(c) The quantity $(p_w - p_f)$ shall not exceed 0.75 of the value p_b given by Eq. (16-2).

1604—Other cross sections

(a) For other cross sections and for cases of nonsymmetrical bending, the ultimate moment shall be computed by a general analysis based on the assumptions given in Section 1503.

(b) The amount of tension reinforcement shall be so limited that the steel ratio, p, does not exceed 75 percent of that corresponding to balanced conditions as defined by Section 1602.

CHAPTER 17 — SHEAR AND DIAGONAL TENSION — ULTIMATE STRENGTH DESIGN*

1700—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

α = 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_y = yield strength of reinforcement, (see Section 301)

F_{sp} = ratio of splitting tensile strength to the square root of the 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_c = shear stress carried by concrete

v_u = nominal ultimate shear stress as a measure of diagonal tension

V = total shear at section

V_u = total ultimate shear

V_u' = ultimate shear carried by web reinforcement

ϕ = capacity reduction factor (see Section 1504)

*The provisions for shear are based upon recommendations of ACI-ASCE Committee 326. The term j is omitted in the determination of nominal shear stress.

1701—Ultimate shear strength*†

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

$$v_u = V_u / bd \quad \text{(17-1)}$$

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. (17-1).

(c) The shear stress, v_c, carried by an unreinforced web shall not exceed $2\phi\sqrt{f_c'}$ 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 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 1701(e).

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

$$v_c = \phi\left(1.9\sqrt{f_c'} + 2500\,\frac{p_w V d}{M}\right) \quad \text{(17-2)}$$

except that v_c shall not exceed $3.5\phi\sqrt{f_c'}$. The shear 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 $V_u d$.

(e) For members subjected to axial load in addition to shear and flexure Eq. (17-2) shall apply except that M' shall be substituted for M, where

$$M' = M - N\left(\frac{4t - d}{8}\right) \quad \text{(17-3)}$$

and v_c shall not exceed

$$3.5\phi\sqrt{f_c'\,(1 + 0.002\,N/A_g)}$$

1702—Web reinforcement

(a) Wherever the value of the ultimate shear stress, v_u, computed by Eq. (17-1) plus effects of torsion, exceeds the shear stress, v_c, permitted for the concrete of an unreinforced web by Section 1701(c), (d) or (e), web reinforcement shall be provided to carry the excess. Such web reinforcement 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.

1703—Stirrups

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

$$A_v = V_u' s / \phi f_y d \quad \text{(17-4)}$$

(b) The area of inclined stirrups shall be computed by Eq. (17-6).

1704—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 a single group of parallel bars all bent up at the same distance from the support, the required area shall be computed by:

$$A_v = \frac{V_u'}{\phi f_y \sin\alpha} \quad \text{(17-5)}$$

where V_u' shall not exceed $3\phi bd\sqrt{f_c'}$.

(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:

$$A_v = \frac{V_u' s}{\phi f_y d\,(\sin\alpha + \cos\alpha)} \quad \text{(17-6)}$$

(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 1706(a).

*The provisions for shear are based upon recommendations of ACI-ASCE Committee 326. The term j is omitted in the determination of nominal shear stress.

†Special provisions for lightweight aggregate concretes are given in Section 1708.

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

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

(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 $2V_u'/3$.

1705—Stress restrictions

(a) The specified yield point for stirrup reinforcement shall not exceed 60,000 psi.

(b) The shear stress, v_u, shall not exceed $10\phi\sqrt{f_c'}$ in sections with web reinforcement.

1706—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, v_u, exceeds $6\phi\sqrt{f_c'}$, every such 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, bs, computed as the product of the width of the web and the spacing of the web reinforcement along the longitudinal axis of the member.

1707—Shear stress in slabs and footings*

(a) The shear strength of slabs and footings in the vicinity of concentrated loads or concentrated reactions is 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 1701.

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 specified 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.

*For transfer of moments and effect of openings see Section 920.

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

$$v_u = V_u / b_o d \quad \text{(17-7)}$$

in which V_u and b_o are taken at the critical section specified in (b). The ultimate shear stress, v_u, so computed shall not exceed $v_c = 4\phi\sqrt{f_c'}$, unless shear reinforcement is provided in accordance with (d), in which case v_u shall not exceed $6\phi\sqrt{f_c'}$.

(d) When v_u exceeds $4\phi\sqrt{f_c'}$, shear reinforcement shall be provided in accordance with Sections 1702 to 1706, except that the design yield strength, f_y, for the shear reinforcement shall be 50 percent of that prescribed in Section 1505(b). Shear reinforcement consisting of bars, rods or wires shall not be considered effective in members with a total thickness of less than 10 in.

1708—Lightweight aggregate concretes

(a) When structural lightweight aggregate concretes are used, the provisions of this chapter shall apply with the following modifications:

1. The limiting value for v_c in Section 1701(c) shall be:

$$0.3\phi F_{sp}\sqrt{f_c'} \quad \text{(17-8)}$$

2. Eq. (17-2) shall be replaced by:

$$v_c = \phi\left(0.28F_{sp}\sqrt{f_c'} + 2500\,\frac{p_w V d}{M}\right) \quad \text{(17-9)}$$

3. The limiting value for shearing stress in slabs and footings, v_u, in Sections 1707(c) and (d) shall be:

$$0.6\phi F_{sp}\sqrt{f_c'} \quad \text{(17-10)}$$

(b) The value of F_{sp} shall be 4.0 unless determined for the particular aggregate in accordance with Section 505.