

PART VI
Chapter 8

Detailing of Reinforcement in Concrete Structures

8.1 Introduction

Provisions of Sections 8.1 and 8.2 of Chapter 8 shall apply for detailing of reinforcement in reinforced concrete members, in general. For reinforced concrete structures, subject to earthquake loadings in seismic design categories B, C and D, special provisions contained in Sec 8.3 of this Chapter shall apply. The definitions and notation provided in the following Sections are related to Sec 8.3. The definitions and notation used in other Sections, unless otherwise mentioned, are similar to those provided in Sections 6.1.1 and 6.1.2 Chapter 6.

8.1.1 Definitions and Notation

8.1.1.1 Definitions

BASE OF STRUCTURE	The level at which earthquake motions are assumed to be imparted to a structure. This level does not necessarily coincide with the ground level.
BOUNDARY MEMBERS	Members along wall and diaphragm edges strengthened by longitudinal and transverse reinforcement. These members do not necessarily require an increase in the thickness of the wall or diaphragm. If required, edges of openings within walls and diaphragms shall be provided with boundary members.
COLLECTOR ELEMENTS	Elements that are used to transmit the inertial forces within the diaphragms to members of the lateral force resisting systems.
CROSS TIE	A continuous bar having a hook not less than 135° with at least a six diameter extension at one end but not less than 75 mm, and a hook not less than 90° with at least a six diameter extension at the other end. The hooks shall engage peripheral longitudinal bars. The 90° hooks of two successive cross ties engaging the same longitudinal bars shall be alternated end for end.

DEVELOPMENT LENGTH OF A STANDARD HOOK	The shortest distance between the critical section and a tangent to the outer edge of the 90° hook.
HOOP	A hoop is a closed tie or continuously round tie. A closed tie can be made up of several reinforcing elements with 135° hooks having a six diameter extension at each end (but not less than 75 mm). A continuously round tie shall have at each end a 135° hook with a six diameter extension that engages the longitudinal reinforcement but not less than 75 mm.
LATERAL FORCE RESISTING SYSTEM	That portion of the structure composed of members designed to resist forces related to earthquake effects.
SHELL CONCRETE	Concrete outside the transverse reinforcement confining the concrete
STRUCTURAL DIAPHRAGMS	Structural members, such as floor and roof slabs, which transmit inertial forces to lateral force resisting members.
STRUCTURAL WALLS	Walls designed to resist combinations of shears, moments, and axial forces induced by earthquake motions. A shear wall is a structural wall.
STRUT	An element of a structural diaphragm used to provide continuity around an opening in the diaphragm.
TIE ELEMENTS	Elements used to transmit inertial forces and prevent separation of building components.

8.1.1.2 Notation

A_{ch}	=	Cross-sectional area of a structural member measured out to out of transverse reinforcement, mm ²
A_{cp}	=	Area of concrete section resisting shear of an individual pier or horizontal wall segment, mm ²
A_{cv}	=	Net area of concrete section bounded by web thickness and length of section in the direction of shear force considered, mm ²
A_g	=	Gross area of section, mm ²
A_j	=	Effective cross-sectional area within a joint, see Sec 8.3.7.3, in a plane parallel to plane of reinforcement generating shear in the joint. The joint depth shall be the overall depth of the column. Where a beam frames into a support of larger width, the effective width of the joint shall not exceed the smaller of : (a) Beam width plus the joint depth (b) twice the smaller perpendicular distance from the longitudinal axis of the beam to the column side (See Sec 8.3.7.3)

A_{sh}	=	Total cross-sectional area of transverse reinforcement (including cross ties) within spacing s and perpendicular to dimension h_c
E	=	Load effects of earthquake or related internal moments and forces
M_{pr}	=	Probable flexural moment strength of members, with or without axial load, determined using the properties of the member at the joint faces assuming a tensile strength in the longitudinal bars of at least $1.25f_y$ and a strength reduction factor ϕ of 1.0, N-mm
M_s	=	Portion of slab moment balanced by support moment
V_c	=	Nominal shear strength provided by concrete, N
V_e	=	Design shear force corresponding to the development of the probable moment strength of the member, N
V_n	=	Nominal shear strength, N
V_u	=	Factored shear force at section, N
b	=	Effective compressive flange width of a structural member, mm
b_w	=	Web width or diameter of circular section, mm
d	=	Distance from extreme compression fibre to centroid of longitudinal tension reinforcement, mm
d_b	=	Bar diameter, mm
f'_c	=	Specified compressive strength of concrete, MPa
f_y	=	Specified yield strength of reinforcement, MPa
f_{yt}	=	Specified yield strength of transverse reinforcement, MPa
h	=	Overall thickness or height of member, mm
h_c	=	Cross-sectional dimension of column core measured to the outside edge of the transverse reinforcement composing area A_{sh} mm centre to centre of confining reinforcement
h_w	=	Height of entire wall (diaphragm) or of the segment of wall (diaphragm) considered, mm
h_x	=	Maximum centre to centre horizontal spacing of crossties or hoop legs on all faces of the column, mm
l_d	=	Development length in tension of deformed bar, deformed wire, plain and deformed welded wire reinforcement, mm

- l_{dh} = Development length in tension of deformed bar or deformed wire with a standard hook, measured from critical section to outside end of hook [straight embedment length between critical section and start of hook (point of tangent) plus inside radius of bend and one bar diameter], mm
- l_o = Minimum length, measured from joint face along axis of structural member, over which special transverse reinforcement must be provided, mm
- l_w = Length of entire wall (diaphragm) or of segment of wall (diaphragm) considered in the direction of shear force, mm
- s = Spacing of transverse reinforcement measured along longitudinal axis of the structural member, mm
- s_o = Maximum spacing of transverse reinforcement, mm
- α_c = Coefficient defining the relative contribution of concrete strength to wall strength
- ρ = Ratio of tension reinforcement to member area = A_s/b_d
- ρ_g = Ratio of total reinforcement area to cross-sectional area of column
- ρ_n = Ratio of distributed shear reinforcement on a plane perpendicular to plane of A_{cv}
- ρ_s = Ratio of volume of spiral reinforcement to the core volume confined by the spiral reinforcement (measured out to out of spiral)
- ρ_v = A_{sv}/A_{cv} ; where A_{sv} is the projection on A_{cv} of area of distributed shear reinforcement crossing the plane of A_{cv}
- ϕ = Strength reduction factor.

8.1.2 Standard Hooks and Minimum Bend Diameters

8.1.2.1 Standard hooks

The term "standard hook" as used in this Code shall mean one of the following:

- 180° bend plus an extension of at least 4 bar diameters, but not less than 65 mm at the free end of the bar.
- 90° bend plus an extension of at least 12 bar diameters at the free end of the bar.

- (c) For stirrup and tie anchorage
- For 16 mm diameter bar and smaller, a 90° bend plus an extension of at least 6 bar diameters at the free end of the bar,
 - For 19 mm to 25 mm diameter bars, a 90° bend plus an extension of at least 12 bar diameters at the free end of the bar,
 - For 25 mm diameter bar and smaller, a 135° bend plus an extension of at least 6 bar diameters at the free end of the bar,
 - For closed ties and continuously wound ties, a 135° bend plus an extension of at least 6 bar diameters, but not less than 75 mm.
- (d) Seismic hook is defined as a hook on a stirrup, hoop, or crosstie having a bend not less than 135°, except that circular hoops shall have a bend not less than 90°. Hooks shall have a six-diameter (but not less than 75 mm) extension that engages the longitudinal reinforcement and projects into the interior of the stirrup or hoop.

8.1.2.2 Minimum bend diameters

- (a) The minimum diameter of bend measured on the inside of the bar, for standard hooks other than for stirrups and ties in sizes of 10 mm to 16 mm diameter shall not be less than the values shown in Table 6.8.1.

Table 6.8.1: Minimum Diameters of Bend

Bar Size	Minimum Diameter of Bend
10 mm $\leq d_b \leq$ 25 mm	$6d_b$
25 mm $< d_b \leq$ 40 mm	$8d_b$
40 mm $< d_b \leq$ 57 mm	$10d_b$

- (b) For stirrups and tie hooks, inside diameter of bend shall not be less than 4 bar diameters for 16 mm diameter bar and smaller. For bars larger than 16 mm diameter, bend diameter shall be in accordance with Table 6.8.1.
- (c) Inside diameter of bend in welded wire reinforcement for stirrups and ties shall not be less than 4 bar diameters for deformed wire larger than ASTM MD40 size (ASTM A1022) and 2 bar diameters for all other wires. Bends with inside diameter of less than 8 bar diameters shall not be less than 4 bar diameters from nearest welded intersection.

8.1.3 Bending

8.1.3.1 Unless otherwise permitted by the engineer, all reinforcement shall be bent cold.

8.1.3.2 Reinforcement partially embedded in concrete shall not be bent in place, except as permitted by the engineer or as shown in the design drawings.

8.1.4 Surface Conditions of Reinforcement

8.1.4.1 When concrete is placed, metal reinforcement shall be free from mud, oil, or other nonmetallic coatings that decrease bond. Epoxy-coating of steel reinforcement in accordance with standards referenced in this Code shall be permitted.

8.1.4.2 Metal reinforcement with rust, mill scale, or a combination of both, shall be considered satisfactory, provided the minimum dimensions (including height of deformations) and weight of a hand-wire-brushed test specimen are not less than applicable ASTM specification requirements.

8.1.5 Placing of Reinforcement

8.1.5.1 Reinforcement shall be accurately placed and adequately supported before concrete is placed, and shall be secured against displacement within tolerances permitted in Sec 8.1.5.2 below.

8.1.5.2 Reinforcement shall be placed within the following tolerances unless otherwise specified by the engineer:

- (a) Tolerances for depth d , and minimum concrete cover in flexural members, walls and compression members shall be as set forth in Table 6.8.2.

Table 6.8.2: Tolerances for Placing Reinforcement

Depth of Member, d	Tolerance for d	Tolerance for Minimum Concrete Cover
$d \leq 200$ mm	± 10 mm	-10 mm
$d > 200$ mm	± 13 mm	-13 mm

- (b) Notwithstanding the provision of (a) above, tolerance for the clear distance to formed soffits shall be minus 6 mm and tolerance for cover shall not exceed minus one third ($1/3$) of minimum concrete cover specified in the design drawings or specifications.
- (c) Tolerance for longitudinal location of bends and ends of reinforcement shall be ± 50 mm, except at discontinuous ends of brackets and corbels, where tolerance shall be ± 13 mm and at discontinuous ends of other members, where tolerance shall be ± 25 mm. The tolerance for concrete cover of Sec 8.1.5.2a shall also apply at discontinuous ends of members.

8.1.5.3 Welded wire reinforcement (with ASTM wire size not greater than MW30 or MD30) used in slabs not exceeding 3 m in span shall be permitted to be curved from a point near the top of slab over the support to a point near the bottom of slab at midspan, provided such reinforcement is either continuous over, or securely anchored at support.

8.1.5.4 Welding of crossing bars shall not be permitted for assembly of reinforcement unless authorized by the engineer.

8.1.6 Spacing of Reinforcement

8.1.6.1 The minimum clear spacing between parallel bars in a layer shall be equal to one bar diameter, but not less than 25 mm, or 1.33 times of maximum nominal size of coarse aggregate, whichever is larger.

8.1.6.2 Where parallel reinforcement is placed in two or more layers, bars in the upper layers shall be placed directly above those in the bottom layer with clear distance between layers not less than 25 mm.

8.1.6.3 For compression members, the clear distance between longitudinal bars shall be not less than 1.5 bar diameters nor 40 mm nor 1.33 times of maximum nominal size of coarse aggregate.

8.1.6.4 Clear distance limitation between bars shall apply also to the clear distance between a contact lap splice and adjacent splices or bars.

8.1.6.5 In walls and one-way slabs the maximum bar spacing shall not be more than three times the wall or slab thickness h nor 450 mm.

8.1.6.6 For two-way slabs, maximum spacing of bars shall not exceed twice the slab thickness h nor 450 mm.

8.1.6.7 For temperature steel, maximum spacing shall not exceed 5 times the slab thickness h nor 450 mm.

8.1.6.8 Bundled bars

- (a) Groups of parallel reinforcing bars bundled in contact to act as a single unit shall be limited to four.
- (b) Bundled bars shall be enclosed within stirrups or ties.
- (c) Bars larger than 32 mm diameter shall not be bundled in beams.
- (d) Individual bars within a bundle terminated within the span of flexural members shall terminate at different points with at least $40d_b$ stagger.
- (e) Where spacing limitations and minimum concrete cover are based on bar diameter d_b , a unit of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area.

8.1.7 Exposure Condition and Cover to Reinforcement

8.1.7.1 The nominal concrete cover to all reinforcement (including links), maximum free water-cement ratio and minimum cement content required for various minimum concrete strengths used in different exposure conditions shall be as specified in Table 6.8.3. However, for mild environment, the minimum concrete cover specified in Sections 8.1.7.2 and 8.1.7.3 for various structural elements may be used.

8.1.7.2 Cast-in-place concrete

- (a) Minimum concrete cover for concrete cast against and permanently exposed to earth shall be 75 mm.
- (b) Concrete exposed to earth or weather, the minimum clear cover shall be as under.

19 mm to 57 mm bar diameter: 50 mm

16 mm diameter bar and smaller: 40 mm

- (c) The following minimum concrete cover may be provided for reinforcement for concrete surfaces not exposed to weather or in contact with ground:

Slabs, Walls:	Minimum Cover
40 mm to 57 mm bar diameter	40
36 mm bar diameter and smaller	20
Beams, Columns :	
Primary reinforcement, Ties, stirrups, spirals	40
Shells, folded plate members :	
19 mm bar diameter and larger	20
16 mm bar diameter and smaller	16

Table 6.8.3*: Concrete Cover and other Requirements for Various Exposure Conditions

Environ ment	Exposure Conditions	Minimum f'_c N/mm ²						
		20	25	30	35	40	45	50
		Nominal cover (mm)						
Mild	Concrete surfaces protected against weather or aggressive conditions	30	25	20	20	20**	20**	20**

Environ ment	Exposure Conditions	Minimum f'_c N/mm ²						
		20	25	30	35	40	45	50
		Nominal cover (mm)						
Moderate	Concrete surface away from severe rain Concrete subject to condensation Concrete surfaces continuously under water Concrete in contact with non-aggressive soil	40	35	30	25	20	20	20
Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or severe condensation		45	40	30	25	25	20
Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes			50	40	30	30	25
Extrem e	Concrete surfaces exposed to abrasive action, e.g. sea water carrying solids or flowing water with pH $\leq$ 4.5 or machinery or vehicles				60	50	40	30
Maximum water/cement ratio		0.5	0.5	0.5	0.45	0.45	0.40	0.40
Minimum cement content, (kg/m ³)		315	325	350	375	400	410	420
* This Table relates to aggregate of 20 mm nominal maximum size.								
** May be reduced to 15 mm provided the nominal maximum aggregate size does not exceed 15 mm								

8.1.7.3 Precast concrete (manufactured under plant control conditions) :

(a) Concrete exposed to earth or weather:

Bar diameter

Minimum cover, mm

Wall Panels:

40 mm to 57 mm diameter 40

36 mm diameter bar and smaller 20

Other Members:

40 mm to 57 mm diameter 50

19 mm to 36 mm diameter 40

16 mm diameter bar and smaller 30

(b) Concrete not exposed to weather or in contact with ground:

<u>Bar diameter</u>	<u>Minimum cover, mm</u>
Slabs, Walls:	
40 mm to 57 mm diameter	30
36 mm diameter bar and smaller	16
Beams, columns :	
Primary reinforcement	$20 \leq d_b \leq 40$
Ties, stirrups, spiral	15
Shells, folded plate members :	
19 mm diameter bar and larger	16
16 mm diameter bar and smaller	10

8.1.7.4 For concrete cast against and permanently exposed to earth, minimum cover shall be 75 mm. If, concrete cover specified in Sec 8.1.7.1 (Table 6.8.3) conflicts with those specified in Sec 8.1.7.2 or Sec 8.1.7.3, the larger value shall be taken.

8.1.7.5 Bundled Bars: Minimum concrete cover shall be equal to the equivalent diameter of the bundle, but need not be greater than 50 mm.

8.1.7.6 Future Extension: Exposed reinforcement, inserts, and plates intended for bonding with future extensions shall be protected from corrosion.

8.1.7.7 Fire Protection: If a thickness of cover for fire protection greater than the concrete covers specified in Sections 8.1.7.1 to 8.1.7.6 is required, such greater thicknesses shall be specified.

8.1.7.8 Corrosive Environments: If a thickness of cover for corrosive environment or other severe exposure conditions greater than the concrete covers specified in Sections 8.1.7.1 to 8.1.7.6 is required, such greater thicknesses shall be specified. For corrosion protection, a specified concrete cover for reinforcement not less than 50 mm for walls and slabs and not less than 65 mm for other members may be used. For precast concrete members a specified concrete cover not less than 40 mm for walls and slabs and not less than 50 mm for other members may be used.

Minimum compressive strength of concrete f'_c for the corrosive environment or other severe exposure conditions shall be 25 MPa with minimum cement of 400 kg per cubic meter. Coarse aggregate shall be 20 mm down well-graded stone chips and fine aggregate shall be coarse sand of minimum FM 2.20.

For any non-structural member like drop wall, railing, fins etc., 12 mm down well graded stone chips may be used as coarse aggregate.

Use of brick chips (khoa) as coarse aggregate is strictly prohibited for the corrosive environment or other severe exposure conditions.

Water cement ratio shall be between 0.4-0.45. Potable water shall be used for all concreting.

