Clauses 8.1.10.2 to 8.1.10.8 do not apply to tendons. Clause 8.1.10.9 applies to tendons only.

NOTE: When detailing flexural reinforcement, designers should be cautious in D-regions and design accordingly.

8.1.10.2 *Distribution of reinforcement*

Tensile reinforcement shall be well distributed in zones of maximum concrete tension, including those portions of flanges of T-beams, L-beams and I-beams over a support.

8.1.10.3 *Continuation of negative moment reinforcement*

Not less than one third of the total negative moment tensile reinforcement required at a support shall be extended a distance equal to the overall depth of the cross-section (D) beyond the point of contra-flexure.

8.1.10.4 *Anchorage of positive moment reinforcement*

Anchorage of positive moment reinforcement shall comply with the following requirements:

(a) At a simple support:

(i) Sufficient positive moment reinforcement shall be anchored for a length (L_{st}) such that the anchored reinforcement shall develop a tensile force of—

(A) $V^* \cot \theta_v / \phi$; plus

(B) the longitudinal torsion tensile force calculated in accordance with Clause 8.3.6, where V^* is the design shear force at a distance, $d \cot \theta_v$ from the anchor point; plus

(C) any other longitudinal tensile forces in the reinforcement.

The anchor point shall be taken either halfway along the length of the bearing, or determined by calculating the width of the compressive strut in accordance with Clause 7.2, taking account of both shear and torsion, and allowing for the truss angle being used. The truss angle (θ_v) is as defined in Clause 8.2.10, and $L_{sy.t}$ is determined from Clause 13.1.2.

(ii) Not less than one half of the tensile reinforcement required at midspan shall extend past the face of the support for a length of $12d_b$ or an equivalent anchorage; or not less than one third of the tensile reinforcement required at midspan shall extend past the face of the support for a length of $8d_b$ plus $D/2$.

(b) At a continuous or flexurally restrained support not less than one quarter of the total positive moment reinforcement required at midspan shall continue past the near face of the support.

8.1.10.5 *Shear strength requirements near terminated flexural reinforcement*

If tensile reinforcement is terminated, the effect on the shear strength shall be assessed in accordance with the principles of 'strut-and-tie modelling'.

This requirement shall be deemed to be satisfied if any one of the following conditions is met:

(a) Not more than a quarter of the maximum tensile reinforcement is terminated within any distance $2D$.

(b) At the cut-off point, $\phi V_u \geq 1.5 V^*$.

(c) Stirrups are provided to give an area of shear reinforcement of $A_{sv} + A_{sv.min}$ for a distance equal to the overall depth of the cross-section (D) along the terminated bar from the cut-off point, where A_{sv} and $A_{sv.min}$ are determined in accordance with Clause 8.2.

8.1.10.6 *Deemed to comply arrangement of flexural reinforcement*

For continuous reinforced beams analysed using simplified methods of analysis, as detailed in Clause 6.10, the following deemed to comply arrangement shall be used and shall be deemed to satisfy the requirements of Clauses 8.1.10.3 to 8.1.10.5:

(a) Of the negative moment tensile reinforcement provided at the support—

  (i) not less than one quarter shall extend over the whole span;

  (ii) not less than one half shall extend $0.3L_n$ or more beyond the face of the support; and

  (iii) the remainder, if any, shall extend $0.2L_n$ or more beyond the face of the support.

  Where adjacent spans are unequal, the extension of negative reinforcement beyond each face of the common support shall be based on the longer span.

(b) Of the positive moment tensile reinforcement provided at midspan—

  (i) not less than one half shall extend into a simple support for a length of $12d_b$;

  (ii) not less than one quarter shall extend into a support where the beam is continuous or flexurally restrained; and

  (iii) the remainder, if any, shall extend to within $0.1L_n$ from the face of the support.

(c) To comply with shear requirements, not more than a quarter of the maximum tensile reinforcement shall be terminated within any distance $2D$.

8.1.10.7 *Restraint of compressive reinforcement*

Compressive reinforcement required for strength in beams shall be adequately restrained by fitments in accordance with Clause 10.7.4.

