforcement shall be in addition to reinforcement designed to resist tension due to moment and axial force.
(b) Mechanical connectors crossing joints between precast elements shall be designed to resist required shear under anticipated joint opening.

12.5.3.7 For any diaphragm, where shear is transferred from the diaphragm to a collector, or from the diaphragm or

COMMENTARY

R12.5.3.5 For diaphragms with cast-in-place topping slab on precast elements, the effective thickness in 12.5.3.5(a) is reduced to the topping slab thickness if the topping slab is not composite with the precast elements. Topping slabs tend to develop cracks above and along the joints between precast elements. Thus, 12.5.3.5(b) limits the shear strength to the shear-friction strength of the topping slab above the joints between the precast elements.

R12.5.3.6 ACI CODE-318 does not contain provisions for untopped diaphragms in buildings assigned to Seismic Design Categories D, E, and F. Diaphragm shear in untopped diaphragms can be resisted by using shear-friction reinforcement in grouted joints (FEMA P-751). Required shear-friction reinforcement is in addition to reinforcement required by design to resist other tensile forces in the diaphragm, such as those due to diaphragm moment and axial force, or due to collector tension. The intent is to reduce joint opening while simultaneously resisting shear through shear-friction. Alternatively, or additionally, mechanical connectors can be used to transfer shear across joints of precast elements. In this case, some joint opening should be anticipated. The mechanical connectors should be capable of maintaining design strength under anticipated joint opening.

R12.5.3.7 In addition to having adequate shear strength within its plane, a diaphragm should be reinforced to transfer shear through shear-friction or mechanical connectors to

CODE

collector to a vertical element of the lateral-force-resisting system, (a) or (b) shall apply:

(a) Where shear is transferred through concrete, the shear-friction provisions of 22.9 shall be satisfied.
(b) Where shear is transferred through mechanical connectors or dowels, effects of uplift and rotation of the vertical element of the lateral-force-resisting system shall be considered.

COMMENTARY

collectors and to vertical elements of the lateral-force-resisting system. In diaphragms that are entirely cast-in-place, reinforcement provided for other purposes usually is adequate to transfer force from the diaphragm into the collectors through shear-friction. However, additional reinforcement may be required to transfer diaphragm or collector shear into vertical elements of the lateral-force-resisting system through shear-friction. Figure R12.5.3.7 illustrates a common detail of dowels provided for this purpose.

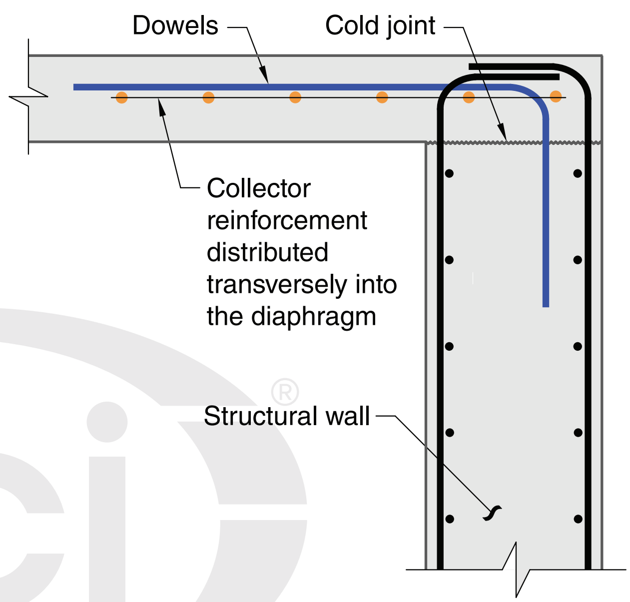

Fig. R12.5.3.7—Typical detail showing dowels provided for shear transfer to a structural wall through shear-friction.

12.5.4 *Collectors*

R12.5.4 *Collectors*

A collector is a region of a diaphragm that transfers forces between the diaphragm and a vertical element of the lateral-force-resisting system. A collector can extend transversely into the diaphragm to reduce nominal stresses and reinforcement congestion, as shown in Fig. R12.5.3.7. Where a collector width extends into the slab, the collector width on each side of the vertical element should not exceed approximately one-half the contact length between the collector and the vertical element.