8.1.8 Reinforcement Details for Columns

8.1.8.1 Offset Bars: Offset bent longitudinal bars shall conform to the following:

- (a) The maximum slope of inclined portion of an offset bar with axis of column shall not exceed 1 in 6.
- (b) Portions of bar above and below an offset shall be parallel to the axis of column.
- (c) Horizontal support at offset bends shall be provided by lateral ties, spirals, or parts of the floor construction. Horizontal support provided shall be designed to resist 1.5 times the horizontal component of the computed force in the inclined portion of the offset bars. Lateral ties or spirals, if used, shall be placed not more than 150 mm away from points of bend.
- (d) Offset bars shall be bent before placement in the forms (see Sec 8.1.3).
- (e) Where the face of the column above is offset 75 mm or more from the face of the column below, longitudinal bars shall not be permitted to be offset bent. The longitudinal bars adjacent to the offset column faces shall be lap spliced using separate dowels. Lap splices shall conform to Sec 8.2.14.

8.1.8.2 Steel Cores: Load transfer in structural steel cores of composite compression members shall be provided by the following:

- (a) Ends of structural steel cores shall be accurately finished to bear at end bearing splices, with positive provision for alignment of one core above the other in concentric contact.
- (b) At end bearing splices, bearing shall be considered effective to transfer not more than 50 percent of the total compressive stress in the steel core.
- (c) Transfer of stress between column base and footing shall be designed in accordance with Sec 6.8.8.
- (d) Base of structural steel section shall be designed to transfer the total load from the entire composite member to the footing; or, the base shall be designed to transfer the load from the steel core only, provided ample concrete section is available for transfer of the portion of the total load carried by the reinforced concrete section to the footing by compression in the concrete and by reinforcement.

8.1.9 Lateral Reinforcement for Columns

8.1.9.1 Lateral reinforcement for compression members shall conform to the provisions of Sections 8.1.9.3 and 8.1.9.4 below and where shear or torsion reinforcement is required, shall also conform to provisions of Sec 6.4.

8.1.9.2 Lateral reinforcement requirements for composite columns shall conform to Sections 6.3.13.7 and 6.3.13.8 Chapter 6.

8.1.9.3 Spirals: Spiral reinforcement for columns shall conform to Sec 6.3.9.3 Chapter 6 and to the following:

- (a) Spirals shall consist of evenly spaced continuous bar or wire of such size and so assembled as to permit handling and placing without distortion from designed dimensions.
- (b) Size of spirals shall not be less than 10 mm diameter for cast-in-place construction.
- (c) The minimum and maximum clear spacing between spirals shall be 25 mm and 75 mm respectively.
- (d) Anchorage of spiral reinforcement shall be provided by 1.5 extra turns of spiral bar or wire at each end of a spiral unit.
- (e) Splices in spiral reinforcement shall be lap splices of 48 spiral diameter for deformed uncoated bar or wire and 72 spiral diameter for other cases, but not less than 300 mm.
- (f) Spirals shall extend from the top of footing or slab in any storey to the level of the lowest horizontal reinforcement in members supported above.
- (g) Spirals shall extend above termination of spiral to bottom of slab or drop panel, where beams or brackets do not frame into all sides of a column.
- (h) Spirals shall extend to a level at which the diameter or width of capital is 2 times that of the column, in case of columns with capitals.
- (i) Spirals shall be held firmly in place and true to line.

8.1.9.4 Ties: Tie reinforcement for compression members shall conform to the following:

- (a) All bars shall be enclosed by lateral ties, at least 10 mm diameter in size for longitudinal bars 32 mm diameter or smaller, and at least 12 mm diameter in size for 36 mm to 57 mm diameter and bundled longitudinal bars.
- (b) Vertical spacing of ties shall not exceed 16 longitudinal bar diameters or 48 tie diameters, or the least dimension of the compression members.

- (c) Ties shall be arranged such that every corner and alternate longitudinal bar shall have lateral support provided by the corner of a tie with an included angle not more than 135° . No vertical bar shall be farther than 150 mm clear on each side along the tie from such a laterally supported bar. Where longitudinal bars are located around the perimeter of a circle, a complete circular tie is allowed.
- (d) The lowest tie in any storey shall be placed within one-half the required tie spacing from the top most horizontal reinforcement in the slab or footing below. The uppermost tie in any storey shall be within one-half the required tie spacing from the lowest horizontal reinforcement in the slab or drop panel above.
- (e) Where beams or brackets provide concrete confinement at the top of the column on all (four) sides, top tie shall be within 75 mm of the lowest horizontal reinforcement in the shallowest of such beams or brackets.
- (f) Where anchor bolts are placed in the top of columns or pedestals, the bolts shall be enclosed by lateral reinforcement that also surrounds at least four vertical bars of the column or pedestal. The lateral reinforcement shall be distributed within 125 mm of the top of the column or pedestal, and shall consist of at least two 12 mm diameter bars or three 10 mm diameter bars.
- (g) Where longitudinal bars are arranged in a circular pattern, individual circular ties per specified spacing may be used.

8.1.10 Lateral Reinforcement for Beams

8.1.10.1 Compression reinforcement in beams shall be enclosed by ties or stirrups satisfying the size and spacing limitations in Sec 8.1.9.4 above. Such ties or stirrups shall be provided throughout the distance where compression reinforcement is required.

8.1.10.2 Lateral reinforcement for flexural framing members subject to stress reversals or to torsion at supports shall consist of closed ties, closed stirrups, or spirals extending around the flexural reinforcement.

8.1.10.3 Closed ties or stirrups shall be formed in one piece by overlapping standard stirrup or tie end hooks around a longitudinal bar, or formed in one or two pieces lap spliced with a Class B splice (lap of $1.3l_d$) or anchored in accordance with Sec 8.2.10.

8.1.11 Shrinkage and Temperature Reinforcement

8.1.11.1 Where the flexural reinforcement extends in one direction only, reinforcement for shrinkage and temperature stresses shall be provided perpendicular to flexural reinforcement in structural slabs. Shrinkage and temperature reinforcement shall be provided in accordance with Sec 8.1.11.2 below.

8.1.11.2 Deformed reinforcement conforming to Sec 5.3.2 Chapter 5 shall be provided in accordance with the following:

- (a) Area of shrinkage and temperature reinforcement shall provide at least the following ratios of reinforcement area to gross concrete area:
 Slabs where reinforcement with $f_y = 275 \text{ N/mm}^2$ or 350 N/mm^2 are used: 0.0020
 Slabs where reinforcement with $f_y = 420 \text{ N/mm}^2$ are used: 0.0018
 Slabs where reinforcement with f_y exceeding 420 N/mm^2 are used: $0.0018 \left(\frac{420}{f_y} \right)$
 In any case, the reinforcement ratio shall not be less than 0.0014.
- (b) Area of shrinkage and temperature reinforcement for brick aggregate concrete shall be at least 1.5 times that provided in (a) above.
- (c) Shrinkage and temperature reinforcement shall be spaced not farther apart than 5 times the slab thickness, nor 450 mm.
- (d) At all sections where required, reinforcement for shrinkage and temperature stresses shall develop the specified yield strength f_y in tension in accordance with Sec 8.2.

8.1.12 Requirements for Structural Integrity

8.1.12.1 In the detailing of reinforcement and connections, members of a structure shall be effectively tied together to improve integrity of the overall structure.

8.1.12.2 The minimum requirements for cast-in-place construction shall be:

- (a) In one-way slab construction, at least one bottom bar shall be continuous or shall be spliced over the support with a Class A tension splice. At non-continuous supports, the bars may be terminated with a standard hook.
- (b) Beams at the perimeter of the structure shall have at least one-sixth of the tension reinforcement required for negative moment at the support, but not less than two bars and one-quarter of the positive moment reinforcement required at midspan, but not less than two bars made continuous over the span length passing through the region bounded by the longitudinal reinforcement of the column around the perimeter and tied with closed stirrups. Closed stirrups need not be extended through any joints. The required continuity may be provided with top reinforcement spliced at mid-span and bottom reinforcement spliced at or near the support with Class B tension splices.

- (c) When closed stirrups are not provided, in other than perimeter beams, at least one-quarter of the positive moment reinforcement required at mid-span, but not less than two bars shall pass through the region bounded by the longitudinal reinforcement of the column and shall be continuous or shall be spliced over the support with a Class B tension splice. At non-continuous supports the bars shall be anchored to develop f_y at the face of the support using a standard hook.

8.1.12.3 To effectively tie elements together, tension ties shall be provided in the transverse, longitudinal, and vertical directions and around the perimeter of the structure for precast concrete construction.

8.1.13 Connections

8.1.13.1 Enclosure shall be provided for splices of continuing reinforcement and for anchorage of terminating reinforcement at connections of principal framing elements (such as beams and columns),

8.1.13.2 External concrete or internal closed ties, spirals, or stirrups shall be used as enclosures at connections.

8.2 Development and Splices of Reinforcement

8.2.1 Development of Reinforcement - General

Calculated tension or compression stress in reinforcement at each section of reinforced concrete members shall be developed on each side of that section by embedment length, hook or mechanical device, or a combination thereof. Hooks may be used in developing bars in tension only.

8.2.2 Limitation

The values of $\sqrt{f'_c}$ used in Sec 8.2 shall not exceed 8.3 MPa. In addition to requirements stated here that affect detailing of reinforcement, structural integrity requirements of Sec 8.1.12 shall be satisfied.

8.2.3 Development of Deformed Bars and Deformed Wires in Tension

8.2.3.1 Development length for deformed bars and deformed wire in tension, l_d shall be determined from either Sec 8.2.3.2 or Sec 8.2.3.3 and applicable modification factors of Sections 8.2.3.4 and 8.2.3.5, but l_d shall not be less than 300 mm.

8.2.3.2 For deformed bars or deformed wire, l_d shall be as follows:

Spacing and cover	19 mm diameter and smaller bars and deformed wires	20 mm diameter and larger bars
Clear spacing of bars or wires being developed or spliced not less than d_b , clear cover not less than d_b , and stirrups or ties throughout l_d not less than the Code minimum Or, Clear spacing of bars or wires being developed or spliced not less than $2d_b$ and clear cover not less than d_b	$\left(\frac{f_y \psi_t \psi_e}{2.1 \lambda \sqrt{f'_c}} \right) d_b$	$\left(\frac{f_y \psi_t \psi_e}{1.7 \lambda \sqrt{f'_c}} \right) d_b$
Other cases		$\left(\frac{f_y \psi_t \psi_e}{1.1 \lambda \sqrt{f'_c}} \right) d_b$

8.2.3.3 For deformed bars or deformed wire, l_d shall be

$$l_d = \left(\frac{f_y}{1.1 \lambda \sqrt{f'_c}} \frac{\psi_t \psi_e \psi_s}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b \quad (6.8.1)$$

In which the confinement term $\frac{c_b + K_{tr}}{d_b}$ shall not be taken greater than 2.5, and

$$K_{tr} = \frac{40 A_{tr}}{sn} \quad (6.8.2)$$

Where, n is the number of bars or wires being spliced or developed along the plane of splitting. It shall be permitted to use $K_{tr} = 0$ as a design simplification even if transverse reinforcement is present.

8.2.3.4 The factors used in the expressions for development of deformed bars and deformed wires in tension in Sec 8.2.3 are as follows:

- Where horizontal reinforcement is placed such that more than 300 mm of fresh concrete is cast below the development length or splice, $\psi_t = 1.3$. For other cases, $\psi_t = 1.0$.
- For epoxy-coated bars or wires with cover less than $3d_b$, or clear spacing less than $6d_b$, $\psi_e = 1.5$. For all other epoxy-coated bars or wires, $\psi_e = 1.2$. For uncoated and zinc-coated (galvanized) reinforcement, $\psi_e = 1.0$. However, the product $\psi_t \psi_e$ need not be greater than 1.7.

- (c) For 19 mm diameter and smaller bars, and deformed wires, $\psi_s = 0.8$.
For 20 mm diameter and larger bars, $\psi_s = 1.0$.
- (d) Where lightweight concrete is used, λ shall not exceed 0.75 unless f_{ct} is specified (see Sec 6.1.9.1 Chapter 6). Where normal weight concrete is used, $\lambda = 1.0$.

8.2.3.5 Excess Reinforcement: Development length may be reduced by the factor $\left[\frac{A_{s \text{ required}}}{A_{s \text{ provided}}} \right]$ where reinforcement in a flexural member is in excess of that required by analysis except where anchorage or development for f_y is specifically required or the reinforcement is designed under the provisions of Sec 8.3.2(b).

8.2.4 Development of Deformed Bars and Deformed Wires in Compression

8.2.4.1 Development length for deformed bars and deformed wire in compression, l_{dc} shall be determined from Sec 8.2.4.2 and applicable modification factors of Sec 8.2.4.3, but l_{dc} shall not be less than 200 mm.

8.2.4.2 For deformed bars and deformed wire, l_{dc} shall be taken as the larger of $\frac{0.24 f_y d_b}{\lambda \sqrt{f'_c}}$ and $0.043 f_y d_b$ with λ as given in Sec 8.2.3.4(d) and the constant 0.043 carries the unit of mm^2/N .

8.2.4.3 Length l_{dc} in Sec 8.2.4.2 shall be permitted to be multiplied by the applicable factors for:

- | | |
|---|--|
| (a) Reinforcement in excess of that required by analysis: | $\left[\frac{A_{s \text{ required}}}{A_{s \text{ provided}}} \right]$ |
| (b) Reinforcement enclosed within spiral reinforcement not less than 6 mm diameter and not more than 100 mm pitch or within 12 mm diameter ties in conformance with Sec 8.1.9.4 and spaced at not more than 100 mm on center: | 0.75 |

8.2.5 Development of Bundled Bars

8.2.5.1 Development length of individual bars within a bundle, in tension or compression, shall be that for the individual bar, increased 20 percent for 3 bar bundles and 33 percent for 4 bar bundles.

8.2.5.2 For determining the appropriate spacing and cover values in Sec 8.2.3.2, the confinement term in Sec 8.2.3.3, and the ψ_e factor in Sec 8.2.3.4(b), a unit of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area and having a centroid that coincides with that of the bundled bars.

8.2.6 Development of Standard Hooks in Tension

8.2.6.1 Development length l_{dh} for deformed bars in tension terminating in a standard hook shall be computed as the product of the basic development length for deformed bars, l_{dh} of Sec 8.2.6.2 below and the applicable modification factor(s) of Sec 8.2.6.3, but l_{dh} shall be not less than $8d_b$ nor less than 150 mm.

8.2.6.2 For deformed bars, l_{dh} shall be $\frac{0.24\psi_e f_y d_b}{\lambda \sqrt{f'_c}}$ with ψ_e taken as 1.2 for epoxy-coated reinforcement, and λ taken as 0.75 for lightweight concrete. For other cases, ψ_e and λ shall be taken as 1.0.

8.2.6.3 Length l_{dh} in Sec 8.2.6.2 shall be permitted to be multiplied by the following applicable factors:

- | | |
|--|--|
| (a) For 36 mm diameter bar and smaller hooks with side cover (normal to plane of hook) not less than 65 mm, and for 90° hook with cover on bar extension beyond hook not less than 50 mm | 0.7 |
| (b) For 90° hooks of 36 mm diameter bar and smaller bars that are either enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than $3d_b$ along l_{dh} ; or enclosed within ties or stirrups parallel to the bar being developed, spaced not greater than $3d_b$ along the length of the tail extension of the hook plus bend | 0.8 |
| (c) For 180° hooks of 36 mm diameter bar and smaller bars that are enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than $3d_b$ along l_{dh} . | 0.8 |
| (d) Where anchorage or development for f_y is not specifically required, reinforcement in excess of that required by analysis | $\left[\frac{A_{s \text{ required}}}{A_{s \text{ provided}}} \right]$ |

In Sections 8.2.6.3(b) and 8.2.6.3(c), d_b is the diameter of the hooked bar, and the first tie or stirrup shall enclose the bent portion of the hook, within $2d_b$ of the outside of the bend.

8.2.6.4 For bars being developed by a standard hook at discontinuous ends of members with both side cover and top (or bottom) cover over hook less than 65 mm, the hooked bar shall be enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than $3d_b$ along l_{dh} . The first tie or stirrup shall enclose the bent portion of the hook, within $2d_b$ of the outside of the bend, where d_b is the diameter of the hooked bar. For this case, the factors of Sec 8.2.6.3(b) and (c) shall not apply.

8.2.6.5 Hooks shall not be considered effective in developing bars in compression.

8.2.7 Development of Flexural Reinforcement - General

8.2.7.1 Tension reinforcement may be developed by bending across the web to be anchored or made continuous with reinforcement on the opposite face of member.

8.2.7.2 Critical sections for development of reinforcement in flexural members are at points of maximum stress and at points within the span where adjacent reinforcement terminates, or is bent. In addition, the provisions of Sec 8.2.8.3 shall also be satisfied.

8.2.7.3 Reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance not less than d nor less than $12d_b$, except at supports of simple spans and at free end of cantilevers.

8.2.7.4 Continuing reinforcement shall have an embedment length not less than the development length l_d beyond the point where the bent or terminated tension reinforcement is no longer needed to resist bending.

8.2.7.5 No flexural bar shall be terminated in a tension zone unless one of the following conditions is satisfied:

- (a) V_u at the location of termination is not over two-thirds of ϕV_n .
- (b) Stirrup area in excess of that normally required for shear and torsion is provided over a distance along each terminated bar or wire equal to $0.75d$ from the point of cut-off. Excess stirrup area A_v shall be not less than $\frac{0.41b_ws}{f_{yt}}$. Spacing, s shall not exceed $\frac{d}{8\beta_b}$, where β_b is the ratio of area of reinforcement cut off to total area of tension reinforcement at the section.
- (c) For 36 mm diameter bar and smaller, the continuing bars provide twice the area required for flexure at the cut-off point and the shear V_u does not exceed three-quarter of ϕV_n .

8.2.7.6 Where the reinforcement stress is not directly proportional to moment, such as in sloped, stepped, or tapered footings, brackets, deep flexural members, or members in which tension reinforcement is not parallel to the compression face, adequate anchorage shall be provided for the tension reinforcement. See Sections 8.2.8.4 and 8.2.9.4 for deep flexural members.

