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14.4.3.3 *Factored one-way shear*

14.4.3.3.1 For one-way shear, critical sections shall be located h from (a) and (b), where h is the footing thickness.

(a) Location defined in Table 14.4.3.2.1
(b) Face of concentrated loads or reaction areas

14.4.3.3.2 Sections between (a) or (b) of 14.4.3.3.1 and the critical section for shear shall be permitted to be designed for V_u at the critical section for shear.

14.4.3.4 *Factored two-way shear*

14.4.3.4.1 For two-way shear, critical sections shall be located so that the perimeter b_o is a minimum but need not be closer than $h/2$ to (a) through (c):

(a) Location defined in Table 14.4.3.2.1
(b) Face of concentrated loads or reaction areas
(c) Changes in footing thickness

14.4.3.4.2 For square or rectangular columns, concentrated loads, or reaction areas, the critical section for two-way shear shall be permitted to be calculated assuming straight sides.

R14.4.3.4 *Factored two-way shear*

R14.4.3.4.1 The critical section defined in this provision is similar to that defined for reinforced concrete elements in 22.6.4.1, except that for plain concrete, the critical section is based on h rather than d.

14.5—Design strength

14.5.1 *General*

14.5.1.1 For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$, including (a) through (d). Interaction between load effects shall be considered.

(a) $\phi M_n \geq M_u$
(b) $\phi P_n \geq P_u$
(c) $\phi V_n \geq V_u$
(d) $\phi B_n \geq B_u$

14.5.1.2 ϕ shall be determined in accordance with 21.2.

14.5.1.3 Tensile strength of concrete shall be permitted to be considered in design.

R14.5—Design strength

R14.5.1 *General*

R14.5.1.1 Refer to R9.5.1.1.

R14.5.1.2 The strength reduction factor ϕ for plain concrete design is the same for all strength conditions. Because both flexural tensile strength and shear strength for plain concrete depend on the tensile strength characteristics of the concrete, with no reserve strength or ductility possible due to the absence of reinforcement, equal strength reduction factors for both bending and shear are considered appropriate.

R14.5.1.3 Flexural tension may be considered in design of plain concrete members to resist loads, provided the calculated stress does not exceed the permissible stress, and construction, contraction, or isolation joints are provided to relieve the resulting tensile stresses due to restraint of creep, shrinkage, and temperature effects.

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14.5.1.4 Flexure and axial strength calculations shall be based on a linear stress-strain relationship in both tension and compression.

14.5.1.5 λ for lightweight concrete shall be in accordance with 19.2.4.

14.5.1.6 No strength shall be assigned to steel reinforcement.

14.5.1.7 When calculating member strength in flexure, combined flexure and axial load, or shear, the entire cross section shall be considered in design, except for concrete cast against soil where overall thickness h shall be taken as 50 mm less than the specified thickness.

14.5.1.8 Unless demonstrated by analysis, horizontal length of wall to be considered effective for resisting each vertical concentrated load shall not exceed center-to-center distance between loads, or bearing width plus four times the wall thickness.

14.5.2 *Flexure*

14.5.2.1 M_n shall be the lesser of Eq. (14.5.2.1a) calculated at the tension face and Eq. (14.5.2.1b) calculated at the compression face:

$$M_n = 0.42\lambda\sqrt{f_c'}S_m \quad (14.5.2.1a)$$

$$M_n = 0.85f_c'S_m \quad (14.5.2.1b)$$

where S_m is the corresponding elastic section modulus.

14.5.3 *Axial compression*

14.5.3.1 P_n shall be calculated by:

$$P_n = 0.60f_c'A_g\left[1-\left(\frac{\ell_c}{32h}\right)^2\right] \quad (14.5.3.1)$$

14.5.4 *Flexure and axial compression*

14.5.4.1 Unless permitted by 14.5.4.2, member dimensions shall be proportioned to be in accordance with Table 14.5.4.1, where M_n is calculated in accordance with Eq. (14.5.2.1b) and P_n is calculated in accordance with Eq. (14.5.3.1).

