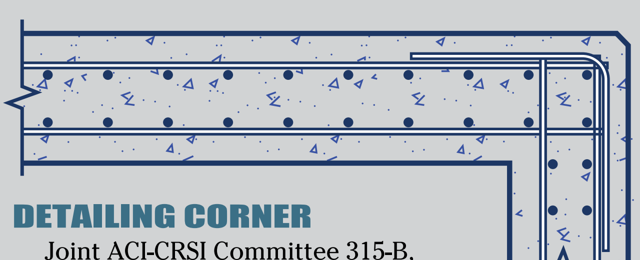
# Wide Beam Stirrup Configurations

As beam-slab floor systems become shallower, wide reinforced concrete beams are being used to directly carry applied loads or serve as transfer girders in the framing scheme. Making beams wider than the column width is also a key constructibility concept to avoid interference between longitudinal beam corner bars and column corner bars. In this discussion, a wide reinforced concrete beam has a width $b_w$ that exceeds its effective depth $d$.

A wide beam will likely have a number of longitudinal tension reinforcing bars distributed across the cross section.



## DETAILING CORNER

Joint ACI-CRSI Committee 315-B, Details of Concrete Reinforcement-Constructibility, has developed forums dealing with constructibility issues for reinforced concrete. To assist the Committee with disseminating this information, staff at the Concrete Reinforcing Steel Institute (CRSI) are presenting these topics in a regular series of articles. If you have a detailing question you would like to see covered in a future article, please send an e-mail to Neal Anderson, CRSI's Vice President of Engineering, at nanderson@crsi.org with the subject line "Detailing Corner."

Wide beams can also have high shear demands, necessitating the use of stirrups to contribute to the shear capacity. Proper stirrup detailing in these members is imperative to ensure that the distributed longitudinal flexure reinforcement and stirrups are fully effective and behave efficiently.

Wide beam shear behavior has been investigated by Leonhardt and Walther;[1] Anderson and Ramirez;[2] and Lubell, Bentz, and Collins.[3] These studies have shown that locating the stirrups solely around the perimeter of the beam core is not efficient in beams under high shear demand. When viewed as a truss, the internal diagonal compressive struts need to be equilibrated at the internal truss joints. This requires a vertical stirrup leg in close proximity to an internal longitudinal bar used to resist flexure.

Based on previous and current test results, Lubell, Bentz, and Collins summarized some simple design guidelines for transverse spacing of vertical stirrup legs in a wide beam:

- Transverse stirrup leg spacing $s_w$ should be the lesser of $d$ or 24 in. (600 mm); but
- The governing $s_w$ should be halved when the nominal shear strength $V_n$ exceeds $5\sqrt{f_c'}b_wd$ lb ($0.42\sqrt{f_c'}b_wd$ N), where $f_c'$ is the specified concrete strength in psi (MPa).

Figure 1, which is a reproduction of Fig. 10 from Reference 3, illustrates how large transverse stirrup leg spacing can significantly reduce the full shear capacity of a wide beam. When the stirrup legs are concentrated around the perimeter of the wide beam, the shear capacity is reduced, as the shear forces in the beam interior must propagate to the beam exterior to be equilibrated by the vertical stirrup legs.

## DESIGN TO FABRICATION

Nesting vertical stirrup legs in a wide beam interior is clearly good detailing practice to ensure this shear