8.2.8 Development of Positive Moment Reinforcement

8.2.8.1 At least one-third of the positive moment reinforcement in simple members and one-fourth of the positive moment reinforcement in continuous members shall extend along the same face of member into the support. In beams, such reinforcement shall extend into the support at least 150 mm.

8.2.8.2 When the flexural member is a part of the primary lateral load resisting system, positive moment reinforcement extended into the support by Sec 8.2.8.1 above shall be anchored to develop the specified yield strength f_y in tension at the face of support.

8.2.8.3 At simple supports and at points of inflection, positive moment tension reinforcement shall be limited to a diameter such that l_d computed for f_y by Sec 8.2.3 satisfies Eq. 6.8.3, except that Eq. 6.8.3 need not be satisfied for reinforcement terminating beyond the centreline of simple supports by a standard hook or a mechanical anchorage at least equivalent to a standard hook.

$$l_d \leq \frac{M_n}{V_u} + l_a \quad (6.8.3)$$

Where,

M_n = nominal moment strength assuming all reinforcement at section to be stressed to f_y .

V_u = factored shear force at section

l_a = at a support, embedded length of bar beyond centre of support; at point of zero moment, shall be limited to d or $12d_b$, whichever is greater.

The value of $\frac{M_n}{V_u}$ may be increased 30 percent when the ends of reinforcement are confined by a compressive reaction.

8.2.8.4 At simple supports of deep beams, positive moment tension reinforcement shall be anchored to develop f_y in tension at the face of the support except that if design is carried out using Appendix I, the positive moment tension reinforcement shall be anchored in accordance with Sec I.4.3 Appendix I. At interior supports of deep beams, positive moment tension reinforcement shall be continuous or be spliced with that of the adjacent spans.

8.2.9 Development of Negative Moment Reinforcement

8.2.9.1 Negative moment reinforcement in a continuous, restrained, or cantilever member, or in any member of a rigid frame, shall be anchored in or through the supporting member by embedment length, hooks or mechanical anchorage.

8.2.9.2 Negative moment reinforcement shall have an embedment length into the span as required by Sections 8.2.1, 8.2.2 and 8.2.7.3.

8.2.9.3 At least one-third of the total tension reinforcement provided for negative moment at the support shall be extended beyond the point of inflection a distance not less than d , $\frac{l_n}{16}$, or $12d_b$, whichever is greater.

8.2.9.4 At interior supports of deep flexural members, negative moment tension reinforcement shall be continuous with that of the adjacent spans.

8.2.10 Development of Shear Reinforcement

8.2.10.1 Shear reinforcement shall be carried as close to compression and tension surfaces of member as cover requirements and proximity of other reinforcement permits.

8.2.10.2 The ends of single leg, simple U, or multiple U-stirrups shall be anchored by one of the following means:

- (a) By a standard hook around longitudinal reinforcement for ASTM MD200 wires, and 16 mm diameter bars and smaller and for 19 mm to 25 mm diameter bars with $f_{yt} \leq 280 \text{ N/mm}^2$.
- (b) For 19 mm to 25 mm diameter stirrups with f_{yt} greater than 280 N/mm², a standard stirrup hook around a longitudinal bar plus an embedment between mid-height of the member and the outside end of the hook equal to or greater than $\frac{0.17d_b f_{yt}}{\lambda \sqrt{f'_c}}$.
- (c) For each leg of welded plain wire reinforcement forming simple U-stirrups, either: (i) Two longitudinal wires spaced at a 50 mm spacing along the member at the top of the U; or (ii) One longitudinal wire located not more than $\frac{d}{4}$ from the compression face and a second wire closer to the compression face and spaced not less than 50 mm from the first wire. The second wire shall be permitted to be located on the stirrup leg beyond a bend, or on a bend with an inside diameter of bend not less than $8d_b$.
- (d) For each end of a single leg stirrup of welded wire reinforcement, two longitudinal wires at a minimum spacing of 50 mm and with the inner wire at least the greater of $\frac{d}{4}$ or 50 mm from $\frac{d}{2}$. Outer longitudinal wire at tension face shall not be farther from the face than the portion of primary flexural reinforcement closest to the face.
- (e) In joist construction, for 13 mm diameter bar and ASTM MD130 wire and smaller, a standard hook.

8.2.10.3 Each bend in the continuous portion of a simple U-stirrup or multiple U-stirrup shall enclose a longitudinal bar between anchored ends.

8.2.10.4 If extended into the region of tension, longitudinal bars bent to act as shear reinforcement shall be continuous with longitudinal reinforcement and, if extended into a region of compression, shall be anchored beyond mid-depth $\frac{d}{2}$ as specified for development length in Sec 8.2.3 for that part of f_{yt} required² to satisfy Eq. 6.6.58.

8.2.10.5 Pairs of U-stirrups or ties so placed as to form a closed unit shall be considered properly spliced when length of laps are $1.3l_d$. In members at least 450 mm deep, such splices with $A_b f_{yt}$ not more than 40 kN per leg shall be considered adequate if stirrup legs extend the full available depth of member.

8.2.11 Development of Plain Bars

For plain bars, the minimum development length shall be twice that of deformed bars specified in Sections 8.2.1 to 8.2.10 above.

8.2.12 Splices of Reinforcement - General

8.2.12.1 Splices of reinforcement shall be made only as required or permitted on design drawings, or in specifications, or as authorized by the engineer.

8.2.12.2 Lap splices

- (a) Lap splices shall not be used for 36 mm diameter bars and larger, except as provided in Sections 8.2.14.2 Chapter 8 and 6.8.8.2.3 Chapter 6.
- (b) Lap splices of bundled bars shall be based on the lap splice length required for individual bars within the bundle, increased in accordance with Sec 8.2.5. Individual bar splices within a bundle shall not overlap. Entire bundles shall not be lap spliced.
- (c) Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than one-fifth the required lap splice length, nor 150 mm.

8.2.12.3 Welded splices and mechanical connections

- (a) Welded splices and other mechanical connections are allowed.
- (b) Except as provided in this Code, all welding shall conform to "Structural Welding Code - Reinforcing Steel" (AWS D1.4).
- (c) Welded splices shall be butted and welded to develop in tension at least 125 percent of specified yield strength f_y of the bar.
- (d) A full mechanical connection shall develop in tension or compression, as required, at least 125 percent of specified yield strength f_y of the bar.
- (e) Welded splices and mechanical connections not meeting the requirements of (c) or (d) above are allowed only for 16 mm diameter bar or smaller and in accordance with Sec 8.2.13.4.

8.2.13 Splices of Deformed Bars and Deformed Wire in Tension

8.2.13.1 The minimum length of lap for tension splices shall be as required for Class A or B splice, but not less than 300 mm, where the classification shall be as follows:

Class - A splice: $1.0l_d$

Class - B splice: $1.3l_d$

Where, l_d is calculated in accordance with Sec 8.2.3 to develop f_y but without the 300 mm minimum of Sec 8.2.3.1 and without the modification factor of Sec 8.2.3.5.

8.2.13.2 Lap splices of deformed bars and deformed wire in tension shall be class B splices except that Class A splices are allowed when the area of reinforcement provided is at least twice that required by analysis over the entire length of the splice, and one-half or less of total reinforcement is spliced within the required lap length.

8.2.13.3 Where area of reinforcement provided is less than twice that required by analysis, welded splices or mechanical connections used shall meet the requirements of Sec 8.2.12.3(c) or Sec 8.2.12.3(d) above.

8.2.13.4 Welded splices or mechanical connections not meeting the requirements of Sec 8.2.12.3(c) or Sec 8.2.12.3(d) shall be permitted for 16 mm diameter bars or smaller if the following requirements are met:

- (a) Splices shall be staggered at least 600 mm and in such manner as to develop at every section at least twice the calculated tensile force at the section but not less than 140 N/mm^2 for total area of reinforcement provided.
- (b) Spliced reinforcement stress shall be taken as the specified splice strength, in computing tensile force developed at each section, but not to exceed f_y . Unspliced reinforcement stress shall be taken as a fraction of f_y defined by the ratio of the shortest actual development length provided beyond the section to l_d but not to be taken greater than f_y .

8.2.13.5 When bars of different size are lap spliced in tension, splice length shall be the larger of l_d of larger bar and tension lap splice length of smaller bar.

8.2.13.6 Splices in tension tie members shall be made with a full welded splice or full mechanical connection in accordance with Sec 8.2.12.3(c) or (d) and splices in adjacent bars shall be staggered at least 750 mm.

8.2.14 Splices of Deformed Bars in Compression

8.2.14.1 The minimum length of lap for compression splice shall be $0.071f_y d_b$ for f_y equal to 420 N/mm^2 or less or $(0.13f_y - 24)d_b$ for f_y greater than 420 N/mm^2 , but not less than 300 mm. For f'_c less than 21 N/mm^2 , length of lap shall be increased by one-third.

8.2.14.2 When bars of different diameters are lap spliced in compression, the splice length shall be the larger of the development length, l_{dc} of the larger bar, and the compression splice length of the smaller bar. Lap splices of 40 mm to 43 mm and 50 mm and 57 mm diameter bars to 36 mm diameter and smaller bars shall be permitted.

8.2.14.3 Welded splices or mechanical connections used in compression shall satisfy the requirements of Sec 8.2.12.3(c) or Sec 8.2.12.3(d).

8.2.14.4 End bearing splices

- (a) Compression splices for bars required to transmit compressive stress only may consist of end bearing of square cut ends held in concentric contact by a suitable device.
- (b) Bar ends shall terminate in flat surfaces within 1.5° of a right angle to the axis of the bars, and shall be fitted within 3 degrees of full bearing after assembly.
- (c) End bearing splices shall be used only in members containing closed ties, closed stirrups or spirals.

8.2.15 Special Splice Requirements for Columns

8.2.15.1 Lap splices, butt welded splices, mechanical connections, or end-bearing splices shall be used with the limitations of Sections 8.2.15.2 to 8.2.15.4 below. A splice shall satisfy the requirements for all load combinations for the column.

8.2.15.2 Lap splices in columns

- (a) Lap splices shall conform to Sec 8.2.14.1, Sec 8.2.14.2, and where applicable to Sec 8.2.15.2(d) or Sec 8.2.15.2(e) below, where the bar stresses due to factored loads is compressive.
- (b) Where the bar stress due to factored loads is tensile and does not exceed $0.5f_y$ in tension, lap splices shall be Class B tension lap splices if more than one-half of the bars are spliced at any section, or Class A tension lap splices if half or fewer of the bars are spliced at any section and alternate lap splices are staggered by l_d .
- (c) Where the bar stress due to factored loads is greater than $0.5f_y$ in tension, lap splices shall be Class B tension lap splices.
- (d) In tied reinforced compression members, if throughout lap splice length ties have an effective area of at least $0.0015h_s$ in both directions, lap splice length is permitted to be multiplied by 0.83, but lap length shall not be less than 300 mm. Tie legs perpendicular to dimension h shall be used in determining effective area.
- (e) For spirally reinforced compression members, lap splice length of bars within a spiral is permitted to be multiplied by 0.75, but lap length shall not be less than 300 mm.

8.2.15.3 Welded splices or mechanical connectors in columns: Welded splices or mechanical connectors in columns shall meet the requirements of Sec 8.2.12.3(c) or Sec 8.2.12.3(d).

8.2.15.4 End bearing splices in columns: End bearing splices complying with Sec 8.2.14.4 may be used for column bars stressed in compression provided the splices are staggered or additional bars are provided at splice locations. The continuing bars in each face of the column shall have a tensile strength at least $0.25f_y$ times the area of the vertical reinforcement in that face.

8.2.16 Splices of Plain Bars

For plain bars, the minimum length of lap shall be twice that of deformed bars specified in Sections 8.2.12 to 8.2.15 above.

8.2.17 Development of headed and mechanically anchored deformed bars in tension

8.2.17.1 Development length for headed deformed bars in tension, l_{dt} shall be determined from Sec 8.2.17.2. Use of heads to develop deformed bars in tension shall be limited to conditions satisfying (a) through (f):

- (a) Bar f_y shall not exceed 420 MPa;
- (b) Bar size shall not exceed 36 mm diameter;
- (c) Concrete shall be normal weight;
- (d) Net bearing area of head A_{brg} shall not be less than $4A_b$;
- (e) Clear cover for bar shall not be less than $2d_b$; and
- (f) Clear spacing between bars shall not be less than $4d_b$.

8.2.17.2 For headed deformed bars, development length in tension l_{dt} shall be $0.19 \frac{\psi_e f_y}{\sqrt{f'_c}} d_b$, where the value of f'_c used to calculate l_{dt} shall not exceed 40 MPa, and factor ψ_e shall be taken as 1.2 for epoxy-coated reinforcement and 1.0 for other cases. Where reinforcement provided is in excess of that required by analysis, except where development of f_y is specifically required, a factor of $\frac{A_{s,required}}{A_{s,provided}}$ may be applied to the expression for l_{dt} . Length l_{dt} shall not be less than the larger of $8d_b$ and 150 mm.

8.2.17.3 Heads shall not be considered effective in developing bars in compression.

8.2.17.4 Any mechanical attachment or device capable of developing f_y of reinforcement is allowed, provided that test results showing the adequacy of such attachment or device are approved by the Engineer. Development of reinforcement shall be permitted to consist of a combination of mechanical anchorage plus additional embedment length of reinforcement between critical section and mechanical attachment or device.

8.2.18 Development of Welded Deformed Wire Reinforcement in Tension

8.2.18.1 Development length for welded deformed wire reinforcement in tension, l_d measured from the point of critical section to the end of wire shall be computed as the product of, l_d from Sec 8.2.3.2 or Sec 8.2.3.3, times welded deformed wire reinforcement factor, ψ_w from 8.2.18.2 or 8.2.18.3. It shall be permitted to reduce l_d in accordance with Sec 8.2.3.5 when applicable, but l_d shall not be less than 200 mm except in computation of lap splices by Sec 8.2.20. When using ψ_w from Sec 8.2.18.2, it shall be permitted to use an epoxy-coating factor ψ_e of 1.0 for epoxy-coated welded deformed wire reinforcement in Sections 8.2.3.2 and 8.2.3.3.

8.2.18.2 For welded deformed wire reinforcement with at least one cross wire within l_d and not less than 50 mm from the point of the critical section, ψ_w shall be the greater of $\left(\frac{f_y - 240}{f_y}\right)$ and $\left(\frac{5d_b}{s}\right)$ but not greater than 1.0, where s is the spacing between the wires to be developed.

8.2.18.3 For welded deformed wire reinforcement with no cross wires within l_d or with a single cross wire less than 50 mm from the point of the critical section, ψ_w shall be taken as 1.0, and l_d shall be determined as for deformed wire.

8.2.18.4 Where any plain wires, or deformed wires larger than ASTM D 31, are present in the welded deformed wire reinforcement in the direction of the development length, the reinforcement shall be developed in accordance with Sec 8.2.19.

8.2.19 Development of Welded Plain Wire Reinforcement in Tension

Yield strength of welded plain wire reinforcement shall be considered developed by embedment of two cross wires with the closer cross wire not less than 50 mm from the point of the critical section. However, l_d shall not be less than

$$l_d = 3.3 \frac{A_b}{s} \frac{f_y}{\lambda \sqrt{f'_c}} \quad (6.8.4)$$

Where l_d is measured from the point of the critical section to the outermost crosswire, s is the spacing between the wires to be developed, and λ as given in Sec 8.2.3.4(d). Where reinforcement provided is in excess of that required, l_d may be reduced in accordance with Sec 8.2.3.5. Length, l_d shall not be less than 150 mm except in computation of lap splices by Sec 8.2.21.

8.2.20 Splices of Welded Deformed Wire Reinforcement in Tension

8.2.20.1 Minimum lap splice length of welded deformed wire reinforcement measured between the ends of each reinforcement sheet shall be not less than the larger of $1.3l_d$ and 200 mm, and the overlap measured between outermost cross wires of each reinforcement sheet shall be not less than 50 mm, where l_d is calculated in accordance with Sec 8.2.18 to develop f_y .

8.2.20.2 Lap splices of welded deformed wire reinforcement, with no cross wires within the lap splice length, shall be determined as for deformed wire.

8.2.20.3 Where any plain wires, or deformed wires larger than ASTM MD200, are present in the welded deformed wire reinforcement in the direction of the lap splice or where welded deformed wire reinforcement is lap spliced to welded plain wire reinforcement, reinforcement shall be lap spliced in accordance with Sec 8.2.21.

8.2.21 Splices of Welded Plain Wire Reinforcement in Tension

Minimum length of lap for lap splices of welded plain wire reinforcement shall be in accordance with Sections 8.2.21.1 and 8.2.21.2.

8.2.21.1 Where A_s provided is less than twice that required by analysis at splice location, length of overlap measured between outermost cross wires of each reinforcement sheet shall be not less than the largest of one spacing of cross wires plus 50 mm, $1.5l_d$ and 150 mm, where l_d is calculated in accordance with Sec 8.2.19 to develop f_y .

8.2.21.2 Where A_s provided is at least twice that required by analysis at splice location, length of overlap measured between outermost cross wires of each reinforcement sheet shall not be less than the larger of $1.5l_d$ and 50 mm, where l_d is calculated in accordance with Sec 8.2.19 to develop f_y .

8.3 Earthquake-Resistant Design Provisions

8.3.1 Scope

This section contains special requirements for design and construction of reinforced concrete members of a structure for which the design forces, related to earthquake motions, have been determined on the basis of energy dissipation in the nonlinear range of response.

8.3.2 Provisions

- (a) The provisions of Chapter 6, shall apply except as modified by the provisions of this Section.
- (b) Structures assigned to seismic design category SDC D (see Chapter 2), all reinforced concrete structures shall satisfy the requirements of special seismic detailing as given in Sections 8.3.3 to 8.3.8 in addition to the requirements of Chapter 6. The provisions for special moment frames shall not permit the use of slab without beam as part of seismic force-resisting system.