8.1.10.8 *Bundled bars*

Groups of parallel longitudinal bars bundled to act as a unit shall—

(a) have not more than four bars in any one bundle;

(b) be tied together in contact; and

(c) be enclosed within stirrups or fitments.

Within the span of a flexural member, individual bars in a bundle shall be terminated so that the points of termination are staggered by a distance greater than or equal to 40 times the diameter of the larger bar within the bundle.

The unit of bundled bars shall be treated as an equivalent single bar of diameter derived from the total area of the bars in the bundle.

8.1.10.9 *Detailing of tendons*

In prestressed members—

(a) detailing of tendons for termination, anchorage and debonding shall be based on a hypothetical bending-moment diagram formed by uniformly displacing the calculated positive and negative bending moment envelopes a distance (D) along the beam from each side of the relevant section of maximum moment;

(b) anchorages and stress development, as appropriate, shall be provided for all tendons in accordance with Clause 12.5 and Section 13;

(c) at a simple support of a pretensioned member, at least one third of the tendons required at the section of maximum positive moment shall be continued to the end of the member without debonding; and

(d) for horizontal curvature of tendons, the designer shall assess the bursting and/or splitting capacity of the beam.

8.2 STRENGTH OF BEAMS IN SHEAR

8.2.1 General

A2 This Clause applies to reinforced and prestressed beams subjected to any combination of shear force, torsion, bending moment and axial force. When torsion acts in conjunction with shear force, the additional requirements of Clause 8.3 shall apply.

This Clause does not apply to non-flexural members covered by Section 12.

8.2.2 Design shear strength of a beam

The design shear strength of a beam shall be taken as ϕV_u where—

(a) $V_u = V_{uc} + V_{us}$, taking account of Clauses 8.2.3 to 8.2.6, where V_{uc} is determined from Clause 8.2.7 and V_{us} is determined from Clauses 8.2.9 and 8.2.10; or

(b) V_u is calculated by means of a method based on strut-and-tie modelling in accordance with Section 7; or

(c) where design for shear and torsion interaction is required in accordance with Clause 8.3, V_{uc} shall be calculated in accordance with Clause 8.2.7.4.

8.2.3 Tapered members

In members that are tapered along their length, the components of inclined tension or compressive forces shall be taken into account in the calculation of shear strength.

8.2.4 Maximum transverse shear near a support

The maximum transverse shear near a support shall be taken as the shear at—

(a) the face of the support; or

(b) a distance of d_o from the face of the support, provided—

(i) diagonal cracking can not take place at the support or extend into it;

(ii) there are no concentrated loads closer than $2d_o$ from the face of the support;

(iii) the value of β_3 in Clauses 8.2.7.1 and 8.2.7.2 is taken to be equal to one; and

(iv) the transverse shear reinforcement required at d_o from the support is continued unchanged to the face of the support.

In both Items (a) and (b) above, longitudinal tensile reinforcement required at d_o from the face of the support shall be continued into the support and shall be fully anchored past that face.

8.2.5 Requirements for shear reinforcement

The following requirements for shear reinforcement shall apply:

(a) Where $V^* \leq 0.5\phi V_{uc}$, no shear reinforcement is required, except that where the overall depth of the beam exceeds 750 mm, minimum shear reinforcement ($A_{sv.min}$) shall be provided in accordance with Clause 8.2.8.

(b) Where $0.5\phi V_{uc} < V^* \leq \phi V_{u.min}$, minimum shear reinforcement ($A_{sv.min}$) shall be provided in accordance with Clause 8.2.8.

The minimum shear reinforcement requirements of Items (a) and (b) may be waived—

(i) for beams, if $V^* \leq \phi V_{uc}$ and D does not exceed the greater of 250 mm and half the width of the web; and

(ii) for slabs to which this Clause applies, if $V^* \leq \phi V_{uc}$.

Where $V^* > \phi V_{u.min}$ shear reinforcement shall be provided in accordance with Clause 8.2.10.

