CHAPTER 15—CAST-IN-PLACE JOINTS

15.1—Scope

15.1.1 This chapter shall apply to the design and detailing of cast-in-place joints including:

(a) Beam-column joints
(b) Slab-column joints.

R15.1—Scope

R15.1.1 A joint is the portion of a structure common to intersecting members, whereas a connection consists of a joint and portions of adjoining members. Chapter 15 is focused on design requirements for beam-to-column and slab-to-column joints. Transfer of moment and shear between slabs and columns is covered in Chapter 8 and 22.6.

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.

15.1.2 Transfer of axial force through the floor system shall be in accordance with 15.8.

15.2—General

15.2.1 Shear resulting from moment transfer in beam-column joints shall be considered in the design of the joint.

15.2.2 At corner joints, the effects of closing and opening moments within the joint shall be considered.

R15.2—General

R15.2.2 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 beam-column corner joints when using the strut-and-tie method. Klein (2008) provides additional guidance on design of corner joints using the strut-and-tie method. The requirements for transverse reinforcement in corner joints are given in 15.7. ACI PRC-352 provides additional guidance on detailing of joints.

15.2.3 *Materials*

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

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

15.3—Design limits

15.3.1 For a beam framing into the joint and generating joint shear, if the beam depth exceeds twice the column depth in the direction of joint shear, 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 15.5.
(b) Detailing provisions of 15.7 shall be satisfied.

R15.3—Design limits

R15.3.1 For joints in which the beam depth exceeds twice the column depth, a diagonal strut between the joint corners, as is assumed in the design method of 15.4, may not be effective. Therefore, the Code requires that such joints be designed using the strut-and-tie method considering the strut and tie angle limitations of 23.2.7.

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15.4—Required strength

15.4.1 *General*

15.4.1.1 Required strength shall be calculated in accordance with the factored load combinations in Chapter 5 and 15.4.2.

15.4.1.2 Required strength shall be calculated in accordance with the analysis procedures in Chapter 6.

15.4.2 *Factored shear in beam-column joint*

15.4.2.1 V_u for a beam-column joint shall be calculated on a plane at midheight 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 strength M_n

15.5—Design strength

15.5.1 *General*

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

$$\phi V_n \geq V_u$$

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R15.4—Required strength

R15.4.2 *Factored shear in beam-column joint*

R15.4.2.1 Joint shear strength is evaluated separately in each principal direction of loading in accordance with 15.4.

R15.5—Design strength

R15.5.1 *General*

R15.5.1.1 Joint shear strength is evaluated separately in each principal direction of loading in accordance with 15.4.

In the 2019 Code, classification of beam and column members framing into joint faces was modified to distinguish 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 15.5.2.2. The minimum cross-section requirements of transverse beams in 15.5.2.5(a) and (b) are illustrated in Fig. R15.5.1.1. These classifications are made for the purpose of establishing nominal joint shear strength in Tables 15.5.2.1 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.

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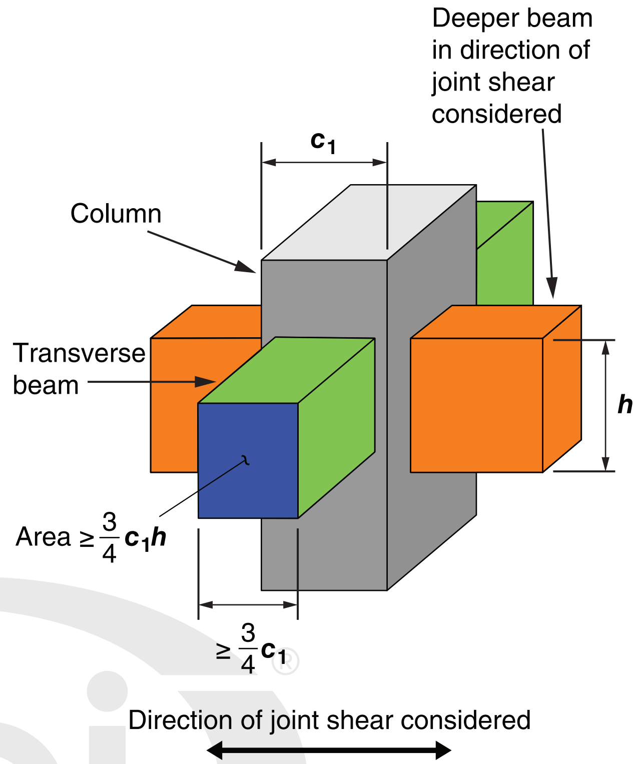

Fig. R15.5.1.1—Minimum cross-section requirements of transverse beams for confinement purposes

15.5.1.2 ϕ shall be determined in accordance with 21.2.1 for shear.

