

### 16.12.2.5

The maximum deviation in elevation between the tops of any three adjacent joists shall not be greater than 0.01 times the joist spacing, and in no case greater than 25 mm. The deviation is the vertical offset from the top of the centre joist to the line joining the tops of the centres of the adjacent joists.

## 17. Composite Beams, Trusses, and Joists

### 17.1 Application

The provisions of Clause 17 shall apply to composite beams consisting of steel sections, trusses, or joists interconnected with either a reinforced concrete slab or a steel deck with a concrete cover slab. Trusses and joists designed to act compositely with the slab or cover slab shall also meet the requirements of Clause 15 and 16, respectively.

### 17.2 Definitions

The following definitions apply to Clause 17:

**Cover slab** — the concrete above the flutes of the steel deck. All flutes are filled with concrete so as to form a ribbed slab.

**Effective cover slab thickness,  $t$**  — the minimum thickness of concrete measured from the top of the cover slab to the top of the steel deck. The minimum thickness is 65 mm unless the adequacy of a lesser thickness has been established by appropriate tests.

**Effective slab thickness,  $t$**  — the overall slab thickness, provided that the slab is cast

- (a) with a flat underside;
- (b) on corrugated steel forms having a height of corrugation not greater than 0.25 times the overall slab thickness; or
- (c) on fluted steel forms whose profile has the following characteristics:
  - (i) the minimum concrete rib width is 125 mm;
  - (ii) the maximum rib height is 40 mm but not more than 0.4 times the overall slab thickness; and
  - (iii) the average width between ribs does not exceed 0.25 times the overall slab thickness 0.2 times the minimum width of concrete ribs.

In all other cases, "effective slab thickness" means the overall slab thickness minus the height of flute corrugation.

**Flute** — the portion of the steel deck that forms a valley.

**Rib** — the portion of the concrete slab that is formed by the flute.

**Slab** — a reinforced cast-in-place concrete slab at least 65 mm in effective thickness. The area equal to the effective width times the effective slab thickness should be free of voids or hollows except for those specifically permitted in the definition of effective slab thickness.

**Steel deck** — a load-carrying steel deck consisting of either

- (a) a single fluted element (non-cellular deck); or
- (b) a two-element section consisting of a fluted element in conjunction with a flat sheet (cellular deck).

The maximum depth of the deck shall be 80 mm and the average width of the minimum flute shall be 50 mm. A steel deck may be of a type intended to act compositely with the cover slab in supporting applied load.

**Steel joist** — an open-web steel joist suitable for composite design (see Clause 16).

**Steel section** — a steel structural section with a solid web or webs suitable for composite design. Web openings shall be permissible only on condition that their effects are fully investigated and accounted for in the design.

**Steel truss** — a steel truss suitable for composite design (see Clause 15).

## 17.3 General

### 17.3.1 Deflections

Calculation of deflections shall take into account the effects of creep of concrete, shrinkage of concrete and increased flexibility resulting from partial shear connection and from interfacial slip. These effects shall be established by test or analysis, where practicable. Consideration shall also be given to the effect of full or partial continuity in the steel beams and concrete slabs in reducing calculated deflections.

In lieu of tests or analysis, the effects of partial shear connection and interfacial slip, creep, and shrinkage may be assessed as follows:

(a) for increased flexibility resulting from partial shear connection and interfacial slip, the deflections shall be calculated using an effective moment of inertia given by

$$I_e = I_s + 0.85 (p)^{0.25} (I_t - I_s)$$

where

$I_s$  = moment of inertia of a steel beam, or of a steel joist or truss adjusted to include the effect of shear deformations, which may be taken into account by decreasing the moment of inertia based on the cross-sectional areas of the top and bottom chords by 15% or by a more detailed analysis

$p$  = fraction of full shear connection (use  $p = 1.00$  for full shear connection)

$I_t$  = transformed moment of inertia of composite beam based on the modular ratio  $n = E/E_c$

(b) for creep, elastic deflections caused by dead loads and long-term live loads, as calculated in Item (a), shall be increased by 15%; and

