ACI 318-19 CODE PROVISION CHANGES PERTAINING TO POST-TENSIONED CONCRETE

BY ASIT BAXI

POST-TENSIONING INSTITUTE ®

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The committee work for the ACI 318-19 Code cycle is complete, and the updated Code is currently available. This paper highlights the noteworthy Code provision changes, including a brief background of the changes from the 318-14[1] to the 318-19[2] Code that apply to post-tensioned concrete structures. Users must verify with their local jurisdictions the Code version that applies to their project.

1. Residential Post-Tensioned Slabs on Ground—1.4.7 and R1.4.7 (2014), R1.4.6 and R1.4.8 (2019)

Sections 1.4.7 and R1.4.7 (2014) excludes the design of most slabs-on-ground, specifically residential post-tensioned slabs-on-ground from the 318 Code. Previous editions of the Code commentary have referred the user to the PTI Publications for Design and Construction of Slabs-on-Ground.

- **Reason for Change**: Further clarify the ACI Code provisions and reference documents that apply to the design of post-tensioned residential slabs-on-ground.
- **318-14**: A misinterpretation of the Code language in Section 1.4.7 of 318-14 has been made that all post-tensioned slabs-on-ground, which transmit vertical loads or lateral forces to the soil, in particular slabs on expansive soils, should be designed per ACI 318. It is an inaccurate interpretation, and also not the intent of the Code. The commentary side of R1.4.7 references ACI 360R and PTI DC 10.5-12.[3] The Code specifically references the use of PTI DC 10.5-12 for post-tensioned residential and light commercial slabs on expansive soils.
- **318-19**: The Commentary side in R1.4.7 (318-14) has moved to R1.4.6 to make it consistent with the Code side of 1.4.6, which applies to "one and two-family dwellings, multiple single-family dwellings, townhouses and accessory structures to these dwellings….".
- The 2015 International Building Code[4] requires the design and construction of residential post-tensioned slabs to be in accordance with PTI DC 10.5 -12[3] and hence makes it the governing document for this application. A detailed discussion on this subject can be found in the PTI Tech Note #21, "Exclusion of Post-Tensioned Residential Slabs-on-Ground from ACI 318."[5] For guidance on the design of post-tensioned slabs on non-expansive soils, the Code commentary refers to ACI 360R (R1.4.8). Additional guidance is also available in the updated PTI document PTI DC 10.5 -19.[6]

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2. Terminology: "Prestressing" versus "Prestressed"—throughout the Code

The term "prestressing" was changed to "prestressed" at many locations in the 318-14 Code cycle. This Code change picked up locations that were missed in the previous cycle.

- Reason for Change: Add terms missed in the previous Code cycle.
- 318-14: Definition of terminology
- reinforcement, prestressed—prestressing reinforcement that has been tensioned to impart forces to concrete
- reinforcement, prestressing—high strength reinforcement such as strand, wire, or bar conforming to 20.3.1
- 318-19: Committee picked up locations missed in the previous cycle.

3. Remove Direct Design Method and Equivalent Frame Method—2.2, 6.2.4.1, R6.2.4.1 (2019), 8.2.1, R8.2.1, 8.3.1.1, R8.3.1.1, 8.4.1.2, R8.4.1.2, 8.4.2.1, 8.4.2.2, R8.4.4.2.2 (2019), 8.6.2.3, R8.6.2.3, 8.10 (2014), R8.10 (2014), 8.11 (2014), R8.11 (2014), 13.3.4.2, R13.3.4.2 (2019), 18.4.5.6, and 18.4.5.7

Provisions for the design of two-way slabs using the direct design and equivalent frame method have been present since the 1971 Code. Sections 8.10 and 8.11 in the 318-14 Code, which contain provisions for the direct design and equivalent frame method respectively, have been removed from the 318-19 Code.

- **Reason for Change**: With design professionals increasingly taking advantage of high-powered computers and powerful analytical tools such as the finite element method and other computer methods, the use of these methods has become mainstream. The direct design and equivalent frame methods are well established and discussed in textbooks. The Code has removed the direct design and equivalent frame method provisions in Sections 8.10 and 8.11, respectively, from the Code, directing users to refer to textbooks. The Code, however, does permit the use of both these methods for the design of two-way slabs.