12.5.4.1 Collectors shall extend from the vertical elements of the lateral-force-resisting system across all or part of the diaphragm depth as required to transfer shear from the diaphragm to the vertical element. It shall be permitted to discontinue a collector along lengths of vertical elements of the lateral-force-resisting system where transfer of design collector forces is not required.

R12.5.4.1 The design procedure in 12.5.1.3(a) models the diaphragm as a full-depth beam with uniform shear flow. If vertical elements of the lateral-force-resisting system do not extend the full depth of the diaphragm, then collectors are required to transfer shear acting along the remaining portions of the diaphragm depth to the vertical element, as shown in Fig. R12.5.4.1. Partial-depth collectors can also be considered, but a complete force path should be designed that is capable of transmitting all forces from the diaphragm to the collector and into the vertical elements (Moehle et al. 2010).

CODE | COMMENTARY

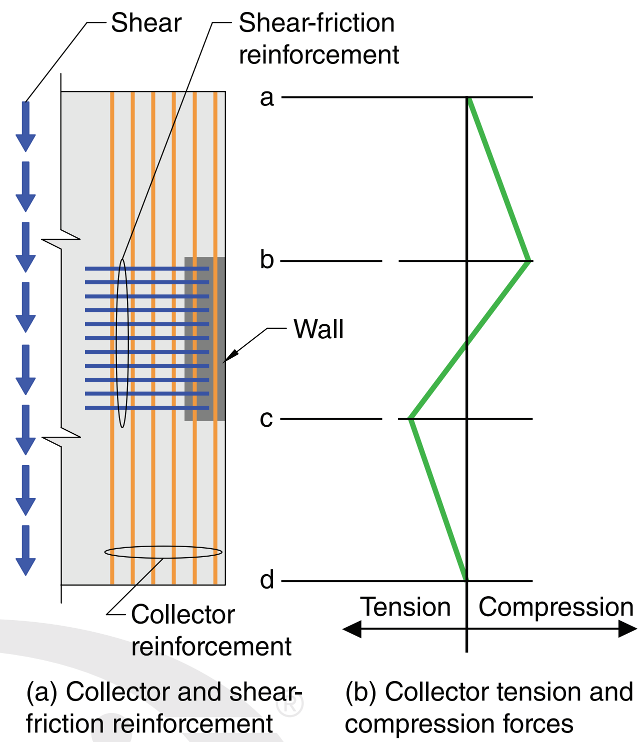

Fig. R12.5.4.1—Full-depth collector and shear-friction reinforcement required to transfer collector force into wall.

12.5.4.2 Collectors shall be designed as tension members, compression members, or both, in accordance with 22.4.

R12.5.4.2 Tension and compression forces in a collector are determined by the diaphragm shear forces they transmit to the vertical elements of the lateral-force-resisting system (refer to Fig. R12.5.4.1). Except as required by 18.12.7.6, the Code does not require that collectors resisting design compressive forces be detailed as columns. However, in structures where collectors resist large compressive forces compared with axial strength, or are designed as struts passing adjacent to edges or openings, detailing with transverse reinforcement similar to column hoops should be considered. Such detailing is required by 18.12.7.6 for some diaphragms in buildings assigned to Seismic Design Categories D, E, and F.

12.5.4.3 Where a collector is designed to transfer forces to a vertical element, collector reinforcement shall extend along the vertical element at least the greater of (a) and (b):

(a) The length required to develop the reinforcement in tension
(b) The length required to transmit the design forces to the vertical element through shear-friction in accordance with 22.9, through mechanical connectors, or through other force transfer mechanisms

R12.5.4.3 In addition to having sufficient development length, the collector reinforcement should be extended as needed to fully transfer its forces into the vertical elements of the lateral-force-resisting system. A common practice is to extend some of the collector reinforcement the full length of the vertical element, such that collector forces can be transmitted uniformly through shear-friction (refer to Fig. R12.5.4.1). Figure R12.5.4.3 shows an example of collector reinforcement extended as required to transfer forces into three frame columns.