(c) for shrinkage of concrete, using a selected free shrinkage strain, strain compatibility between the steel and concrete, and a time-dependent modulus of elasticity of the concrete in tension,  $E_{ct}$  (see Appendix H) as it dries, shrinks, and creeps, the deflection shall be calculated as

$$\Delta_s = \frac{\epsilon_f A_c L^2 y}{8 n_t I_t}$$

where

$\epsilon_f$  = free shrinkage strain of the concrete

$A_c$  = effective area of the concrete slab

$L$  = span of beam

$y$  = distance from the centroid of effective area of concrete slab to the elastic neutral axis

$n_t$  = modular ratio,  $E/E_{ct}$

where

$E_{ct}$  = effective modulus of concrete in tension

$I_t$  = transformed moment of inertia of the composite beam but based on the modular ratio  $n_t$

### 17.3.2 Vertical Shear

The web area of steel sections or the web system of steel trusses and joists shall be proportioned to carry the total vertical shear,  $V_f$ .

### 17.3.3 End Connections

End connections of steel sections, trusses, and joists shall be proportioned to transmit the total end reaction of the composite beam.

## 17.4 Design Effective Width of Concrete

### 17.4.1

Slabs or cover slabs extending on both sides of the steel section or joist shall be deemed to have a design effective width,  $b$ , equal to the lesser of

- (a) 0.25 times the composite beam span; or
- (b) the average distance from the centre of the steel section, truss, or joist to the centres of adjacent parallel supports.

### 17.4.2

Slabs or cover slabs extending on one side only of the supporting section or joist shall be deemed to have a design effective width,  $b$ , not greater than the width of the top flange of the steel section or top chord of the steel joist or truss plus the lesser of

- (a) 0.1 times the composite beam span; or
- (b) 0.5 times the clear distance between the steel section, truss, or joist and the adjacent parallel support.

## 17.5 Slab Reinforcement

### 17.5.1 General

Slabs shall be adequately reinforced to support all loads and to control both cracking transverse to the composite beam span and longitudinal cracking over the steel section or joist. Reinforcement shall not be less than that required by the specified fire-resistance design of the assembly.

### 17.5.2 Parallel Reinforcement

Reinforcement parallel to the span of the beam in regions of negative bending moment of the composite beam shall be anchored by embedment in concrete that is in compression. The reinforcement of slabs that are to be continuous over the end support of steel sections or joists fitted with flexible end connections shall be given special attention. In no case shall such reinforcement at the ends of beams supporting ribbed slabs perpendicular to the beam be less than two 15 M bars or equivalent.

### 17.5.3 Transverse Reinforcement, Solid Slabs

Unless it is known from experience that longitudinal cracking caused by composite action directly over the steel section or joist is unlikely, additional transverse reinforcement or other effective means shall be provided. Such additional reinforcement shall be placed in the lower part of the slab and anchored so as to develop the yield strength of the reinforcement. The area of such reinforcement shall be not less than 0.002 times the concrete area being reinforced and shall be uniformly distributed.

## **17.5.4 Transverse Reinforcement, Ribbed Slabs**

### **17.5.4.1**

Where the ribs are parallel to the beam span, the area of transverse reinforcement shall be not less than 0.002 times the concrete cover slab area being reinforced and shall be uniformly distributed.

### **17.5.4.2**

Where the ribs are perpendicular to the beam span, the area of transverse reinforcement shall not be less than 0.001 times the concrete cover slab area being reinforced and shall be uniformly distributed.

## **17.6 Interconnection**

### **17.6.1**

Except as permitted by Clauses 17.6.2 and 17.6.4, interconnection between steel sections, trusses, or joists and slabs or steel decks with cover slabs shall be attained by the use of shear connectors as prescribed in Clause 17.7.

### **17.6.2**

Uncoated steel sections, trusses, or joists that support slabs and are totally encased in concrete do not require interconnection by means of shear connectors, provided that

- (a) a minimum of 50 mm of concrete covers all portions of the steel section, truss, or joist except as noted in Item (c);
- (b) the cover in Item (a) is reinforced to prevent spalling; and
- (c) the top of the steel section, truss, or joist is at least 40 mm below the top and 50 mm above the bottom of the slab.

