## Editions of Standards and the Building Code

This Guide follows the requirements of ACI 318-14, *Building Code Requirements for Structural Concrete* (ACI 2014), along with the pertinent requirements of the 2015 *International Building Code* (ICC 2015), and ASCE/SEI 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 2016). In this document, the terms ACI 318, IBC, and ASCE 7, used without a publication date, refer to these documents. These editions may not have been adopted yet by many jurisdictions. Design engineers are responsible for verifying the current applicable building code provisions adopted by the authority having jurisdiction over their project. Discussion with and approval by the building official should occur to verify that a later version of a code or standard not yet adopted locally may be used.

At the time of this writing, most jurisdictions in the United States have adopted the provisions of ACI 318-11, *Building Code Requirements for Structural Concrete* (ACI 2011). Most, though not all, of the technical requirements for special moment frames are the same in ACI 318-11 and ACI 318-14. Notable technical differences are (1) requirements for columns with high axial forces, (2) provisions on use of headed reinforcement in beam-column joints, and (3) restrictions on aspect ratio of beam-column joints. In terms of its format and organization, ACI 318-14 has been completely revised as compared with ACI 318-11, with most seismic provisions now appearing in Chapter 18.

Also as of this writing, most jurisdictions in the United States adopt ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2010). Most of the seismic requirements of ASCE 7-10 and ASCE 7-16 are the same. Notable technical differences that may affect the design of special moment frames include (1) modal response spectrum analysis must account for 100 percent of the mass of the structure; (2) modal response spectrum base shear is scaled to 100 percent of the equivalent lateral force base shear, not 85 percent; and (3) for structures with a Type 4 out-of-plane offset irregularity as defined in ASCE 7-16 Table 12.3-1, transfer forces are increased by the overstrength factor, $\Omega_o$. There are also many changes in Chapter 11 and Chapter 22 related to seismic maps and coefficients.

The First Edition of this Guide (NIST GCR 8-917-1) was published in August 2008. The codes and standards referenced in that edition were current as of then but have been updated by the documents referenced in this Second Edition. The First Edition, which may still be relevant in some engineering applications with regard to buildings constructed under the earlier editions of the codes and standards, references ACI 318-08, *Building Code Requirements for Structural Concrete* (ACI 2008), ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2006), and the 2006 *International Building Code* (ICC 2006).

beam | SMF

### 5.4.2 Beam Transverse Reinforcement

Beams in special moment frames are required to have either hoops or stirrups along their entire length. Hoops fully enclose the beam cross section and are provided to confine the concrete, restrain longitudinal bar buckling, improve bond between reinforcing bars and concrete, confine lap splices where present, and resist shear. Stirrups, which generally are not closed, are used where only shear resistance is required.

Beams of special moment frames can be divided into three different zones when considering where hoops or stirrups can be placed: the zones where flexural yielding is expected to occur, preferably at beam ends; the zone along lap-spliced bars, if any; and the remaining lengths of the beam.

The zones where plastic hinging is intended to occur, of length $2h_b$ on either side of the plastic hinge, needs to be well confined because this is where the beam is expected to undergo flexural yielding and, if yielding is at the beam ends, this is the location with the highest shear. Therefore, closely spaced, closed hoops are required in these zones, as shown in **Figure 5-13**. If flexural yielding is expected anywhere along the beam span other than the ends of the beam, hoops must extend $2h_b$ on both sides of that yielding location. This latter condition is one associated with non-reversing beam plastic hinges (see Section 5.2), and avoiding this condition is recommended. Subsequent discussion assumes that this type of behavior is avoided by design.

In BNBC 2020
s≦{300mm, 8×smallest longitudinal bar diameter, d/4, 24×hoop bar diameter}