15.5.2 *Shear strength of beam-column joints*

15.5.2.1 V_n of a beam-column joint shall be calculated in accordance with Table 15.5.2.1.

Table 15.5.2.1—Beam-column joint nominal shear strength V_n

Column	Beam in direction of V_u	Confinement by transverse beams according to 15.5.2.5	V_n, lb[1]
Continuous or meets 15.5.2.3	Continuous or meets 15.5.2.4	Confined	$24\lambda\sqrt{f_c'}A_j$
		Not confined	$20\lambda\sqrt{f_c'}A_j$
	Other	Confined	$20\lambda\sqrt{f_c'}A_j$
		Not confined	$15\lambda\sqrt{f_c'}A_j$
Other	Continuous or meets 15.5.2.4	Confined	$20\lambda\sqrt{f_c'}A_j$
		Not confined	$15\lambda\sqrt{f_c'}A_j$
	Other	Confined	$15\lambda\sqrt{f_c'}A_j$
		Not confined	$12\lambda\sqrt{f_c'}A_j$

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

R15.5.2 *Shear strength of beam-column joints*

15.5.2.2 Effective cross-sectional area within a beam-column joint, A_j, shall be calculated as the product of joint

R15.5.2.2 The effective area of the joint, A_j, is illustrated in Fig. R15.5.2.2. In no case is A_j greater than the column

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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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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 15.5.2.1 are based on the recommendations of ACI PRC-352, although it is noted that the ACI PRC-352 definition of effective cross sectional joint area is sometimes different than A_j. Values of effective joint width calculated using ACI PRC-352 and ACI CODE-318, however, are the same or similar for many design situations.

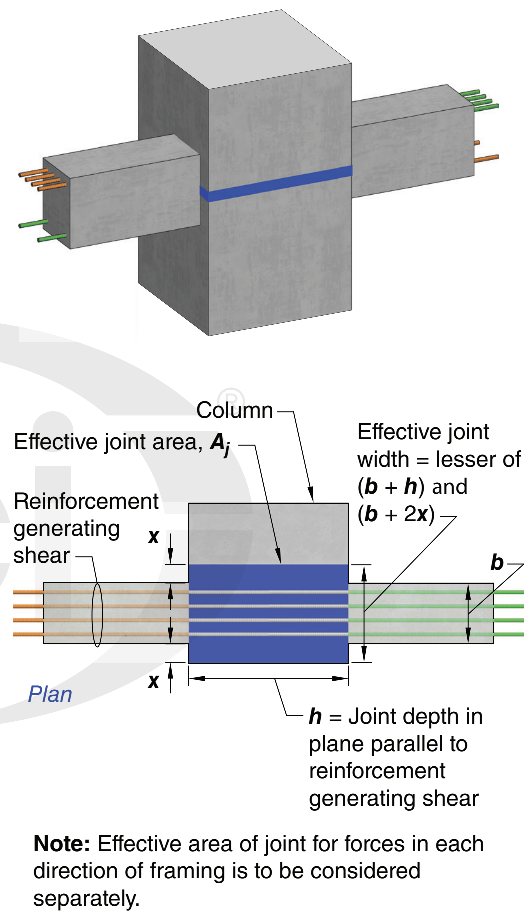

Fig. R15.5.2.2—Effective joint area.

15.5.2.3 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.

R15.5.2.3 and **R15.5.2.4** 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.

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

(a) The beam extends at least one beam depth h beyond the joint face.

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(b) Longitudinal and transverse reinforcement from the beam on the opposite side of the joint is continued through the extension.