8.2.6 Shear strength limited by web crushing

In no case shall the ultimate shear strength (V_u) be taken as greater than—

$$V_{u.max} = 0.2\, f'_c\, b_v\, d_o + P_v \qquad \text{. . . 8.2.6}$$

where

b_v = $(b_w - 0.5\Sigma d_d)$

Σd_d = sum of the diameters of the grouted ducts, if any, in a horizontal plane across the web

P_v = vertical component of the prestressing force at the section under consideration

8.2.7 Shear strength of a beam excluding shear reinforcement

8.2.7.1 *Reinforced beams*

The ultimate shear strength (V_{uc}) of a reinforced beam, excluding the contribution of shear reinforcement, shall be calculated from the following equation:

$$V_{uc} = \beta_1\, \beta_2\, \beta_3\, b_v\, d_o f_{cv} \left(\frac{A_{st}}{b_v\, d_o} \right)^{1/3} \qquad \text{. . . 8.2.7.1}$$

where

for members where the cross-sectional area of shear reinforcement provided (A_{sv}) is equal to or greater than the minimum area specified in Clause 8.2.8—

β_1 = $1.1(1.6 - d_o/1000) \geq 1.1$

otherwise—

β_1 = $1.1(1.6 - d_o/1000) \geq 0.8$

β_2 = 1, for members subject to pure bending; or

= $1 - (N^*/3.5A_g) \geq 0$ for members subject to axial tension; or

= $1 + (N^*/14A_g)$ for members subject to axial compression

β_3 = 1, or may be taken as—

$2d_o/a_v$ but not greater than 2, provided the applied loads and the support are orientated so as to create diagonal compression over the length (a_v)

a_v = distance from the section at which shear is being considered to the face of the nearest support

f_{cv} = $f_c'^{\,1/3} \leq 4$ MPa

A2 A_{st} = cross-sectional area of longitudinal reinforcement provided in the tensile zone and fully anchored in accordance with the principles of Clause 8.1.10.1, in the direction of reducing moment, at the cross-section under consideration

8.2.7.2 *Prestressed beams*

The ultimate shear strength (V_{uc}) of a prestressed beam, excluding the contribution of shear reinforcement, shall be taken as not greater than the lesser of the values obtained from the following, unless the cross-section under consideration is cracked in flexure, in which case only Item (a) shall apply:

(a) *Flexure-shear cracking*:

$$V_{uc} = \beta_1 \beta_2 \beta_3 b_v d_o f_{cv} \left[\frac{(A_{st} + A_{pt})}{b_v d_o} \right]^{1/3} + V_o + P_v \qquad \ldots 8.2.7.2(1)$$

where

β_1, β_2, β_3, f_{cv} and A_{st} are as given in Clause 8.2.7.1 except that in determining β_2, N^* is taken as the value of the axial force excluding prestress

V_o = shear force which would occur at the section when the bending moment at that section was equal to the decompression moment (M_o) given by—

$M_o = Z\sigma_{cp.f}$

$\sigma_{cp.f}$ = compressive stress due to prestress, at the extreme fibre where cracking occurs

For statically determinate structures:

$$V_o = \frac{M_o}{\left| M^* / V^* \right|} \qquad \ldots 8.2.7.2(2)$$

where M^* and V^* are the bending moment and shear force respectively, at the section under consideration, due to the design loading for strength.

Where the prestress and the applied moment both produce tension on the same extreme fibre of a member, V_o shall be taken as zero.

For statically indeterminate structures, secondary shear forces and bending moments, due to prestress, shall be taken into account when determining M_o and V_o.

(b) *Web-shear cracking*:

$$V_{uc} = V_t + P_v \qquad \ldots 8.2.7.2(3)$$

where

V_t = shear force, which, in combination with the prestressing force and other action effects at the section, would produce a principal tensile stress of f'_{ct} at either the centroidal axis or the intersection of flange and web, whichever is the more critical

8.2.7.3 *Secondary effects on V_{uc}*

Where stresses due to secondary effects such as creep, shrinkage and differential temperature are significant, they shall be taken into account in the calculation of V_{uc} both for reinforced and prestressed concrete beams.

8.2.7.4 *Reversal of loads and members in torsion*

Where loading cases occur that result in cracking in a zone usually in compression, the value of V_{uc} obtained from Clause 8.2.7.1 or 8.2.7.2 may not apply and V_{uc} shall be assessed or be taken as zero.