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R14.5.1.7 The reduced overall thickness h for concrete cast against earth is to allow for unevenness of excavation and for some contamination of the concrete adjacent to the soil.

R14.5.2 *Flexure*

R14.5.2.1 Equation (14.5.2.1b) may control for nonsymmetrical cross sections.

R14.5.3 *Axial compression*

R14.5.3.1 Equation (14.5.3.1) is presented to reflect the general range of braced and restrained end conditions encountered in plain concrete elements. The effective length factor was omitted as a modifier of ℓ_c, the vertical distance between supports, because this is conservative for walls with assumed pin supports that are required to be braced against lateral translation as in 14.2.2.2.

R14.5.4 *Flexure and axial compression*

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Table 14.5.4.1—Combined flexure and axial compression

Location	Interaction equation	
Tension face	$\frac{M_u}{S_m} - \frac{P_u}{A_g} \leq 0.42\phi\lambda\sqrt{f_c'}$	(a)
Compression face	$\frac{M_u}{\phi M_n} + \frac{P_u}{\phi P_n} \leq 1.0$	(b)

14.5.4.2 For walls of solid rectangular cross section where $M_u \leq P_u(h/6)$, M_u need not be considered in design and P_n is calculated by:

$$P_n = 0.45 f_c' A_g \left[1 - \left(\frac{\ell_c}{32h}\right)^2\right] \quad (14.5.4.2)$$

R14.5.4.2 If the resultant load falls within the middle third of the wall thickness, plain concrete walls may be designed using the simplified Eq. (14.5.4.2). Eccentric loads and lateral forces are used to determine the total eccentricity of the factored axial force P_u. Equation (14.5.4.2) reflects the range of braced and restrained end conditions encountered in wall design. The limitations of 14.2.2.2, 14.3.1.1, and 14.5.1.8 apply whether the wall is proportioned by 14.5.4.1 or by 14.5.4.2.

14.5.5 *Shear*

14.5.5.1 V_n shall be calculated in accordance with Table 14.5.5.1.

Table 14.5.5.1—Nominal shear strength

Shear action	Nominal shear strength V_n		
One-way	$0.11\lambda\sqrt{f_c'}b_w h$		(a)
Two-way	Lesser of:	$0.11\left(1+\frac{2}{\beta}\right)\lambda\sqrt{f_c'}b_o h$ [1]	(b)
		$0.22\lambda\sqrt{f_c'}b_o h$	(c)

[1]β is the ratio of long side to short side of concentrated load or reaction area.

R14.5.5 *Shear*

R14.5.5.1 Proportions of plain concrete members usually are controlled by tensile strength rather than shear strength. Shear stress (as a substitute for principal tensile stress) rarely will control. However, because it is difficult to foresee all possible conditions where shear may have to be investigated, such as shear keys, Committee 318 maintains the investigation of this basic stress condition.

The shear requirements for plain concrete assume an uncracked section. Shear failure in plain concrete will be a diagonal tension failure, occurring when the principal tensile stress near the centroidal axis becomes equal to the tensile strength of the concrete. Because the major portion of the principal tensile stress results from shear, the Code safeguards against tension failure by limiting the permissible shear at the centroidal axis as calculated from the equation for a section of homogeneous material:

$$v = VQ/Ib$$

where v and V are the shear stress and shear force, respectively, at the section considered; Q is the statical moment of the area above or below the centroid of the gross section calculated about the centroidal axis; I is the moment of inertia of the gross section; and b is the section width where shear stress is being calculated.