15.5.2.5 A beam-column joint shall be considered to be confined for the direction of joint shear considered if two transverse beams satisfying (a) through (d) are provided:

(a) Each transverse beam covers at least three-quarters of the width of the column face into which it frames.
(b) Each transverse beam covers an area on the joint face that is at least three-quarters of the product of the width of the column face into which the transverse beam frames and the depth of the deeper beam in the direction of joint shear considered.
(c) Transverse beams extend at least one beam depth h beyond the joint faces.
(d) Transverse beams contain at least two continuous top and bottom bars satisfying 9.6.1.2 and No. 3 or larger stirrups satisfying 9.6.3.4 and 9.7.6.2.2.

15.6—Reinforcement limits

15.6.1 Column longitudinal reinforcement in joints shall satisfy 10.6.1.1. If the joint includes dowel reinforcement, the area of column longitudinal reinforcement considered shall include the area of the dowel bars.

15.7—Reinforcement detailing

15.7.1 *Beam-column joint transverse reinforcement*

15.7.1.1 Beam-column joints shall satisfy 15.7.1.2 through 15.7.1.4 unless (a) through (c) are satisfied:

(a) Joint is considered confined by transverse beams in accordance with 15.5.2.5 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

15.7.1.2 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.

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

15.7.1.4 Spacing of joint transverse reinforcement s shall not exceed 8 in. within the depth of the deepest beam framing into the joint.

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R15.5.2.5 Tests under reversed cyclic loading (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.

R15.6—Reinforcement limits

R15.6.1 Refer to R10.6.1.1.

R15.7—Reinforcement detailing

R15.7.1 *Beam-column joint transverse reinforcement*

R15.7.1.1 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 PRC-352). These joints may also require transverse reinforcement to prevent buckling of longitudinal column reinforcement.

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15.7.2 *Slab-column joint transverse reinforcement*

15.7.2.1 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.

15.7.3 *Beam-column joint longitudinal reinforcement*

15.7.3.1 Development of longitudinal reinforcement terminated in the joint or within a column or beam extension, as defined in 15.5.2.3(a) and 15.5.2.4(a), shall be in accordance with 25.4.

15.7.3.2 Longitudinal reinforcement terminated by a hook or a head in a joint shall extend as close as practicable to the far face of the joint core.

15.7.3.3 Longitudinal reinforcement terminated in the joint with a standard hook shall have the hook turned toward middepth of the beam or column.

15.8—Transfer of column axial force through the floor system

15.8.1 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 2 ft into the floor system from face of column for the full depth of the floor system and be integrated with floor concrete.

(b) Design axial strength of a column through a floor system shall be calculated using the lower value of concrete strength with vertical dowels that satisfy 15.6.1 and transverse reinforcement as required to achieve design strength.

(c) For beam-column joints laterally supported on four sides by beams that satisfy (i) or slab-column joints that satisfy (ii), design axial strength of the column through the floor system shall be permitted to be calculated using a 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 used in the calculation shall not exceed 2.5 times the floor system concrete strength.

(i) Each beam covers at least three-quarters of the column face width and at least 75 percent of an area equal to the product of the width of the column face into which it frames and the depth of the deepest beam framing into the joint.

(ii) Slab confines all four faces of the slab-column joint.

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R15.7.3 *Beam-column joint longitudinal reinforcement*

R15.7.3.1 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.

R15.7.3.2 Extending the bar to the far side of the column core helps engage the entire joint in resisting the anchorage forces and improves joint performance.

R15.8—Transfer of column axial force through the floor system

R15.8.1 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 15.8.1(a) or 15.8.1(b) may be applied to corner or edge columns. Methods in 15.8.1(a), (b), or (c) may be applied to interior columns.

Application of the concrete placement procedure described in 15.8.1(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 documents where the higher- and lower-strength concretes are to be placed.

In joints with f_c' less than $0.7f_c'$ of the column, dowel reinforcement may be required for transmission of axial force in accordance with 15.8.1(b).

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 15.8.1(c) on the ratio of concrete strengths assumed in design.

As an alternative to 15.8.1(a) or 15.8.1(c), 15.8.1(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).