8.2.8 Minimum shear reinforcement

The minimum area of shear reinforcement ($A_{sv.min}$) provided in a beam shall be given by—

$$A_{sv.min} = 0.06\sqrt{f'_c}\, b_v s / f_{sy.f} \geq 0.35 b_v s / f_{sy.f} \qquad \ldots 8.2.8$$

where

s = centre-to-centre spacing of shear reinforcement, measured parallel to the longitudinal axis of the member

8.2.9 Shear strength of a beam with minimum reinforcement

The ultimate shear strength of a beam provided with minimum shear reinforcement ($A_{sv.min}$), ($V_{u.min}$) shall be taken as—

$$V_{u.min} = V_{uc} + 0.10\sqrt{f'_c}\, b_v d_o \geq V_{uc} + 0.6 b_v d_o \quad \text{. . . 8.2.9}$$

8.2.10 Contribution to shear strength by the shear reinforcement

The contribution to the ultimate shear strength by shear reinforcement in a beam (V_{us}) shall be determined from the following equations:

(a) For perpendicular shear reinforcement—

$$V_{us} = \left(A_{sv} f_{sy.f} d_o / s\right)\cot\theta_v \quad \text{. . . 8.2.10(1)}$$

(b) For inclined shear reinforcement—

$$V_{us} = \left(A_{sv} f_{sy.f} d_o / s\right)\left(\sin\alpha_v \cot\theta_v + \cos\alpha_v\right) \quad \text{. . . 8.2.10(2)}$$

where, for both Items (a) and (b)—

θ_v = angle between the axis of the concrete compression strut and the longitudinal axis of the member and shall be taken as either—

(i) 45°; or

(ii) chosen in the range of 30° to 60° except that the minimum value of θ_v shall be taken as varying linearly from 30°, when $V^* = \phi V_{u.min}$ to 45°, when $V^* = \phi V_{u.max}$

α_v = angle between the inclined shear reinforcement and the longitudinal tensile reinforcement

8.2.11 Hanging reinforcement

Loads applied to a member other than at the top chord of the member shall be transferred to the top chord, within the load application region, by the provision of hanging reinforcement of area consistent with strut-and-tie modelling.

8.2.12 Detailing of shear reinforcement

8.2.12.1 *Types*

Shear reinforcement shall comprise one or more—

(a) stirrups or fitments making an angle of between 45° and 90° with the longitudinal bars; and

(b) welded wire mesh placed to have wires perpendicular to the axis of the beam.

8.2.12.2 *Spacing*

Shear reinforcement shall be spaced longitudinally not further apart than 0.5*D* or 300 mm, whichever is less. Where $V^* \leq \phi V_{u.min}$, the spacing may be increased to 0.75*D* or 500 mm, whichever is less.

The maximum transverse spacing across the width of the member shall not exceed the lesser of 600 mm and *D*.

8.2.12.3 *Extent*

Shear reinforcement, of area not less than that calculated as being necessary at any cross-section, shall be provided for a distance (*D*) from that cross-section in the direction of decreasing shear. The first fitment at each end of a span shall be positioned not more than 50 mm from the face of the adjacent support.

Shear reinforcement shall extend as close to the compression face and the tension face of the member as cover requirements and the proximity of other reinforcement and tendons will permit. Bends in bars used as fitments shall enclose a longitudinal bar with a diameter not less than the diameter of the fitment bar. The enclosed bar shall be in contact with the fitment bend.

8.2.12.4 *Anchorage of shear reinforcement*

The anchorage of shear reinforcement transverse to the longitudinal flexural reinforcement may be achieved by a hook or cog complying with Clause 13.1.2.7 or by welding of the fitment to a longitudinal bar or by a welded splice.

NOTE: The type of anchorage used should not induce splitting or spalling of the concrete cover.

Notwithstanding the above, fitment cogs are not to be used when the fitment cog is located within 50 mm of any concrete surface.