### **17.6.3**

Studs may be welded through a maximum of two steel sheets in contact, each not more than 1.71 mm in overall thickness, including coatings (1.52 mm in nominal base steel thickness plus zinc coating not greater than nominal 275 g/m<sup>2</sup>). Otherwise, holes for placing studs shall be made through the sheets as necessary. Welded studs shall meet the requirements of CSA Standard W59.

### **17.6.4**

Other methods of interconnection that have been adequately demonstrated by test and verified by analysis may be used to effect the transfer of forces between the steel section, truss, or joist and the slab or steel deck with cover slab. In such cases, the design of the composite member shall conform to the design of a similar member employing shear connectors, insofar as practicable.

### **17.6.5**

The diameter of a welded stud shall not exceed 2.5 times the thickness of the part to which it is welded, unless test data satisfactory to the designer are provided to establish the capacity of the stud as a shear connector.

## **17.7 Shear Connectors**

### **17.7.1 General**

The resistance factor,  $\phi_{sc}$ , to be used with the shear resistances given in Clause 17.7 shall be taken as 0.80. The factored shear resistance,  $q_r$ , of other shear connectors shall be established by tests acceptable to the designer.

### 17.7.2 End-Welded Studs

End-welded studs shall be headed or hooked with  $h/d \geq 4$ . The projection of a stud in a ribbed slab, based on its length prior to welding, shall be at least two stud diameters above the top surface of the steel deck.

#### 17.7.2.1

In solid slabs

$$q_{rs} = 0.50 \phi_{sc} A_{sc} \sqrt{f'_c E_c} \leq \phi_{sc} A_{sc} F_u$$

where

$q_{rs}$  = factored shear resistance

$F_u$  = 415 MPa for commonly available studs

#### 17.7.2.2

In ribbed slabs with ribs parallel to the beam

(a) when  $w_d/h_d \geq 1.50$

$$q_{rr} = q_{rs}$$

(b) when  $w_d/h_d < 1.50$

$$q_{rr} = \phi_{sc} \left[ 0.92 \frac{w_d}{h_d} dh(f'_c)^{0.8} + 11 s d(f'_c)^{0.2} \right] \leq q_{rs}$$

where

$s$  = longitudinal stud spacing

#### 17.7.2.3

In ribbed slabs with ribs perpendicular to the beam

(a) when  $h_d = 75$  mm

$$q_{rr} = 0.35 \phi_{sc} \rho A_p \sqrt{f'_c} \leq q_{rs}$$

(b) when  $h_d = 38$  mm

$$q_{rr} = 0.61 \phi_{sc} \rho A_p \sqrt{f'_c} \leq q_{rs}$$

where

$A_p$  = the concrete pull-out area, taking the deck profile and stud burn-off into account. For a single stud, the apex of the pyramidal pull-out area, with four sides sloping at  $45^\circ$ , is taken as the centre of the top surface of the head of the stud. For a pair of studs, the pull-out area has a ridge extending from stud to stud.

$\rho$  = 1.0 for normal-density concrete (2150 to 2500 kg/m<sup>3</sup>)  
 = 0.85 for semi-low-density concrete (1850 to 2150 kg/m<sup>3</sup>)

**17.7.2.4**

The longitudinal spacing of stud connectors in both solid slabs and in ribbed slabs when ribs of formed steel deck are parallel to the beam shall not be less than six stud diameters. The maximum spacing of studs shall not exceed 1000 mm (see also Clause 17.8).

The transverse spacing of stud connectors shall not be less than four stud diameters.

