RFIs on Circular Ties, Rotating Hooks, Staggered Lap Splices, and Closure Strips

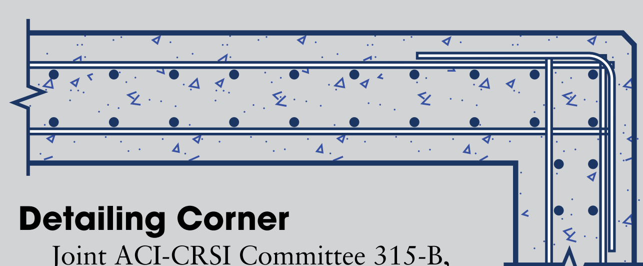
RFIs 11-05, 11-06, 11-07, 11-08, and 11-09

In this month's "Detailing Corner," CRSI staff responds to some outstanding requests for information (RFIs) submitted by reinforcing bar detailers, structural engineers, and construction engineers. We thank those who contacted us and encourage all readers to participate in this forum.

RFI 11-05: Construction details for drilled shafts commonly show the ends of circular ties hooked around a single vertical bar (Fig. 1(a)). Bar placement is slowed because a longitudinal bar must be threaded through the two hooks. We typically resolve this problem by estimating and detailing circular ties with ends partially lapped and hooked around two separate vertical bars (Fig. 1(b)). The longitudinal bar placement is simplified because threading isn't required. Also, because the alternate detail provides a short lap splice in addition to the hooked anchorages, we believe it is superior to the common detail. We were therefore surprised when, on a recent project, the cages assembled using the alternate detail were rejected by the Inspector, the Contractor, and the Engineer—all saying the original detail was better than the alternate we provided. Could you please comment?

Response: The timing of this RFI couldn't be better. Up through ACI 318-08,[1] Section 7.10.5.3 of the Code addressed circular ties with the statement: "Where longitudinal bars are located around the perimeter of a circle, a complete circular tie shall be permitted." A "complete circular tie" was not defined, and explicit requirements for anchorage of discrete circular ties were not provided. However, the commentary to Section 7.10.5 stated:

> Where longitudinal bars are arranged in a circular pattern, only one circular tie per specified spacing is required. This requirement can be satisfied by a



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."

> continuous circular tie (helix) at larger pitch than required for spirals under [Section] 10.9.3, the maximum pitch being equal to the required tie spacing (see also [Section] 7.10.4.3).

Although this commentary didn't provide guidance for discrete circular ties, ACI 315-99[2] provides a Type T3 tie detail (Fig. 1(c)), showing a circular tie with end extensions. The end extensions are sufficient to provide a lap splice, so this is commonly interpreted as a complete circular tie.

In ACI 318-11,[3] a complete circular tie has been explicitly defined with the addition of a new Section 7.10.5.4:

> **7.10.5.4 –** Where longitudinal bars are located around the perimeter of a circle, a complete circular tie shall be permitted. The ends of the circular tie shall overlap by not less than 6 in. (152 mm) and terminate with standard hooks that engage a longitudinal column bar. Overlaps at ends of adjacent circular ties shall be staggered around the perimeter enclosing the longitudinal bars.

The requirements of the new ACI 318 section on circular ties closely match your alternate detail shown in Fig. 1(b). Therefore, your alternate detail should be acceptable, provided the circular tie lap is at least 6 in. (152 mm) and successive circular ties are arranged around the perimeter so that the lap splices are staggered (that is, not engaging the same two longitudinal bars). It's anticipated that ACI 315 will be updated to supplement the Type 3 tie with a tie similar to the Type 3A tie currently used in Canada,[4] as illustrated in Fig. 1(d).