8.2.12.5 *End anchorage of mesh*

Where mesh is used as shear reinforcement, the ends shall be anchored—

(a) in accordance with Clause 8.2.12.4, if the wires are bent at least to the dimensions of a standard fitment hook; or

(b) by embedding two or more transverse wires at least 25 mm within the compressive zone.

8.3 STRENGTH OF BEAMS IN TORSION

8.3.1 General

This Clause applies to reinforced and prestressed beams subjected to any combination of torsion, flexure and shear. It does not apply to non-flexural members covered by Section 12.

8.3.2 Secondary torsion

Where torsional strength is not required for the equilibrium of the structure and the torsion in a member is induced solely by the angular rotation of adjoining members, it shall be permissible to disregard the torsional stiffness in the analysis and torsion in the member, if the torsion reinforcement requirements of Clauses 8.3.7 and the detailing requirements of Clause 8.3.8 are satisfied.

8.3.3 Torsional strength limited by web crushing

To prevent web crushing under the combined action of torsion and flexural shear, beams shall be proportioned so that the following inequality is satisfied:

$$\frac{T^*}{\phi T_{\mathrm{u.max}}} + \frac{V^*}{\phi V_{\mathrm{u.max}}} \leq 1 \qquad \ldots 8.3.3$$

where

$V_{\mathrm{u.max}}$ is calculated from Clause 8.2.6 and

$T_{\mathrm{u.max.}} = 0.2 f'_{\mathrm{c}} J_{\mathrm{t}}$

The torsional modulus (J_{t}) may be taken as—

= $0.33x^2y$ for solid rectangular sections;

= $0.33\Sigma x^2y$ for solid T- shaped, L- shaped, or I-shaped sections; and

= $2A_{\mathrm{m}}b_{\mathrm{w}}$ for thin walled hollow sections, A_{m} being the area enclosed by the median lines of the walls of a single cell and b_{w} being a minimum thickness of the wall of a hollow section

8.3.4 Requirements for torsional reinforcement

In the calculation of T^* and V^* in Items (a) and (b), the elastic uncracked stiffness shall be used.

Requirements for torsional reinforcement shall be determined from the following:

A2 (a) Torsional reinforcement is required if—

(i) $T^* > 0.25\phi T_{uc}$; or ... 8.3.4(1)

(ii) $$\frac{T^*}{\phi T_{uc}} + \frac{V^*}{\phi V_{uc}} > 0.5$$ ... 8.3.4(2)

or if the overall depth does not exceed the greater of 250 mm and half the width of the web—

$$\frac{T^*}{\phi T_{uc}} + \frac{V^*}{\phi V_{uc}} > 1.0$$ ... 8.3.4(3)

where T_{uc} and V_{uc} are calculated in accordance with Clauses 8.3.5 and 8.2.7 respectively.

A2 (b) If Item (a) above is satisfied, torsional reinforcement consisting of transverse closed fitments and longitudinal reinforcement shall be provided, in addition to any other reinforcement, such that—

$$\frac{T^*}{\phi T_{us}} \le 1$$ ... 8.3.4(4)

where T_{us} is calculated in accordance with Clause 8.3.5.

At least the minimum torsional reinforcement required by Clause 8.3.7 shall be provided in addition to any other fitments.

Longitudinal torsional reinforcement shall comply with Clause 8.3.6 and both transverse and longitudinal torsional reinforcement shall comply with Clause 8.3.7.

Shear reinforcement shall be provided with V_{uc} assessed in accordance with Clause 8.2.7.4.

8.3.5 Torsional strength of a beam

For the purpose of Clause 8.3.4, the ultimate strength of a beam in pure torsion (T_{uc} or T_{us}) shall be determined from the following:

(a) For a beam without closed fitments, the ultimate strength in pure torsion (T_{uc}) shall be calculated from—

$$T_{uc} = J_t\left(0.3\sqrt{f'_c}\right)\sqrt{(1+10\sigma_{cp}/f'_c)}$$ ... 8.3.5(1)

(b) For a beam with closed fitments, the ultimate strength in pure torsion (T_{us}) shall be calculated from—

$$T_{us} = f_{sy.f}\,(A_{sw}/s)2A_t \cot\theta_v$$ ... 8.3.5(2)

where

A_t = area of a polygon with vertices at the centre of longitudinal bars at the corners of the cross-section