CODE

COMMENTARY

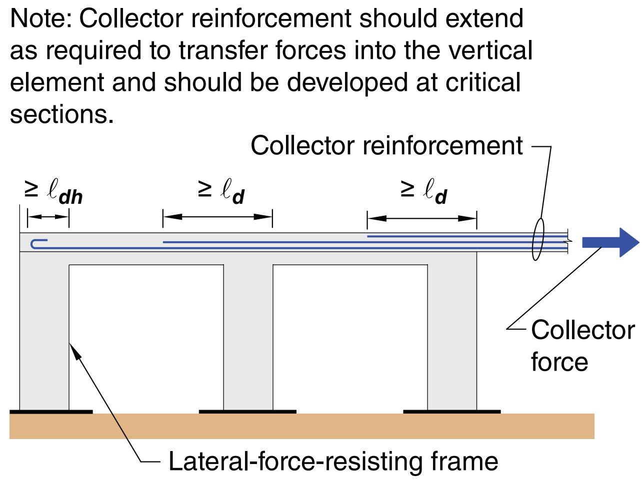

Fig. R12.5.4.3—Schematic force transfer from collector into vertical element of the lateral-force-resisting system.

12.6—Reinforcement limits

12.6.1 Except for slabs-on-ground, diaphragms shall satisfy reinforcement limits for one-way slabs in accordance with 7.6 or two-way slabs in accordance with 8.6, as applicable.

12.6.2 For diaphragms that comprise a cast-in-place topping slab on precast elements, the topping slab shall be reinforced in accordance with 24.4 in each direction.

12.6.3 Reinforcement designed to resist diaphragm in-plane forces shall be in addition to reinforcement designed to resist other load effects, except reinforcement designed to resist shrinkage and temperature load effects shall be permitted to also resist diaphragm in-plane forces

R12.6—Reinforcement limits

R12.6.1 Minimum reinforcement for diaphragms that comprise a cast-in-place topping on steel decking can be found in SDI SD.

12.7—Reinforcement detailing

12.7.1 *General*

12.7.1.1 Concrete cover for reinforcement shall be in accordance with 20.5.1.

12.7.1.2 Development lengths of deformed and prestressed reinforcement shall be in accordance with 25.4, unless longer lengths are required by Chapter 18.

12.7.1.3 Splices of deformed reinforcement shall be in accordance with 25.5.

12.7.1.4 Bundled bars shall be in accordance with 25.6.

12.7.2 *Reinforcement spacing*

12.7.2.1 Minimum spacing s of reinforcement shall be in accordance with 25.2.

R12.7—Reinforcement detailing

R12.7.1 *General*

R12.7.1.1 For a structure assigned to Seismic Design Category D, E, or F, concrete cover may be governed by the requirements of 18.12.7.7.

R12.7.2 *Reinforcement spacing*

R12.7.2.1 For a structure assigned to Seismic Design Category D, E, or F, spacing of confining reinforcement in collectors may be governed by the requirements of 18.12.7.6

CODE

12.7.2.2 Maximum spacing *s* of deformed reinforcement shall be the lesser of five times the diaphragm thickness and 18 in.

12.7.3 *Diaphragm and collector reinforcement*

12.7.3.1 Except for slabs-on-ground, diaphragms shall satisfy reinforcement detailing of one-way slabs in accordance with 7.7 or two-way slabs in accordance with 8.7, as applicable.

12.7.3.2 Calculated tensile or compressive force in reinforcement at each section of the diaphragm or collector shall be developed on each side of that section.

12.7.3.3 Reinforcement provided to resist tension shall extend beyond the point at which it is no longer required to resist tension at least ℓ_d, except at diaphragm edges and at expansion joints.

COMMENTARY

R12.7.3 *Diaphragm and collector reinforcement*

R12.7.3.2 Critical sections for development of reinforcement generally are at points of maximum stress, at points where adjacent terminated reinforcement is no longer required to resist design forces, and at other points of discontinuity in the diaphragm.

R12.7.3.3 For a beam, the Code requires flexural reinforcement to extend the greater of d and $12d_b$ past points where it is no longer required for flexure. These extensions are important for a beam to protect against development or shear failure that could result from inaccuracies in calculated locations of tensile stress. Similar failures in diaphragms have not been reported. To simplify design and avoid excessively long bar extensions that could result if the beam provisions were applied to diaphragms, this provision only requires that tension reinforcement extend ℓ_d beyond points where it is no longer required to resist tension.

Notes