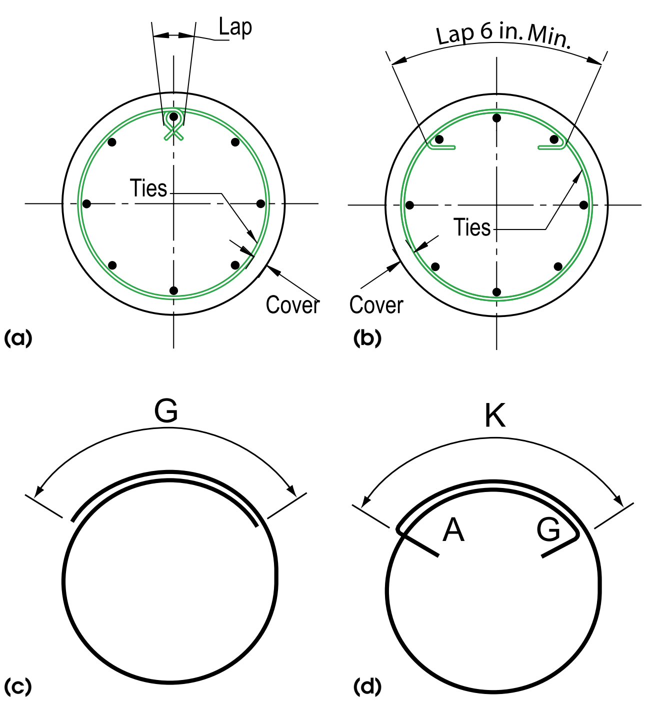


Fig. 1: Construction details for circular ties in drilled shafts: (a) tie hooked around single bar; (b) tie lapped and hooked around separate vertical bars; (c) the Type 3 circular tie detail per Reference 2; and (d) the Type 3A circular tie detail per Reference 4 (1 in. = 25 mm)

RFI 11-06: "Detailing Concrete Columns" (*Concrete International*, V. 33, No. 8, Aug. 2011, pp. 47-53) led to a discussion in our office regarding the required lap splice length for circular ties. As illustrated in Fig. 2, our state DOT office uses a Class B splice modified for the top bar effect and coating. We also require that the splices on alternate circular ties be rotated 90 degrees. Do the ACI or AASHTO codes specifically spell out the lap length requirements?

Response: The response to RFI 11-05 addresses the **new** ACI 318 Code provisions for detailing single, circular tie terminations. While the lap-splice detail you present was commonly considered to comply with previous Code requirements for a complete circular tie, it's not ideal from detailing and structural behavior perspectives, as spalling of the column cover (shell) concrete would be expected to expose the splice regions and eliminate the confining effect of the cover on the splice. The new Code provisions provide a much more positive anchorage. Should the concrete cover spall because of load, damage, or corrosion, the tie will remain effective in confining the longitudinal bars and column core.

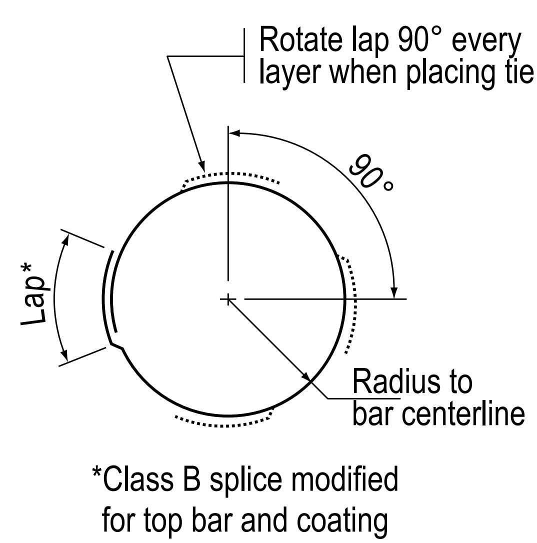


Fig. 2: A standard DOT detail for complete circular ties, adapted from Fig. 6.6.4.1.2.2–1 of Reference 6