14.5.6 *Bearing*

14.5.6.1 B_n shall be calculated in accordance with Table 14.5.6.1.

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Table 14.5.6.1—Nominal bearing strength

Relative geometric conditions	B_n		
Supporting surface is wider on all sides than the loaded area	Lesser of:	$\sqrt{A_2/A_1}(0.85f_c'A_1)$	(a)
		$2(0.85f_c'A_1)$	(b)
Other	$0.85f_c'A_1$		(c)

14.6—Reinforcement detailing

14.6.1 At least two No. 16 bars shall be provided around window, door, and similarly sized openings. Such bars shall extend at least 600 mm beyond the corners of openings or shall be anchored to develop f_y in tension at the corners of the openings.

CHAPTER 15—BEAM-COLUMN AND SLAB-COLUMN JOINTS

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15.1—Scope

15.1.1 This chapter shall apply to the design and detailing of cast-in-place beam-column and slab-column joints.

15.2—General

15.2.1 Beam-column joints shall satisfy the detailing provisions of 15.3 and strength requirements of 15.4.

15.2.2 Beam-column and slab-column joints shall satisfy 15.5 for transfer of column axial force through the floor system.

15.2.3 If gravity load, wind, earthquake, or other lateral forces cause transfer of moment at beam-column joints, the shear resulting from moment transfer shall be considered in the design of the joint.

15.2.4 At corner joints between two members, the effects of closing and opening moments within the joint shall be considered.

15.2.5 If a beam framing into the joint and generating joint shear has depth exceeding twice the column depth, analysis and design of the joint shall be based on the strut-and-tie method in accordance with Chapter 23 and (a) and (b) shall be satisfied:

(a) Design joint shear strength determined in accordance with Chapter 23 shall not exceed ϕV_n calculated in accordance with 15.4.2.
(b) Detailing provisions of 15.3 shall be satisfied.

15.2.6 A column extension assumed to provide continuity through a beam-column joint in the direction of joint shear considered shall satisfy (a) and (b):

(a) The column extends above the joint at least one column depth, h, measured in the direction of joint shear considered.
(b) Longitudinal and transverse reinforcement from the column below the joint is continued through the extension.

15.2.7 A beam extension assumed to provide continuity through a beam-column joint in the direction of joint shear considered shall satisfy (a) and (b):

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R15.1—Scope

A joint is the portion of a structure common to intersecting members, whereas a connection is comprised of a joint and portions of adjoining members. Chapter 15 is focused on design requirements for beam-to-column and slab-to-column joints.

For structures assigned to Seismic Design Categories (SDC) B through F, joints may be required to withstand several reversals of loading. Chapter 18 provides requirements for earthquake-resistant structures that are applied in addition to the basic requirements for joints in Chapter 15.

R15.2—General

Tests of joints with extensions of beams with lengths at least equal to their depths have indicated similar joint shear strengths to those of joints with continuous beams. These findings suggest that extensions of beams and columns, when properly dimensioned and reinforced with longitudinal and transverse bars, provide effective confinement to the joint faces (Meinheit and Jirsa 1981). Extensions that provide beam and column continuity through a joint do not contribute to joint shear force if they do not support externally applied loads.

Tests (Hanson and Conner 1967) have shown that beam-column joints laterally supported on four sides by beams of approximately equal depth exhibit superior behavior compared to joints without all four faces confined by beams under reversed cyclic loading.

Corner joints occur where two non-colinear members transfer moment and terminate at the joint. A roof-level exterior joint is an example of a corner joint between two members, also referred to as a knee joint. Corner joints are vulnerable to flexural failure from either closing or opening moments even if flexural strengths at the joint faces are sufficient. Considering transfer of moment across a diagonal section through a corner joint connecting to a cantilevered member is critical because the moment acting through the joint cannot be redistributed.

Chapter 23 provides requirements for design and detailing of corner joints when using the strut-and-tie method. Klein (2008) provides additional guidance on design of frame corners using the strut-and-tie method. The requirements for transverse reinforcement in corner joints are given in 15.3. ACI 352R provides additional guidance on detailing of joints.