SMF

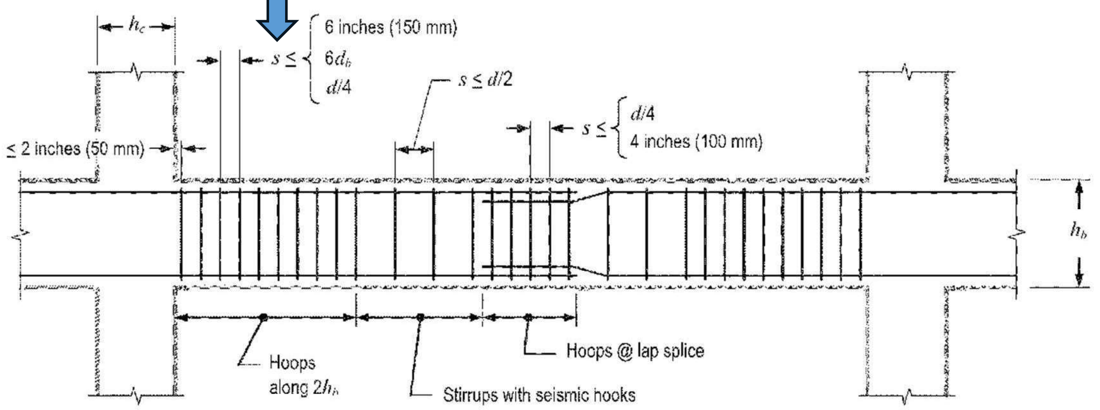


**Figure 5-13.** Hoop and stirrup location and spacing requirements.

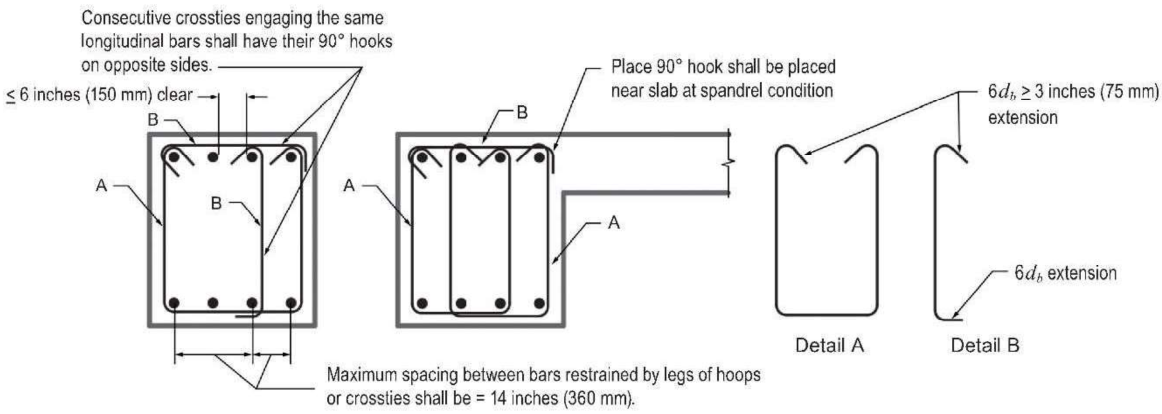


**Figure 5-14.** Hoop reinforcement detail.

## Placement of Hoops and Stirrups

Hoops are required along the beam end zones (where flexural yielding is expected) and along lap splices, with spacing limits as noted in **Figure 5-13**. Elsewhere, transverse reinforcement is required at a spacing not to exceed $d/2$ or $d/4$, depending on the level of shear, and is permitted to be in the form of beam stirrups with seismic hooks.

Where hoops are being provided at each end of a beam and along a reinforcement splice, there may not be much length of the beam left where stirrups are acceptable. Because of this aspect, and to prevent placement errors, it may be practical to extend the hoop detail and spacing over the entire length of the beam. A quick quantity comparison should be conducted to determine the difference in the amount of detailed reinforcement. Both the weight of reinforcement and the number of pieces to be placed in the field affect the cost and should be considered when specifying the hoops and stirrups. If a design with hoops and stirrups with different configurations and spacing is specified, ironworkers and special inspectors need to have a clear understanding of the placement requirements. Some engineers take it upon themselves to communicate these unique conditions to the special inspector. This is typically most crucial early in the construction process when the first few levels of beams are constructed. Generally after the first few levels, the reinforcement pattern is properly replicated.

Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers, Second Edition

### 5.5.3 Shear and Confinement Reinforcement

Transverse reinforcement is required in columns to (a) confine the core concrete, (b) provide lateral support to longitudinal reinforcement, (c) confine longitudinal reinforcement lap splices, and (d) provide shear strength. To perform these various functions, the required reinforcement varies over the column length, as illustrated in **Figure 5-18**. The provided transverse reinforcement can simultaneously serve as confinement reinforcement, longitudinal bar support, lap splice confinement, and shear reinforcement. It is not required to sum the reinforcement required for each purpose, but, instead, independently satisfy all the requirements.

The column transverse reinforcement should initially be selected based on the confinement requirements of ACI 318 §18.7.5. These confinement requirements apply at the ends of the column where flexural yielding may occur, along a length $\ell_o$ (**Figure 5-18**). For rectangular cross sections, the total cross-sectional area of rectangular hoop reinforcement in each principal direction of the column cross section is not to be less than that required by the equations in **Table 5-1**. Of the applicable equations (a), (b), and (c), the required confinement is determined by the expression that gives the larger/largest amount.

