

supports its own weight plus the weight of the slab and slab forms. ACI Sec. 17.2 allows either construction process and requires that each element be strong enough to support all loads which it supports by itself. If the beam is shored, ACI Sec. 17.3 requires that the shores be left in place until the composite section has adequate strength to support all loads and to limit deflections and cracking.

Tests have shown that the ultimate strength of a composite beam is the same whether the member was shored or unshored during construction. For this reason, ACI Sec. 17.2.4 allows strength computations to be made considering only the final member.

## Horizontal Shear

In the beam shown in Fig. 17-9a, there are no horizontal shear stresses transferred from the slab to the beam. It acts as two independent members. In Fig. 17-9b, horizontal shear stresses act on the interface and the slab and beam act in a composite manner. The ACI Code provisions for horizontal shear are given in ACI Sec. 17-5. Although the mechanism of horizontal shear transfer and that of shear friction are similar, if not identical, there is a considerable difference between the two sets of provisions, as shown in Fig. 17-10. The difference results from the fact that Eq. 17-1, ACI Sec. 17.5.2.3, and ACI Sec. 11.7 are all empirical attempts to fit test data.<sup>17-1 to 17-3, 17-8 to 17-10</sup> Equation 17-1 is valid for relatively short shear planes with lengths up to several feet, but is believed to give too high shear strengths for long shear transfer regions where the maximum stress is localized. It is also unconservative for low values of  $\rho_v f_y$ .

The tests reported in Ref. 17-3 included members with and without shear keys along the interface. The presence of shear keys stiffened the connection at low slips but had no significant effect on its strength.

From strength of materials, the horizontal shear stresses,  $v_h$ , on the contact surface between an uncracked elastic precast beam and a slab can be computed from

$$v_h = \frac{VQ}{I_c b_v} \quad (17-6)$$

where

$V$  = shear force acting on the section in question

$Q$  = first moment of the area of the slab or flange about the neutral axis of the composite section

$I_c$  = moment of inertia of the composite section

$b_v$  = width of the interface between the precast beam and the cast-in-place slab

Equation 17-6 applies to uncracked elastic beams and is only an approximation for cracked concrete beams. The ACI Code gives two ways of calculating the horizontal shear stress.

ACI Sec. 17.5.2 defines the horizontal shear force,  $V_{nh}$ , to be transferred as

$$\phi V_{nh} \geq V_u \quad (17-7)$$

(ACI Eq. 17-1)

This gives

$$v_{nh} = \frac{V_u / \phi}{b_v d} \quad (17-8)$$

This is based on the observation that in an element directly over the beam web,  $v_{nh} = v_n$  and  $v_n = V_n / b_v d$ .

Alternatively, ACI Sec. 17.5.3 allows horizontal shear to be computed from the change in compressive or tensile force in the slab in any segment of its length.

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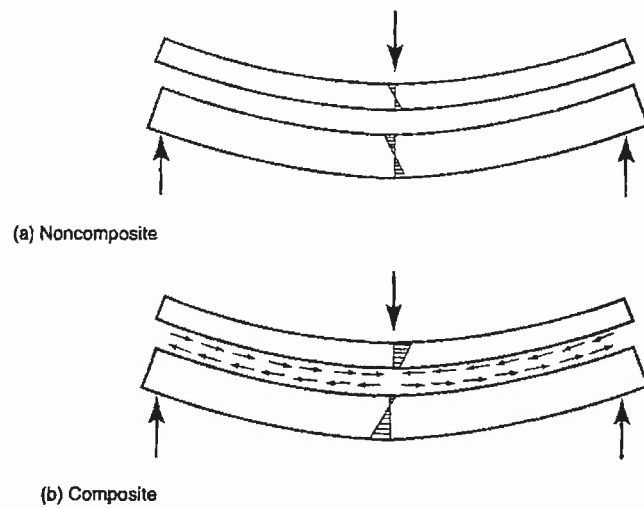


Fig. 17-9  
Horizontal shear transfer in a  
composite beam.