- (c) Structures assigned to SDC C (see Chapter 2), all reinforced concrete structures shall be built to satisfy the requirements of intermediate seismic detailing as given in Sec 8.3.10 in addition to the requirements of Chapter 6.
- (d) Structures assigned to SDC B (see Chapter 2), all reinforced concrete structures shall be built to satisfy the requirements of ordinary detailing as given in Sec 8.3.9 in addition to the requirements of Chapter 6.
- (e) Structures in lower SDCs are permitted to design with detailing provisions of higher SDCs to take advantage of lower design force levels.

8.3.3 General Requirements

8.3.3.1 Analysis and proportioning of structural members

- (a) The interaction of all structural and nonstructural members shall be considered in the analysis.
- (b) Rigid members which are not a part of the lateral force resisting system are allowed provided their effect on the response of the system is considered and accommodated in the structural design. Consequences of failure of structural and nonstructural members which are not a part of the lateral force resisting system shall also be considered.
- (c) Structural members below base of structure required to transmit forces resulting from earthquake effects to the foundation shall also comply with the requirements of this section.
- (d) All structural members which are not a part of the lateral force resisting system shall conform to Sec 8.3.9.

8.3.3.2 Strength reduction factors

Strength reduction factors shall be in accordance with Sections 6.2.3.2 to 6.2.3.4.

8.3.3.3 Concrete in special moment frames and special structural walls

Compressive strength f'_c of the concrete shall be not less than 21 N/mm². Specified compressive strength of light-weight concrete, f'_c shall not exceed 35MPa unless demonstrated by experimental evidence. Modification factor λ for lightweight concrete in Sec 8.3 shall be in accordance with Sec 6.1.8 unless noted otherwise.

8.3.3.4 Reinforcement in special moment frames and special structural walls

- (a) Requirements of Sec 8.3.3.4 shall apply to special moment frames, special structural walls and all components of special structural walls including coupling beams and wall piers.

- (b) Deformed reinforcement resisting earthquake-induced flexural and axial force, or both, shall comply with ASTM A706 Grade 420. Alternatively only BDS ISO 6935-2 Grades 300, 350, 400 and 420 or ASTM A615 Grades 275 and 420 reinforcement shall be permitted if:
 - (i) The actual yield strength based on mill tests does not exceed f_y by more than 125 N/mm² (retests shall not exceed this value by more than an additional 20 N/mm²); and
 - (ii) The ratio of the actual tensile strength to the actual yield strength is not less than 1.25.
 - (iii) Minimum elongation in 200 mm shall be at least 14 percent for bar dia. 10 mm to 20 mm, at least 12 percent for bar dia. 22 mm through 36 mm, and at least 10 percent for bar dia. 40 mm to 60 mm.
- (c) The value of f_{yt} used to compute the amount of confinement reinforcement shall not exceed 700 N/mm².
- (d) The value of f_y or f_{yt} used in design of shear reinforcement shall conform to Sec 6.4.3.2.

8.3.3.5 Welding

Reinforcement required by factored load combinations which include earthquake effect shall not be welded except as specified in Sections 8.3.4.2(d) and 8.3.5.3(b). In addition, welding shall not be permitted on stirrups, ties, inserts, or other similar elements to longitudinal reinforcement required by design.

8.3.4 Flexural Members of Special Moment Frames

8.3.4.1 Scope

Requirements of this section shall apply to special moment frame members; (i) resisting earthquake induced forces, and (ii) proportioned primarily to resist flexure. These frame members shall also satisfy the following conditions. The requirements are also shown in Figure 6.8.1.

- (a) Factored axial compressive force on frame member shall not exceed $0.1A_g f'_c$.
- (b) Clear span for the member, l_n shall not be less than four times its effective depth.
- (c) The width to depth ratio shall be at least 0.3.

- (d) The width shall not be (i) less than 250 mm and (ii) more than the width of the supporting member (measured on a plane perpendicular to the longitudinal axis of the flexural member) plus distances on each side of the supporting member neither exceeding three-fourths of the depth of the flexural member c_1 nor width of supporting member c_2 .

8.3.4.2 Longitudinal reinforcement

- (a) At any section of a flexural member and for the top as well as for the bottom reinforcement, the amount of reinforcement shall be not less than $0.25 \frac{f'_c}{f_y} b_w d$ or $1.4 \frac{b_w d}{f_y}$ and the reinforcement ratio, ρ shall not exceed 0.025 (Figure 6.8.2). At least two bars shall be provided continuously both top and bottom. The positive moment strength at the face of the joint shall be not less than one-half of the negative moment strength provided at that face as shown in Figure 6.8.2. Neither the negative nor the positive moment strength at any section along the member length shall be less than one-fourth the maximum moment strength provided at the face of either joint.
- (b) Lap splices of flexural reinforcement shall be permitted only if hoop or spiral reinforcement is provided over the lap length. Maximum spacing of the transverse reinforcement enclosing the lapped bars shall not exceed $\frac{d}{4}$ nor 100 mm. Lap splices shall not be used; (i) within the joints, (ii) within a distance of twice the member depth from the face of the joint, and (iii) at locations where analysis indicates flexural yielding caused by inelastic lateral displacements of the frame. These requirements are shown in Figure 6.8.3.

Welded splices and mechanical connections conforming to Sections 8.2.12.3(a) to 8.2.12.3(d) are allowed for splicing provided not more than alternate bars in each layer of longitudinal reinforcement are spliced at a section and the centre to centre distance between splices of adjacent bars is 600 mm or more measured along the longitudinal axis of the frame member. Welded splices and mechanical connections (Type 1) shall not be used within a distance equal to twice the member depth from the column or beam faces for special moment frames or from sections where yielding of the reinforcement is likely to occur as a result of inelastic lateral displacement.

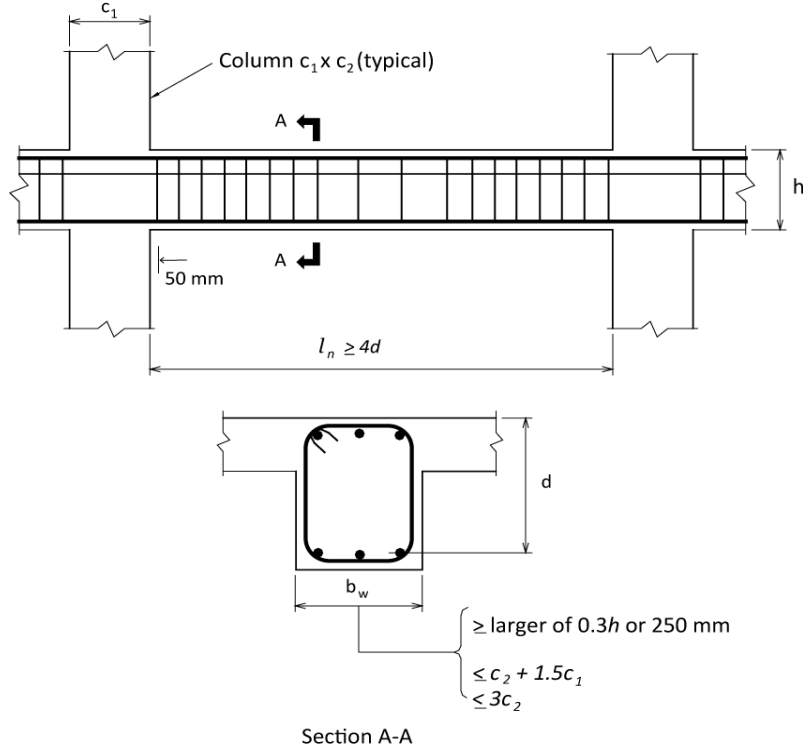


Figure 6.8.1. General requirement for flexural members of special moment frames (Sec 8.3.4.1)

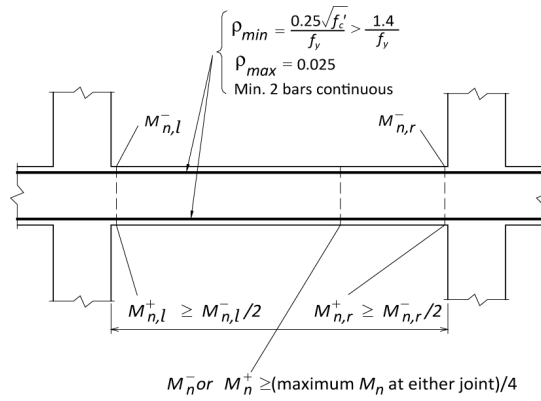
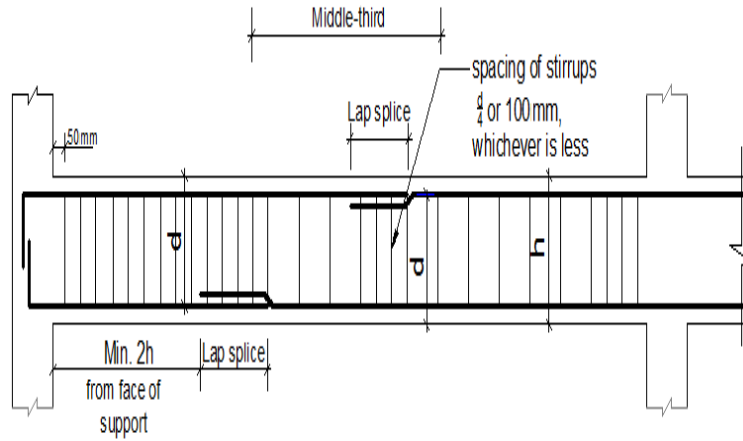


Figure 6.8.2 Flexural Requirements for Flexural Members of Special Moment Frames (Sec 8.3.4.2)



Notes: (i) For beam bottom bars lap shall not be provided within a distance of twice the member depth from the face of the support; (ii) Preferred lap location of top bar is within middle third of the span but may be provided beyond 2h from the face of the support; (iii) Not more than 50% of the bars shall be spliced at one location; (iv) Lap splices are to be confined by stirrups with maximum spacing $d/4$ or 100 mm whichever is smaller.

Figure 6.8.3 Lap splice requirements for flexural members of special moment frames (Sec 8.3.4.2)

8.3.4.3 Transverse reinforcement

- (a) Hoops shall be provided in the following regions of frame members:
 - (i) At both ends of the flexural member, over a length equal to twice the member depth measured from the face of the supporting member toward midspan (Figure 6.8.4).
 - (ii) Over lengths equal to twice the member depth (Figure 6.8.4), on both sides of a section where flexural yielding is likely to occur in connection with inelastic lateral displacements of the frame.
- (b) The first hoop shall be located not more than 50 mm from the face of the supporting member (Figure 6.8.4). Maximum spacing of the hoops shall not exceed (i) $\frac{d}{4}$ (ii) eight times the diameter of the smallest longitudinal bars, (iii) 24 times the diameter of the hoop bars, and (iv) 300 mm.
- (c) Where hoops are required, longitudinal bars on the perimeter shall have lateral support conforming to 8.1.9.4(c), and where hoops are not required, stirrups with seismic hooks shall be spaced not more than $\frac{d}{2}$ throughout the length of the member (Figure 6.8.4).

- (d) Hoops in flexural members are allowed to be made up of two pieces of reinforcement consisting of a U-stirrup having hooks not less than 135° with 6 diameter but not less than 75 mm extension anchored in the confined core and a cross tie to make a closed hoop (Figure 6.8.5). Consecutive cross ties engaging the same longitudinal bar shall have their 90° hooks at opposite sides of the flexural member. If the longitudinal reinforcing bars secured by the cross ties are confined by a slab only on one side of the flexural frame member, the 90° hooks of the cross ties shall all be placed on that side.

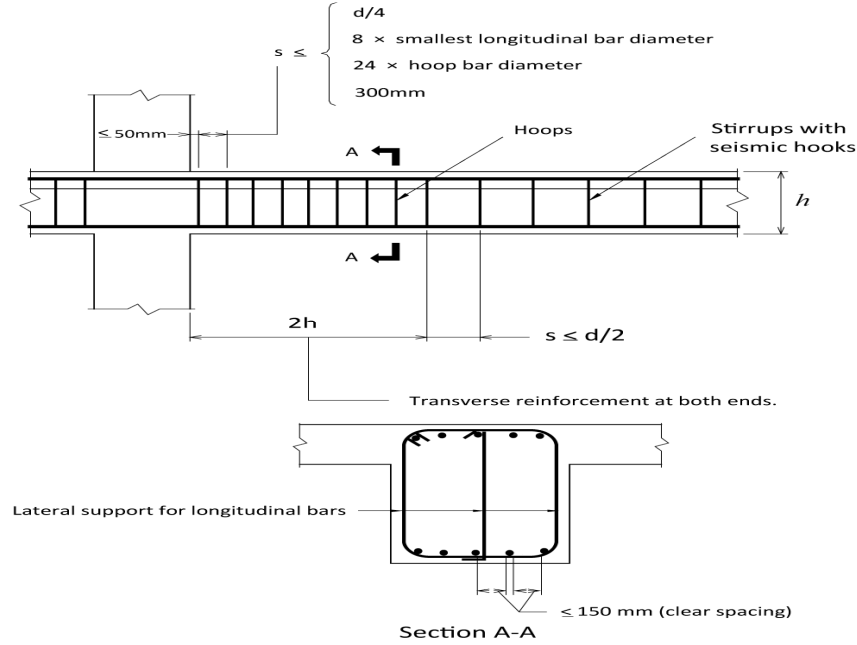


Figure 6.8.4 Transverse Reinforcement Requirements for Flexural Members of Special Moment Frames (Sec 8.3.4.3)

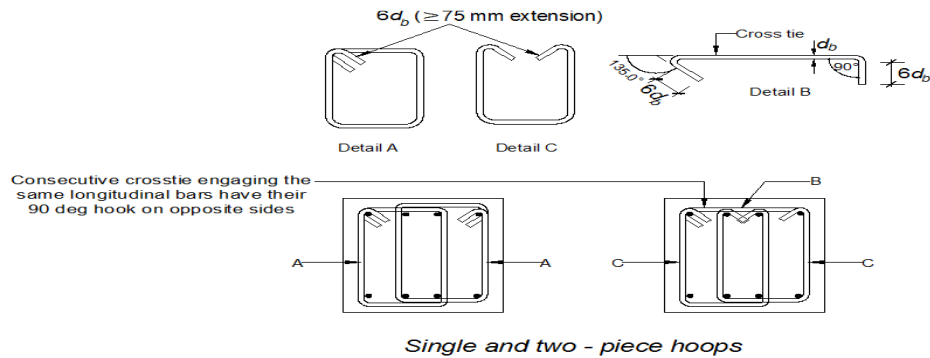


Figure 6.8.5 Hoop Reinforcement Requirements for Flexural Members of Special Moment Frames (Sec 8.3.4.3)

8.3.5 Special Moment Frame Members Subjected to Bending and Axial Load

8.3.5.1 Scope

The requirements of this section shall apply to columns and other frame members serving to resist earthquake forces and having a factored axial force exceeding $0.1A_g f'_c$. These frame members shall also satisfy the following conditions. The requirements are also shown in Figure 6.8.6.

- (a) The shortest cross-sectional dimension shall not be less than 300 mm.
- (b) The ratio of the shortest cross-sectional dimension to the perpendicular dimension shall not be less than 0.4.

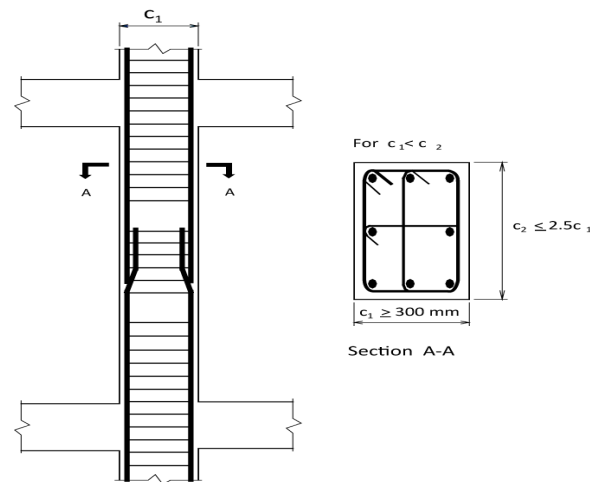


Figure 6.8.6 General requirements for special moment frames subjected to bending and axial load (Sec 8.3.5.1)

8.3.5.2 Minimum flexural strength of columns

- (a) Flexural strength of any column designed to resist a factored axial compressive force exceeding $0.1A_g f'_c$ shall satisfy (b) or (c) below. Lateral strength and stiffness of columns not satisfying (b) below shall be ignored in calculating the strength and stiffness of the structure but shall conform to Sec 8.3.9.
- (b) The flexural strength of the columns shall satisfy the following relation:

$$\sum M_c \geq 1.2 \sum M_g \quad (6.8.5)$$

Where,

$\sum M_c$ = sum of nominal flexural strengths of columns framing into the joint, evaluated at the face of the joint. Column flexural strength shall be calculated for the factored axial force, consistent with the direction of lateral forces considered, resulting in the lowest flexural strength.

$\sum M_g$ = sum of nominal flexural strength of the beams framing into the joint evaluated at the face of the joint.

Flexural strengths shall be summed such that the column moments oppose the beam moments. Eq. 6.8.5 shall be satisfied for beam moments acting in both directions in the vertical plane of the frame considered.

- (c) If the requirements of (b) above is not satisfied at a joint, columns supporting reactions from that joint shall be provided with transverse reinforcement as specified in Sec 8.3.5.4 over their entire height.

8.3.5.3 Longitudinal reinforcement

The provisions of longitudinal reinforcement are as shown in Figure 6.8.7 and stated as under.

- (a) The reinforcement ratio, ρ_g shall not be less than 0.01 and shall not exceed 0.06.
- (b) Lap splices are permitted only within the centre half of the member length and shall be designed as tension splices. Welded splices and mechanical connections conforming to Sections 8.2.12.3(a) to 8.2.12.3(d) are allowed for splicing the reinforcement at any section provided not more than alternate longitudinal bars are spliced at a section and the distance between splices is 600 mm or more along the longitudinal axis of the reinforcement.

