

## CHAPTER 12 — SHEAR AND DIAGONAL TENSION — WORKING STRESS DESIGN\*

### 1200—Notation

$A_g$	= gross area of section
$A_s$	= area of tension reinforcement
$A_v$	= total area of web reinforcement in tension within a distance, $s$ , measured in a direction parallel to the longitudinal reinforcement
$\alpha$	= angle between inclined web bars and longitudinal axis of member
$b$	= width of compression face of flexural member
$b'$	= width of web in I- and T-sections
$b_o$	= periphery of critical section for slabs and footings
$d$	= distance from extreme compression fiber to centroid of tension reinforcement
$f'_c$	= compressive strength of concrete (see Section 301)
$f_v$	= tensile stress in web reinforcement
$F_{sp}$	= ratio of splitting tensile strength to the square root of compressive strength (see Section 505)
$M$	= bending moment
$M'$	= modified bending moment
$N$	= load normal to the cross section, to be taken as positive for compression, negative for tension, and to include the effects of tension due to shrinkage and creep
$p_w$	= $A_s/b'd$
$s$	= spacing of stirrups or bent bars in a direction parallel to the longitudinal reinforcement
$t$	= total depth of section
$v$	= shear stress
$v_c$	= shear stress carried by concrete
$V$	= total shear
$V'$	= shear carried by web reinforcement

\*The provisions for shear are based on recommendations of ACI-ASCE Committee 326. The term  $j$  is omitted in determination of normal shear stress.

### 1201—Shear stress\*†

(a) The nominal shear stress, as a measure of diagonal tension, in reinforced concrete members shall be computed by:

$$v = V/bd \dots \dots \dots (12-1)^*$$

For design, the maximum shear shall be considered as that at the section a distance,  $d$ , from the face of the support.† Wherever applicable, effects of torsion shall be added and effects of inclined flexural compression in variable-depth members shall be included.

(b) For beams of I- or T-section,  $b'$  shall be substituted for  $b$  in Eq. (12-1).

(c) The shear stress,  $v_c$ , permitted on an unreinforced web shall not exceed  $1.1\sqrt{f'_c}$  at a distance  $d$  from the face of the support unless a more detailed analysis is made in accordance with (d) or (e). The shear stresses at sections between the face of the support and the section a distance  $d$  therefrom shall not be considered critical.‡ For members with axial tension,  $v_c$  shall not exceed the value given in (e).

(d) The shear stress permitted on an unreinforced web shall not exceed that given by:

$$v_c = \sqrt{f'_c} + 1300 \frac{p_w Vd}{M} \dots \dots \dots (12-2)$$

but not to exceed  $1.75\sqrt{f'_c}$ . The shear stresses at sections between the face of the support and the section a distance  $d$  therefrom shall not be considered critical.‡  $V$  and  $M$  are the shear and bending moment at the section considered, but  $M$  shall be not less than  $Vd$ .

(e) For members subjected to axial load in addition to shear and flexure, Eq. (12-2) shall apply except that  $M'$  shall be substituted for  $M$  where

$$M' = M - N \frac{(4t-d)}{8} \dots \dots \dots (12-3)$$

and  $v_c$  shall not exceed

$$v_c = 1.75 \sqrt{f'_c (1 + 0.004 N/A_g)} \dots \dots \dots (12-4)$$

When all longitudinal reinforcement at a section acts in compression use Eq. (12-4).†

### 1202—Web reinforcement

(a) Wherever the value of the shear stress,  $v$ , computed by Eq. (12-1), plus effects of torsion, exceeds the shear stress,  $v_c$ , permitted for the concrete of an unreinforced web by Sections 1201(c), (d), or (e), web reinforcement shall be provided to carry the excess. Such web rein-

\*The provisions for shear are based on recommendations of ACI-ASCE Committee 326. The term  $j$  is omitted in determination of normal shear stress.

†Special provisions for lightweight aggregate concretes are given in Section 1209.