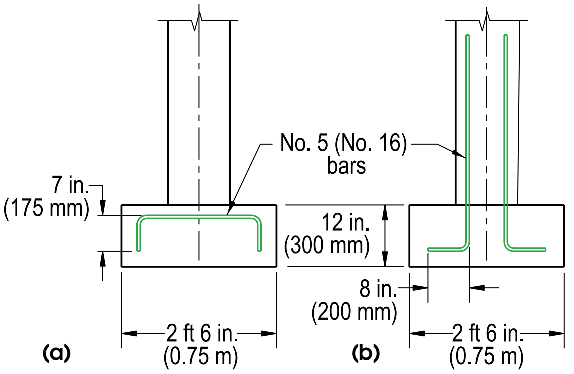
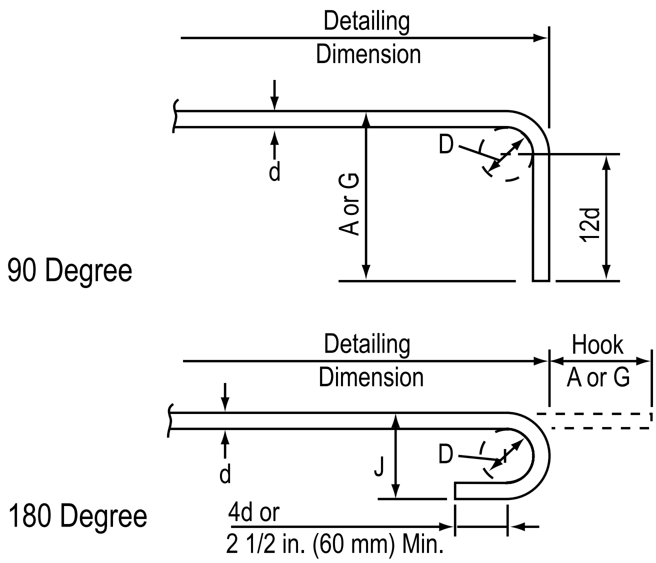


Fig. 3: Because the "A or G" dimension is 10 in. (250 mm) for a No. 5 (No. 16) bar (refer to Fig. 4), the restricted depth provided in this footing will necessitate rotation of the 90-degree hook extensions on: (a) the footing bars; and (b) the column dowels

To our knowledge, the AASHTO LRFD Bridge Design Specifications[5] remain unchanged from your DOT detail (Fig. 2). However, the recent ACI 318 Code hook anchorage modification to the single circular tie pattern provides a better tie detail, which we would recommend adopting given the reasons herein.

RFI 11-07: As a standard practice, we detail 180-degree hooks when a section is too shallow to allow adequate cover or hook extension for 90-degree hooks (Fig. 3). Alternatively, we detail 90-degree hooks with the hooks rotated to reduce the projected length of the hook extensions. Rotating the hooks is easily accomplished on vertical dowels, because the hook extensions are horizontal, and generally rest on and are tied to continuous bars. However, gravity will force the hook extensions for top horizontal bars, such as in slabs or footings, to rotate to the vertical, so each bar extension, if rotated, must be supported with spacers or tied to another "sacrificial" bar. Could you please comment?

Response: Section 12.5 of ACI 318 defines the same development length (ℓ_{dh}) for both 90- and 180-degree standard hooks, so a 180-degree hook can make for a better fit in tight places. As shown in



Bar Size No.	90-Degree Hook "A or G"	180-Degree Hook "J" Dimension	Difference In Width
3	6 in.	3 in.	3 in.
4	8 in.	4 in.	4 in.
5	10 in.	5 in.	5 in.
6	1 ft	6 in.	6 in.
7	1 ft 2 in.	7 in.	7 in.
8	1 ft 4 in.	8 in.	8 in.
9	1 ft 7 in.	11 3/4 in.	7 1/4 in.
10	1 ft 10 in.	1 ft 1 1/4 in.	8 3/4 in.
11	2 ft 0 in.	1 ft 2 3/4 in.	9 1/4 in.
14	2 ft 7 in.	1 ft 9 3/4 in.	9 1/4 in.
18	3 ft 5 in.	2 ft 4 1/2 in.	1 ft 0 1/2 in.