8.3.6 Longitudinal torsional reinforcement

Longitudinal torsional reinforcement shall be provided to resist the following design tensile forces, taken as additional to any other design tensile forces:

(a) In the flexural tensile zone, a force of—

$$0.5 f_{sy.f}\left(\frac{A_{sw}}{s}\right)u_t \cot^2\theta_v \text{; and} \qquad \ldots 8.3.6(1)$$

(b) In the flexural compressive zone, a force of—

$$0.5 f_{sy.f}\left(\frac{A_{sw}}{s}\right)u_t \cot^2\theta_v - F_c^* \text{; but not less than zero,} \qquad \ldots 8.3.6(2)$$

where

θ_v = angle between the axis of the concrete compression strut and the longitudinal axis of the member (see Clause 8.2.10)

u_t = perimeter of the polygon defined for A_t

F_c^* = absolute value of the design force in the compressive zone due to flexure

8.3.7 Minimum torsional reinforcement

Where torsional reinforcement is required as specified in Clause 8.3.4—

(a) longitudinal torsional reinforcement shall be provided in accordance with Clause 8.3.6; and

(b) minimum transverse reinforcement shall be provided to satisfy the greater of—

(i) the minimum shear reinforcement required by Clause 8.2.8 in the form of closed ties or fitments; and

(ii) a torsional capacity equal to $0.25T_{uc}$.

8.3.8 Detailing of torsional reinforcement

Torsional reinforcement shall be detailed in accordance with Clause 8.2.12.4 and the following:

(a) Torsional reinforcement shall consist of both closed fitments and longitudinal reinforcement.

(b) A closed fitment shall be capable of developing full yield stress in each leg and capable of transferring the yield force to an adjacent leg, unless a more refined analysis shows that over part of the fitment full yield stress is not required. The spacing (s) of the closed fitments shall be not greater than the lesser of $0.12u_t$ and 300 mm.

(c) The longitudinal reinforcement shall be placed as close as practicable to the corners of the cross-section and, in all cases, at least one longitudinal bar shall be provided at each corner of the closed fitments.

8.4 LONGITUDINAL SHEAR IN COMPOSITE AND MONOLITHIC BEAMS

8.4.1 General

This Clause applies to the transfer of longitudinal shear forces, across interface shear planes through webs and flanges of—

(a) composite beams constructed of precast concrete sections and cast in situ toppings or flanges; and

(b) beams constructed monolithically.

8.4.2 Design shear stress

The design shear stress (τ^*) acting on the interface shall be taken as follows:

$$\tau^* = \beta V^*/(z b_f) \quad \text{. . . 8.4.2}$$

where

z = internal moment lever arm of the section

For a shear plane that passes through a region in compression—

β = ratio of the compressive force in the member (calculated between the extreme compressive fibre and the shear plane) and the total compression force in the section

For a shear plane that passes through a region in tension—

β = ratio of the tensile force in the longitudinal reinforcement (calculated between the extreme tensile fibre and the shear plane) and the total tension force in the section

8.4.3 Shear stress capacity

The design shear stress at the shear interface shall not exceed $\phi\tau_u$ where—

A1

$$\tau_u = \mu\left(\frac{A_{sf} f_{sy}}{s b_f} + \frac{g_p}{b_f}\right) + k_{co} f'_{ct} \quad \text{. . . 8.4.3}$$

$$\leq \text{lesser of } (0.2 f'_c, 10 \text{ MPa})$$

where

τ_u = unit shear strength

g_p = permanent distributed load normal to the shear interface per unit length, newtons per millimetre (N/mm)

μ = coefficient of friction given in Table 8.4.3

k_{co} = cohesion coefficient given in Table 8.4.3

b_f = width of the shear plane, in millimetres (mm)

A_{sf} = area of fully anchored shear reinforcement crossing the interface (mm^2)

f_{sy} = yield strength of shear reinforcement not exceeding 500 MPa

s = spacing of anchored shear reinforcement crossing interface