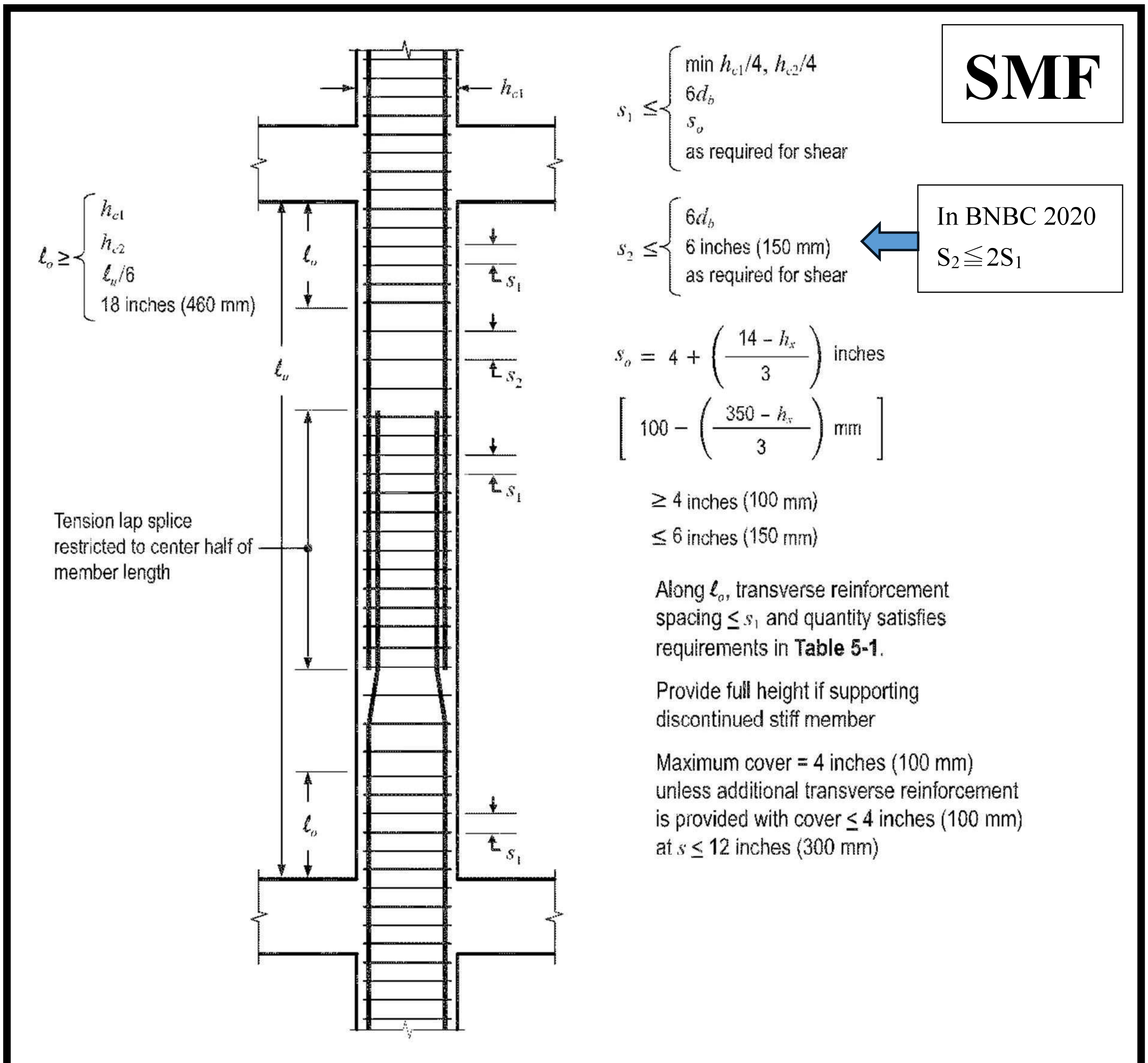


**Figure 5-18.** Column transverse reinforcement spacing requirements.

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| Conditions | Applicable Equations | |
|---|---|---|
| $P_u \leq 0.3A_g f'_c$ and $f'_c \leq 10{,}000$ psi (70 MPa) | (a) and (b) | $\frac{A_{sh}}{sb_c} \geq 0.3\left(\frac{A_g}{A_{ch}} - 1\right)\frac{f'_c}{f_{yt}}$ (a) <br> $\frac{A_{sh}}{sb_c} \geq 0.09\frac{f'_c}{f_{yt}}$ (b) <br> $\frac{A_{sh}}{sb_c} \geq 0.2\,k_f k_n \frac{P_u}{f_{yt}A_{ch}}$ (c) |
| $P_u > 0.3A_g f'_c$ or $f'_c > 10{,}000$ psi (70 MPa) | (a), (b), and (c) | |