Fig. 4: Differences in widths of standard 90- and 180-degree hooks (1 in. = 25 mm)

Fig. 4, the difference in the widths of the two standard hooks (the "A or G" dimension of the 90-degree hook and the "J" dimension of the 180-degree hook) can vary from 3 in. for a No. 3 bar (75 mm for a No. 10 bar) to 12.5 in. for a No. 18 bar (320 mm for a No. 57 bar).

Note that 180-degree hooks must be embedded in a section with adequate depth to provide proper cover over the hook end. This will likely not govern, but it needs to be checked. For example, if 90-degree hooks are replaced with 180-degree hooks (Fig. 3(b)) on column dowels, the dowels must be embedded deep enough into the footing to allow the hook ends to have the required concrete cover over the projecting tail of the hook. For cases like these, Table 1 provides the minimum embedment for 180-degree hooks to provide 2 in. (50 mm) of concrete cover beyond the hook.

Table 1:
Minimum embedment required to provide 2 in. (50 mm) cover over the tail of a 180-degree standard hook

Bar size no.	Minimum embedment, in.
3	6
4	7
5	7
6	8
7	9
8	10
9	13
10	14
11	16
14	20
18	26

(1 in. = 25 mm)

If switching from a 90-degree hook to a 180-degree hook does not provide the required clearance, then rotating 90-degree hooks can be investigated. Besides the constructibility issues raised in the RFI, it's important to note that there are currently no provisions or guidance on how far hooks can be rotated or tilted without affecting their ability to develop the bars or compromising the performance of the reinforced concrete member itself. As an example, consider a slab with all the top bars at a support terminating in hooks. If all the hooks were rotated 90 degrees with the hooks lying in a single plane, would this arrangement cause a weakened, splitting plane in the concrete and lead to reduced performance? Perhaps.

In an effort to answer this question, research is currently underway to study the effect of rotating hooks. The specific goals of the research project are to:

- Evaluate 90- and 180-degree ACI standard hooks to determine the influence of the hook rotation angle on the development of the bar;
- Study the influence of confinement on the development of rotated hooks; and
- Develop design recommendations for limits of rotating hooks.

This research project is being sponsored by the CRSI Education & Research Foundation with testing being conducted at the Missouri University of Science & Technology.

RFI 11-08: Rather than placing lap splices side-by-side (Fig. 5(a)), we detail staggered laps, as shown in Fig. 5(b). An alternate is shown in Fig. 5(c), where there is a gap between the lap splices. Does the configuration shown in Fig. 5(c) have any advantages over that shown in Fig. 5(b)?

Response: Although there is no general requirement for the staggering of lap splices, ACI 318[3] acknowledges the benefits of staggering by requiring staggered configurations of bars and splices under various conditions, as listed in Table 2.

Although it is allowed, the reinforcing bar layout configuration shown in Fig. 5(b) is not the most ideal. Because the bar ends of successive terminated bars are aligned, there is a strong tendency for a splitting crack to develop in the concrete, coincident with the bar ends. This is illustrated in Fig. 6(a). Transverse reinforcement in this region may provide confinement and help the situation, but providing a gap between the ends of the staggered lap splices is more desirable. The layout condition shown in Fig. 5(c) is better, as the crack width will be narrower if it develops at the bar ends. A condition similar to Fig. 5(c) is shown in Fig. 6(b).