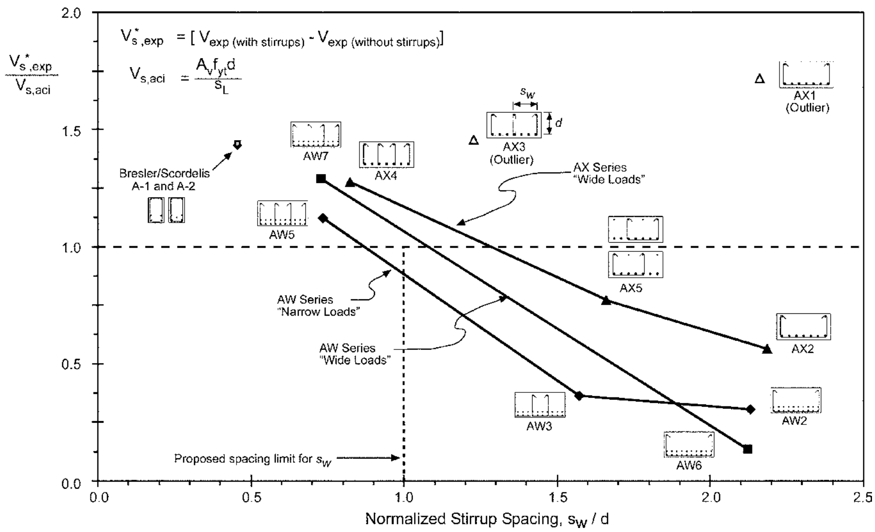



**Fig. 1: Influence of transverse stirrup leg spacing on the shear capacity.[3] Beams with perimeter stirrups only (as shown in the lower right portion of the plot) have capacities that are well below the strengths calculated using ACI 318-08, while beams with well-distributed stirrup legs (as shown in the upper left portion of the plot) have shear capacities exceeding values calculated using ACI 318-08**

behavior, but detailing of the separate stirrup components can be a fabrication nightmare if done improperly—the stirrup detail must be buildable. When designing stirrups in beams of various widths and depths, the configuration of the stirrups can either simplify or hinder the placement of the reinforcing steel. With the growing trend of using preassembled beam reinforcement, compliance with required concrete cover and ease of placement needs to be addressed at the design level. Figure 2 shows a commonly used stirrup configuration for a wide beam. While it's simple for the designer to specify three closed stirrups with evenly spaced legs in the beam stirrup set, such a configuration presents two problems:

- No stirrup is the full net width of the beam (gross beam width minus concrete cover on each side). This forces the reinforcing bar placer to measure the overall width of the stirrup set and make sure the stirrups are securely assembled to maintain the necessary width. Preassembly of the beam cage and hoisting with a crane may cause the net width to change slightly, increasing the risk of inadequate side concrete cover; and
- If wide beam reinforcement is "stick-built" in place, the closed, one-piece stirrups make it difficult to place all of the reinforcing steel into the beam. Long, large size longitudinal bars are especially difficult to maneuver into the stirrups, so productivity is significantly reduced.

## ALTERNATE CONFIGURATIONS

Figures 3 and 4 show two examples of suitable alternate designs that will ease reinforcing bar placement for either preassembly or in-place installation. In both cases, a large, open stirrup is detailed to the full net width within the beam, and a stirrup cap—a top horizontal bar with a 135-degree stirrup hook at one end and a 90-degree stirrup hook at the other—will close the detail. The full-width stirrup will help maintain the correct concrete cover and ease installation after preassembly. Moreover, this full-width, closed stirrup configuration is important if the wide beam is subjected to significant torsional forces; the perimeter stirrup detail confines the beam core, but more importantly, it confines the corner bars. ACI 318-08,[4] Section 11.5.4, gives additional information on torsional reinforcement detailing.

To facilitate the interior stirrup leg placement, two configurations can be contemplated. Both configurations will allow the aforementioned recommended transverse stirrup leg spacing to be maintained. Figure 3 shows a U-stirrup pair with identical dimensions and 135-degree hooks. This configuration simplifies the detail by limiting the stirrup piece types required on the job site. Figure 4 shows a smaller-width hooked U-stirrup nested in a larger-width hooked U-stirrup in the beam interior. With the open-top design of the stirrups, the placer can load all of the longitudinal reinforcing bars from the top and avoid tedious maneuvering of the bars. After the longitudinal bars have been installed, the stirrup cap can be installed to create closed stirrup configurations.

## REVIEW OF CODE REQUIREMENTS

For the benefit of the designer, the following is a list of important ACI 318 requirements concerning beam stirrup configurations:

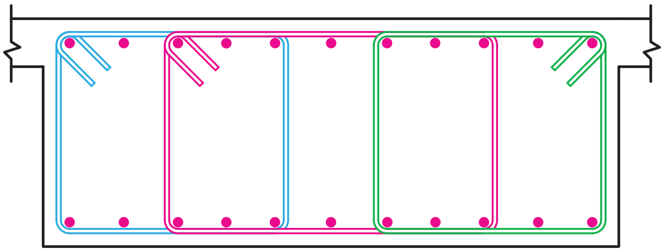


**Fig. 2: Beam stirrup configuration with three closed stirrups distributed across the beam width**

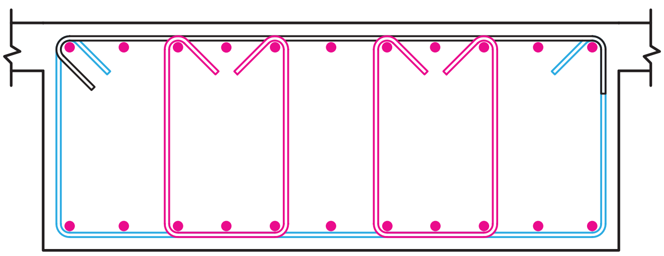


**Fig. 3: An alternate configuration consisting of a single U-stirrup (with 135-degree hooks) across the net width of the beam, two identical U-stirrups (each with 135-degree hooks) distributed across the beam interior, and a stirrup cap**

