8.8.2 Effective width of flange for strength and serviceability for T-beams and L-beams

In the absence of a more accurate determination, the effective width of the flange for strength and serviceability shall be taken as—

(a) for T-beams .... $b_{ef} = b_w + 0.2a$; and

(b) for L-beams .... $b_{ef} = b_w + 0.1a$,

where a is the distance between points of zero bending moment, which, for continuous beams, may be taken as $0.7L$.

In both Items (a) and (b) above, the overhanging part of the flange considered effective shall not exceed half the clear distance to the next parallel member. The effective width so determined may be taken as constant over the entire span.

8.9 SLENDERNESS LIMITS FOR BEAMS

8.9.1 General

Unless a detailed analysis is carried out, beams shall comply with the limits specified in Clauses 8.9.2 to 8.9.4, as appropriate.

8.9.2 Simply supported and continuous beams

For a simply supported or continuous beam, the distance L_l between points at which lateral restraint is provided shall be such that L_l/b_{ef} does not exceed the lesser of $240b_{ef}/D$ and 60.

8.9.3 Cantilever beams

For a cantilever beam having lateral restraint only at the support, the ratio of the clear projection (L_n) to the width (b_{ef}) at the support shall be such that L_n/b_{ef} does not exceed the lesser of $100b_{ef}/D$ and 25.

8.9.4 Reinforcement for slender prestressed beams

For a prestressed beam in which L_l/b_{ef} exceeds 30, or for a prestressed cantilever beam in which L_n/b_{ef} exceeds 12, the following reinforcement shall be provided:

(a) Stirrups providing a steel area $A_{sv.min}$ in accordance with Clause 8.2.6.

(b) Additional longitudinal reinforcement, consisting of at least one bar in each corner of the compression face, such that—

$$A_{sc} \geq 0.35A_{pt} f_{pb}/f_{sy} \quad \text{. . . 8.9.4}$$

8.10 COMPOSITE MEMBERS

8.10.1 General

Composite flexural members shall consist of precast prestressed concrete beams connected to cast-in-place reinforced concrete such that the two components function as a monolithic unit.

NOTES:

1 Typical cross-sections of composite members are depicted in Figure 8.10.1.

2 For standard precast prestressed concrete beam sections, see Appendix D.

A continuous composite member can consist of a succession of simply supported prestressed concrete beams made continuous by the provision of non-prestressed reinforcement in the cast-in-place concrete over the intermediate supports.

Monolithic action of composite beams up to the strength ULS in bending of the member shall be deemed to comply where—

(a) longitudinal shear at the contact surface can be transferred without excessive slip;

(b) separation of the elements normal to the contact surface is prevented.

NOTE: The transfer of shear can be achieved by a combination of bond, roughness, steel ties and shear keys.