**Table 5-1.** Required transverse reinforcement along lengths $\ell_o$ (ACI 318 §18.7.5.4).

In Equation (c) of **Table 5-1**, variables $k_f$ and $k_n$ are defined by

$$k_f = \frac{f'_c}{25{,}000} + 0.6 \geq 1.0 \text{ (psi)}$$

$$k_f = \frac{f'_c}{175} + 0.6 \geq 1.0 \text{ (MPa)}$$

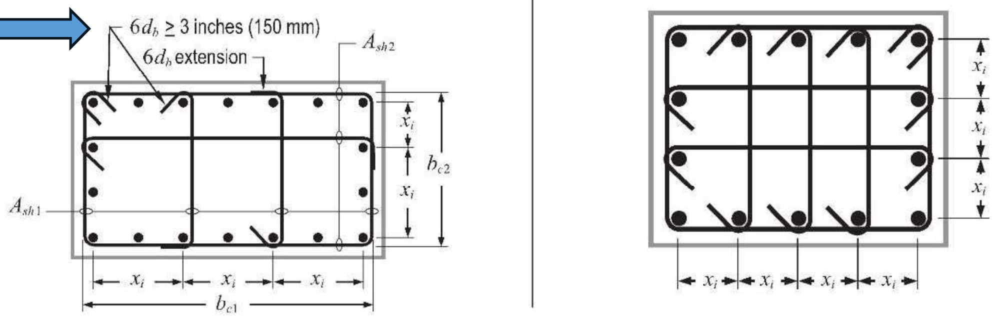
$$k_n = \frac{n_l}{n_l - 2}$$

where $n_l$ is the number of longitudinal bars or bar bundles around the perimeter of a column core that are laterally supported by the corner of hoops or by seismic hooks.

In addition to the requirements of **Table 5-1**, other confinement reinforcement detailing requirements also apply depending on the axial force and specified concrete compressive strength. If $P_u \leq 0.3A_g f'_c$ and $f'_c \leq 10{,}000$ psi (70 MPa), it is acceptable to support alternate longitudinal bars using crossties with 135° and 90° hooks, provided no unsupported bar is farther than 6 inches (150 mm) clear from a laterally supported bar, and supported bars are not more than 14 inches (360 mm) apart (**Figure 5-19a**). If $P_u > 0.3A_g f'_c$ or $f'_c > 10{,}000$ psi (70 MPa), then every longitudinal bar must be supported by a crosstie having included angle not less than 135° on both ends with maximum spacing between supported bars not exceeding 8 inches (200 mm) (**Figure 5-19b**).

- Every corner and alternate longitudinal bar shall have lateral support, and no bar shall be farther than 6 inches (150 mm) clear from a laterally supported bar.
- Consecutive crossties around the perimeter and along the length have their 90° hooks on opposite sides of column.
- The dimension $x_i$ from centerline to centerline of supported bars shall not exceed 14 inches (360 mm).

- Every longitudinal bar around the perimeter of the column core shall have lateral support, provided by the corner of a hoop or by a seismic hook.
- The dimension $x_i$ from centerline to centerline of supported bars shall not exceed 8 inches (200 mm).




(a) $P_u \leq 0.3A_g f'_c$ and $f'_c \leq 10{,}000$ psi (70 MPa)

(b) $P_u > 0.3A_g f'_c$ or $f'_c > 10{,}000$ psi (70 MPa)

**Figure 5-19.** Column transverse reinforcement detail (ACI 318 §18.7.5.2).

In BNBC 2020
6db ≧75mm

In BNBC 2020
There is no difference of reinforcement at the value of fc’

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## Column Hoop Spacing

Similar to the discussion on beam hoops and stirrups, when a lap splice of the vertical column reinforcement is present, there is often not much space left to take advantage of the more relaxed column hoop spacing outside the $\ell_o$ regions shown in **Figure 5-18**. For this reason, it is common practice to specify a uniform hoop spacing to prevent misplaced hoops during construction. Where bars are not spliced at every floor, perhaps every other floor, more economy can be realized by specifying a larger spacing between the $\ell_o$ regions. The benefit can be seen by counting the number of hoops that can be saved as the spacing is relaxed.

## Hoop Configuration

Column hoops (see **Figure 5-20**) should be configured with at least three hoop or crosstie legs restraining longitudinal bars along each face. A single perimeter hoop without crossties, although permitted by ACI 318 for small column cross sections, is discouraged because confinement effectiveness is low.

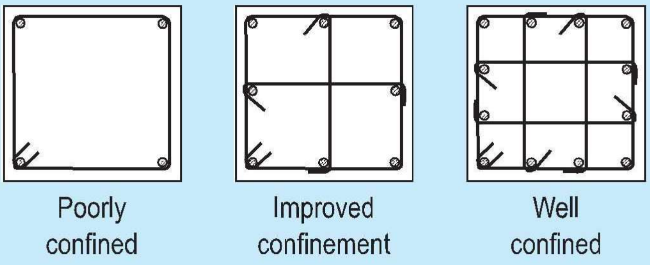


**Figure 5-20.** Column hoops.

ACI 318 does not permit the perimeter of a hoop to be made up of interlocking headed deformed bars because there are concerns about the heads becoming disengaged during construction or during an earthquake. ACI 318 is silent about the use of headed deformed bars as crossties. If used, the heads must fully engage the supported longitudinal reinforcement.

■Reference 04（ACI-318-19）

The use of IMF as part of Dual Systems assigned to SDC D is not the intent of ACI.