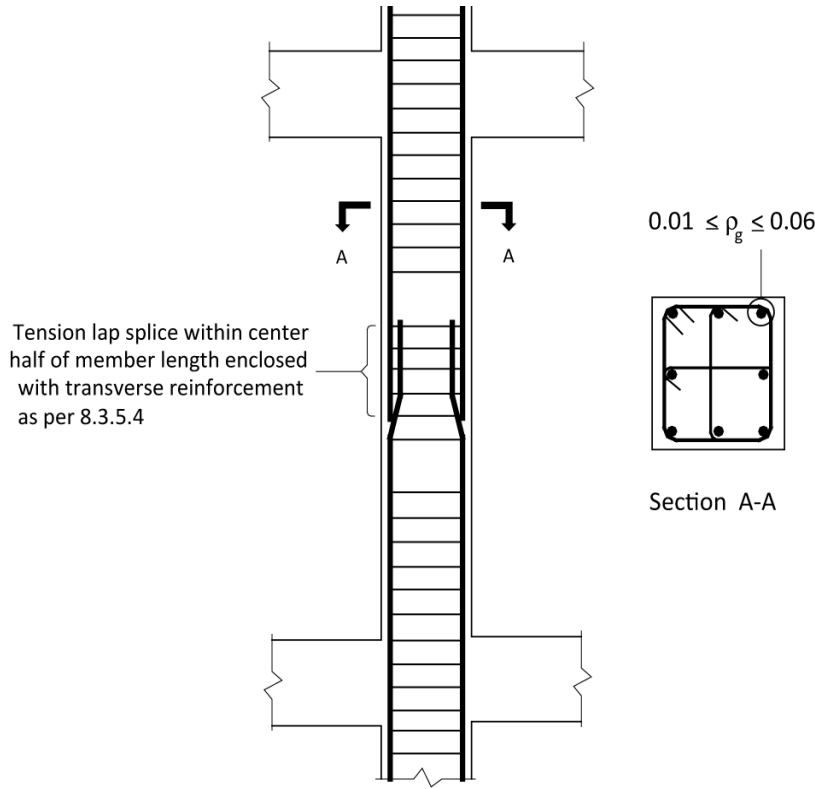


Figure 6.8.7 Longitudinal reinforcement requirements (SMF) (Sec 8.3.5.3)

8.3.5.4 Transverse reinforcement

- (a) Transverse reinforcement shall be provided as specified below and shown in Figures 6.8.8 and 6.8.9 unless a larger amount is required by Sec 8.3.8.
- (i) The volumetric ratio of spiral or circular hoop reinforcement, ρ_s shall not be less than that indicated by the following equation:

$$\rho_s = \frac{0.12f'_c}{f_{yt}} \quad (6.8.6)$$

and shall not be less than that required by Eq. (6.6.12).

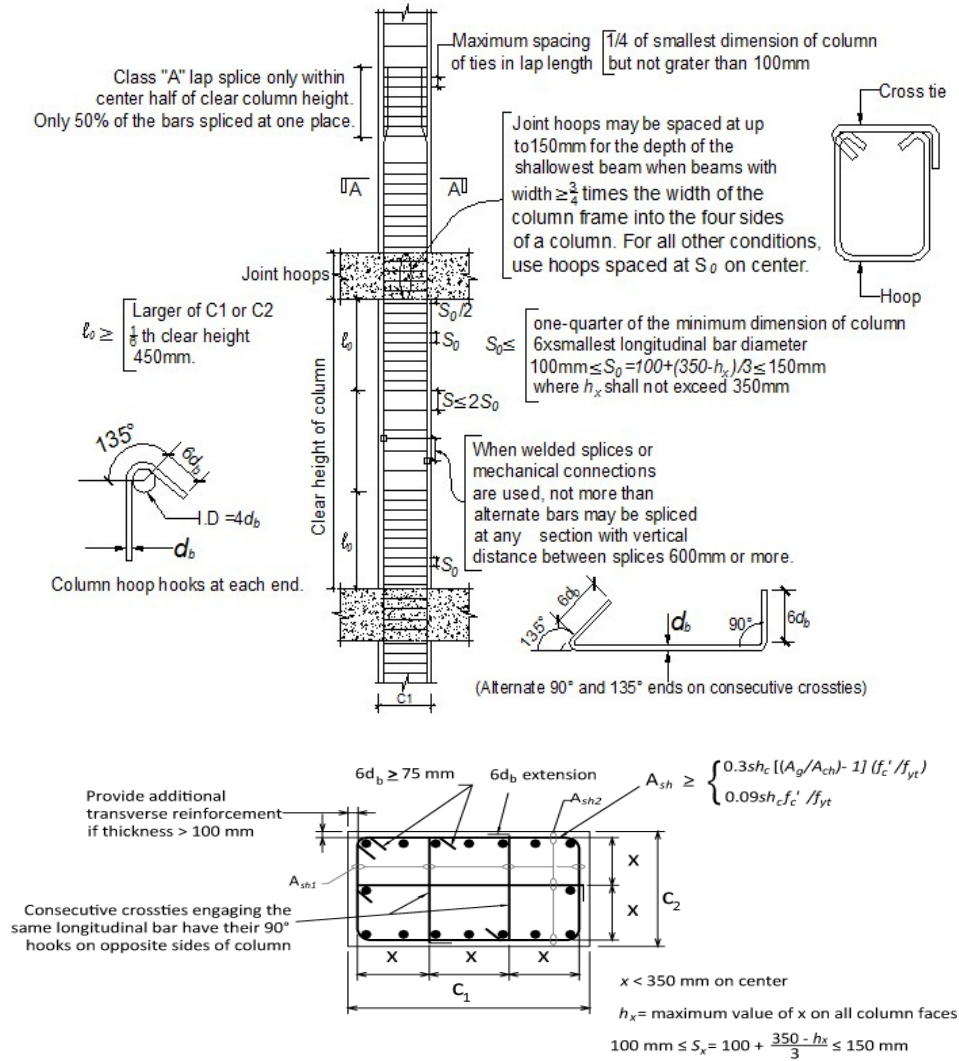
- (ii) The total cross-sectional area of rectangular hoop reinforcement shall not be less than that given by the following equations:

$$A_{sh} = 0.3 \left(\frac{shcf'_c}{f_{yt}} \right) \left(\frac{A_g}{A_{ch}} - 1 \right) \quad (6.8.7)$$

$$A_{sh} = 0.09 \left(\frac{shcf'_c}{f_{yt}} \right) \quad (6.8.8)$$

- (iii) Transverse reinforcement shall be provided by either single or overlapping hoops or cross ties of the same bar size and spacing. Each end of the cross ties shall engage a peripheral longitudinal reinforcing bar. Consecutive cross ties shall be alternated end for end along the longitudinal reinforcement.
- (iv) If the design strength of member core satisfies the requirements of the specified loading combinations including earthquake effect, Eq. 6.8.7 and Eq. 6.6.12 need not be satisfied.
- (b) Spacing of transverse reinforcement along the length l_o of the member shall not exceed the smallest of (i) one-quarter of the minimum dimension (ii) six times the diameter of the smallest longitudinal bar and (iii) $s_o = 100 + \frac{(350-h_x)}{3}$. The value of s_o shall not exceed 150 mm and need not be taken less than 100 mm.
- (c) Spacing of cross ties or legs of overlapping hoops shall not be more than 350 mm on centre in the direction perpendicular to the longitudinal axis of the member.
- (d) The volume of transverse reinforcement in amount specified in (a) through (c) above shall be provided over a length l_o from each joint face and on both sides of any section where flexural yielding is likely to occur in connection with inelastic lateral displacements of the frame. The length l_o shall not be less than (i) the depth of the member at the joint face or at the section where flexural yielding is likely to occur, (ii) one-sixth of the clear span of the member, and (iii) 450 mm.
- (e) If the factored axial force in columns supporting reactions from discontinued stiff members, such as walls, exceeds $0.1A_gf'_c$ they shall be provided with transverse reinforcement as specified in (a) through (c) above over their full height beneath the level at which the discontinuity occurs. Transverse reinforcement shall extend into the discontinued member for at least the development length of the largest longitudinal reinforcement in the column in accordance with Sec 8.3.7.4. If the lower end of the column terminates on a wall, transverse reinforcement as specified above shall extend into the wall for at least the development length of the largest longitudinal reinforcement in the column at the point of termination. If the column terminates on a footing or mat, transverse reinforcement as specified in above shall extend at least 300 mm into the footing or mat.

- (f) Where transverse reinforcement as specified in (a) through (c) above, is not provided throughout the full length of the column, the remainder of the column length shall contain spiral or hoop reinforcement with centre to centre spacing not exceeding the smaller of 6 times the diameter of the longitudinal column bars or 150 mm.



Note: In beam column joints where members frame into all four sides of the joint and each member width is at least three-fourths the column width, the spacing of transverse reinforcement shall be 150 mm within the overall depth of the shallowest frame member. For all other conditions spacing shall be S_0 . Use hoops and cross ties in beam column joint.

Figure 6.8.8 Transverse reinforcement requirements- rectangular hoop for members subjected to bending and axial load rectangular hoop (SMF) (Sec 8.3.5.4)

8.3.6 Special Structural Walls and Coupling Beams

8.3.6.1 Scope: Requirements of Sec 8.3.6 apply to special structural walls and all components of special structural walls including coupling beams and wall piers forming part of the seismic-force-resisting system.

8.3.6.2 Reinforcement

- (a) The distributed web reinforcement ratios, ρ_l and ρ_t , for structural walls shall not be less than 0.0025, except that if V_u does not exceed $0.083A_{cv}\lambda\sqrt{f'_c}$, ρ_l and ρ_t shall be permitted to be reduced to the values required as specified below. Reinforcement spacing each way in structural walls shall not exceed 450 mm. Reinforcement contributing to V_n shall be continuous and shall be distributed across the shear plane.
- (i) Minimum ratio of vertical reinforcement area to gross concrete area, ρ_v , shall be:
- | | |
|---|--------|
| Deformed bar not larger than 16 mm diameter with f_y not less than 420 MPa: | 0.0012 |
| Other deformed bars: | 0.0015 |
| Welded wire reinforcement not larger than ASTM MW 200 or MD 200: | 0.0012 |
- (ii) Minimum ratio of horizontal reinforcement area to gross concrete area, ρ_h , shall be:
- | | |
|---|--------|
| Deformed bar not larger than 16 mm diameter with f_y not less than 420 MPa: | 0.0020 |
| Other deformed bars: | 0.0025 |
| Welded wire reinforcement not larger than ASTM MW 200 or MD 200: | 0.0020 |
- (b) At least two curtains of reinforcement shall be used in a wall if V_u exceeds $0.17A_{cv}\lambda\sqrt{f'_c}$.
- (c) Reinforcement in structural walls shall be developed or spliced for f_y in tension in accordance with Sec 8.2, except:
- (i) The effective depth of the member shall be permitted to be taken as $0.8l_w$ for walls where, reinforcement extended beyond the point at which it is no longer required to resist flexure for a distance equal to d or $12d_b$, whichever is greater, except at supports of simple spans and at free end of cantilevers.
- (ii) The requirements of Sections 8.2.8, 8.2.9, and 8.2.10 need not be satisfied.

At locations where yielding of longitudinal reinforcement is likely to occur as a result of lateral displacements, development lengths of longitudinal reinforcement shall be 1.25 times the values calculated for f_y in tension.

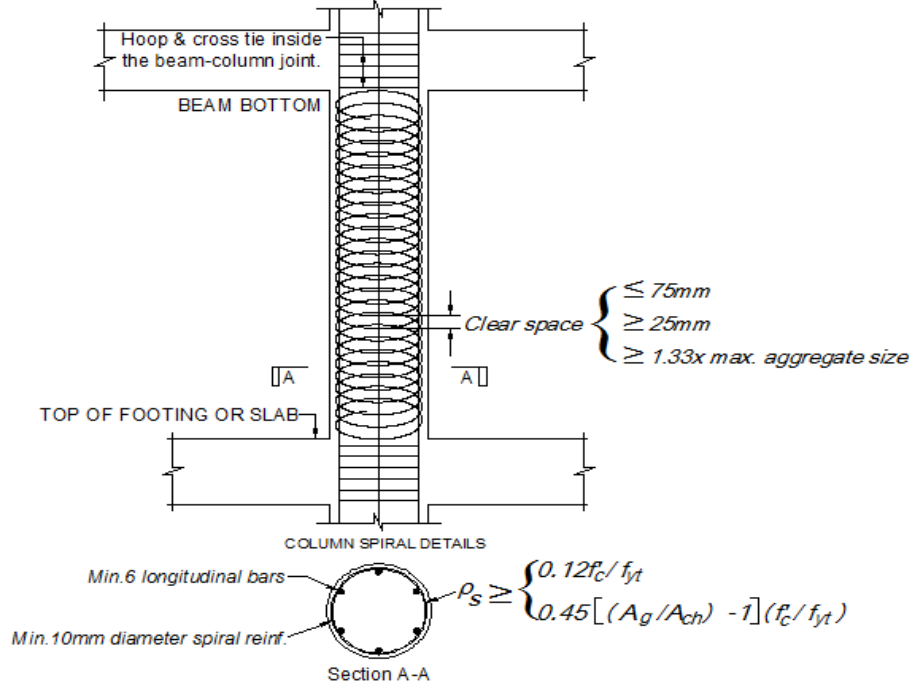


Figure 6.8.9 Transverse reinforcement requirements- spiral hoop (SMF) (Sections 8.1.9.3, 8.3.7.2)

8.3.6.3 Design forces: V_u shall be obtained from the lateral load analysis in accordance with the factored load combinations.

8.3.6.4 Shear strength

- (a) V_n of structural walls shall not exceed

$$V_n = A_{cv}(\alpha_c \lambda \sqrt{f'_c} + \rho_t f_y) \quad (6.8.9)$$

Where, the coefficient α_c is 0.25 for $h_w/l_w \leq 1.5$, is 0.17 for $h_w/l_w \geq 2.0$, and varies linearly between 0.25 and 0.17 for h_w/l_w between 1.5 and 2.0.

- (b) In Sec 8.3.6.4(a), the value of ratio h_w/l_w used for determining V_n for segments of a wall shall be the larger of the ratios for the entire wall and the segment of wall considered.
- (c) Walls shall have distributed shear reinforcement providing resistance in two orthogonal directions in the plane of the wall. If h_w/l_w does not exceed 2.0, reinforcement ratio ρ_l shall not be less than reinforcement ratio ρ_t .

- (d) For all vertical wall segments resisting a common lateral force, combined V_n shall not be taken larger than $0.66A_{cv}\sqrt{f'_c}$, where, A_{cv} is the gross combined area of all vertical wall segments. For any one of the individual vertical wall segments, V_n shall not be taken larger than $0.83A_{cw}\sqrt{f'_c}$, where A_{cw} is the area of concrete section of the individual vertical wall segment considered.
- (e) For horizontal wall segments as shown in Figure 6.8.10, including coupling beams, V_n shall not be taken larger than $0.83A_{cw}\sqrt{f'_c}$, where A_{cw} is the area of concrete section of a horizontal wall segment or coupling beam.

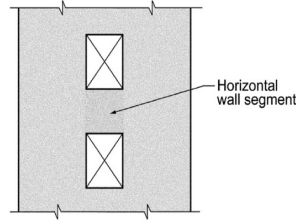


Figure 6.8.10 Wall with openings

8.3.6.5 Design for flexure and axial loads

- (a) Structural walls and portions of such walls subject to combined flexural and axial loads shall be designed in accordance with Sections 6.3.2 and 6.3.3 except that Sec 6.3.3.7 and the nonlinear strain requirements of Sec 6.3.2.2 shall not apply. Concrete and developed longitudinal reinforcement within effective flange widths, boundary elements, and the wall web shall be considered effective. The effects of openings shall be considered.
- (b) Unless a more detailed analysis is performed, effective flange widths of flanged sections shall extend from the face of the web a distance equal to the smaller of one-half the distance to an adjacent wall web and 25 percent of the total wall height.

8.3.6.6 Boundary elements of special structural walls

- (a) The need for special boundary elements at the edges of structural walls shall be evaluated in accordance with Sec 8.3.6.6(b) or (c). The requirements of Sec 8.3.6.6(d) and (e) also shall be satisfied.

- (b) This section applies to walls or wall piers that are effectively continuous from the base of structure to top of wall and designed to have a single critical section for flexure and axial loads. Walls not satisfying these requirements shall be designed by Sec 8.3.6.6(c).

- (i) Compression zones shall be reinforced with special boundary elements where

$$c \geq \frac{l_w}{600(\delta_u/h_w)} \quad (6.8.10)$$

In Eq. 6.8.10, c corresponds to the largest neutral axis depth calculated for the factored axial force and nominal moment strength consistent with the design displacement δ_u . Ratio $\frac{\delta_u}{h_w}$ in Eq. 6.8.10 shall not be taken less than 0.007;

- (ii) Where special boundary elements are required by b(i), the special boundary element reinforcement shall extend vertically from the critical section a distance not less than the larger of l_w or $\frac{M_u}{4V_u}$.

- (c) Structural walls not designed to the provisions of (b) shall have special boundary elements at boundaries and edges around openings of structural walls where the maximum extreme fiber compressive stress, corresponding to load combinations including earthquake effects, E , exceeds $0.2f'_c$. The special boundary element shall be permitted to be discontinued where the calculated compressive stress is less than $0.15f'_c$. Stresses shall be calculated for the factored forces using a linearly elastic model and gross section properties. For walls with flanges, an effective flange width as defined in Sec 8.3.6.5(b) shall be used.