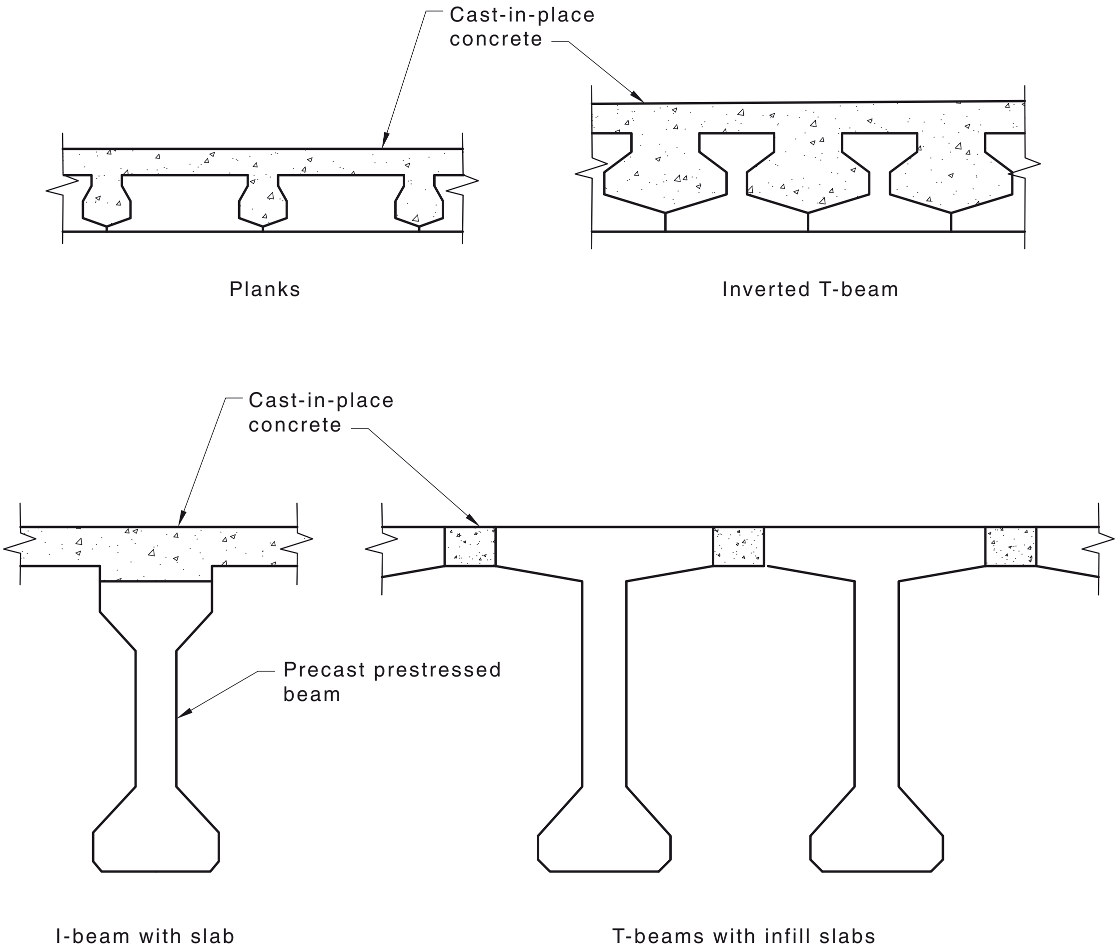

FIGURE 8.10.1 TYPICAL CROSS-SECTIONS OF COMPOSITE MEMBERS

8.10.2 Design requirements

8.10.2.1 *General*

The following design requirements shall be met:

(a) The construction sequence that influences the design of composite members shall be indicated on the drawings.

(b) The individual elements of the composite member shall be investigated for any critical loads during construction (for example, handling and erection as well as for the loads applied after their interconnection).

(c) The effects of residual creep in the precast beam and differential shrinkage between the precast beam and the cast-in-place concrete shall be considered, and the member shall be designed for the following two cases:

(i) Final residual creep with final differential shrinkage.

(ii) Zero residual creep with zero differential shrinkage.

NOTE: Zero residual creep and differential shrinkage represent conditions at a time shortly after completion of construction.

Methods of calculating the effects of residual creep and differential shrinkage shall be as specified in Clause 8.10.3.2.

Residual creep and differential shrinkage in a composite member shall be regarded as always acting together.

8.10.2.2 *Analysis*

The following assumptions shall be applied:

(a) The effective width of the concrete slab shall be used in the design of a concrete member and shall be determined in accordance with Clause 8.8.

(b) The effective cross-sectional area of the concrete slab shall be transformed to an equivalent area of beam concrete by applying the modular ratio factor (α_c) of the slab concrete and the beam concrete in the composite member.

8.10.3 Design for applied loads

8.10.3.1 *General*

All components and composite members shall be designed in accordance with this Section for all loads to which they are subjected.

NOTE: Particular attention should be given to the validity of any assumptions about concrete stress-strain relationships being adopted when high compression stresses occur at SLS.

8.10.3.2 *Effects due to residual creep and differential shrinkage*

8.10.3.2.1 *General*

Residual creep is that portion of the creep that occurs in the precast element after establishing composite action.

The procedures in Clauses 8.10.3.2.2 and 8.10.3.2.3 shall be used to determine the effects of residual creep in a composite member subject to dead load and prestress only, and the effects of differential shrinkage respectively.

NOTE: If a more refined solution is required or where spans in excess of 30 m are envisaged, consideration should be given to other methods, such as superposition or rate of flow method.