For joints in which the beam depth is significantly greater than the column depth a diagonal strut between the joint corners may not be effective. Therefore, the Code requires that joints in which the beam depth exceeds twice the column depth be designed using the strut-and-tie method of Chapter 23.

Transfer of bending through joints between slabs and corner or edge columns is covered in Chapter 8.

In the 2019 Code, classification of beam and column members framing into joint faces was modified to distin-

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(a) The beam extends at least one beam depth h beyond the joint face.
(b) Longitudinal and transverse reinforcement from the beam on the opposite side of the joint is continued through the extension.

15.2.8 A beam-column joint shall be considered to be confined for the direction of joint shear considered if two transverse beams satisfying (a), (b), and (c) are provided:

(a) Width of each transverse beam is at least three-quarters of the width of the column face into which the beam frames
(b) Transverse beams extend at least one beam depth h beyond the joint faces
(c) Transverse beams contain at least two continuous top and bottom bars satisfying 9.6.1.2 and No. 10 or larger stirrups satisfying 9.6.3.4 and 9.7.6.2.2

15.2.9 For slab-column connections transferring moment, strength and detailing requirements shall be in accordance with applicable provisions in Chapter 8 and Sections 15.3.2 and 22.6.

15.3—Detailing of joints

15.3.1 *Beam-column joint transverse reinforcement*

15.3.1.1 Beam-column joints shall satisfy 15.3.1.2 through 15.3.1.4 unless (a) through (c) are satisfied:

(a) Joint is considered confined by transverse beams in accordance with 15.2.8 for all shear directions considered
(b) Joint is not part of a designated seismic-force-resisting system
(c) Joint is not part of a structure assigned to SDC D, E, or F

15.3.1.2 Joint transverse reinforcement shall consist of ties, spirals, or hoops satisfying the requirements of 25.7.2 for ties, 25.7.3 for spirals, and 25.7.4 for hoops.

15.3.1.3 At least two layers of horizontal transverse reinforcement shall be provided within the depth of the shallowest beam framing into the joint.

15.3.1.4 Spacing of joint transverse reinforcement s shall not exceed 200 mm within the depth of the deepest beam framing into the joint.

15.3.2 *Slab-column joint transverse reinforcement*

15.3.2.1 Except where laterally supported on four sides by a slab, column transverse reinforcement shall be continued through a slab-column joint, including column capital, drop panel, and shear cap, in accordance with 25.7.2 for ties, 25.7.3 for spirals, and 25.7.4 for hoops.

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guish those members contributing to joint shear from those that do not contribute to joint shear but may serve to confine the joint. For a given joint shear direction, lateral confinement is provided by transverse beams while the width of the beams generating joint shear is accounted for through the effective joint width in 15.4.2.4. These classifications are made for the purpose of establishing nominal joint shear strength in Tables 15.4.2.3 and 18.8.4.3. For beam-column joints with circular columns, the column width and depth may be taken as those of a square section of equivalent area.

R15.3—Detailing of joints

R15.3.1 *Beam-column joint transverse reinforcement*

Tests (Hanson and Connor 1967) have shown that the joint region of a beam-to-column connection in the interior of a building does not require shear reinforcement if the joint is laterally supported on four sides by beams of approximately equal depth. However, joints that are not restrained in this manner, such as at the exterior of a building, require shear reinforcement to prevent deterioration due to shear cracking (ACI 352R). These joints may also require transverse reinforcement to prevent buckling of longitudinal column reinforcement.

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15.3.3 *Longitudinal reinforcement*

15.3.3.1 Development of longitudinal reinforcement terminated in the joint or within a column or beam extension, as defined in 15.2.6(a) and 15.2.7(a), shall be in accordance with 25.4.

15.3.3.2 Longitudinal reinforcement terminated in the joint with a standard hook shall have the hook turned toward mid-depth of the beam or column.