- **318-19**: While these provisions have been removed from the Code, there are quite a few provisions affected by this change creating the chance of an unintended consequence because of this change. Users are encouraged to go back to the 318-14 Code for reference if needed.

4. Improved definition of A_{cf}— 2.2, 8.6.2.3, R8.6.2.3, 8.11.2.2 (2014), and Fig. R8.11.2 (2014)

This provision pertains to the amount of minimum bonded deformed longitudinal reinforcement in the negative moment region at columns in two-way post-tensioned slabs with unbonded and bonded tendons.

- **Reason for Change**: To improve the definition of A_{cf}, and avoid confusion with the term "equivalent frames."
- **318-14**: Definition is "…greater gross cross-sectional area of the slab-beam strips of the two orthogonal equivalent frames intersecting at a column of a two-way slab."
- **318-19**: Definition revised as follows: "greater gross cross-sectional area of the two orthogonal slab-beam strips intersecting at a column of a two-way prestressed slab." Removal of the term "equivalent frames" generalizes the definition and prevents confusion that it only applies to slabs analyzed using the equivalent frame method. This definition applies to any method (including computer methods) used for the analysis of two-way slabs that satisfy Section 6.2.

5. Maximum spacing of deformed reinforcement in Class T and C prestressed one-way slabs with unbonded tendons—7.7.2.3, R7.7.2.3 (2019)

Previous editions of the 318 Code have not placed maximum bar spacing requirements for prestressed one-way slabs with unbonded tendons. Traditionally, the ACI 423.3R[7] report has been used for guidance.

- **Reason for Change**: During the 318-14 Code reorganization, Section 7.7.2.3, which in previous Codes applied only to nonprestressed slabs, was inadvertently changed to include prestressed slabs. This provision was corrected by an erratum in the 318-14 Code to apply only to nonprestressed members and is available on ACI's website.
- The committee reviewed this matter further, and it was determined that Class C and T members (especially with stress ratios of $9\sqrt{f_c'}$ and higher) have a relatively low level of prestress, and require some measure of crack control. Extending spacing requirements for nonprestressed members in 7.7.2.3 was the logical thing to do. A survey of PT design professionals across the country was conducted to gauge current design practice on this subject.
- **318-14**: Code incorrectly applied 7.7.2.3 (3*h* or 18 in. [460 mm] max. spacing requirement) to prestressed concrete members. This was corrected by erratum so that it would apply only to nonprestressed members.
- **318-19**: Code revised to make 7.7.2.3 (3*h* or 18 in. [460 mm] max. spacing required) applicable to Class C and T prestressed one-way slabs with unbonded tendons. A spacing of 4*h* or 24 in. [610 mm] was proposed for Class T members because it has been used successfully by many design professionals (based on the survey mentioned previously). However, the proposed spacing was overruled. The committee ultimately decided to keep the 3*h* or 18 in. (460 mm) max requirement for both Class C and T members.
- Table 1 provides practical spacing options to the design professional for better crack control and overall reduced reinforcing bar quantities.

6. Gravity Shear and Story Drift Limits for Unbonded Post-Tensioned Slab-Column Connections—18.4.5.8, R18.4.5.8, 18.14.5.1, and R18.14.5.1

Section 18.4.5.8 applies to intermediate moment frames with two-way slabs that are part of the seismic-force-resisting system. Section 18.14.5.1 applies to two-way slabs that are not part of the seismic-force-resisting system.

- **Reason for Change**: Laboratory test data (Kang and Wallace[8] and others—refer to R18.4.5.8 and R18.14.5.1) indicate that there is greater lateral drift capacity for unbonded post-tensioned slab-column connections under a given gravity shear load. Hence, increased drift limits have been provided.
- **318-19**: There are now separate gravity shear and lateral drift limits for slab-column connections in nonprestressed and unbonded post-tensioned two-way slabs.

7. ACI 423 Prestress Loss document reference—R20.3.2.6.1

Section 20.3.2.6 covers provisions for prestress losses in prestressed members.

- **Reason for Change**: To replace the current commen-

Table 1—Recommended bar size and spacing options for Class T and C prestressed one-way slabs. Note: 1 in. = 25.4 mm.