- (d) Where special boundary elements are required by Sec 8.3.6.6(b) or (c), following (i) to (v) shall be satisfied as shown in Figure 6.8.11:

- (i) The boundary element shall extend horizontally from the extreme compression fiber a distance not less than the larger of $c - 0.1l_w$ and $\frac{c}{2}$, where c is the largest neutral axis depth calculated for the factored axial force and nominal moment strength consistent with δ_u ;
- (ii) In flanged sections, the boundary element shall include the effective flange width in compression and shall extend at least 300 mm into the web;
- (iii) The boundary element transverse reinforcement shall satisfy the requirements of Sec 8.3.5.4 as shown in Figure 6.8.8, except Eq. 6.8.7 need not be satisfied and the transverse reinforcement spacing limit of 8.3.5.4.b(i) shall be one-third of the least dimension of the boundary element;

- (iv) The boundary element transverse reinforcement at the wall base shall extend into the support at least l_d according to Sec 8.3.6.2(c), of the largest longitudinal reinforcement in the special boundary element unless the special boundary element terminates on a footing, mat, or pile cap, where special boundary element transverse reinforcement shall extend at least 300 mm into the footing, mat, or pile cap;
- (v) Horizontal reinforcement in the wall web shall extend to within 150 mm of the end of the wall. Reinforcement shall be anchored to develop f_y in tension within the confined core of the boundary element using standard hooks or heads. Where the confined boundary element has sufficient length to develop the horizontal web reinforcement, and $\frac{A_{sh}f_{yt}}{s}$ of the web reinforcement is not greater than $\frac{s}{s}$ of the boundary element transverse reinforcement parallel to the web reinforcement, it shall be permitted to terminate the web reinforcement without a standard hook or head.
- (e) Where special boundary elements are not required by Sec 8.3.6.6(b) or (c), (i) and (ii) shall be satisfied as shown in Figure 6.8.12:
 - (i) If the longitudinal reinforcement ratio at the wall boundary is greater than $\frac{2.8}{f_y}$, boundary transverse reinforcement shall satisfy Sec 8.3.5.4.(a).(iii), Sec 8.3.5.4.(c) as shown in Figure 6.8.8 and Sec 8.3.6.6.(d).(i). The maximum longitudinal spacing of transverse reinforcement in the boundary shall not exceed 200 mm;
 - (ii) Except when V_u in the plane of the wall is less than $0.083A_{cv}\lambda\sqrt{f'_c}$, horizontal reinforcement terminating at the edges of structural walls without boundary elements shall have a standard hook engaging the edge reinforcement or the edge reinforcement shall be enclosed in U-stirrups having the same size and spacing as, and spliced to, the horizontal reinforcement.

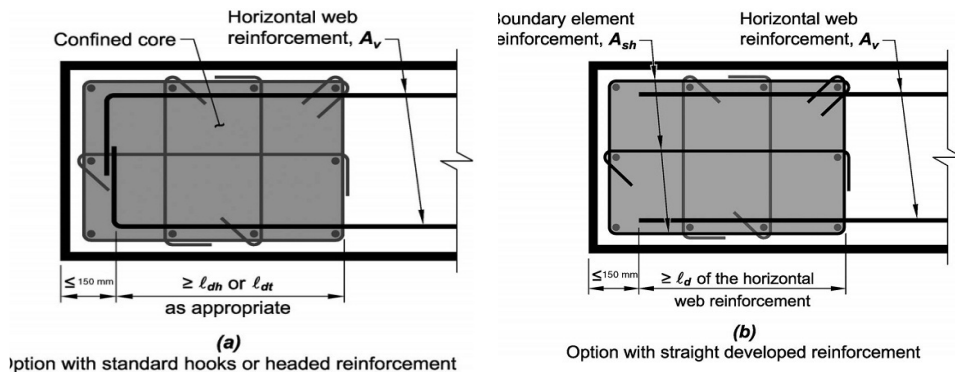


Figure 6.8.11 Development of wall horizontal reinforcement in confined boundary element

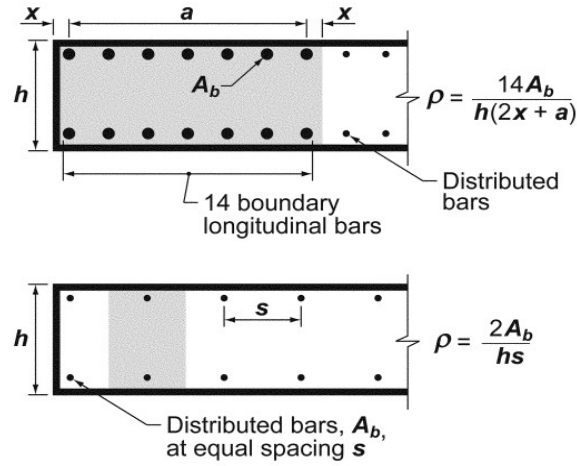


Figure 6.8.12 Longitudinal reinforcement ratios for typical wall boundary conditions.

8.3.6.7 Coupling beams

- (a) Coupling beams with $\frac{l_n}{h} > 4$ shall satisfy the requirements of Sec 8.3.7. The provisions of Sec 8.3.7.1(c) and (d) need not be satisfied if it can be shown by analysis that the beam has adequate lateral stability.
- (b) Coupling beams with $\frac{l_n}{h} < 2$ and with V_u exceeding $0.33A_{cw}\lambda\sqrt{f'_c}$, shall be reinforced with two intersecting groups of diagonally placed bars symmetrical about the midspan, unless it can be shown that loss of stiffness and strength of the coupling beams will not impair the vertical load-carrying ability of the structure, the egress from the structure, or the integrity of nonstructural components and their connections to the structure.
- (c) Coupling beams not governed by Sec 8.3.6.7(a) or (b) shall be permitted to be reinforced either with two intersecting groups of diagonally placed bars symmetrical about the midspan or according to Sections 8.3.7.2 to 8.3.7.4.
- (d) Coupling beams reinforced with two intersecting groups of diagonally placed bars symmetrical about the midspan shall satisfy (i), (ii), and either (iii) or (iv). Requirements of Sec 6.4.5 Chapter 6 shall not apply.
 - (i) V_n shall be determined by

$$V_n = 2A_{vd}f_y\sin\alpha \leq 0.83A_{cw}\sqrt{f'_c} \quad (6.8.11)$$

Where, α is the angle between the diagonal bars and the longitudinal axis of the coupling beam.

- (ii) Each group of diagonal bars shall consist of a minimum of four bars provided in two or more layers. The diagonal bars shall be embedded into the wall not less than 1.25 times the development length for f_y in tension.
- (iii) Each group of diagonal bars shall be enclosed by transverse reinforcement having out-to-out dimensions not smaller than $\frac{b_w}{2}$ in the direction parallel to b_w and $\frac{b_w}{5}$ along the other sides, where b_w is the web width of the coupling beam. The transverse reinforcement shall satisfy Sec 8.3.5.4 as shown in Figure 6.8.8 and shall have spacing measured parallel to the diagonal bars satisfying Sec 8.3.5.4 and not exceeding six times the diameter of the diagonal bars, and shall have spacing of crossties or legs of hoops measured perpendicular to the diagonal bars not exceeding 350 mm. For the purpose of computing A_g for use in Figure 6.8.9 and Eq. 6.8.7, the concrete cover as required in Sec 8.1.7 shall be assumed on all four sides of each group of diagonal bars. The transverse reinforcement, or its alternatively configured transverse reinforcement satisfying the spacing and volume ratio requirements of the transverse reinforcement along the diagonals, shall continue through the intersection of the diagonal bars. Additional longitudinal and transverse reinforcement shall be distributed around the beam perimeter with total area in each direction not less than $0.002b_ws$ and spacing not exceeding 300 mm as shown in Figure 6.8.13(a).
- (iv) Transverse reinforcement shall be provided for the entire beam cross section satisfying Sec 8.3.5.4 as shown in Figure 6.8.8, with longitudinal spacing not exceeding the smaller of 150 mm and six times the diameter of the diagonal bars, and with spacing of crossties or legs of hoops both vertically and horizontally in the plane of the beam cross section not exceeding 200 mm. Each crosstie and each hoop leg shall engage a longitudinal bar of equal or larger diameter. It shall be permitted to configure hoops as shown in Figure 6.8.13(b).

8.3.6.8 Wall piers

- (a) Wall piers shall satisfy the special moment frame requirements for columns of Sec 8.3.5.3 with joint faces taken as the top and bottom of the clear height of the wall pier. Alternatively, wall piers with $\frac{l_w}{b_w} > 2.5$ shall satisfy (i) to (vi) below:
 - (i) Design shear force shall be determined in accordance with Sec 8.3.8.1 with joint faces taken as the top and bottom of the clear height of the wall pier. Where the Code includes provisions to account for overstrength of the seismic-force-resisting system, the design shear force need not exceed Ω_o times the factored shear determined by analysis of the structure for earthquake effects.

- (ii) V_n and distributed shear reinforcement shall satisfy Sec 8.3.6.4.
 - (iii) Transverse reinforcement shall be in the form of hoops except it shall be permitted to use single-leg horizontal reinforcement parallel to l_w , where only one curtain of distributed shear reinforcement is provided. Single-leg horizontal reinforcement shall have 180° bends at each end that engage wall pier boundary longitudinal reinforcement.
 - (iv) Vertical spacing of transverse reinforcement shall not exceed 150 mm.
 - (v) Transverse reinforcement shall extend at least 300 mm above and below the clear height of wall pier.
 - (vi) Special boundary elements shall be provided if required by Sec 8.3.6.6(c).
- (b) For wall piers at the edge of a wall, horizontal reinforcement shall be provided in adjacent wall segments above and below the wall pier and be proportioned to transfer the design shear force from the wall pier into the adjacent wall segments as shown in Figure 6.8.14.

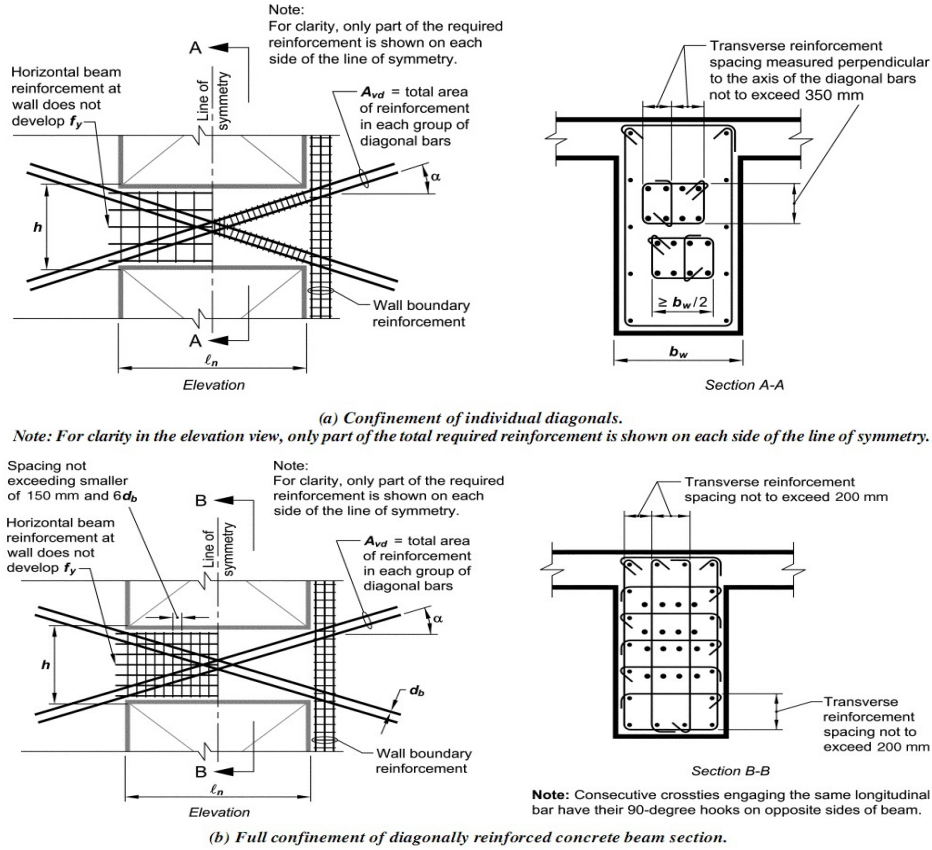


Figure 6.8.13 Coupling beams with diagonally oriented reinforcement. Wall Boundary reinforcement shown on one side only for clarity.

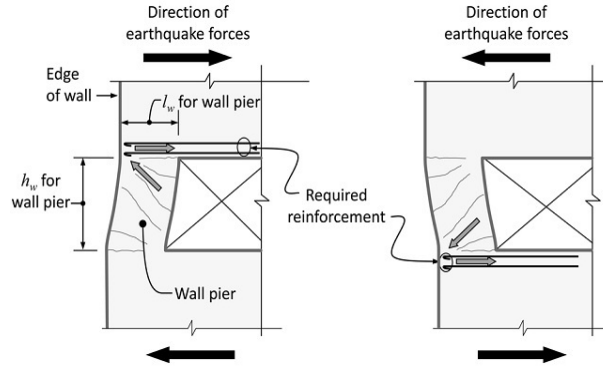


Figure 6.8.14 Required horizontal reinforcement in wall segments above and below wall piers at the edge of a wall.

8.3.6.9 Construction joints: All construction joints in structural walls shall conform to Sec 5.16.4 and contact surfaces shall be roughened as in Sec 6.4.5.9.

8.3.6.10 Discontinuous walls: Columns supporting discontinuous structural walls shall be reinforced in accordance with Sec 8.3.5.4(e).

8.3.7 Joints of Special Moment Frames

8.3.7.1 General requirements

- Forces in longitudinal beam reinforcement at the faces of joints of reinforced concrete frames shall be determined for a stress of $1.25f_y$ in the reinforcement.
- Joint strength shall be calculated by the appropriate strength reduction factors specified in Sec 6.2.3.1.
- Beam longitudinal reinforcement terminated in a column shall be extended to the far face of the confined column core and anchored in tension as per Sec 8.3.7.4 below and in compression according to Sec 8.2.
- Where longitudinal beam reinforcement extends through a beam-column joint, the column dimension parallel to the beam reinforcement shall not be less than 20 times the diameter of the largest longitudinal beam bar for normal-weight concrete. For light-weight concrete, the dimension shall not be less than 26 times the bar diameter.

8.3.7.2 Transverse reinforcement

The provisions of transverse reinforcement are shown in Figures 6.8.15 and 6.8.16, stated as under.

- As specified in Sec 8.3.5.4, transverse hoop reinforcement shall be provided within the joint, unless the joint is confined by structural members as specified in (b) below.
- Within the depth of the shallowest framing member, transverse reinforcement equal to at least one-half the amount required by Sec 8.3.5.4(a) shall be provided where members frame into all four sides of the joint and where each member width is at least three-fourths the column width. At these locations, the spacing specified in Sec 8.3.5.4(b) may be increased to 150 mm.
- As required by Sec 8.3.5.4, transverse reinforcement shall be provided through the joint to provide confinement for longitudinal beam reinforcement outside the column core if such confinement is not provided by a beam framing into the joint.

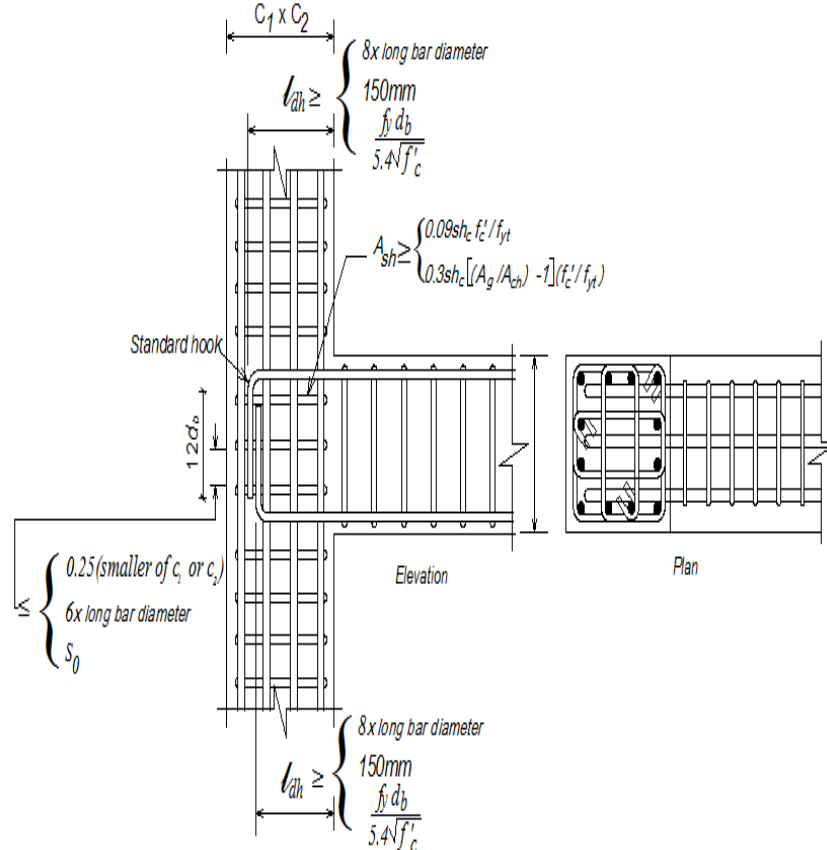


Figure 6.8.15 General requirements and transverse reinforcement requirements for joints not confined by structural member

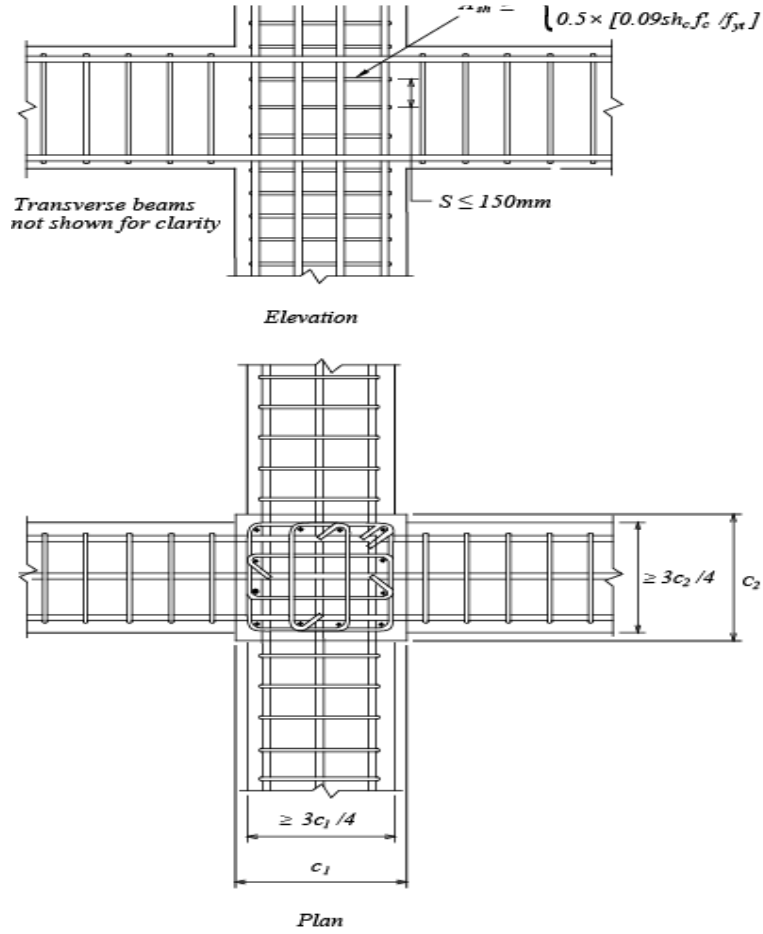


Figure 6.8.16 Transverse reinforcement requirements for joints confined by structural member

8.3.7.3 Shear Strength

The nominal shear strength for the joint shall be taken not greater than the forces specified below:

Joints confined on all four faces: $1.7\sqrt{f'_c} A_j$

Joints confined on three faces or on two opposite faces: $1.2\sqrt{f'_c} A_j$

Others: $1.0\sqrt{f'_c} A_j$

A member that frames into a face is considered to provide confinement to the joint if at least three-quarters of the face of the joint is covered by the framing member. A joint is considered to be confined if such confining members frame into all faces of the joint.