8.10.3.2.2 *Effect of creep*

The calculation of stresses between the precast beam and the cast-in-place concrete slab shall be as follows:

(a) *Simply supported members* Calculation of stresses due to sustained loads shall be based on the assumption that the stresses in any cross-section lie between the following extreme distributions:

(i) The stress distribution due to dead load (beam and cast-in-place concrete) and the prestress after all losses, acting on the precast beam.

(ii) The stress distribution due to dead load (beam and cast-in-place concrete) and prestress after all losses acting on the composite section. The member shall be considered monolithic, and the eccentricity of the prestressing force shall be measured to the centroid of the composite section.

The stresses in the composite section caused only by residual creep in the precast beam shall be calculated multiplying the difference in stress between Items (i) and (ii) by:

$$\left[1-e^{-\phi_{cc.j}}\right] \quad \text{. . . 8.10.3.2.2}$$

where

$\phi_{cc.j}$ = residual creep coefficient, which depends on the amount of creep strain that will occur after the precast beam and the cast-in-place concrete are made composite

The final stresses in the composite section due to dead load (precast beam and cast-in-place concrete), prestress and creep shall be the sum of stresses in Item (i) and the stresses due to residual creep.

(b) *Continuous members* Stresses in a continuous composite member due to dead load, prestress after all losses and creep shall be calculated by considering the continuous member separated into simply supported spans, and then restoring continuity by applying restraint moments at the supports. The final stresses at any section shall be the sum of the stresses occurring in each simply supported span calculated in accordance with Item (a) above and those stresses caused by $\left[1-e^{-\phi_{cc.j}}\right]$ the continuity restraint moments resulting from the application of both the dead load and prestress to the continuous composite section [described in Item (a)(ii)].

The restraint moments may be calculated by any method using elastic analysis. The restraint moment calculation shall be based on the assumption that continuity and composite action are established in all spans simultaneously at time (t_j). A minimum and maximum estimated value of t_j shall be used in the calculation of creep and shrinkage effects.

NOTE: In a composite member, creep occurring in the precast beam results in a redistribution of stresses between the beam and the cast-in-place concrete slab. The magnitude of these stresses depends on the age of the precast beam when composite behaviour is established. If a large proportion of the creep in the beam has taken place by the time the slab is cast, the effect of subsequent creep will be small.

8.10.3.2.3 *Effect of differential shrinkage*

Differential shrinkage effects between the precast beam and the cast-in-place concrete shall be evaluated as follows:

(a) *Simply supported members* Stresses and deformations in the composite member, due to differential shrinkage, shall be evaluated assuming a uniform differential shrinkage force along the member calculated as follows:

$$\text{differential shrinkage force} = E_c A_{cs} \phi_{cs.j} \left(\frac{1-e^{-\phi_{cc.j}}}{\phi_{cc.j}} \right) \qquad \ldots 8.10.3.2.3$$

where

A_{cs} = area of cast-in-place concrete

$\phi_{cc.j}$ = differential shrinkage

NOTE: The term $\left(\frac{1-e^{-\phi_{cc.j}}}{\phi_{cc.j}} \right)$ accounts for the influence of residual creep in the beam, and some values of this factor are given in Table 8.10.3.2.3.

The stresses in the composite beam shall be obtained from the sum of a direct tensile force equal to the differential shrinkage force acting at the centroid of the cast-in-place concrete only and a corresponding compressive force equal to the differential shrinkage force at the centroid of the cast-in-place concrete, and acting on the composite section.

(b) *Continuous members* Stresses and deformation in a continuous member due to differential shrinkage shall be calculated by considering the continuous member as separated into simply supported spans, and then restoring continuity by applying restraint moments at the supports. The final stresses at the cross-section shall be the sum of the stresses occurring in the section in the simply supported span, calculated in accordance with Item (a) and those stresses caused by the continuity moments.

NOTE: In the cast-in-place concrete directly over the piers, stresses are produced only by the continuity restraint moments.

The restraint moment calculation shall be based on the same time of establishment of continuity assumptions as in Clause 8.10.3.2.2(a).

