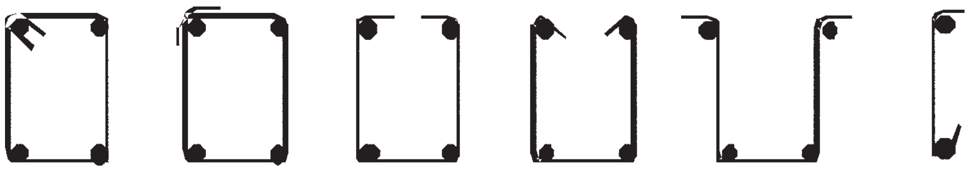

Fig. 8.5.2a—Typical stirrup shapes for girders and beams.

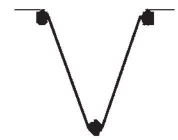

Fig. 8.5.2b—Typical stirrup shape for joists, in addition to Fig. 8.5.2a.

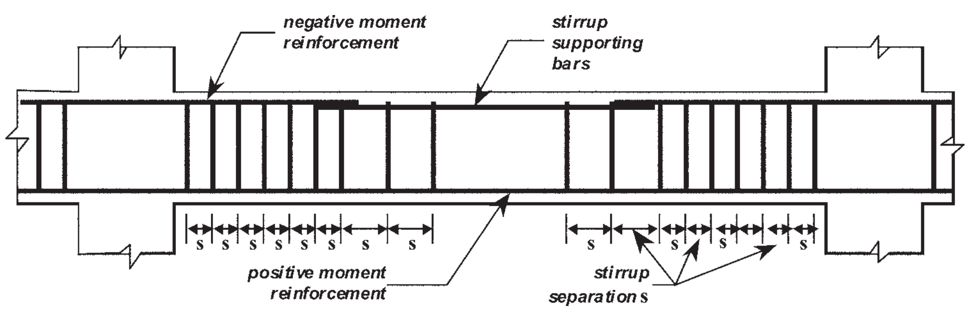

Fig. 8.5.3—Typical stirrup spacing along the girder, beam, or joist.

negative moment reinforcement cutoff points should be based on the longer span.

8.4.15.4 *Reinforcement splicing*—Negative moment reinforcement between cutoff point and the support should not be lap spliced.

8.4.15.5 *End anchorage*—Negative moment reinforcement at the end of a girder, beam, or joist should end in a standard hook at the far edge of the supporting girder, beam, column, or reinforced concrete wall, complying with anchorage distance described by 5.8.3. At the external edge of cantilevers, negative moment reinforcement should end in a standard hook.

8.4.15.6 *Stirrup support*—In areas where no negative reinforcement is needed, top bars should be provided for attachment and anchorage of stirrups. The diameter of these top bars should be equal to or greater than the stirrup bar diameter. Minimum lap length of these top bars should be 6 in. (150 mm).

8.5—Transverse reinforcement

8.5.1 *Description*—Transverse reinforcement for girders, beams, and joists should consist of stirrups that enclose the longitudinal reinforcement and are placed perpendicular to the longitudinal axis of the member at varying intervals.

The main functions for transverse reinforcement in girders, beams, and joists are:

(a) Contribute to member shear strength;

(b) Provide lateral support for longitudinal reinforcement subjected to compression stresses;

(c) Act as hanger reinforcement in girders, supporting beams, and joists;

(d) Contribute to member torsion strength; and

(e) Provide confinement to the concrete in seismic zones at selected locations within the member.

8.5.2 *Stirrup shape*—A stirrup should consist of single or multiple vertical legs. Each vertical leg should engage a longitudinal bar either by bending around it when the stirrup continues or by using a standard stirrup hook (5.6) to surround the longitudinal bar at the stirrup end (Fig. 8.5.2a and 8.5.2b).

8.5.2.1 *Permitted stirrup shape for girders and beams*—All stirrups in girders and beams should be closed stirrups with 135-degree hooks, as shown in Fig. 8.5.2a(a). The other stirrup shapes are in common use but are shown to clarify that they are not to be used with this guide. In seismic areas, the stirrup shape is further limited.

8.5.2.2 *Permitted stirrup shape for joists*—All stirrup types shown in Fig. 8.5.2a and 8.5.2b may be used in joists.