Slab – h (in.)	As = 0.002h (in.^{2})	Bar spacing (in.)						$3h$	ACI 318-19 ($3h$ or 18 in.)	Most practical selection options
		#3	No. 4	No. 5	No. 6	No. 7	No. 8			
4	0.096	13.15	25.00	38.75	55.00	75.00	98.75	12.00	12.00	No. 3 @ 12 in.
5	0.12	11.00	20.00	31.00	44.00	60.00	79.00	15.00	15.00	No. 3 @ 10in. or No. 4 @ 15in.
6	0.144	9.17	16.67	25.83	36.67	50.00	65.83	18.00	18.00	No. 3 @ 9in. or No. 4 @ 16in.
7	0.168	7.86	14.29	22.14	31.43	42.86	56.43	21.00	18.00	No. 4 @ 14in.
8	0.192	6.88	12.50	19.38	27.50	37.50	49.38	24.00	18.00	No. 4 @ 12in.
9	0.216	6.11	11.11	17.22	24.44	33.33	43.89	27.00	18.00	No. 4 @ 10in. or No. 5 @ 16in.
10	0.24	5.50	10.00	15.50	22.00	30.00	39.50	30.00	18.00	No. 4 @ 10in. or No. 5 @ 15in.
11	0.265	5.00	9.09	14.09	20.00	27.27	35.91	33.00	18.00	No. 4 @ 9in. or No. 5 @ 14in.
12	0.288	4.58	8.33	12.92	18.33	25.00	32.92	36.00	18.00	No. 5 @ 12in.
13	0.312	4.23	7.69	11.92	16.92	23.08	30.38	39.00	18.00	No. 5 @ 10in. or No. 6 @ 16in.
14	0.336	3.93	7.14	11.07	15.71	21.43	28.21	42.00	18.00	No. 5 @ 10in. or No. 6 @ 15in.

tary references in R20.3.2.6.1.

- **318-14**: The references on prestress losses in the commentary were from the 1970s. Joint ACI-ASCE Committee 423 formed Subcommittee 423-E, Prestress Losses, to update the document.
- **318-19**: R20.3.2.6.1 now references the comprehensively updated Joint ACI-ASCE 423 document 423.10R-16,[2] "Guide to Estimating Prestress Losses."

8. Minimum value of V_{ci} for prestressed members—2.2, 22.5.8.2 (2014), 22.5.8.3.1 (2014) and R22.5.8.3.1 (2014), 22.5.6.2 (2019), AND 22.5.6.3.1 (2019) and R22.5.6.3.1 (2019)

The calculation of V_c for prestressed members is provided in Sections 22.5.8.1 to 22.5.8.3.

- **Reason for Change**: To modify the minimum value of V_{ci} for one-way shear strength of prestressed members to be consistent with the minimum value specified for the approximate method in 22.5.8.2
- **318-14:** Per 22.5.8.3.1, V_{ci} is the greater of (a) and (b) as follows.
- $V_{ci} = 0.6\lambda\sqrt{f_c'}b_w d + V_d + \dfrac{V_i M_{cre}}{M_{\max}}$ (22.5.8.3.1a)
- $V_{ci} = 1.7\lambda\sqrt{f_c'}b_w d$ (22.5.8.3.1b)
- Per 22.5.8.2, for prestressed members where $A_{ps}f_{se} \geq \mathbf{0.4}(A_{ps}f_{pu} + A_s f_y)$ is satisfied, if V_c is calculated per the approximate method, the minimum value of V_c is permitted to be at least
- $V_c = 2\lambda\sqrt{f_c'}b_w d$ (Eq. 22.5.5.1), which is not consistent with Eq. (22.5.8.3.1b). This has been corrected in the 318-19 code.
- **318-19**: Per 22.5.6.3.1, the minimum value has been revised based on the level of prestress.
- For members with $A_{ps}f_{se} < \mathbf{0.4}(A_{ps}f_{pu} + A_s f_y)$ – less prestress, the minimum value of V_{ci} has been kept the same as in the 318-14 code; that is $V_{ci} = 1.7\lambda\sqrt{f_c'}b_w d$
- For members with $A_{ps}f_{se} \geq \mathbf{0.4}(A_{ps}f_{pu} + A_s f_y)$, the minimum value of V_{ci} has been revised to $2\lambda\sqrt{f_c'}b_w d$.