According to Stöckl,[7] the staggering of lap splices in beams (providing a "negative" gap, as shown in Fig. 6(c)) can reduce the width of flexural cracks at the ends of lap splices, provided that the stagger distance is at least one-half the lap splice length. For a Class A lap splice, with the lap splice length ℓ_{dl} equal to tension development length ℓ_d, the minimum stagger would be $0.5\ell_d$. This is illustrated in Fig. 6(c). For a Class B lap splice, with the lap length of $1.3\ell_d$, the minimum stagger would be $0.65\ell_d$. In either case, a closer stagger where the staggered regions overlap (a negative gap) provides the best structural behavior and will be consistent with the recommendations from Reference 7.

As an aside, one needs to be mindful of the various stagger lengths listed in Table 2. Depending on the condition, these lengths are expressed in terms of either bar diameters, dimensions (in. or mm), or ℓ_d.

RFI 11-09: "Closure Strips and Lapped Reinforcement" (*Concrete International*, V. 33, No. 4, Apr. 2011, pp. 49-53) has the following statement on p. 51:

> When determining the required lap splice lengths of the reinforcing bars, it's worth noting ACI 318-08, Section 12.2.5, which permits a reduction in tension development based on the amount of reinforcement required versus the amount of reinforcement provided. (Note: lap splice lengths are multiples of tension development lengths; Class A = $1.0\ell_d$ and Class B = $1.3\ell_d$.) As noted earlier, closure strips are usually placed where moments are small, so the amount of reinforcement in the closure strip could very well be more than is structurally required at that location.

This paragraph is erroneous. Lap splice lengths must not be reduced by invoking ACI 318-08, Section 12.2.5. Section 12.15.1 of ACI 318-08 explicitly excludes the provisions of Section 12.2.5, so a warning against this common mistake would be more appropriate. Perhaps a discussion of this exclusion should be covered in a future "Detailing Corner" article.

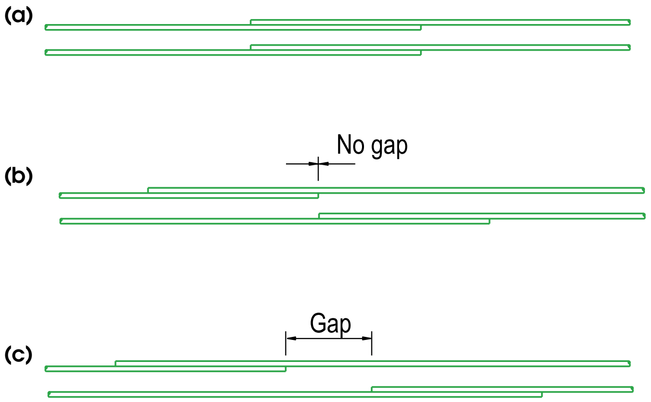


Fig. 5: Lap splice options: (a) aligned; (b) staggered, with no gap; and (c) staggered, with a gap

Table 2: Stagger requirements for splices per ACI 318-11

Condition	Stagger distance
Bars within a bundle (Section 7.6.6.4)	$40d_b$
Mechanical or welded splices that do not meet the 1.25 yield-strength requirement (Section 12.15.5.1)	24 in.
Mechanical or welded splices in tension tie members (Section 12.15.6)	30 in.
Lap splices in columns (Section 12.17.2.2)	ℓ_d
End-bearing splices in columns (Section 12.17.4)	No length specified
Splices of principal tensile reinforcement in shells (Section 19.4.12)	ℓ_d

(1 in. = 25 mm)