**17.7.3 Channel Connectors**

In solid slabs of normal-density concrete with  $f'_c \geq 20$  MPa and a density of at least 2300 kg/m<sup>3</sup>

$$q_{rs} = 36.5\phi_{sc}(t + 0.5w)L_c\sqrt{f'_c}$$

**17.8 Ties**

Mechanical ties shall be provided between the steel section, truss, or joist and the slab or steel deck to prevent separation. Shear connectors may serve as mechanical ties if suitably proportioned. The maximum spacing of ties shall not exceed 1000 mm, and the average spacing in a span shall not exceed 600 mm or be greater than that required to achieve any specified fire-resistance rating of the composite assembly.

**17.9 Design of Composite Beams with Shear Connectors****17.9.1**

The composite beam shall consist of steel section, truss or joist, shear connectors, ties, and slab or steel deck with cover slab.

The flat width of the top chord or that of a component member of the top chord shall not be less than

$$1.4d + 20 \text{ mm}$$

where

$d$  = diameter of the stud connector

**17.9.2**

The properties of the composite section shall be based on the maximum effective area (equal to effective width times effective thickness), neglecting any concrete area in tension. If a steel truss or joist is used, the area of its top chord shall be neglected in determining the properties of the composite section and only Clause 17.9.3(a) is applicable.

**17.9.3**

The factored moment resistance,  $M_{rc}$ , of the composite section with the slab or cover slab in compression shall be calculated as follows, where  $\phi = 0.90$  and the resistance factor for concrete

$\phi_c = 0.60$ :

(a) Case 1 — full shear connection and plastic neutral axis in the slab; ie,  $Q_r \geq \phi A_s F_y$  and  $\phi A_s F_y \leq 0.85\phi_c b t f'_c$  where  $Q_r$  equals the sum of the factored resistances of all shear connectors between points of maximum and zero moment

$$M_{rc} = T_r e' = \phi A_s F_y e'$$

where

$e'$  = is the lever arm and is calculated from the equation

$$a = \frac{\phi A_s F_y}{0.85 \phi_c b f'_c}$$

(b) Case 2 — full shear connection and plastic neutral axis in the steel section; ie,  $Q_r \geq 0.85 \phi_c b t f'_c$  and  $0.85 \phi_c b t f'_c < \phi A_s F_y$

$$M_{rc} = C_r e + C'_r e'$$

$$C'_r = 0.85 \phi_c b t f'_c$$

$$C_r = \frac{\phi A_s F_y - C'_r}{2}$$

(c) Case 3 — partial shear connection; ie,  $Q_r < 0.85 \phi_c b t f'_c$  and  $Q_r < \phi A_s F_y$

$$M_{rc} = C_r e + C'_r e'$$

$$C'_r = Q_r$$

$$C_r = \frac{\phi A_s F_y - C'_r}{2}$$

where

$e'$  = the lever arm and is calculated from the equation

$$a = \frac{C'_r}{0.85 \phi_c b f'_c}$$

#### 17.9.4

No composite action shall be assumed in calculating flexural strength when  $Q_r$  is less than 0.4 times the lesser of  $0.85 \phi_c b t f'_c$  and  $\phi A_s F_y$ . No composite action shall be assumed in calculating deflections when  $Q_r$  is less than 0.25 times the lesser of  $0.85 \phi_c b t f'_c$  and  $\phi A_s F_y$ .

#### 17.9.5

For full shear connection, the total horizontal shear,  $V_h$ , at the junction of the steel section, truss, or joist and the concrete slab or steel deck, to be resisted by shear connectors distributed between the point of maximum bending moment and each adjacent point of zero moment shall be calculated as

$$V_h = \phi A_s F_y$$

or

$$V_h = 0.85 \phi_c b t f'_c$$

for Cases 1 and 2 as defined in Clause 17.9.3(a) and (b), respectively, and  $Q_r \geq V_h$ .

#### 17.9.6

For partial shear connection, the total horizontal shear,  $V_h$ , as defined in Clause 17.9.3(c) shall be

$$V_h = Q_r$$

**17.9.7**

Composite beams employing steel sections and concrete slabs may be designed as continuous members. The factored moment resistance of the composite section, with the concrete slab in the tension area of the composite section, shall be the factored moment resistance of the steel section alone, except that when sufficient shear connectors are placed in the negative moment region, suitably anchored concrete slab reinforcement parallel to the steel sections and within the design effective width of the concrete slab may be included in calculating the properties of the composite section. The total horizontal shear,  $V_h$ , to be resisted by shear connectors between the point of maximum negative bending moment and each adjacent point of zero moment shall be taken as  $\phi_r A_r F_{yr}$ .