## CODE

**18.2.1.2** All members shall satisfy Chapters 1 to 17 and 19 to 26. Structures assigned to SDC B, C, D, E, or F also shall satisfy 18.2.1.3 through 18.2.1.7, as applicable. Where Chapter 18 conflicts with other chapters of this Code, Chapter 18 shall govern.

**18.2.1.3** Structures assigned to SDC B shall satisfy 18.2.2.

**18.2.1.4** Structures assigned to SDC C shall satisfy 18.2.2, 18.2.3, and 18.13.

**18.2.1.5** Structures assigned to SDC D, E, or F shall satisfy 18.2.2 through 18.2.8 and 18.12 through 18.14.

**18.2.1.6** Structural systems designated as part of the seismic-force-resisting system shall be restricted to those designated by the general building code, or determined by other authority having jurisdiction in areas without a legally adopted building code. Except for SDC A, for which Chapter 18 does not apply, (a) through (h) shall be satisfied for each structural system designated as part of the seismic-force-resisting system, in addition to 18.2.1.3 through 18.2.1.5:

(a) Ordinary moment frames shall satisfy 18.3

(b) Ordinary reinforced concrete structural walls need not satisfy any detailing provisions in Chapter 18, unless required by 18.2.1.3 or 18.2.1.4

(c) Intermediate moment frames shall satisfy 18.4

(d) Intermediate precast walls shall satisfy 18.5

(e) Special moment frames shall satisfy 18.2.3 through 18.2.8 and 18.6 through 18.8

(f) Special moment frames constructed using precast concrete shall satisfy 18.2.3 through 18.2.8 and 18.9

(g) Special structural walls shall satisfy 18.2.3 through 18.2.8 and 18.10

(h) Special structural walls constructed using precast concrete shall satisfy 18.2.3 through 18.2.8 and 18.11

**18.2.1.7** A reinforced concrete structural system not satisfying this chapter shall be permitted if it is demonstrated by experimental evidence and analysis that the proposed system will have strength and toughness equal to or exceeding those provided by a comparable reinforced concrete structure satisfying this chapter.

## COMMENTARY

Chapter 18 in addition to all other applicable requirements of this Code.

Sections 18.2.1.3 through 18.2.1.5 identify those parts of Chapter 18 that apply to the building based on its assigned SDC, regardless of the vertical elements of the seismic-force-resisting system. ASCE/SEI 7 defines the permissible vertical elements of the seismic-force-resisting system and applies where adopted. The remaining commentary of R18.2 summarizes the intent of ACI 318 regarding which vertical elements should be permissible in a building considering its SDC. Section 18.2.1.6 defines the requirements for the vertical elements of the seismic-force-resisting system.

The design and detailing requirements should be compatible with the level of inelastic response assumed in the calculation of the design earthquake forces. The terms “ordinary,” “intermediate,” and “special” are used to facilitate this compatibility. For any given structural element or system, the terms “ordinary,” “intermediate,” and “special,” refer to increasing requirements for detailing and proportioning, with expectations of increased deformation capacity. Structures assigned to SDC B are not expected to be subjected to strong ground motion, but instead are expected to experience low levels of ground motion at long time intervals. This Code provides some requirements for beam-column ordinary moment frames to improve deformation capacity.

Structures assigned to SDC C may be subjected to moderately strong ground motion. The designated seismic-force-resisting system typically comprises some combination of ordinary cast-in-place structural walls, intermediate precast structural walls, and intermediate moment frames. The general building code also may contain provisions for use of other seismic-force-resisting systems in SDC C. Provision 18.2.1.6 defines requirements for whatever system is selected.

Structures assigned to SDC D, E, or F may be subjected to strong ground motion. It is the intent of ACI Committee 318 that the seismic-force-resisting system of structural concrete buildings assigned to SDC D, E, or F be provided by special moment frames, special structural walls, or a combination of the two. In addition to 18.2.2 through 18.2.8, these structures also are required to satisfy requirements for continuous inspection (26.13.1.3), diaphragms and trusses (18.12), foundations (18.13), and gravity-load-resisting elements that are not designated as part of the seismic-force-resisting system (18.14). These provisions have been developed to provide the structure with adequate deformation capacity for the high demands expected for these seismic design categories.

The general building code may also permit the use of intermediate moment frames as part of dual systems for some buildings assigned to SDC D, E, or F. It is not the intent of ACI Committee 318 to recommend the use of intermediate moment frames as part of moment-resisting frame or dual systems in SDC D, E, or F. The general building code may also permit substantiated alternative or nonprescriptive designs or, with various supplementary provisions, the use

<comments>

According to the ACI 318-19, Structures assigned to SDC D may be subjected to strong ground motion. It is the intent of ACI Committee 318 that the seismic-force-resisting system of structural concrete buildings assigned to SDC D be provided by special moment frames, special structural walls, or a combination of the two.