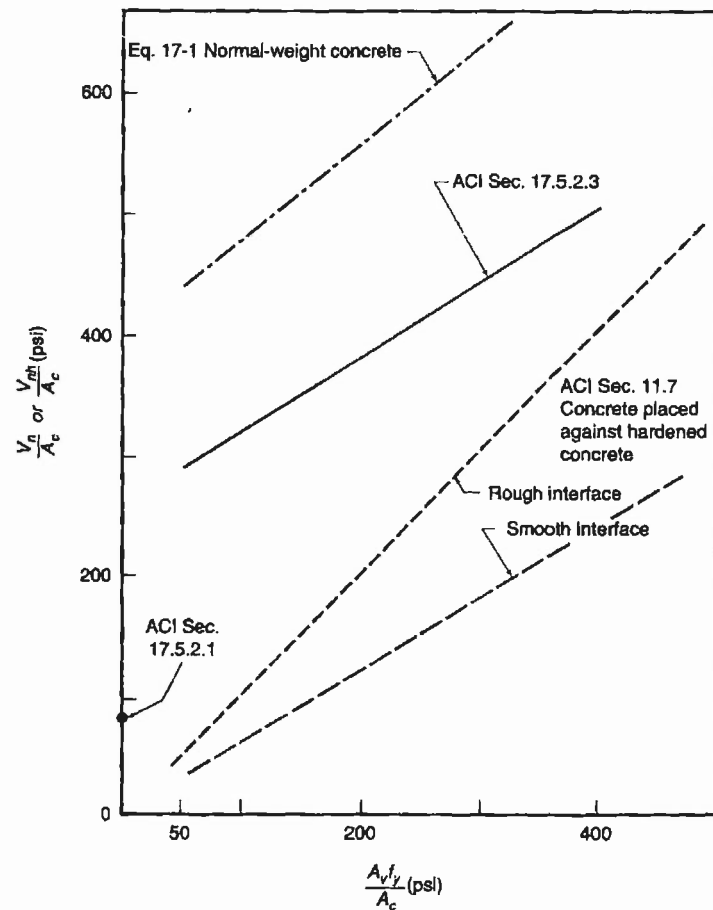


Fig. 17-10  
Comparison of ACI Sec.  
11.7, shear friction; ACI Sec.  
17.5, horizontal shear  
strength; and Eq. 17-1.

Figure 17-11 illustrates this clause. At midspan, the force in the compression zone is  $C$  as shown in Fig. 17-11a. All of this force acts above the interface. At the end of the beam, the force in the flange is zero. Thus the horizontal shear force to be transferred across the interface between midspan and the support is

$$V_{nh} = C \quad (17-9)$$

A similar derivation could be made if the flange were in tension. ACI Sec. 17.5.3.1 says that when ties are provided to resist the horizontal shear calculated using Eq. 17-9, their distribution should approximately reflect the distribution of shear forces in the member. This implies that the horizontal shear stresses should be calculated from

$$v_{nh} = \frac{KV_{nh}}{A_c} \quad (17-10)$$

where  $A_c$  is the contact area, and  $K$  is a factor to account for the distribution of the shear forces along the member.  $K$  is equal to the shear at a point divided by the average shear. For the beam in Fig. 17-11,  $K$  would vary from 2 at the end of the beam to zero at midspan. Thus the distribution of the horizontal shear stresses from Eqs. 17-9 and 17-10 would be as shown in Fig. 17-11b. For a constant shear force,  $K$  would be 1.

The two procedures give similar results, as will be seen in Example 17-2. The limits on  $V_{nh}$  from ACI Secs. 17.5.2.1 to 17.5.2.3 are given in Table 17-1.