8.5.2.3 *Minimum clear spacing between stirrups legs*—In girders, beams, and joists, the minimum clear space between stirrups or parallel legs in a stirrup should be 1 in. (25 mm).

8.5.2.4 *Stirrup support*—Stirrups should be attached to longitudinal bars so that stirrups do not displace during concrete placement (8.4.15.6).

8.5.2.5 *Stirrup leg splicing*—Stirrup bars should not be lap spliced.

8.5.3 *Location of transverse reinforcement*—Stirrup spacing intervals *s* should comply with 8.5.4.5 (Fig. 8.5.3).

8.5.4 *Contribution of transverse reinforcement to shear strength*

8.5.4.1 *General*—Beam-action shear accompanies flexural moments and occurs in girders, beams, and joists along their length, and is of greater magnitude in the vicinity of supports and concentrated loads.

Table 8.5.4.5—Shear reinforcement in girders, beams, and joists: maximum spacing *s*

Value of factored required shear strength V_u	Limiting value of ϕV_s	Minimum area of shear reinforcement A_v within a distance s	Maximum spacing s
$\frac{\phi V_c}{2} > V_u$		Not needed	
$\phi V_c > V_u \ge \frac{\phi V_c}{2}$		$A_v = 0.75\sqrt{f'_c}\frac{b_w s}{f_{yt}}$ $\left[A_v = 0.062\sqrt{f'_c}\frac{b_w s}{f_{yt}} \text{ (SI)}\right]$	$s \le \text{min. of} \begin{cases} d/2 \\ 24 \text{ in. (600 mm)} \end{cases}$
$V_u \ge \phi V_c$	$2\phi V_c > \phi V_s$	$A_v = \frac{(V_u - \phi V_c)s}{\phi f_{yt} d}$	$s \le \text{min. of} \begin{cases} d/2 \\ 24 \text{ in. (600 mm)} \\ A_v f_{yt}/(50 b_w) \\ [A_v f_{yt}/(0.35 b_w) \text{ (SI)}] \end{cases}$
	$4\phi V_c > \phi V_s > 2\phi V_c$	$A_v = \frac{(V_u - \phi V_c)s}{\phi f_{yt} d}$	$s \le \text{min. of} \begin{cases} d/4 \\ 12 \text{ in. (300 mm)} \\ A_v f_{yt}/(50 b_w) \\ [A_v f_{yt}/(0.35 b_w) \text{ (SI)}] \end{cases}$
	$\phi V_s \ge 4\phi V_c$	Not permitted	

8.5.4.2 *Design shear strength*—Design shear strength ϕV_n of a girder, beam, or joist section should be computed following the procedure in 5.13.4 for beam-action shear as:

$$\phi V_n = \phi(V_c + V_s) \tag{8.5.4.2}$$

where ϕV_c is the concrete contribution to the design shear strength; ϕV_s is the shear reinforcement contribution to the design shear strength; and $\phi = 0.75$.

8.5.4.3 *Contribution of concrete to shear strength*—At each location to be investigated (Fig. 8.5.4.3), the concrete contribution of the web of the girder, beam, or joist should be taken into account (Fig. 8.5.3) and should be computed using Eq. (8.5.4.3), with $\phi = 0.75$.

$$\phi V_c = \phi 2\sqrt{f'_c} b_w d \quad \left[\phi V_c = \phi 0.17\sqrt{f'_c} b_w d \text{ (SI)}\right] \tag{8.5.4.3}$$

8.5.4.4 *Contribution of transverse reinforcement to shear strength*—For reinforcement perpendicular to the member axis, its contribution to design shear strength should be:

$$\phi V_s = \phi \frac{A_v f_{yt} d}{s} \tag{8.5.4.4a}$$

where A_v is the area of shear reinforcement perpendicular to the member axis (the stirrup bar area A_b multiplied by the number of vertical stirrup legs) within a distance s; f_{yt} is the yield strength of the shear reinforcement steel; and $\phi = 0.75$.