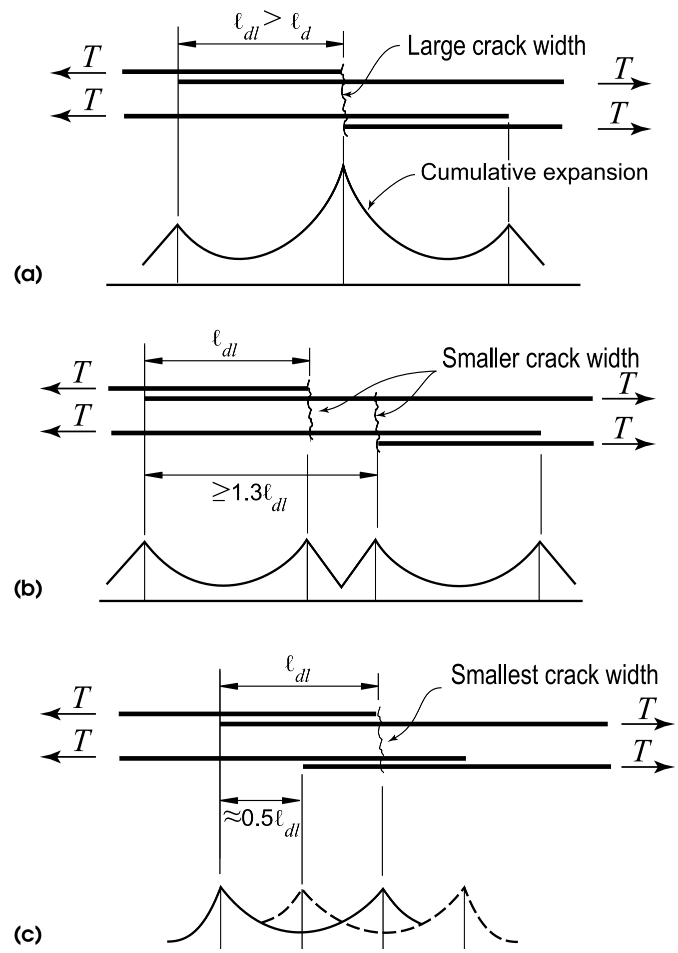


Fig. 6: Crack widths are functions of splice locations: (a) superimposed effects can be adverse, resulting in large crack width even when lap length ℓ_{dl} exceeds tension development length ℓ_d; (b) avoiding superposition reduces crack width; and (c) low superposition results in smallest crack width (based on Reference 7)

Response: You are correct. Section 12.15.1 of ACI 318-08 excludes the modification factor of Section 12.2.5 (Excess Reinforcement) from the calculation of tension lap splice lengths.

Justification for this exclusion is explained in Commentary Section R12.15.1:

> The development length ℓ_d used to obtain lap length should be based on f_y because the splice classifications already reflect any excess reinforcement at the splice location; therefore, the factor from 12.2.5 for excess A_s should not be used.

Accordingly, tension lap splice lengths should be based on the specified yield strength of the reinforcement, f_y, regardless of splice location or demand (stress). Thank you for this correction.

References

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary," American Concrete Institute, Farmington Hills, MI, 2008, 473 pp.
2. ACI Committee 315, "Details and Detailing of Concrete Reinforcement (ACI 315-99)," American Concrete Institute, Farmington Hills, MI, 1999, 44 pp.
3. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary," American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.
4. RSIO, "Reinforcing Steel Manual of Standard Practice," fourth edition, Reinforcing Steel Institute of Canada, Richmond Hill, ON, Canada, 2004, 128 pp.
5. "AASHTO LRFD Bridge Design Specifications, Customary U.S. Units, fifth edition, with 2010 Interim Revisions," American Association of State Highway and Transportation Officials, Washington, DC, 2010, 1822 pp.
6. "LRFD Design Manual," Iowa Department of Transportation, Ames, IA, 2001, p. 6.6:45 (www.iowadot.gov/bridge/manuallrfd.htm)
7. Stöckl, S., "Übergreifungsstöße von zugbeanspruchten Bewehrungsstäben (Lap Splicing of Reinforcing Bars Subject to Tension)," Beton- und Stahlbetonbau, V. 10, Ernst & Sohn, Berlin, Germany, 1972, pp. 229-234. (in German)

Thanks to Amadeus Magpile of Barlines Rebar Estimating and Detailing, Inc., and Neal Anderson of CRSI for providing the information in this article.

Selected for reader interest by the editors.