15.4—Strength requirements for beam-column joints

15.4.1 *Required shear strength*

15.4.1.1 Joint shear force V_u shall be calculated on a plane at mid-height of the joint using flexural tensile and compressive beam forces and column shear consistent with (a) or (b):

(a) The maximum moment transferred between the beam and column as determined from factored-load analysis for beam-column joints with continuous beams in the direction of joint shear considered
(b) Beam nominal moment strengths M_n

15.4.2 *Design shear strength*

15.4.2.1 Design shear strength of cast-in-place beam-column joints shall satisfy:

$$\phi V_n \geq V_u$$

15.4.2.2 ϕ shall be in accordance with 21.2.1 for shear.

15.4.2.3 V_n of the joint shall be calculated in accordance with Table 15.4.2.3.

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R15.3.3 *Longitudinal reinforcement*

R15.3.3.1 Where bars are continued through an unloaded extension at the opposite face, the bar length within the extension can be considered as part of the development length.

R15.4—Strength requirements for beam-column joints

Joint shear strength is evaluated separately in each principal direction of loading in accordance with 15.4.

R15.4.2 *Design shear strength*

The effective area of the joint, A_j, is illustrated in Fig. R15.4.2. In no case is A_j greater than the column cross-sectional area. A circular column may be considered as having a square section of equal area. The varied levels of shear strength provided by 15.4.2.3 are based on the recommendations of ACI 352R, although it is noted that the ACI 352R definition of effective cross-sectional joint area is sometimes different than A_j. Values of effective joint width calculated using ACI 352R and ACI 318, however, are the same or similar for many design situations.

15 Joints

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Table 15.4.2.3—Nominal joint shear strength V_n

Column	Beam in direction of V_u	Confinement by transverse beams according to 15.2.8	V_n, N[1]
Continuous or meets 15.2.6	Continuous or meets 15.2.7	Confined	$2.0\lambda\sqrt{f_c'}A_j$
		Not confined	$1.7\lambda\sqrt{f_c'}A_j$
	Other	Confined	$1.7\lambda\sqrt{f_c'}A_j$
		Not confined	$1.3\lambda\sqrt{f_c'}A_j$
Other	Continuous or meets 15.2.7	Confined	$1.7\lambda\sqrt{f_c'}A_j$
		Not confined	$1.3\lambda\sqrt{f_c'}A_j$
	Other	Confined	$1.3\lambda\sqrt{f_c'}A_j$
		Not confined	$1.0\lambda\sqrt{f_c'}A_j$

[1]λ shall be 0.75 for lightweight concrete and 1.0 for normalweight concrete.

15.4.2.4 Effective cross-sectional area within a joint, A_j, shall be calculated as the product of joint depth and effective joint width. Joint depth shall be the overall depth of the column, h, in the direction of joint shear considered. Effective joint width shall be the overall width of the column where the beam is wider than the column. Where the column is wider than the beam, effective joint width shall not exceed the lesser of (a) and (b):

(a) Beam width plus joint depth
(b) Twice the perpendicular distance from longitudinal axis of beam to nearest side face of the column