8.3.7.4 Development length of bars in tension

- (a) The development length, l_{dh} , for bar sizes 10 mm to 36 mm in diameter with a standard 90° hook shall be not less than (i) $8d_b$, (ii) 150 mm, and (iii) the length required by Eq. 6.8.9.

$$l_{dh} = \frac{f_y d_b}{5.4 \sqrt{f'_c}} \quad (6.8.12)$$

For light-weight concrete, l_{dh} for a bar with a standard 90° hook shall not be less than (i) $10d_b$, (ii) 190 mm, and (iii) 1.25 times the length required by Eq. 6.8.12. The 90° hook shall be located within the confined core of a column or a boundary element.

- (b) For bar sizes 10 mm to 36 mm diameter, the development length, l_d for a straight bar shall be not less than (i) 2.5 times the length required by (a) above, if the depth of the concrete cast in one lift beneath the bar does not exceed 300 mm, and (ii) 3.5 times the length required by (a) above, if the depth of the concrete cast in one lift beneath the bar exceeds 300 mm.
- (c) Straight bars terminated at a joint shall pass through the confined core of a column or of a boundary member. Any portion of the straight embedment length not within the confined core shall be increased by a factor of 1.6.

8.3.8 Shear Strength Requirements**8.3.8.1 Design forces**

- (a) **Frame Members Subjected Primarily to Bending:** The design shear force V_e shall be determined from consideration of the maximum forces that can be generated at the faces of the joints at each of the member. It shall be assumed that moments of opposite sign corresponding to probable strength M_{pr} act at the joint faces, and that the member is loaded with the factored tributary gravity load along its span.
- (b) **Frame Members Subjected to Combined Bending and Axial Load:** The design shear force V_e shall be determined from consideration of the maximum forces that can be generated at the faces of the joints at each end of the member. These joint forces shall be determined using the maximum probable moment strengths M_{pr} of the member associated with the range of factored axial loads on the member. The member shears need not exceed those determined from joint strengths based on the probable moment strength M_{pr} of the transverse members framing into the joint. In no case, V_e shall be less than the factored shear determined by the analysis of the structure.

- (c) Structural Walls and Diaphragms: The design shear force V_e shall be obtained from the lateral load analysis in accordance with the factored loads and combinations specified in Chapter 2, loads.

8.3.8.2 Transverse reinforcement in frame members

- (a) For determining the required transverse reinforcement in frame members, the quantity V_c shall be assumed to be zero if the factored axial compressive force including earthquake effects is less than $0.05A_g f'_c$ when the earthquake-induced shear forces, calculated in accordance with Sec 8.3.8.1(a), represents one-half or more of total design shear.
- (b) Stirrups or ties required to resist shear shall be closed hoops over lengths of members as specified in Sections 8.3.4.3, 8.3.5.4 and 8.3.7.2.

8.3.8.3 Shear strength of special structural walls and diaphragms

- (a) Nominal shear strength of structural walls and diaphragms shall be determined using either (b) or (c) below.
- (b) Nominal shear strength, V_n of structural walls and diaphragms shall be assumed not to exceed the shear force calculated from

$$V_n = A_{cv}(0.17\lambda\sqrt{f'_c} + \rho_n f_y) \quad (6.8.13)$$

- (c) For walls and wall segments having a ratio of $\frac{h_w}{l_w}$ less than 2.0, nominal shear strength of wall and diaphragm shall be determined from

$$V_n = A_{cv}(\alpha_c \lambda \sqrt{f'_c} + \rho_n f_y) \quad (6.8.14)$$

Where the coefficient α_c is 0.25 for $\frac{h_w}{l_w} \leq 1.5$, is 0.17 for $\frac{h_w}{l_w} \geq 2.0$, and varies linearly between 0.25 and 0.17 for $\frac{h_w}{l_w}$ between 1.5 and 2.0.

- (d) Value of ratio $\frac{h_w}{l_w}$ used in (c) above for determining V_n for segments of a wall or diaphragm shall be the larger of the ratios for the entire wall (diaphragm) and the segment of wall (diaphragm) considered.
- (e) Walls and diaphragms shall have distributed shear reinforcement providing resistance in two orthogonal directions in the plane of the wall. If the ratio $\frac{h_w}{l_w}$ does not exceed 2.0, reinforcement ratio, ρ_v shall not be less than reinforcement ratio ρ_n .

- (f) Nominal shear strength of all wall piers sharing a common lateral force shall not be assumed to exceed $0.67A_{cv}\sqrt{f'_c}$, where A_{cv} is the total cross-sectional area, and the nominal shear strength of any one of the individual wall piers shall not be assumed to exceed $0.83A_{cp}\sqrt{f'_c}$

Where A_{cp} represents the cross-sectional area of the pier considered.

- (g) Nominal shear strength of horizontal wall segments shall be assumed not to exceed $0.83A_{cp}\sqrt{f'_c}$ where A_{cp} represents the cross-sectional area of a horizontal wall segment.

8.3.9 Ordinary Moment Frame Members not Proportioned to Resist Forces Induced by Earthquake Motion

8.3.9.1 Induced moments

Frame members assumed not to contribute to lateral resistance shall be detailed according to (a) or (b) below depending on the magnitude of moments induced in those members when subjected to twice the lateral displacement under the factored lateral forces.

- (a) Members with factored gravity axial forces not exceeding $0.1A_gf'_c$ shall satisfy Sections 8.3.4.2(a) and 8.3.8.1(a) and members with factored gravity axial forces exceeding $0.1A_gf'_c$ shall satisfy Sections 8.3.5.4, 8.3.7.2(a) and 8.3.8.1(b) when the induced moment exceeds the design moment strength of the frame member.
- (b) The member shall satisfy Sec 8.3.4.2(a) when the induced moment does not exceed the design moment strength of the frame members.

8.3.9.2 Tie requirements

All frame members with factored axial compressive forces exceeding $0.1A_gf'_c$ shall satisfy the following special requirements unless they comply with Sec 8.3.5.4.

- (a) Ties shall have hooks not less than 135° with extensions not less than 6 tie bar diameter or 60 mm. Cross ties as defined in Sec 8.3.2 are allowed.
- (b) The maximum tie spacing shall be s_0 over a length l_0 measured from the joint face. The spacing s_0 shall be not more than (i) eight diameters of the smallest longitudinal bar enclosed, (ii) 24 tie bar diameters, and (iii) one-half the least cross-sectional dimension of the column. The length l_0 shall not be less than (i) one-sixth of the clear height of the column, (ii) the maximum cross-sectional dimension of the column, and (iii) 450 mm.
- (c) The first tie shall be within a distance equal to $0.5s_0$ from the face of the joint.
- (d) The tie spacing shall not exceed $2s_0$ in any part of the column.

8.3.10 Requirements for Intermediate Moment Frames

8.3.10.1 Scope

For structures assigned to SDC C, structural frames proportioned to resist forces induced by earthquake motions shall satisfy the requirements of Sec 8.3.10 in addition to those of Chapter 6.

8.3.10.2 Reinforcement requirements

Reinforcement details in a frame member shall satisfy 8.3.10.4 below if the factored compressive axial load for the member does not exceed $0.1A_g f'_c$. If the factored compressive axial load is larger, frame reinforcement details shall satisfy Sec 8.3.10.5 below unless the member has spiral reinforcement according to Eq. 6.6.12. If a two-way slab system without beams is treated as part of a frame resisting earthquake effect, reinforcement details in any span resisting moments caused by lateral force shall satisfy Sec 8.3.10.6 below.

8.3.10.3 Shear requirements

Design shear strength of beams and columns resisting earthquake effect, E , shall not be less than the smaller of (i) sum of the shear associated with development of nominal moment strengths of the member at each restrained end of clear span and the shear calculated for factored gravity loads, or (ii) maximum shear obtained from design load combinations that include E , with the E assumed to be twice that prescribed by this Code.

8.3.10.4 Beams

- (a) The positive moment strength at the face of the joint shall not be less than one-third the negative moment strength provided at that face (Figure 6.8.17). Neither the negative nor positive moment strength at any section along the length of the member shall be less than one-fifth of the maximum moment strength provided at the face of either joint.
- (b) At both ends of the member, stirrups shall be provided over lengths equal to twice the member depth measured from the face of the supporting member toward midspan (Figure 6.8.18). The first stirrup shall be located not more than 50 mm from the face of the supporting member. Maximum stirrup spacing shall not exceed (a) $\frac{d}{4}$ (b) 8 times the diameter of the smallest longitudinal bar enclosed, (c) 24 times the diameter of the stirrup bar, and (d) 300 mm.
- (c) Stirrups shall be placed at not more than $\frac{d}{2}$ throughout the length of the member.

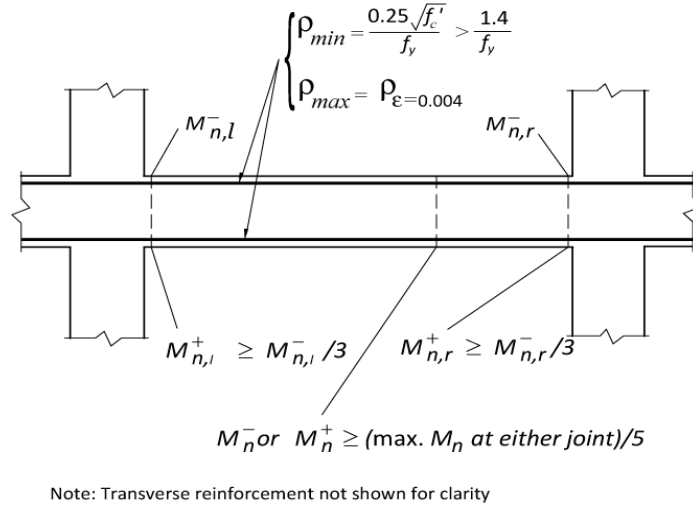


Figure 6.8.17 Flexural requirements for beams (IMF)

8.3.10.5 Columns

- Maximum tie spacing shall not exceed s_0 over a length l_0 measured from the joint face. The spacing s_0 shall not exceed (i) 8 times the diameter of the smallest longitudinal bar enclosed, (ii) 24 times the diameter of the tie bar, (iii) one-half of the smallest cross-sectional dimension of the frame member, and (iv) 300 mm. The length l_0 shall not be less than (i) one-sixth of the clear span of the member, (ii) maximum cross-sectional dimension of the member, and (iii) 450 mm.
- The first tie shall be located not more than $\frac{s_0}{2}$ from the joint face.
- Joint reinforcement shall conform to Sec 6.4.9.
- Tie spacing shall not exceed $2s_0$ throughout the length of the member.

These requirements are shown in Figure 6.8.19.

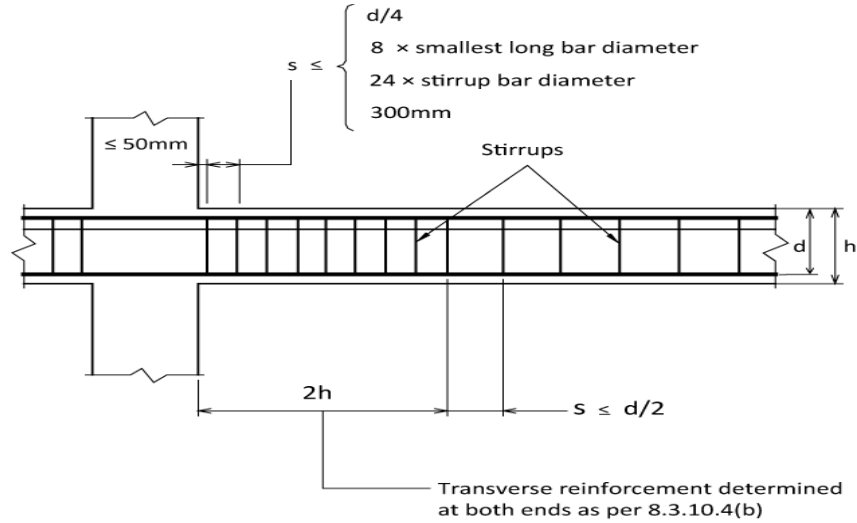


Figure 6.8.18 Transverse reinforcement requirements for beams (IMF)

8.3.10.6 Two-way slabs without beams

- The factored slab moment at the supports relating to earthquake effect shall be determined for load combinations specified in Chapter 2, Loads. All reinforcement provided to resist the portion of slab moment balanced by support moment shall be placed within the column strip defined in Sec 6.5.2.1 (Figure 6.8.20).
- The fractional part of the column strip moment shall be resisted by reinforcement placed within the effective width (Figure 6.8.20) specified in Sec 6.5.5.3.2.
- Not less than one-half of the total reinforcement in the column strip at the support shall be placed within the effective slab width (Figure 6.8.15) specified in Sec 6.5.5.3.2.
- Not less than one-quarter of the top steel at the support in the column strip shall be continuous throughout the span (Figure 6.8.21).
- Continuous bottom reinforcement in the column strip shall be not less than one-third of the top reinforcement at the support in the column strip.

- (f) Not less than one-half of all bottom reinforcement at midspan shall be continuous and shall develop its yield strength at the face of support (Figure 6.8.22).
- (g) At discontinuous edges of the slab all top and bottom reinforcement at the support shall be developed at the face of the support (Figures 6.8.21 and 6.8.22).
- (h) For edge and corner connections flexural reinforcement perpendicular to the edge is not considered fully effective unless it is placed within the effective slab width as shown in Figure 6.8.23.