Whereas, the use of intermediate moment frames as part of dual systems for some buildings assigned to SDC D is permitted but not recommended.

From the above explanation, it seems that designers can design the structures assigned to SDC D by SMF and IMF (but not recommended by ACI committee). Therefore, Part6 8.3.2 (b) (BNBC) says *"Structures assigned to seismic design category SDC D, all reinforced concrete structures shall satisfy the requirements of special seismic detailing as given in Sections 8.8.3 to 8.3.8…"*.

However, designers can design as IMF mentioned in BNBC table 6.2.19 and ACI 318-19.

Code and Commentary of the OMF of ACI



**CODE**

**18.2.7.1** Mechanical splices shall be classified as (a) or (b):

(a) Type 1 – Mechanical splice conforming to 25.5.7

(b) Type 2 – Mechanical splice conforming to 25.5.7 and capable of developing the specified tensile strength of the spliced bars

**18.2.7.2** Except for Type 2 mechanical splices on Grade 60 reinforcement, mechanical splices shall not be located within a distance equal to twice the member depth from the column or beam face for special moment frames or from critical sections where yielding of the reinforcement is likely to occur as a result of lateral displacements beyond the linear range of behavior. Type 2 mechanical splices on Grade 60 reinforcement shall be permitted at any location, except as noted in 18.9.2.1(c).

**18.2.8** *Welded splices in special moment frames and special structural walls*

**18.2.8.1** Welded splices in reinforcement resisting earthquake-induced forces shall conform to 25.5.7 and shall not be located within a distance equal to twice the member depth from the column or beam face for special moment frames or from critical sections where yielding of the reinforcement is likely to occur as a result of lateral displacements beyond the linear range of behavior.

**18.2.8.2** Welding of stirrups, ties, inserts, or other similar elements to longitudinal reinforcement required by design shall not be permitted.

## 18.3—Ordinary moment frames

**18.3.1** *Scope*

**18.3.1.1** This section shall apply to ordinary moment frames forming part of the seismic-force-resisting system.

**18.3.2** Beams shall have at least two continuous bars at both top and bottom faces. Continuous bottom bars shall have area not less than one-fourth the maximum area of bottom bars along the span. These bars shall be anchored to develop $f_y$ in tension at the face of support.

**18.3.3** Columns having unsupported length $\ell_u \leq 5c_1$ shall have $\phi V_n$ at least the lesser of (a) and (b):

(a) The shear associated with development of nominal moment strengths of the column at each restrained end of the unsupported length due to reverse curvature bending. Column flexural strength shall be calculated for the factored

**COMMENTARY**

**R18.2.8** *Welded splices in special moment frames and special structural walls*

**R18.2.8.1** Welding of reinforcement should be in accordance with AWS D1.4 as required in Chapter 26. The locations of welded splices are restricted because reinforcement tension stresses in yielding regions can exceed the strength requirements of 25.5.7. The restriction on welded splices applies to all reinforcement resisting earthquake effects, including transverse reinforcement.

**R18.2.8.2** Welding of crossing reinforcing bars can lead to local embrittlement of the steel. If welding of crossing bars is used to facilitate fabrication or placement of reinforcement, it should be done only on bars added for such purposes. The prohibition of welding crossing reinforcing bars does not apply to bars that are welded with welding operations under continuous, competent control, as in the manufacture of welded-wire reinforcement.

## R18.3—Ordinary moment frames

This section applies only to ordinary moment frames assigned to SDC B. The provisions for beam reinforcement are intended to improve continuity in the framing members and thereby improve lateral force resistance and structural integrity; these provisions do not apply to slab-column moment frames. The provisions for columns are intended to provide additional capacity to resist shear for columns with proportions that would otherwise make them more susceptible to shear failure under earthquake loading.

Code and Commentary of the IMF of ACI



**CODE**

axial force, consistent with the direction of the lateral forces considered, resulting in the highest flexural strength.

(b) The maximum shear obtained from design load combinations that include ***E***, with $\Omega_o E$ substituted for ***E***.

**18.3.4** Beam-column joints shall satisfy Chapter 15 with joint shear $V_u$ calculated on a plane at mid-height of the joint using tensile and compressive beam forces and column shear consistent with beam nominal moment strengths $M_n$.

## 18.4—Intermediate moment frames

**18.4.1** *Scope*

**18.4.1.1** This section shall apply to intermediate moment frames including two-way slabs without beams forming part of the seismic-force-resisting system.

**18.4.2** *Beams*

**18.4.2.1** Beams shall have at least two continuous bars at both top and bottom faces. Continuous bottom bars shall have area not less than one-fourth the maximum area of bottom bars along the span. These bars shall be anchored to develop $f_y$ in tension at the face of support.