TABLE 8.10.3.2.3

FACTORS USED FOR RESIDUAL CREEP AND DIFFERENTIAL SHRINKAGE CALCULATIONS IN COMPOSITE MEMBERS

$\phi_{cc.j}$	**0**	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**
$1-e^{-\phi_{cc.j}}$	0	0.393	0.632	0.865	0.950	0.982	0.993
$\dfrac{1-e^{-\phi_{cc.j}}}{\phi_{cc.j}}$	1.0	0.787	0.632	0.432	0.317	0.245	0.199

8.10.3.3 *Design for continuity at a support*

8.10.3.3.1 *General*

This Clause applies to the design of composite structures erected as single spans of precast prestressed concrete beams of uniform depth and made continuous afterwards for live load and superimposed dead load.

The analysis of the continuous member shall be based on the assumption of uniform moment of inertia using the uncracked cross-section including the actual width of the member.

The time-dependent effects of creep and shrinkage shall be calculated in accordance with Clause 8.10.3.2.

8.10.3.3.2 *Positive moment connection at supports*

In addition to those positive moments due to live load, support settlement and thermal effects, positive moments can develop due to the combined effects of differential creep and shrinkage. Where positive moments occur at supports, fully anchored non-prestressed longitudinal reinforcement shall be cast into the ends of the precast beams to permit the connection of the bottom flanges of adjoining beams at supports. Reinforcement shall be designed for the SLS in accordance with Clause 8.6.1.

The reinforcement shall be spliced in accordance with Section 13.

NOTE: If overlapping cogged bars or hooked bars are used, the distance between the end face of the beam and the inside edge of the leg of the bar projecting from the beam should be not less than 12 times the bar diameter.

8.10.3.3.3 *Negative moment zones*

The value of f'_c for the beam concrete and the width of the bottom flange of the beam shall be used in the strength calculation for the cross-section directly over internal supports.

The negative moment reinforcement shall be distributed evenly within the effective width and extended at the same rate beyond that area.

8.10.4 Shear

The shear resistance of a composite section shall be in accordance with Clause 8.2.

The interface shear connection shall be in accordance with Clause 8.4.

SECTION 9 DESIGN OF SLABS FOR STRENGTH AND SERVICEABILITY

9.1 STRENGTH OF SLABS IN BENDING

9.1.1 General

The strength of a slab in bending shall be determined in accordance with Clause 8.1, except that minimum tensile steel A_{st} shall be provided such that—

$$A_{st} = 0.0025bd \qquad \text{. . .9.1.1}$$

NOTE: AS 3600 should be referred to where the two-way design of a flat slab is required.

9.1.2 Distribution reinforcement for slabs

Reinforcement shall be placed in the bottom of all slabs transverse to the main reinforcement.

For road bridges, unless a more accurate analysis is carried out, the amount of distribution reinforcement shall be a percentage of the main reinforcement required for positive moment as follows:

(a) Main reinforcement parallel to traffic:

$$\text{Percentage} = \frac{1750}{\sqrt{L}} \qquad \text{. . . 9.1.2(1)}$$

(Minimum 30%)

(b) Main reinforcement perpendicular to traffic:

$$\text{Percentage} = \frac{3500}{\sqrt{L}} \qquad \text{. . . 9.1.2(2)}$$

(Minimum 30%)

For main reinforcement perpendicular to traffic, the amount of distribution reinforcement in the outer quarters of the span may be reduced by a maximum of 50%.

For rail bridges, the distribution reinforcement for slabs shall be based on a rational analysis using rail traffic loading as specified in AS 5100.2.

9.1.3 Edge stiffening

Edge stiffening of slabs shall be considered as follows:

(a) *Longitudinal* Edge beams shall be provided for all slabs having main reinforcement parallel to traffic. An edge beam may consist of a kerb section, a beam integral with the slab, or a slab edge additionally reinforced or extended.

(b) *Transverse* Transverse edges at the ends of the bridge and at intermediate points where the continuity of the slab is disrupted shall be additionally reinforced or supported by edge beams or diaphragms designed for the full effects of the wheel loads.

The need for longitudinal or transverse edge stiffening of slabs shall be based on a rational analysis of the slab using the specified loadings plus any other loading that may be applied to the edge of the slab during the life of the structure.

9.1.4 Detailing of tensile reinforcement

Tensile reinforcement shall be arranged as follows:

(a) The termination and anchorage of flexural reinforcement shall be based on a hypothetical bending-moment diagram formed by displacing the calculated positive and negative bending-moment envelopes a distance D along the slab from each side of the relevant sections of maximum moment.