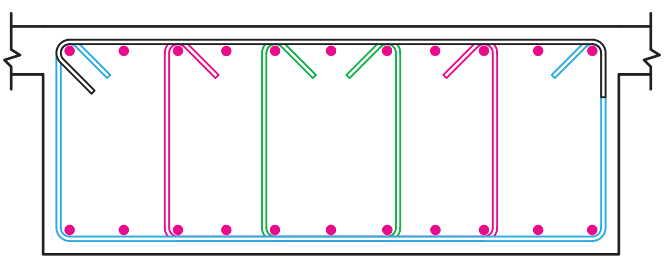


**Fig. 4: A second alternate configuration consisting of a single U-stirrup across the net width of the beam, two smaller-width U-stirrups nested in the beam interior, and a stirrup cap**

- Transverse reinforcement for perimeter beams and beams with torsion must be closed, one-piece or closed, two-piece stirrups (Sections 7.13.2.3 and 11.5.4.1);
- Transverse reinforcement must be as close to the compression and tension surfaces of the beam as concrete cover requirements and proximity of other reinforcement permits (Section 12.13.1);
- Ends of stirrup caps and U-shaped stirrups must be anchored with a standard hook around a longitudinal bar (Section 12.13.2.1). No. 6, 7, and 8 (No. 19, 22, and 25) stirrups with yield strengths exceeding 40 ksi (280 MPa) must also have a minimum embedment between the midheight of the beam and the outside end of the hook (Section 12.13.2.2 defines the embedment);
- Between anchored ends of a stirrup, each bend in the stirrup must enclose a longitudinal bar (Section 12.13.3);
- Pairs of U-stirrups or ties (in either case, with no end hooks) can be placed to form a closed unit, but they must have minimum laps of 130% of the bar development length, or the bars must meet certain size and strength restrictions and the splices must extend over the full available depth of the member (Section 12.13.5);
- When hoops are required for confinement, every corner and alternate longitudinal bar on the perimeter of the section must have lateral support provided by a corner of a stirrup or tie. Additional restrictions are placed on the tie configuration and spacing (Sections 7.10.5.3 and 21.5.3.3); and
- A seismic hoop can comprise a U-stirrup with seismic hooks closed by a top crosstie (in effect, a stirrup cap with a minimum 3 in. [76 mm] extension on the 135-degree hook). Consecutive crossties must have their 90-degree hooks at opposite sides of the beam. If there is a slab on only one side of the beam, then the 90-degree hooks must be placed on that side (Section 21.5.3.6).

## SUMMARY

Wherever possible, the designer should use beam stirrup configurations with a large outer stirrup. The large outer stirrup will allow the side concrete cover to be maintained, and the open, two-piece configuration will allow accurate and efficient installation of the longitudinal reinforcing bars. A separate stirrup cap can be used where needed for torsion or confinement.

*Thanks to Joint ACI-CRSI Committee 315 member Greg Birley and Neal Anderson of CRSI for providing the information in this article.*

Selected for reader interest by the editors.

## References

1. Leonhardt, F., and Walther, R., “The Stuttgart Shear Tests 1961,” *Translation* No. 111, Cement and Concrete Association (CCA), London, UK, 1964, 134 pp.

2. Anderson, N.S., and Ramirez, J.A., “Detailing of Stirrup Reinforcement,” *ACI Structural Journal*, V. 86, No. 5, Sept.-Oct. 1989, pp. 507-515.

3. Lubell, A.S.; Bentz, E.C.; and Collins, M.P., “Shear Reinforcement Spacing in Wide Members,” *ACI Structural Journal*, V. 106, No. 2, Mar.-Apr. 2009, pp. 205-214.

4. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary,” American Concrete Institute, Farmington Hills, MI, 473 pp.