In all cases the contact surfaces must be clean and free from laitance. The words "intentionally roughened" imply that the surface has been roughened with a "full amplitude" of  $\frac{1}{4}$  in., where "full amplitude" refers to the total height (twice the amplitude) of the roughness. The "wave length" of the roughness is intended to be of the same magnitude as the

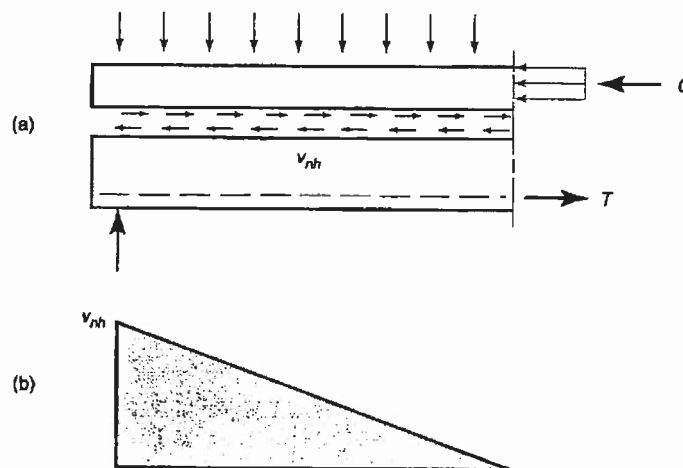


Fig. 17-11  
Horizontal shear stresses in a  
composite beam.

TABLE 17-1 CALCULATION OF  $V_{nh}$

ACI Section	Contact Surfaces	Ties	$V_{nh}$
17.5.2.1	Intentionally roughened	None	$80b_v d$
17.5.2.2	Not roughened	Minimum from 17.6	$80b_v d$
17.5.2.3	Intentionally roughened	$A_v f_y$	$\left(260 + \frac{0.6A_v f_y}{b_v s}\right) \lambda b_v d$

EXAMPLE

height, say  $\frac{1}{4}$  to  $\frac{3}{4}$  in. When the factored shear force,  $V_u = \phi V_{nh}$ , at the section exceeds  $\phi(500b_v d)$ , where 500 is in psi, ACI Sec. 17.5.2.4 requires design using shear friction in accordance with ACI Sec. 11.7.4. This limit reflects the range of test data used to derive ACI Sec. 17.5.2.3.

ACI Sec. 17.6 requires that the ties provided for horizontal shear be not less than the minimum stirrups required for shear given by

$$A_v = \frac{50b_v s}{f_y} \quad (17-11)$$

(ACI Eq. 11-13)

The tie spacing shall not exceed 4 times the least dimension of the supported element, which is usually the thickness of the slab, but not more than 24 in. The ties must be fully anchored in both the beam stem and the slab.

## Deflections

The beam cross section considered when calculating deflections depends on whether the beam was shored or unshored when the composite slab is placed. If it is shored so that the full dead load of both the precast beam and the slab is carried by the composite section, ACI Sec. 9.5.5.1 allows the designer to consider the loads to be carried by the full composite section when computing deflections. The modulus of elasticity should be based on the strength of the concrete in the compression zone, while the modulus of rupture should be based on the strength of the concrete in the tension zone. For nonprestressed beams constructed using shores, it is not necessary to check deflections if the overall height of the composite section satisfies ACI Table 9.5(a).

ACI Sec. 9.5.5.2 covers the calculation of deflections for unshored construction of nonprestressed beams. If the thickness of the precast member satisfies ACI Table 9.5(a), it is not necessary to consider deflections. If the thickness of the composite section satisfies the table but the thickness of the precast member does not, it is not necessary to compute deflections occurring after the section becomes composite, but it is necessary to compute the instantaneous deflections and that part of the sustained load deflections occurring prior to the beginning of effective composite action. This can be assumed to occur when the modulus of elasticity of the slab reaches 70 to 80% of its 28-day value, which occurs about 4 to 7 days after the slab is placed.