**18.4.2.2** The positive moment strength at the face of the joint shall be at least one-third the negative moment strength provided at that face of the joint. Neither the negative nor the positive moment strength at any section along the length of the beam shall be less than one-fifth the maximum moment strength provided at the face of either joint.

**18.4.2.3** $\phi V_n$ shall be at least the lesser of (a) and (b):

(a) The sum of the shear associated with development of nominal moment strengths of the beam at each restrained end of the clear span due to reverse curvature bending and the shear calculated for factored gravity and vertical earthquake loads

(b) The maximum shear obtained from design load combinations that include ***E***, with ***E*** taken as twice that prescribed by the general building code

**18.4.2.4** At both ends of the beam, hoops shall be provided over a length of at least $2h$ measured from the face of the supporting member toward midspan. The first hoop shall be located not more than 2 in. from the face of the supporting member. Spacing of hoops shall not exceed the smallest of (a) through (d):

(a) $d/4$

(b) Eight times the diameter of the smallest longitudinal bar enclosed

(c) 24 times the diameter of the hoop bar

**COMMENTARY**

## R18.4—Intermediate moment frames

The objective of the requirements in 18.4.2.3 and 18.4.3.1 is to reduce the risk of failure in shear in beams and columns during an earthquake. Two options are provided to determine the factored shear force.

**R18.4.2** *Beams*

According to 18.4.2.3(a), the factored shear force is determined from a free-body diagram obtained by cutting through the beam ends, with end moments assumed equal to the nominal moment strengths acting in reverse curvature bending, both clockwise and counterclockwise. Figure R18.4.2 demonstrates only one of the two options that are to be considered for every beam. To determine the maximum beam shear, it is assumed that its nominal moment strengths ($\phi$ = **1.0** for moment) are developed simultaneously at both ends of its clear span. As indicated in Fig. R18.4.2, the shear associated with this condition $[(M_{nl} + M_{nr})/\ell_n]$ is added algebraically to the shear due to the factored gravity loads and vertical earthquake effects to obtain the design shear for the beam. For the example shown, dead load, live load, and snow load have been assumed to be uniformly distributed. The figure also shows that vertical earthquake effects are to be included, as is typically required by the general building code. For example, ASCE/SEI 7 requires vertical earthquake effects, $0.2S_{DS}$, to be included.

Provision 18.4.2.3(b) bases $V_u$ on the load combination including the earthquake effect ***E***, which should be doubled. For example, the load combination defined by Eq. (5.3.1.e) would be

$$U = 1.2D + 2.0E + 1.0L + 0.2S$$

where ***E*** is the value specified by the general building code. The factor of 1.0 applied to ***L*** is allowed to be reduced to 0.5 in accordance with 5.3.3.

Transverse reinforcement at the ends of the beam is required to be hoops. In most cases, transverse reinforcement required by 18.4.2.3 for the design shear force will be more than those required by 18.4.2.4.

Beams may be subjected to axial compressive force due to prestressing or applied loads. The additional requirements

Code and Commentary of the SMF of ACI



CODE

18.5—Intermediate precast structural walls

18.5.1 *Scope*

**18.5.1.1** This section shall apply to intermediate precast structural walls forming part of the seismic-force-resisting system.

18.5.2 *General*

**18.5.2.1** In connections between wall panels, or between wall panels and the foundation, yielding shall be restricted to steel elements or reinforcement.

**18.5.2.2** For elements of the connection that are not designed to yield, the required strength shall be based on $1.5S_y$ of the yielding portion of the connection.

**18.5.2.3** In structures assigned to SDC D, E, or F, wall piers shall be designed in accordance with 18.10.8 or 18.14.

18.6—Beams of special moment frames

18.6.1 *Scope*

**18.6.1.1** This section shall apply to beams of special moment frames that form part of the seismic-force-resisting system and are proportioned primarily to resist flexure and shear.

**18.6.1.2** Beams of special moment frames shall frame into columns of special moment frames satisfying 18.7.

COMMENTARY

satisfy shear and moment strength requirements of Chapter 8 under load combinations including earthquake effect.

R18.5—Intermediate precast structural walls

Connections between precast wall panels or between wall panels and the foundation are required to resist forces induced by earthquake motions and to provide for yielding in the vicinity of connections. If mechanical splices are used to directly connect primary reinforcement, the probable strength of the splice should be at least 1.5 times the specified yield strength of the reinforcement.

R18.6—Beams of special moment frames

R18.6.1 *Scope*

This section applies to beams of special moment frames resisting lateral loads induced by earthquake motions. In previous Codes, any frame member subjected to a factored axial compressive force exceeding $(A_g f_c'/10)$ under any load combination was to be proportioned and detailed as described in 18.7. In the 2014 Code, all requirements for beams are contained in 18.6 regardless of the magnitude of axial compressive force.