Reinforcement contribution to the design shear strength should not be taken greater than:

$$\phi V_s \le \phi 8\sqrt{f'_c} b_w d = 4\phi V_c \quad \left[\phi V_s \le \phi 0.66\sqrt{f'_c} b_w d = 4\phi V_c \text{ (SI)}\right] \tag{8.5.4.4b}$$

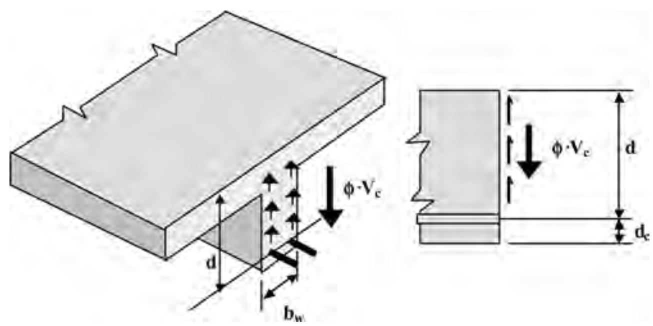

Fig. 8.5.4.3—Contribution of concrete to beam-action shear strength in girders, beams, and joists.

8.5.4.5 *Design of shear reinforcement*—Shear reinforcement in girders, beams, and joists should be provided using stirrups perpendicular to the member axis with a maximum spacing s, measured along member axis:

(a) Where the factored shear V_u is less than $\phi V_c/2$, the use of shear reinforcement may be waived;

(b) Where V_u exceeds $\phi V_c/2$ and is less than ϕV_c, a minimum area of shear reinforcement should be provided as specified by Eq. (8.5.4.5). The spacing s along the member axis should not exceed the smaller of $d/2$ and 24 in. (600 mm) (Fig. 8.5.4.5).

$$A_v = 0.75\sqrt{f'_c}\frac{b_w s}{f_{yt}} \quad \left[A_v = 0.062\sqrt{f'_c}\frac{b_w s}{f_{yt}} \text{ (SI)}\right] \tag{8.5.4.5}$$

where A_v is A_b multiplied by the number of stirrup legs; and

(c) Where V_u exceeds ϕV_c, the difference $(V_u - \phi V_c)$ should be provided for by shear reinforcement, using Eq. (8.5.4.3) and (8.5.4.4a), and the limitations (1) through (4) should apply (Table 8.5.4.5):

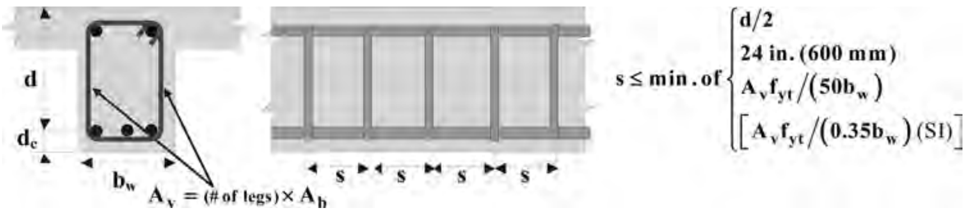

Fig. 8.5.4.5—Minimum shear reinforcement in girders, beams, and joists when ($\phi V_c/2 \le V_u < \phi V_c$).

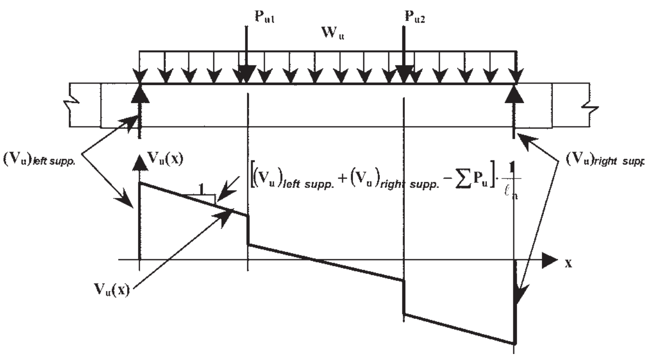

Fig. 8.5.4.6—Calculation of the shear diagram of a girder, beam, or joist.

(1) Minimum shear reinforcement area should not be less than that determined using Eq. (8.5.4.5);

(2) Where the value of ϕV_s, calculated using Eq. (8.5.4.4a), is less than $2\phi V_c$, the spacing limits of (b) should be used;

(3) Where the value of ϕV_s, calculated using Eq. (8.5.4.4a), is greater than $2\phi V_c$, spacing limits should be half the values specified in (b); and

(4) The value of ϕV_s, calculated using Eq. (8.5.4.4a), should not be taken greater than $4\phi V_c$.