ACI Sec. 9.5.5.1 states that if deflections are computed, they should account for the curvatures induced by the differential shrinkage between the slab and the precast beam. Shrinkage of the slab relative to the beam, causes the slab to shorten relative to the beam. Because the slab and beam are joined together, this relative shortening causes the beam to deflect downward, adding to the deflections due to loads. Some of the shrinkage of the concrete in the beam will have occurred before the beam is erected in the structure. All of the slab shrinkage occurs after the slab is cast. As the slab shrinks relative to the beam, tensile stresses are induced in the slab and compressive stresses in the beam. These are redistributed to some degree by creep of the concrete in the slab and beam. This effect can be modeled using an *age-adjusted effective modulus*,  $E_{cum}$ , and an *age-adjusted transformed section* in the calculations as discussed in Sec. 3-4 and in Refs. 17-11 and 17-12.

### EXAMPLE 17-2 Design of a Composite Beam

Precast simply supported beams that span 24 ft and are spaced 10 ft on centers are composite with a slab that supports an unfactored live load of 100 psf, a partition load of 20 psf, and a superimposed

### 8.3.7 Minimum torsional reinforcement

Where torsional reinforcement is required as specified in Clause 8.3.4 —

- (a) all of the minimum shear reinforcement required by Clause 8.2.8 shall be provided in the form of closed ties; and
- (b) longitudinal torsional reinforcement shall be provided in accordance with Clause 8.3.6.

### 8.3.8 Detailing of torsional reinforcement

Torsional reinforcement shall be detailed in accordance with the following:

- (a) Torsional reinforcement shall consist of both closed ties and longitudinal reinforcement.
- (b) The closed ties shall be continuous around all sides of the cross-section and anchored so as to develop full strength at any point, unless a more refined analysis shows that over part of the tie full anchorage is not required. The spacing ( $s$ ) of the closed ties shall not be 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 ties.

## 8.4 LONGITUDINAL SHEAR IN BEAMS

### 8.4.1 Application

This Clause applies to the transfer of longitudinal shear forces, across interface shear planes through webs and flanges of composite beams, and across shear planes through flanges cast monolithically.

### 8.4.2 Design shear force

For the purpose of this Clause, the design longitudinal shear force acting on a shear plane shall be taken as follows:

- (a) For a shear plane through a flange, equal to  $V^* A_1/A_2$   
where
  - (i) for a flange in compression —  
 $A_1/A_2$  = the ratio of the area of flange outstanding beyond the shear plane to the total area of flange;
  - (ii) for a flange in tension —  
 $A_1/A_2$  = the ratio of the area of longitudinal reinforcement in the flange outstanding beyond the shear plane to the total area of longitudinal tensile reinforcement
- (b) For a shear plane through the web, equal to  $V^*$ .

### 8.4.3 Design shear strength

The design longitudinal shear strength shall be taken as  $\phi V_{uf}$  where —

$$V_{uf} = \beta_4 A_s f_{sy} d/s + \beta_5 b_f d f'_{ct} \leq 0.2 f'_c b_f d$$

where

- $\beta_4, \beta_5$  = the shear plane surface coefficients given in Clause 8.4.4  
 $A_s$  = cross-sectional area of reinforcement anchored each side of the shear plane  
 $f_{sy}$  = the yield strength of the reinforcement crossing the shear plane  
 $d$  = effective depth of the composite beam  
 $s$  = spacing of reinforcement crossing the shear plane  
 $b_f$  = the width of the shear interface  
 $f'_{ct}$  = the characteristic principal tensile strength of the concrete

#### 8.4.4 Shear plane surface coefficients

The shear plane surface coefficients,  $\beta_4$  and  $\beta_5$ , for the surface condition of the shear plane, shall be determined from Table 8.4.4, except that where the beam is subject to high levels of differential shrinkage, temperature effects, tensile stress, or fatigue effects across the shear plane, the value of  $\beta_5$  should be reduced.