**17.9.8**

The number of shear connectors to be located on each side of the point of maximum bending moment (positive or negative, as applicable), distributed between that point and the adjacent point of zero moment, shall be not less than

$$n = \frac{V_h}{q_r}$$

Shear connectors may be spaced uniformly, except that in a region of positive bending the number of shear connectors,  $n'$ , required between any concentrated load applied in that region and the nearest point of zero moment shall be not less than

$$n' = n \left( \frac{M_{f1} - M_r}{M_f - M_r} \right)$$

where

$M_{f1}$  = positive bending moment under factored load at concentrated load point

$M_r$  = factored moment resistance of the steel section alone

$M_f$  = maximum positive bending moment under factored load

**17.9.9**

In the end panels of composite joists and trusses, the top chord shall be designed to resist all factored forces, ignoring any composite action unless adequate shear connectors are placed over the seat or along a top chord extension to carry horizontal shear. Studs shall not be placed closer than their height to the end of the concrete slab.

**17.9.10**

The shear that is to be developed on the longitudinal shear surfaces,  $A_{cv}$ , of composite beams with solid slabs or with cover slabs and steel deck parallel to the beam, shall be taken as

$$V_u = \Sigma q_r - 0.85 \phi_c f'_c A_c - \phi_r A_r F_{yr}$$

where

$A_r$  = area of longitudinal reinforcement within the concrete area,  $A_c$

For normal-weight concrete, the factored shear resistance along any potential longitudinal shear surfaces in the concrete slab shall be taken as

$$V_r = (0.80 \phi_r A_r F_{yr} + 2.76 \phi_c A_{cv}) \leq 0.50 \phi_c f'_c A_{cv}$$



where

$A_T$  = area of transverse reinforcement crossing shear planes,  $A_{cv}$

## 17.10 Design of Composite Beams without Shear Connectors

### 17.10.1

Uncoated steel sections or joists supporting concrete slabs and encased in concrete in accordance with Clause 17.6.2 may be proportioned assuming that the composite section supports the total load.

### 17.10.2

The properties of the composite section for determination of load-carrying capacity shall be calculated by ultimate strength methods, neglecting any area of concrete in tension.

### 17.10.3

As an alternative method of design, encased simple-span steel sections or joists may be proportioned assuming that the steel section, truss, or joist alone supports 0.90 times the total load.

## 17.11 Unshored Beams

For composite beams that are unshored during construction, the stresses in the tension flange of the steel section, truss, or joist due to the loads applied before the concrete strength reaches  $0.75f'_c$  plus the stresses at the same location due to the remaining specified loads considered to act on the composite section shall not exceed  $F_y$ .

## 17.12 Beams during Construction

The steel section, truss, or joist alone shall be proportioned to support all factored loads applied prior to hardening of the concrete without exceeding its calculated capacity under the conditions of lateral support or shoring, or both, to be furnished during construction.

## 18. Composite Columns

### 18.1 Resistance Prior to Composite Action

The factored resistance of the steel member prior to the attainment of composite action shall be determined in accordance with Clause 13.

### 18.2 Concrete-Filled Hollow Structural Sections

#### 18.2.1 General

##### 18.2.1.1 Scope

Clause 18.2 applies to composite members consisting of steel hollow structural sections completely filled with concrete, provided that

- (a) the width-to-thickness ratio of the walls of rectangular hollow structural sections does not exceed  $1350/\sqrt{F_y}$ ;
- (b) the outside diameter-to-thickness ratio of circular hollow structural sections does not exceed  $28\,000/F_y$ ; and
- (c) the concrete strength is between 20 and 80 MPa for axially loaded columns and between 20 and 40 MPa for columns subjected to axial compression and bending.