8.5.4.6 *Shear diagram*—The value of V_u at the support face should be determined in conformance with 8.6 or 8.7. A diagram showing the shear variation within the span should be constructed, with the value of V_u at the left support face taken as positive. The shear from this point proceeding to the right should be decreased at a rate equal to:

$$\frac{\left[(V_u)_{\text{left supp.}} + (V_u)_{\text{right supp.}} - \sum P_u\right]}{\ell_n} \quad (8.5.4.6)$$

where ΣP_u corresponds to the sum of all factored concentrated loads on the span. At the point where a concentrated load is applied, the value of P_u should be subtracted from the value of shear at the left of the load point. For beams with point loads, proceeding to the right, at the face of the right support, the negative value of V_u is reached (Fig. 8.5.4.6). At all sections within the span, the value of ϕV_n, as determined from Eq. (8.5.4.2), should be equal to or greater than the absolute value of $V_u(x)$, as shown in Fig. 8.5.4.6.

Limits for ϕV_n, as defined in Table 8.5.4.5, should be marked in the shear diagram, and stirrup spacing s should be defined for different regions within the shear diagram. The first stirrup should be placed not further than $s/2$ from the face of the supporting member, with s being the stirrup spacing at the support. The minimum stirrup spacing should comply with 8.5.2.3. If the computed s is less than 2 in. (50 mm), using stirrups with more vertical legs or a larger bar diameter should be investigated.

8.5.5 *Hanger stirrups*—Where a beam is supported by a girder of similar depth, hanger reinforcement should be provided in the joint. The reaction from the supported beam tends to push down the bottom of the supporting girder. This reaction should be resisted by hanger reinforcement in the form of closed stirrups placed in both members. Hanger stirrups are in addition to stirrups needed for shear (Fig. 8.5.5) and should comply with 8.5.5.1 and 8.5.5.2.

8.5.5.1 *Hanger stirrup area:*

(a) Provide hanger stirrups where V_u from the supported beam at the interface is equal to or greater than $\phi 3\sqrt{f_c'}b_w d$ $\left[\phi 0.25\sqrt{f_c'}b_w d\right]$, where $\phi = 0.75$;

(b) Provide hanger stirrups where h_b is equal to or less than one-half the total depth of the supporting girder, where h_b is the vertical dimension from the bottom of the supporting girder to the bottom of the supported beam (Fig. 8.5.5);

(c) The area of hanger reinforcement, A_i, should be determined from Eq. (8.5.5.1):

$$A_i \ge \frac{\left[1-(h_b/h_g)\right]V_u}{\phi f_{yt}} \quad (8.5.5.1)$$

where V_u is the beam factored shear at the support face; A_i is the total area of hanger stirrups; h_g is the girder height; f_{yt} is the stirrup specified yield strength; and $\phi = 0.75$.

8.5.5.2 *Hanger stirrup placement*—At least two-thirds of A_i should be evenly distributed within the supported beam width b_w, plus h_b at each side. The remaining area of hanger stirrups, not more than one-third of A_i, should be evenly distributed within $d/4$ from the supporting girder face, where d is the supported beam effective depth. Beam bottom longitudinal bars should be placed above the girder bottom longitudinal bars.

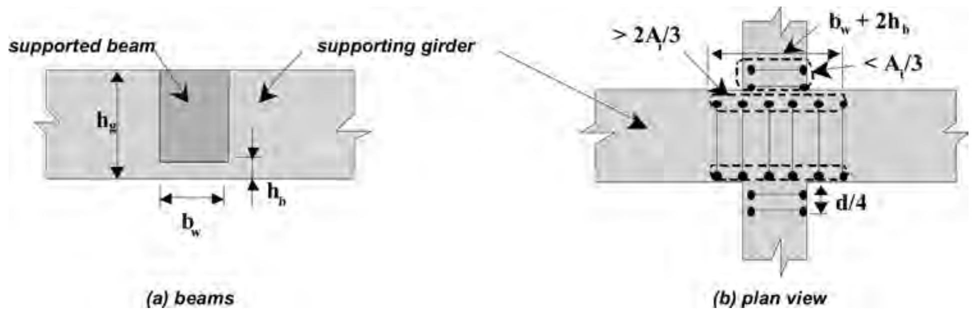

Fig. 8.5.5—Hanger reinforcement.