**TABLE 8.4.4**  
**SHEAR PLANE SURFACE COEFFICIENTS**

Surface condition of the shear plane	Coefficients	
	$\beta_4$	$\beta_5$
A smooth surface, as obtained by casting against a form, or finished to a similar standard	0.6	0.1
A surface trowelled or tamped, so that the fines have been brought to the top, but where some small ridges, indentations or undulations have been left; slip-formed and vibro-beam screeded; or produced by some form of extrusion technique	0.6	0.2
A surface deliberately roughened — (a) by texturing the concrete to give a pronounced profile; (b) by compacting but leaving a rough surface with coarse aggregate protruding but firmly fixed in the matrix; (c) by spraying when wet, to expose the coarse aggregate without disturbing it; or (d) by providing mechanical shear keys.	0.9	0.4
Monolithic construction	0.9	0.5

#### 8.4.5 Shear plane reinforcement

Where reinforcement is required to increase the longitudinal shear strength, the reinforcement shall consist of shear reinforcement anchored to develop its full strength at the shear plane. Shear and torsional reinforcement already provided, and which crosses the shear plane, may be taken into account for this purpose.

An area of shear reinforcement not less than  $0.35b_f s/f_{sy,f}$  shall be provided.

#### 8.4.6 Minimum thickness of structural components

The average thickness of structural components subject to interface shear shall be not less than 50 mm with a minimum local thickness not less than 30 mm.

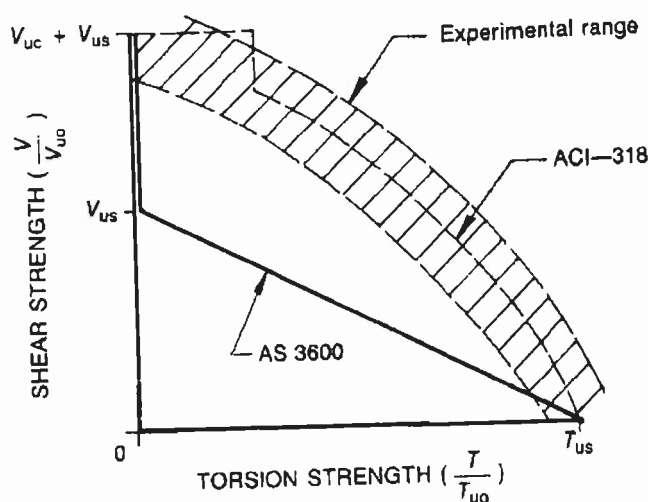


FIGURE C8.3.4 SHEAR-TORSION INTERACTION

Note that the implications of Clause 8.3.4(b) are that if any torsion is present and the shear is such that fitments are required, then  $V_{uc}$  must be taken as zero; a substantial increase in the shear reinforcement is required, and additional reinforcement is needed to resist the torsion.

#### C8.3.5 Torsional strength of a beam (Refs 13, 21, 22, and 23).

- (a) *Without torsion reinforcement* The torsional strength of a concrete beam without torsional reinforcement is largely related to a maximum principal tensile stress failure of the concrete, with the stress being determined more accurately by the plastic stress distribution than the elastic. The Standard has a simplified version of the torsional modulus (e.g.  $0.4x^2y$  for a rectangular section) (Ref. 23). The last term in the equation allows for the influence of prestress on the maximum principal stress.
- (b) *With torsion reinforcement* The method given is a variable angle truss formulation with the value of  $\theta_t$  restricted to the value given in Clause 8.3.5(b). For further details, see Reference 13.

**C8.3.6 Longitudinal torsional reinforcement** The expressions given in this Clause are once again obtained from variable angle truss formulation (see Refs 7 and 13).

Longitudinal torsional reinforcement, including minimum reinforcement, is additional to the longitudinal flexural reinforcement required for the load case of simultaneous flexure and torsion. The torsional reinforcement does not have to be added to the longitudinal flexural reinforcement provided, if any, for the load case of flexure without torsion.

**C8.3.7 Minimal torsional reinforcement** The minimum quantity of closed ties and longitudinal reinforcement is provided on the basis of maintaining the torsional capacity of the uncracked concrete section.