This Code is written with the assumption that special moment frames comprise horizontal beams and vertical columns interconnected by beam-column joints. It is acceptable for beams and columns to be inclined provided the resulting system behaves as a frame—that is, lateral resistance is provided primarily by moment transfer between beams and columns rather than by strut or brace action. In special moment frames, it is acceptable to design beams to resist combined moment and axial force as occurs in beams that act both as moment frame members and as chords or collectors of a diaphragm. It is acceptable for beams of special moment frames to cantilever beyond columns, but such cantilevers are not part of the special moment frame that forms part of the seismic-force-resisting system. It is acceptable for beams of a special moment frame to connect into a wall boundary if the boundary is reinforced as a special moment frame column in accordance with 18.7. A concrete braced frame, in which lateral resistance is provided primarily by axial forces in beams and columns, is not a recognized seismic-force-resisting system.

## CODE

(c) For Grade 60, $6d_b$ of the smallest primary flexural reinforcing bar excluding longitudinal skin reinforcement required by 9.7.2.3

(d) For Grade 80, $5d_b$ of the smallest primary flexural reinforcing bar excluding longitudinal skin reinforcement required by 9.7.2.3

**18.6.4.5** Where hoops are required, they shall be designed to resist shear according to 18.6.5.

**18.6.4.6** Where hoops are not required, stirrups with seismic hooks at both ends shall be spaced at a distance not more than $d/2$ throughout the length of the beam.

**18.6.4.7** In beams having factored axial compressive force exceeding $A_g f_c'/10$, hoops satisfying 18.7.5.2 through 18.7.5.4 shall be provided along lengths given in 18.6.4.1. Along the remaining length, hoops satisfying 18.7.5.2 shall have spacing $s$ not exceeding the least of 6 in., $6d_b$ of the smallest Grade 60 enclosed longitudinal beam bar, and $5d_b$ of the smallest Grade 80 enclosed longitudinal beam bar. Where concrete cover over transverse reinforcement exceeds 4 in., additional transverse reinforcement having cover not exceeding 4 in. and spacing not exceeding 12 in. shall be provided.

## COMMENTARY

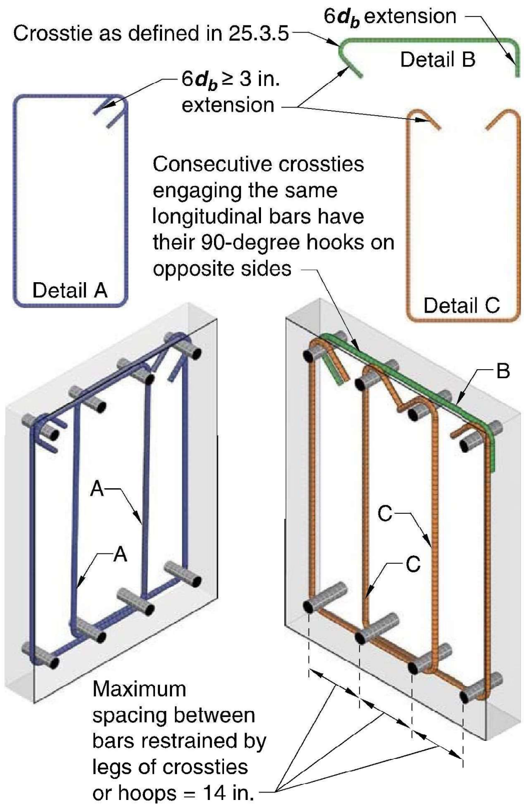


***Fig. R18.6.4**— Examples of overlapping hoops and illustration of limit on maximum horizontal spacing of supported longitudinal bars.*

### 18.6.5 *Shear strength*

### 18.6.5.1 *Design forces*

The design shear force $V_e$ shall be calculated from consideration of the forces on the portion of the beam between faces of the joints. It shall be assumed that moments of opposite sign corresponding to probable flexural strength, $M_{pr}$, act at the joint faces and that the beam is loaded with the factored gravity and vertical earthquake loads along its span.

### 18.6.5.2 *Transverse reinforcement*

Transverse reinforcement over the lengths identified in 18.6.4.1 shall be designed to resist shear assuming $V_c = 0$ when both (a) and (b) occur:

### R18.6.5 *Shear strength*

Unless a beam possesses a moment strength that is on the order of 3 or 4 times the design moment, it should be assumed that it will yield in flexure in the event of a major earthquake. The design shear force should be selected so as to be a good approximation of the maximum shear that may develop in a member. Therefore, required shear strength for frame members is related to flexural strengths of the designed member rather than to factored shear forces indicated by lateral load analysis. The conditions described by 18.6.5.1 are illustrated in Fig. R18.6.5. The figure also shows that vertical earthquake effects are to be included, as is typically required by the general building code. For example, ASCE/SEI 7 requires vertical earthquake effects, $0.2S_{DS}$, to be included.

Because the actual yield strength of the longitudinal reinforcement may exceed the specified yield strength and because strain hardening of the reinforcement is likely to