8.6—Joists and beams supported by girders

8.6.1 *General*—Section 8.6 applies to joists and beams, monolithic with and supported by girders. Two-way joist systems or waffle-on-beams systems as described in 6.1.3.3 should also comply with 8.6. Waffle-slab systems without beams spanning between columns as described in 6.1.4.4 should be designed using Chapter 9 for slab-column systems.

8.6.2 *Dimensional limits*

8.6.2.1 *Joists*—In addition to Chapter 8, joists should comply with the dimensional limits of 1.3 and the restrictions of 6.1.3.1. Ducts, shafts, and openings should comply with 6.8. Minimum depth should comply with 6.5.3 for one-way joists and 6.5.4 for two-way joists.

8.6.2.2 *Beams*—In addition to Chapter 8, beams supported by girders should comply with the dimensional limits of 1.3 and the restrictions of 6.1.2. Ducts, shafts, and openings should comply with 6.8. Minimum depth should comply with 6.5.3. Beam web width b_w should not be less than 8 in. (200 mm). Maximum spacing between lateral supports of isolated beams should be 50 times the least width b of the compression flange.

8.6.2.3 *Cantilevers*—All cantilevers of joists or beams should be continuous with at least one interior span. A double cantilever without an interior span is not permitted.

8.6.3 *Required moment strength*

8.6.3.1 *Cantilevers*—The factored negative moment M_u (required moment strength) for beam and joist cantilevers supported by girders, beams, or reinforced concrete walls should be calculated using Eq. (8.6.3.1), assuming:

(a) One-half of the distributed factored load W_u acts as a concentrated load at the cantilever tip along with all concentrated loads that act on the cantilever span ΣP_u; and

(b) One-half W_u acts as uniformly distributed load over the full span.

$$M_u^- = \frac{3W_u\ell_n^2}{4} + \ell_n \sum P_u \qquad (8.6.3.1)$$

The cantilever required negative moment strength at the support should equal or exceed the maximum negative factored moment at the first interior support and one-third the positive factored moment of the first interior span.

8.6.3.2 *Single-span joists and beams supported by beams, girders, or reinforced concrete walls*—Factored positive and negative moment M_u (required moment strength) for single-span beams and single-span one-way joists should be calculated using Table 8.6.3.2, where ΣP_u is the sum of all factored concentrated loads that act on the span.

Table 8.6.3.2—Factored moment for single-span beams and joists

Positive moment: $$M_u^+ = \frac{W_u\ell_n^2}{8} + \frac{\ell_n}{4}\sum P_u$$	(8.6.3.2a)
Negative moment at supports: $$M_u^- = \frac{W_u\ell_n^2}{24} + \frac{\ell_n}{16}\sum P_u$$	(8.6.3.2b)

8.6.3.3 *Multi-span joists and beams supported by beams, girders, or walls*—Factored positive and negative moment M_u (required moment strength) for beams and one-way joists, with two or more spans, supported by beams, girders, or reinforced concrete walls, should be calculated using Table 8.6.3.3, where ΣP_u is the sum of all factored concentrated loads that act on the span.

8.6.3.4 *Use of frame analysis*—Frame analysis, which meets 8.1.2, may be used to determine factored moments and shears as a substitute for values in 8.6.3.1 to 8.6.3.3.

8.6.3.5 *Two-way joists supported by beams, girders, or walls*—Required moment strength for two-way joists supported by beams, girders, or structural walls may be obtained using 7.9.1 and 7.9.2, ignoring the minimum depth of the supporting beams or girders as given by 7.9.1(c) and 6.1.3.3.

8.6.4 *Required shear strength*

8.6.4.1 *Cantilevers of joists and beams supported by beams, girders, or walls*—Factored shear V_u at the cantilever support should be calculated using Eq. (8.6.4.1):

$$V_u = W_u\ell_n + \sum P_u \qquad (8.6.4.1)$$

where ΣP_u is the sum of all factored concentrated loads that act on the span.

8.6.4.2 *Single-span joists and beams supported by beams, girders, or walls*—Factored shear V_u for single-span beams and single-span one-way joists should be calculated using Eq. (8.6.4.2):