  (i) Not less than one-third of the total negative moment reinforcement required at a support shall be extended a distance $12d_b$ or D, whichever is greater, beyond the point of contraflexure.

  (ii) At a simply supported discontinuous end of a slab, not less than one half of the total positive moment reinforcement required at midspan shall be anchored by extension past the face of the support for a distance of $12d_b$ or D, whichever is greater, or by an equivalent anchorage.

  Where no shear reinforcement is required in accordance with Clause 9.2, the extension of the midspan positive moment reinforcement past the face of the support may be reduced to—

    (A) $8d_b$ provided at least one half of the reinforcement is so extended; or

    (B) $4d_b$ provided all the reinforcement is so extended.

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

(b) At an exterior restrained corner of a slab supported on beams or walls and restrained against uplift, reinforcement shall be provided in both the top and the bottom of the slab for the induced torsional moments based on a rational analysis. For an orthogonal corner, in the absence of a rational analysis, the following reinforcement arrangement shall be deemed to comply:

  (i) The reinforcement shall consist of two layers perpendicular to the edges of the slab and extend from each edge for a distance not less than 0.2 times the shorter span.

  (ii) The area of the reinforcement in each of the four layers shall be not less than $0.75A_{st}$ where A_{st} is the area of the maximum positive moment reinforcement required at midspan.

(c) At an exterior corner of a two-way rectangular slab supported on four sides and restrained against uplift, reinforcement shall be provided in both the top and the bottom of the slab. This reinforcement shall consist of two layers perpendicular to the edges of the slab and extend from each edge for a distance not less than 0.2 times the shorter span. The area of the reinforcement in each of the four layers shall be not less than—

  (i) for corners where neither edge is continuous .... $0.75A_{st}$; and

  (ii) for corners where one edge is continuous ....$0.5A_{st}$,

  where A_{st} is the area of the maximum positive moment reinforcement required at midspan.

  NOTE: All reinforcement provided in a section may be included as part of this reinforcement requirement at an exterior corner.

9.1.5 Spacing of reinforcement and tendons

The minimum clear distance between parallel bars (including bundled bars), ducts and tendons shall be such that the concrete can be properly placed and compacted in accordance with Clause 17.3.3.

The maximum spacing of reinforcement and tendons shall be determined in accordance with Clause 9.4.

9.2 STRENGTH OF SLABS IN SHEAR

9.2.1 General

The strength of a slab in shear shall be calculated as follows:

(a) Where a slab acts essentially as a wide beam and shear failure may occur across the entire width or over a substantial width, the strength shall be calculated in accordance with Clause 8.2.

(b) Where the potential failure surface may form a truncated cone or pyramid around the support or loaded area, the strength of the slab shall be determined in accordance with Clauses 9.2.3 and 9.2.4.

Where failure modes specified in Items (a) and (b) are possible, the shear strength shall be calculated in accordance with both Items (a) and (b), and the smaller value shall be taken as the critical strength.

9.2.2 Design shear strength of slabs

The design shear strength of a slab shall be taken as ϕV_u, where V_u shall be determined in accordance with Clause 8.2, Clause 9.2.3 or Clause 9.2.4 as appropriate.

9.2.3 Shear strength of slabs without moment transfer

The ultimate shear strength of a slab with no moment transfer (V_{uo}) shall be taken equal to V_u and shall be calculated as follows:

(a) Where no shear reinforcement or fabricated shear head is provided—

$$V_{uo} = ud_{om}\left(f_{cv} + 0.3\sigma_{cp}\right) \quad \text{. . . 9.2.3(1)}$$

(b) Where shear reinforcement or a fabricated shear head is provided—

$$V_{uo} = ud_{om}\left(0.5\sqrt{f'_c} + 0.3\sigma_{cp}\right) \leq 0.2ud_{om}f'_c \quad \text{. . . 9.2.3(2)}$$

where

u = length of the critical shear perimeter as defined below

d_{om} = mean value of d_o, averaged around the critical shear perimeter (u)

f_{cv} = concrete shear strength, given by

$$0.17\left(1 + \frac{2}{\beta_h}\right)\sqrt{f'_c} \leq 0.34\sqrt{f'_c} \quad \text{. . . 9.2.3(3)}$$

σ_{cp} = average intensity of effective prestress in the concrete

β_h = ratio of the longest overall dimension of the effective loaded area (Y) to the shortest overall dimension (X) measured perpendicular to Y (see Figure 9.2.3)

For the purpose of this Clause, the critical shear perimeter (u) is defined by a line geometrically similar to the boundary of the effective area of a support or load and located at a distance of $d_{om}/2$ from the boundary as shown in Figure 9.2.3. The effective area of a support or load shall be that area totally enclosing the actual support or load for which the perimeter is a minimum.