The amended Clause fulfils this purpose, is simpler than the original version and is consistent with similar requirements in other Standards such as the Canadian Code and Eurocode 2.

### C8.4 LONGITUDINAL SHEAR IN BEAMS

**C8.4.1 Application** This Clause covers the design for interface shear' in composite concrete flexural members and also the requirements for transverse reinforcement in the flanges of monolithic T and L-beams.

The Clauses are different from those previously provided in AS 1480 and AS 1481 and the approach now adopted follows closely the FIP Guide to Good Practice (Ref. 24).

**C8.4.2 Design shear forces** The longitudinal shear force per unit length ( $v$ ) along a shear plane can be related directly to the vertical shear force ( $V^*$ ) and the lever arm ( $jd$ ) between the tensile and compressive forces resulting from the bending moment, as indicated in Figure C8.4.2. For moment equilibrium—

$$V^*(\delta L) = (\Delta C)jd = (\Delta T)jd$$

and for horizontal equilibrium along a shear plane through the web—

$$v_w = \Delta C/\delta L = \Delta T/\delta L = V^*/jd$$

For shear planes through the flanges, only a portion of the out-of-balance compression force  $\Delta C$  (or tension force  $\Delta T$ ) has to be transmitted across the shear plane, this proportion being directly related to the area in compression  $A_1$  (or tension) outstanding beyond the shear plane to the total area  $A_2$  in compression (or tension). Hence—

$$v_f = (V^*/jd) (A_1/A_2)$$

For the purposes of this Clause, the design longitudinal shear force acting on the shear plane is taken as  $Vjd$  hence eliminating the need to calculate the lever arm  $jd$ . The longitudinal shear strength ( $V_{ur}$ ) in Clause 9.4.3 is expressed in a similar manner so that  $V^*$  or  $V^*A_1/A_2$  can be directly compared to the design strength  $\phi V_{ur}$ .

**C8.4.3 Design strength** The equation for design strength is composed of two parts, a strength related to the amount and yield strength of the transverse steel crossing the shear plane; and a strength related to the indirect tensile strength of the concrete. This format is consistent with that in Reference 25 for the design of composite structural steel and concrete members, which was based on the shear-friction concept. For shear planes through monolithic construction, there is close agreement between the equations in both Standards.

**C8.4.4 Shear planes surface coefficients** The coefficients  $\beta_4$  and  $\beta_5$  account for the surface condition at the shear plane. The coefficient  $\beta_4$  is closely related to the coefficient of friction for the shear plane and  $\beta_5$  accounts for concrete-related factors, such as aggregate interlock, which are sensitive to changes in the surface condition. The values have been obtained from an extensive test program (Ref. 24).

**C8.4.5 Shear plane reinforcement** The minimum requirements are identical to those required for conventional vertical shear reinforcement given in Clause 9.2.5 except that  $A_{sv,min}$  is the area of shear reinforcement at a spacing,  $s$ , that crosses the shear plane. This reinforcement must be anchored both sides of the shear plane to develop its full yield strength.

Where conventional shear reinforcement, as provided in Clause 8.2.10, also crosses a shear plane, it can be counted as shear plane reinforcement for the purpose of determining the design strength in accordance with Clause 8.4.3.

**C8.4.6 Minimum thickness of structural components** This Clause is particularly important for toppings. Thin toppings require careful curing and variations in thickness should be minimized. Conventional methods of achieving full anchorage of the reinforcement crossing the shear plane or interface may not be possible and alternative proven methods should be considered.