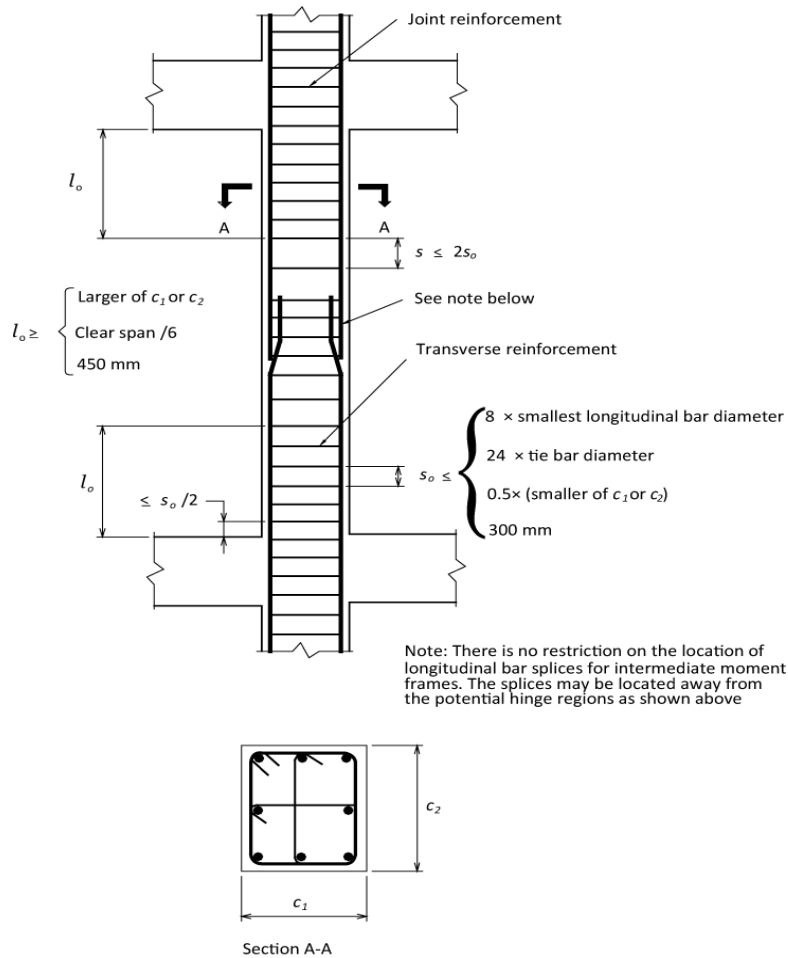


Figure 6.8.19 Transverse reinforcement requirements for columns (IMF)

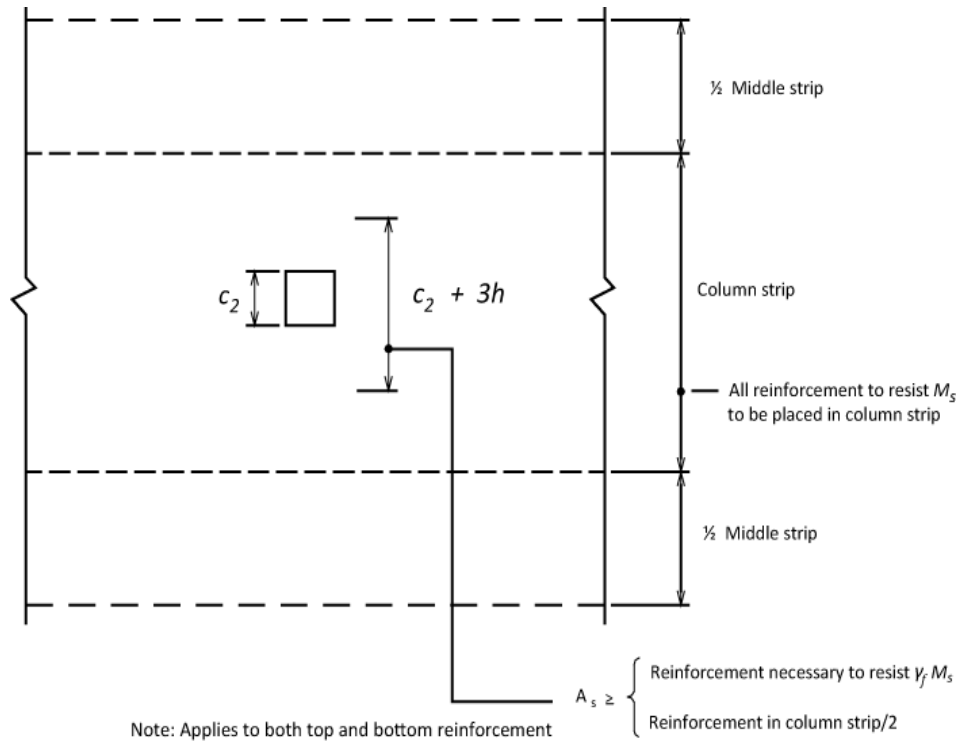


Figure 6.8.20 Reinforcement details at support of two-way slabs without beams

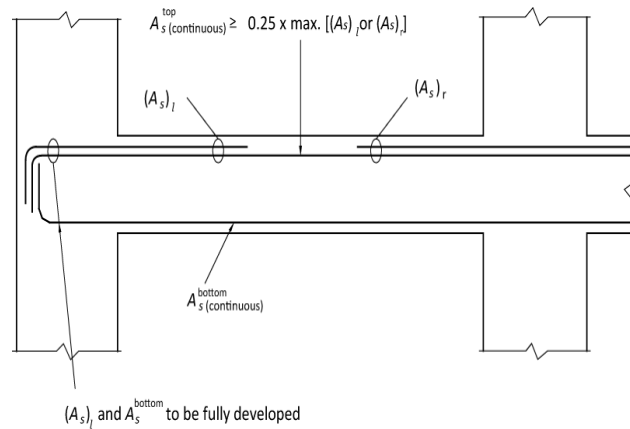


Figure 6.8.21 Reinforcement Details in Two-way Slabs without beams: Column Strip

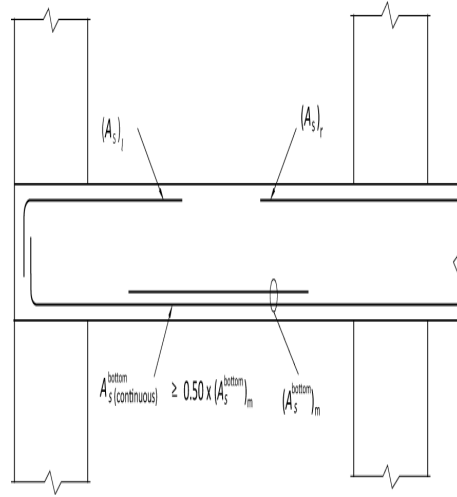


Figure 6.8.22 Reinforcement details in two-way slabs without beams: middle strip

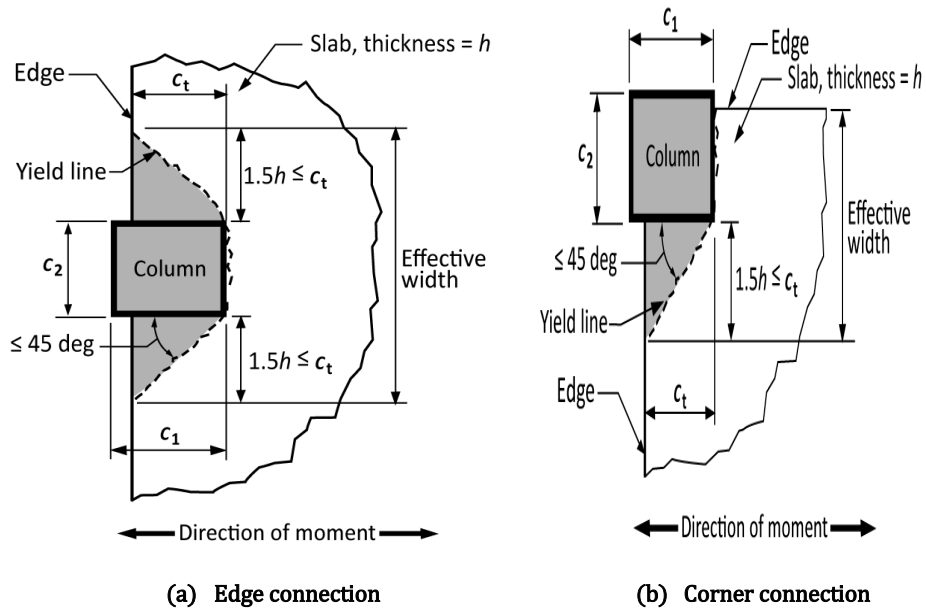


Figure 6.8.23 Effective width for reinforcement placement in edge and corner connections.

8.3.11 Requirements for Foundation**8.3.11.1 Scope**

Foundations resisting earthquake induced forces or transferring earthquake-induced forces between structure and ground in structures assigned to SDC D shall comply with Sec 8.3.11 and other applicable Code provisions.

The provisions in this section for piles, drilled piers, caissons, and slabs-on-ground shall supplement other applicable Code design and construction criteria.

8.3.11.2 Footings, foundation mats, and pile caps

- (a) Longitudinal reinforcement of columns and structural walls resisting forces induced by earthquake effects shall extend into the footing, mat, or pile cap, and shall be fully developed for tension at the interface.
- (b) Columns designed assuming fixed-end conditions at the foundation shall comply with Sec 8.3.11.2(a) and, if hooks are required, longitudinal reinforcement resisting flexure shall have 90° hooks near the bottom of the foundation with the free end of the bars oriented toward the centre of the column.
- (c) Columns or boundary elements of special structural walls that have an edge within one-half the footing depth from an edge of the footing shall have transverse reinforcement in accordance with Sec 8.3.5.4 provided below the top of the footing. This reinforcement shall extend into the footing, mat, or pile cap and be developed for f_y in tension.
- (d) Where earthquake effects create uplift forces in boundary elements of special structural walls or columns, flexural reinforcement shall be provided in the top of the footing, mat, or pile cap to resist actions resulting from the design load combinations, and shall not be less than required by Sec 6.3.5.

8.3.11.3 Grade beams and slabs-on-ground

- (a) Grade beams designed to act as horizontal ties between pile caps or footings shall have continuous longitudinal reinforcement that shall be developed within or beyond the supported column or anchored within the pile cap or footing at all discontinuities.
- (b) Grade beams designed to act as horizontal ties between pile caps or footings shall be proportioned such that the smallest cross-sectional dimension shall be equal to or greater than the clear spacing between connected columns divided by 20, but need not be greater than 450 mm. Closed ties shall be provided at a spacing not to exceed the lesser of one-half the smallest orthogonal cross-sectional dimension and 300 mm.

- (c) Grade beams and beams that are part of a mat foundation subjected to flexure from columns that are part of the seismic-force-resisting system shall conform to Sec 8.3.4.
- (d) Slabs-on-ground that resist seismic forces from walls or columns that are part of the seismic-force-resisting system shall be designed as structural diaphragms in accordance with Sec 8.3.6. The design drawings shall clearly state that the slab on ground is a structural diaphragm and part of the seismic-force-resisting system.

8.3.11.4 Piles, piers, and caissons

- (a) Provisions of Sec 8.3.11.4 shall apply to concrete piles, piers, and caissons supporting structures designed for earthquake resistance.
- (b) Piles, piers, or caissons resisting tension loads shall have continuous longitudinal reinforcement over the length resisting design tension forces. The longitudinal reinforcement shall be detailed to transfer tension forces within the pile cap to supported structural members as shown in Figure 6.8.24.
- (c) Where tension forces induced by earthquake effects are transferred between pile cap or mat foundation and precast pile by reinforcing bars grouted or post-installed in the top of the pile, the grouting system shall have been demonstrated by test to develop at least $1.25f_y$ of the bar.
- (d) Piles, piers, or caissons shall have transverse reinforcement, Figure 6.8.24, in accordance with Sec 8.3.5.4 at locations—
 - (i) Top of the member for at least 5 times the member cross-sectional dimension, but not less than 1.8 m below the bottom of the pile cap;
 - (ii) Portion of piles in soil that is not capable of providing lateral support, or in air and water, along the entire unsupported length plus the length required in (i).
- (e) For precast concrete driven piles, the length of transverse reinforcement provided shall be sufficient to account for potential variations in the elevation in pile tips.
- (f) Concrete piles, piers, or caissons in foundations supporting one- and two-story stud bearing wall construction are exempt from the transverse reinforcement requirements of Sec 8.3.11.4(d) and (e).

- (g) Pile caps incorporating batter piles shall be designed to resist the full compressive strength of the batter piles acting as short columns. The slenderness effects of batter piles shall be considered for the portion of the piles in soil that is not capable of providing lateral support, or in air or water.

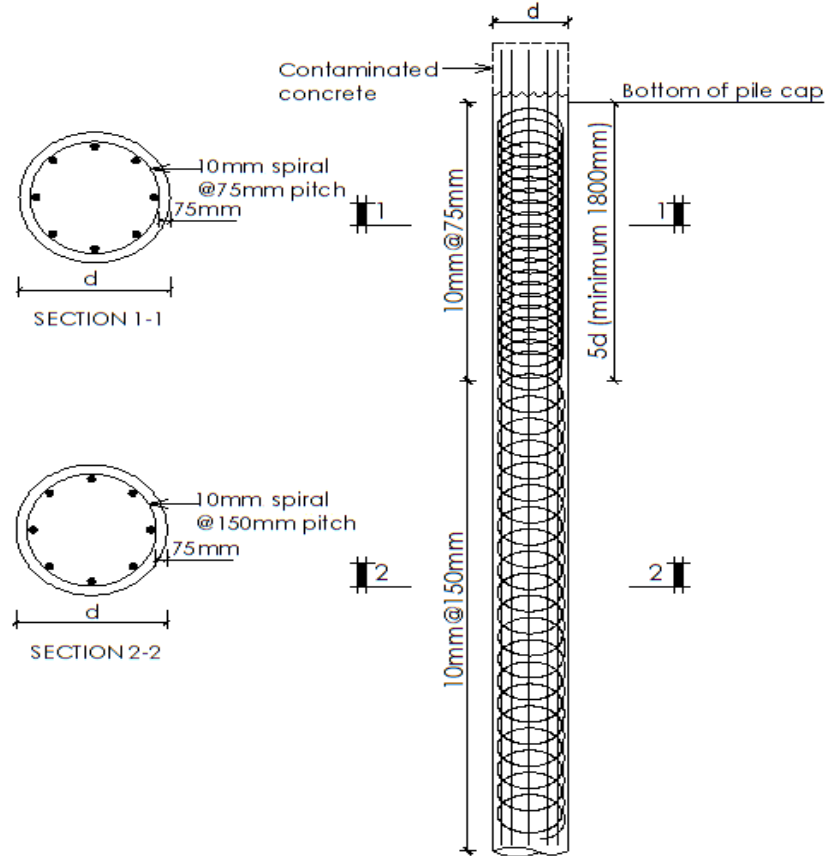


Figure 6.8.24 Spiral details of cast-in-situ pile in seismic zone 4 and SDC D

8.3.12 Requirement Members not Designated as Part of the Seismic-Force-Resisting System

8.3.12.1 Scope

- (a) Requirements of Sec 8.3.12 apply to frame members not designated as part of the seismic-force-resisting system in structures assigned to SDC D.

Frame members assumed not to contribute to lateral resistance, except two-way slabs without beams, shall be detailed according to Sec 8.3.12.2 or Sec 8.3.12.3 depending on the magnitude of moments induced in those members when subjected to the design displacement δ_u . If effects of δ_u are not explicitly checked, it shall be permitted to apply the requirements of Sec 8.3.12.3. For two-way slabs without beams, slab-column connections shall meet the requirements of Sec 8.3.12.5.

8.3.12.2 Induced moment and shear do not exceed design capacities

Where the induced moments and shears under design displacements, δ_u , combined with the factored gravity moments and shears do not exceed the design moment and shear strength of the frame member, the conditions of Sections 8.3.12.2(a), 8.3.12.2(b), and 8.3.12.2(c) shall be satisfied. The gravity load combinations of $(1.2D + 1.0L + 0.2S)$ or $0.9D$, whichever is critical, shall be used. The load factor on the live load, L , shall be permitted to be reduced to 0.5 except for garages, areas occupied as places of public assembly, and all areas where L is greater than 4.8 kN/m^2 .

- (a) Members with factored gravity axial forces not exceeding $\frac{A_g f'_c}{10}$ shall satisfy Sec 8.3.4.2(a). Stirrups shall be spaced not more than $\frac{d}{2}$ throughout the length of the member.
- (b) Members with factored gravity axial forces exceeding $\frac{A_g f'_c}{10}$ shall satisfy Sections 8.3.5.3(a) and 8.3.5.4. The maximum longitudinal spacing of ties shall be s_o for the full member length. Spacing s_o shall not exceed the smaller of six diameters of the smallest longitudinal bar enclosed and 150 mm.
- (c) Members with factored gravity axial forces exceeding $0.35P_o$ shall satisfy Sec 8.3.12.2(b). The amount of transverse reinforcement provided shall be one-half of that required by Sec 8.3.5.4(a) but shall not be spaced greater than s_o for the full member length.

8.3.12.3 Induced moment or shear exceeds design capacities

If the induced moment or shear under design displacements, δ_u exceeds ϕM_n or ϕV_n of the frame member, or if induced moments are not calculated, the conditions of Sec 8.3.12.3(a), (b) and (c) shall be satisfied.

- (a) Materials shall satisfy 8.3.3.3 and 8.3.3.4. Welded splices shall satisfy 8.3.3.5.
- (b) Members with factored gravity axial forces not exceeding $\frac{A_g f'_c}{10}$ shall satisfy Sections 8.3.4.2 and 8.3.8. Stirrups shall be spaced at not more than $\frac{d}{2}$ throughout the length of the member.
- (c) Members with factored gravity axial forces exceeding $\frac{A_g f'_c}{10}$ shall satisfy Sections 8.3.5.3, 8.3.5.4, 8.3.7.1 and 8.3.8.

8.3.12.4 Two-way slabs without beams

For slab-column connections of two-way slabs without beams, slab shear reinforcement satisfying the requirements of Sections 6.4.10.3 and 6.4.10.5 and providing V_s not less than $0.29\sqrt{f'_c} b_o d$ shall extend at least four times the slab thickness from the face of the support, unless either (i) or (ii) is satisfied :

- (i) The requirements of Sec 6.4.10.7 using the design shear V_{ug} and the induced moment transferred between the slab and column under the design displacement;
- (ii) The design story drift ratio does not exceed the larger of 0.005 and $\left[0.035 - 0.05 \left(\frac{V_{ug}}{\phi V_c}\right)\right]$.

Design story drift ratio shall be taken as the larger of the design story drift ratios of the adjacent stories above and below the slab-column connection. V_c is defined in Sec 6.4.10.2. V_{ug} is the factored shear force on the slab critical section for two-way action, calculated for the load combination $1.2D + 1.0L + 0.2S$.

The load factor on the live load, L , shall be permitted to be reduced to 0.5 except for garages, areas occupied as places of public assembly, and all areas where L is greater than 4.8 kN/m^2 .

PART VI
Chapter 9
Prestressed Concrete Structures

9.1 General

The Prestressed Concrete Structures Chapter of the Code is divided into the following three Divisions:

Division A : Design

Division B : Material and Construction

Division C : Maintenance

Division A : Scope, Definitions, Notation, Design And Analysis (Sections 9.2 To 9.18)

9.2 Scope

9.2.1 Provisions of this Chapter shall apply to members prestressed with wires, strands, or bars conforming to the specifications of prestressing tendons given in Sec 9.5.1.3.

9.2.2 All provisions of this Code not specifically excluded, and not in conflict with provisions of this Chapter 9, shall apply to prestressed concrete.

9.3 Definitions, Symbols and Notation

9.3.1 Definitions

ACTION	Mechanical force or environmental effect to which the structure (or structural component) is subjected.
ANALYSIS	Acceptable methods of evaluating the performance indices or verifying the compliance of specific criteria.
ANCHORAGE	In post-tensioning, a mechanical device used to anchor the tendon to the concrete; in pretensioning, a device used to anchor the tendon until the concrete has reached a pre-determined strength, and the prestressing force has been transferred to the concrete; for reinforcing bars, a length of reinforcement, or a mechanical anchor or hook, or combination thereof at the end of a bar needed to transfer the force carried by the bar into the concrete.