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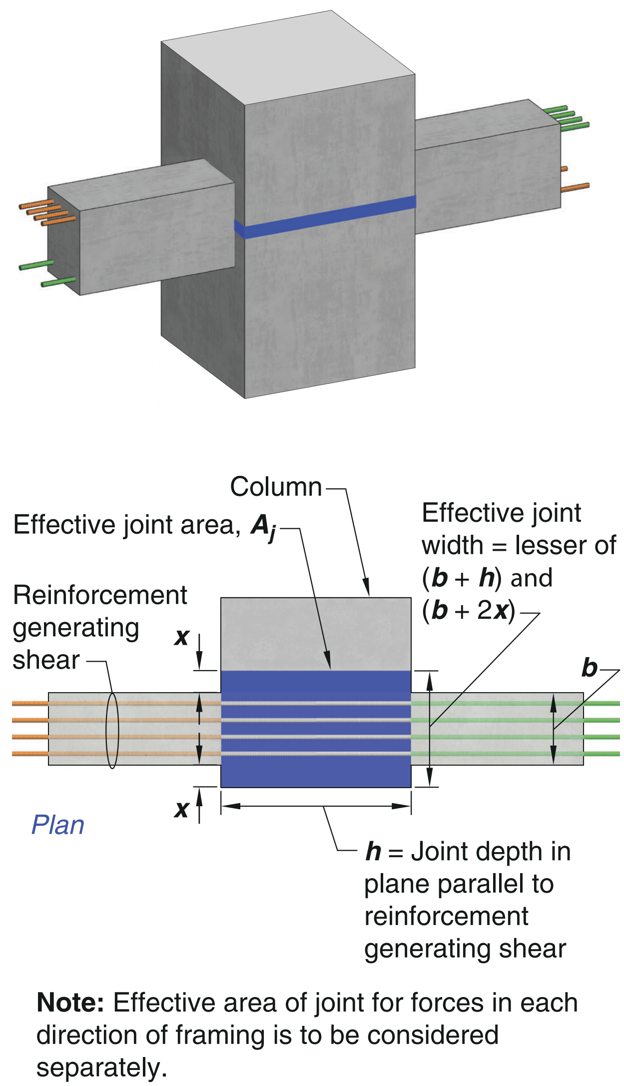

Fig. R15.4.2—Effective joint area.

15.5—Transfer of column axial force through the floor system

15.5.1 If f_c' of a floor system is less than $0.7f_c'$ of a column, transmission of axial force through the floor system shall be in accordance with (a), (b), or (c):

(a) Concrete of compressive strength specified for the column shall be placed in the floor system at the column location. Column concrete shall extend outward at least 600 mm into the floor system from face of column for the full depth of the floor system and be integrated with floor concrete.
(b) Design strength of a column through a floor system shall be calculated using the lower value of concrete strength with vertical dowels and transverse reinforcement as required to achieve design strength.
(c) For beam-column joints laterally supported on four sides by beams of approximately equal depth that satisfy

R15.5—Transfer of column axial force through the floor system

The requirements of this section consider the effect of floor system concrete strength on column axial strength (Bianchini et al. 1960). If floor system concrete strength is less than 70 percent of column concrete strength, methods in 15.5.1(a) or 15.5.1(b) may be applied to corner or edge columns. Methods in 15.5.1(a), (b), or (c) may be applied to interior columns.

Application of the concrete placement procedure described in 15.5.1(a) requires the placing of two different concrete mixtures in the floor system. The Code requires that column concrete be placed through the thickness of the floor system and that mixtures be placed and remain plastic such that the two can be vibrated so they are well integrated. Additional inspection may be required for this process. As required in Chapter 26, it is the responsibility of the licensed design professional to indicate on the construction docu-

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15.2.7 and 15.2.8(a) and for slab-column joints supported on four sides by the slab, it shall be permitted to calculate the design strength of the column using an assumed concrete strength in the column joint equal to 75 percent of column concrete strength plus 35 percent of floor system concrete strength, where the value of column concrete strength shall not exceed 2.5 times the floor system concrete strength.

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ments where the higher- and lower-strength concretes are to be placed.

Research (Ospina and Alexander 1998) has shown that heavily loaded slabs do not provide as much confinement as lightly loaded slabs when ratios of column concrete strength to slab concrete strength exceed approximately 2.5. Consequently, a limit is given in 15.5.1(c) on the ratio of concrete strengths assumed in design.

As an alternative to 15.5.1(a) or 15.5.1(c), 15.5.1(b) permits the use of dowel bars and confinement reinforcement to increase the effective compressive strength of concrete in the column core (Paultre and Légeron 2008; Richart et al. 1929).

Notes