CODE

9.6.3.4 If shear reinforcement is required and torsional effects can be neglected according to 9.5.4.1, $A_{v,min}$ shall be in accordance with Table 9.6.3.4.

Table 9.6.3.4—Required $A_{v,min}$

Beam type	$A_{v,min}/s$			
Nonprestressed and prestressed with $A_{ps}f_{se} < 0.4(A_{ps}f_{pu} + A_sf_y)$	Greater of:	$0.062\sqrt{f_c'}\dfrac{b_w}{f_{yt}}$		(a)
		$0.35\dfrac{b_w}{f_{yt}}$		(b)
Prestressed with $A_{ps}f_{se} \geq 0.4(A_{ps}f_{pu} + A_sf_y)$	Lesser of:	Greater of:	$0.062\sqrt{f_c'}\dfrac{b_w}{f_{yt}}$	(c)
			$0.35\dfrac{b_w}{f_{yt}}$	(d)
		$\dfrac{A_{ps}f_{pu}}{80f_{yt}d}\sqrt{\dfrac{d}{b_w}}$		(e)

9.6.4 *Minimum torsional reinforcement*

9.6.4.1 A minimum area of torsional reinforcement shall be provided in all regions where $T_u \geq \phi T_{th}$ in accordance with 22.7.

9.6.4.2 If torsional reinforcement is required, minimum transverse reinforcement $(A_v + 2A_t)_{min}/s$ shall be the greater of (a) and (b):

(a) $0.062\sqrt{f_c'}\dfrac{b_w}{f_{yt}}$

(b) $0.35\dfrac{b_w}{f_{yt}}$

9.6.4.3 If torsional reinforcement is required, minimum area of longitudinal reinforcement $A_{\ell,min}$ shall be the lesser of (a) and (b):

(a) $\dfrac{0.42\sqrt{f_c'}A_{cp}}{f_y} - \left(\dfrac{A_t}{s}\right)p_h\dfrac{f_{yt}}{f_y}$

(b) $\dfrac{0.42\sqrt{f_c'}A_{cp}}{f_y} - \left(\dfrac{0.175b_w}{f_{yt}}\right)p_h\dfrac{f_{yt}}{f_y}$

COMMENTARY

R9.6.3.4 Tests (Roller and Russell 1990) have indicated the need to increase the minimum area of shear reinforcement as the concrete strength increases to prevent sudden shear failures when inclined cracking occurs. Therefore, expressions (a) and (c) in Table 9.6.3.4 provide for a gradual increase in the minimum area of transverse reinforcement with increasing concrete strength. Expressions (b) and (d) in Table 9.6.3.4 provide for a minimum area of transverse reinforcement independent of concrete strength and govern for concrete strengths less than 30 MPa.

Tests (Olesen et al. 1967) of prestressed beams with minimum web reinforcement based on 9.6.3.4 indicate that the lesser of $A_{v,min}$ from expressions (c) and (e) is sufficient to develop ductile behavior. Expression (e) is discussed in Olesen et al. (1967).

R9.6.4 *Minimum torsional reinforcement*

R9.6.4.2 The differences in the definitions of A_v and A_t should be noted: A_v is the area of two legs of a closed stirrup, whereas A_t is the area of only one leg of a closed stirrup. If a stirrup group has more than two legs, only the legs adjacent to the sides of the beam are considered, as discussed in R9.5.4.3.

Tests (Roller and Russell 1990) of high-strength reinforced concrete beams have indicated the need to increase the minimum area of shear reinforcement to prevent shear failures when inclined cracking occurs. Although there are a limited number of tests of high-strength concrete beams in torsion, the equation for the minimum area of transverse closed stirrups has been made consistent with calculations required for minimum shear reinforcement.

R9.6.4.3 Under combined torsion and shear, the torsional cracking moment decreases with applied shear, which leads to a reduction in torsional reinforcement required to prevent brittle failure immediately after cracking. When subjected to pure torsion, reinforced concrete beam specimens with less than 1 percent torsional reinforcement by volume have failed at first torsional cracking (MacGregor and Ghoneim 1995). Equation 9.6.4.3(a) is based on a 2:1 ratio of torsion stress to shear stress and results in a torsional reinforcement volumetric ratio of approximately 0.5 percent (Hsu 1968). Tests of prestressed concrete beams have shown that a similar amount of longitudinal reinforcement is required.