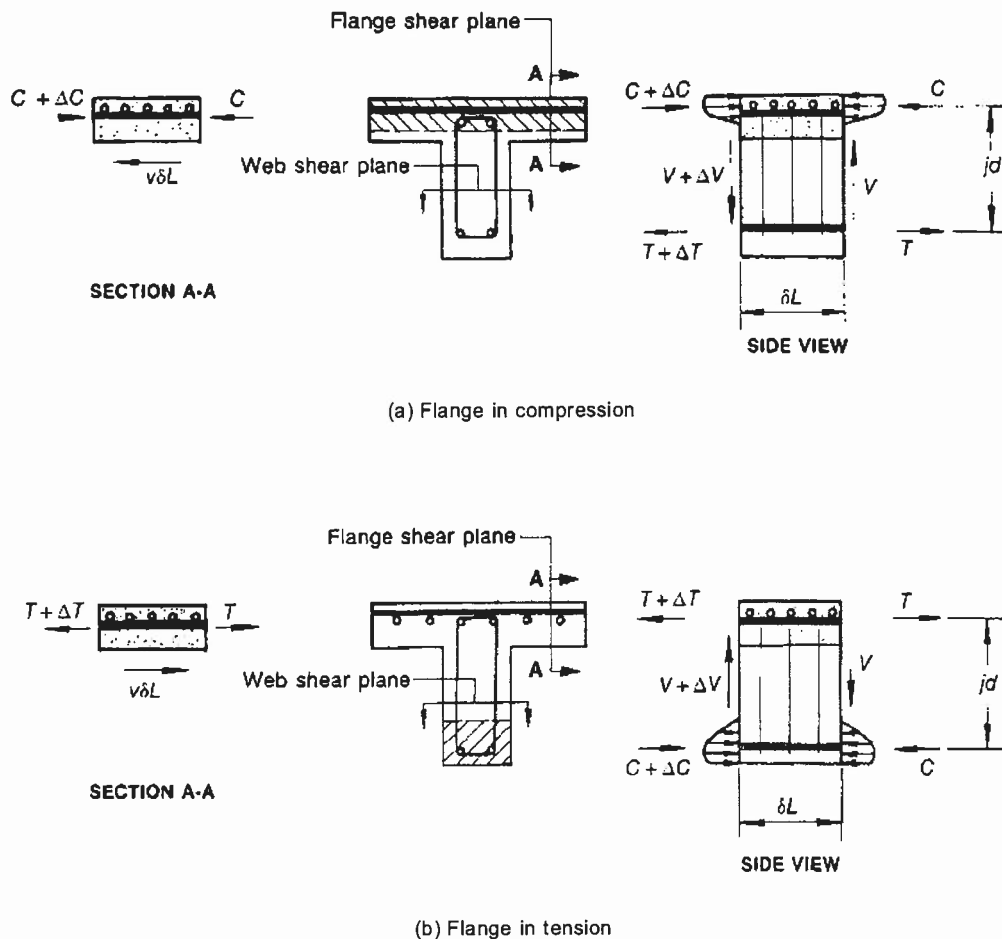


FIGURE C8.4.2 SHEAR FORCE RELATIONSHIPS

## C8.5 DEFLECTION OF BEAMS

**INTRODUCTION** Design and construction for deflection control is far more complex than strength design and there is no simple mathematical solution to the problem. The loading, both in magnitude and time of application and duration, is highly variable. The effects of creep and shrinkage and early age cracking are also difficult to predict. Moreover, the approach of making a conservative assessment of each of these parameters can lead to an overly conservative design (Refs 27 and 28). To design effectively for serviceability, the designer must have an understanding of the non-linear behaviour of concrete structures.

**C8.5.1 General** Serviceability problems, arising from shortcomings in the information given in Section 10 of AS 1480, created a need to revise this part of the Standard. Changes have been made in the span-to-depth ratios and in deflection limitations given in Clause 2.4.2 to reduce the likelihood of excessive deflections of flexural members. However, the use of these procedures without a critical assessment of the variables used may not eliminate serviceability problems.

**C8.5.2 Beam deflection by refined calculation** This Clause provides for refined methods, based on estimated creep and shrinkage properties and the integration of curvatures, to obtain the deflection. The designer is free to choose suitable procedures.