That part of the critical shear perimeter that is enclosed by radial projections from the centroid of the support or load to the extremities of any critical opening shall be regarded as ineffective.

An opening shall be regarded as critical if it is located at a clear distance of less than $2.5b_o$ from the critical shear perimeter, where b_o is the width of the critical opening as shown in Figure 9.2.3(b).

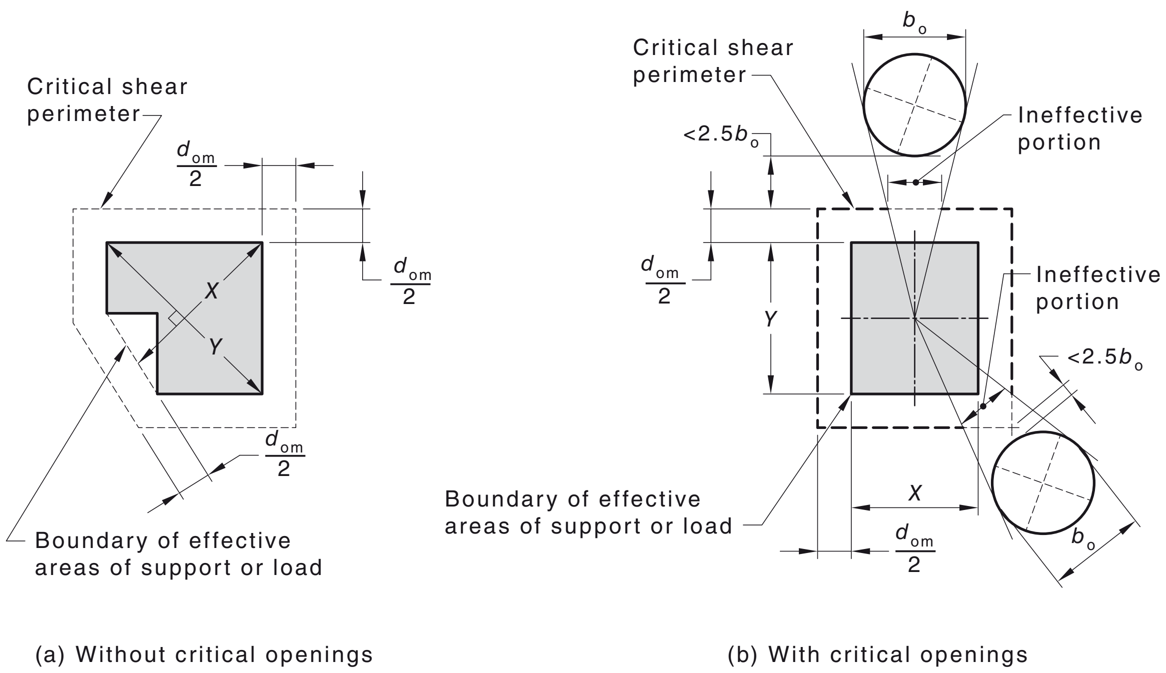

FIGURE 9.2.3 CRITICAL SHEAR PERIMETER

9.2.4 Shear strength of slabs with moment transfer

If a bending moment is designated to be transferred from a slab to a support, it shall comply with the relevant provisions of AS 3600.

9.3 DEFLECTION OF SLABS

9.3.1 General

The deflection of a slab shall be determined in accordance with Clause 9.3.2 or Clause 9.3.3.

9.3.2 Slab deflection by refined calculation

The calculation of the deflection of a slab by refined calculation shall make allowance for the following:

(a) Two-way action, where existing.

(b) Cracking and tension stiffening.

(c) Shrinkage and creep properties of the concrete.