‡This provision does not apply to brackets and other short cantilevers.



forcement shall also be provided for a distance equal to the depth,  $d$ , of the member beyond the point theoretically required. Web reinforcement between the face of the support and the section at a distance  $d$  therefrom shall be the same as required at that section.

(b) Web reinforcement may consist of:

1. Stirrups perpendicular to the longitudinal reinforcement
2. Stirrups making an angle of 45 deg or more with the longitudinal tension reinforcement
3. Longitudinal bars bent so that the axis of the bent bar makes an angle of 30 deg or more with the axis of the longitudinal portion of the bar
4. Combinations of 1 or 2 with 3

(c) Stirrups or other bars to be considered effective as web reinforcement shall be anchored at both ends according to the provisions of Section 919.

### 1203—Stirrups

(a) The area of steel required in stirrups placed perpendicular to the longitudinal reinforcement shall be computed by:

$$A_v = V's/f_v d \quad (12-5)$$

(b) The area of inclined stirrups shall be computed by Eq. (12-7).

### 1204—Bent bars

(a) Only the center three-fourths of the inclined portion of any longitudinal bar that is bent up for web reinforcement shall be considered effective for that purpose.

(b) When the web reinforcement consists of a single bent bar or of a single group of parallel bars all bent up at the same distance from the support, the required area shall be computed by:

$$A_v = \frac{V'}{f_v \sin \alpha} \quad (12-6)$$

in which  $V'$  shall not exceed  $1.5 bd \sqrt{f'_c}$ .

(c) Where there is a series of parallel bars or groups of bars bent up at different distances from the support, the required area shall be computed by:

$$A_v = \frac{V's}{f_v d (\sin \alpha + \cos \alpha)} \quad (12-7)$$

(d) Bent bars used alone as web reinforcement shall be so spaced that the effective inclined portion defined in (a) meets the requirements of Section 1206 (a).

(e) Where more than one type of web reinforcement is used to reinforce the same portion of the web, the total shear resistance shall be

computed as the sum of the resistances computed for the various types separately. In such computations, the resistance of the concrete,  $v_c$ , shall be included only once, and no one type of reinforcement shall be assumed to resist more than  $2V'/3$ .

### 1205—Stress restrictions

(a) The tensile stress in web reinforcement,  $f_v$ , shall not exceed the values given in Section 1003.

(b) The shear stress,  $v$ , shall not exceed  $5\sqrt{f'_c}$  in sections with web reinforcement.

### 1206—Web reinforcement restrictions

(a) Where web reinforcement is required, it shall be so spaced that every 45-deg line, representing a potential diagonal crack and extending from middepth,  $d/2$ , of the member to the longitudinal tension bars, shall be crossed by at least one line of web reinforcement. When the shear stress exceeds  $3\sqrt{f'_c}$ , every such 45-deg line shall be crossed by at least two lines of web reinforcement.

(b) Where web reinforcement is required, its area shall not be less than 0.15 percent of the area,  $b_s$ , computed as the product of the width of the web and the spacing of the web reinforcement along the longitudinal axis of the member.

### 1207—Shear stress in slabs and footings\*

(a) The shear capacity of slabs and footings in the vicinity of concentrated loads or concentrated reactions shall be governed by the more severe of two conditions:

1. The slab or footing acting essentially as a wide beam, with a potential diagonal crack extending in a plane across the entire width. This case shall be considered in accordance with Section 1201.

2. Two-way action existing for the slab or footing, with potential diagonal cracking along the surface of a truncated cone or pyramid around the concentrated load or reaction. The slab or footing in this case shall be designed as required in the remainder of this section.

(b) The critical section for shear to be used as a measure of diagonal tension shall be perpendicular to the plane of the slab and located at a distance  $d/2$  out from the periphery of the concentrated load or reaction area.

(c) The nominal shear stress shall be computed by:

$$v = V/b_o d \quad (12-8)$$

in which  $V$  and  $b_o$  are taken at the critical section specified in (b). The shear stress,  $v$ , so computed shall not exceed  $2\sqrt{f'_c}$ , unless shear rein-

\*For transfer of moments and effects of openings see Section 920.