9. Serviceability stress calculations for prestressed members—R24.5.2.1 and R24.5.2.3

Service load flexural stress calculation for prestressed members is specified in Sections 24.5.2.2 and 24.5.2.3 of the Code. Section 24.5.2.2 permits the use of the uncracked gross concrete section for Class U and T members, whereas Section 24.5.2.3 requires the use of a cracked transformed section for Class C members. However, the 318-14 Code does not distinguish between unbonded and bonded post-tensioned members.

- **Reason for Change**: To provide guidance on the difference between bonded and unbonded post-tensioned members when calculating gross and cracked transformed section properties.
- **318-14**: Does not make a distinction between unbonded and bonded members.
- **318-19**: Makes a distinction between bonded and unbonded members. As stated in the commentary, "Due to lack of strain compatibility, it is inappropriate to include the area of unbonded prestressed reinforcement in the calculation of gross or cracked section properties, although the effective prestress force should be considered when determining the location of the neutral axis." For unbonded members, the area of the void created by the sheathing (monostrand unbonded) or the duct that they are in (monostrand or multi-strand unbonded) must be deducted in the concrete section calculation. As referenced in both the

-14 and -19 Code commentary, a method for evaluating stresses, deflections, and crack control in cracked prestressed members is given in Mast.[9]

10. Clarify requirements for anchorage zone reinforcement for unbonded monostrand tendon anchorages in slabs—25.9.4.4.6 AND R25.9.4.4.6

Section 25.9.4.4.6 provides general zone anchorage provisions for slabs with unbonded monostrand tendons.

- **Reason for Change:** To clarify and adequately address the location of backup bars in the general zone of the anchorage, especially for thick slabs, and clarify the depth of the bursting steel (hairpin or stirrups) reinforcement. This Code change is a significant change for the post-tensioning industry and is discussed in detail.
- **318-14:** General zone reinforcement provisions for slabs with unbonded monostrand tendons are shown in Fig. 1. For thick slabs, this provision could result in a condition where the backup bars that are placed at the corner of the hairpins are not in front of or close to the bearing surface of the anchor; refer to Fig. 3b. This could result in a potentially unsafe bearing condition. The Code is not entirely clear about the depth of the hairpins, which could result in a condition shown in Fig. 3c. This issue has been observed in the field where hairpins from thinner slab members have been erroneously used for thicker slabs.
- **318-19:** The Code update provides clarity on the location of the backup bars and the depth of the bursting reinforcement, which could be hairpins or stirrups.

In the current update, the Code provides two options for backup bar placement. In the first option, only one set of two No. 4 or larger backup bars are required. The first option can only apply to slabs that are 8 in. (203 mm) thick or less. In this option, the backup bars must be placed enclosed in the hairpins with the hairpins placed at a distance between $3/8h$ to $h/2$. Additionally, the center of the backup bar cannot be placed farther than 4 in. (102 mm) from the bearing face of the anchor (refer to Fig. 2c and 3d). For example, for an 8 in. (203 mm) slab, the hairpins must be placed between a distance of 3 to 3-3/8 in. (76 to 86 mm) from the bearing face so that the center of the backup bar does not exceed the 4 in. (102 mm) requirement in 25.9.4.4.6a. Table 2 provides the

25.9.4.4.6 For monostrand anchorage devices for 1/2 in. or smaller diameter strands in normalweight concrete slabs, reinforcement satisfying (a) and (b) shall be provided in the general zone, unless a detailed analysis in accordance with 25.9.4.3 shows that this reinforcement is not required:

(a) Two horizontal bars at least No. 4 in size shall be provided parallel to the slab edge. They shall be permitted to be in contact with the front face of the anchorage device and shall be within a distance of $\boldsymbol{h/2}$ ahead of each device. Those bars shall extend at least 6 in. either side of the outer edges of each device.

(b) If the center-to-center spacing of anchorage devices is 12 in. or less, the anchorage devices shall be considered as a group. For each group of six or more anchorage devices, $\boldsymbol{n+1}$ hairpin bars or closed stirrups at least No. 3 in size shall be provided, where $\boldsymbol{n}$ is the number of anchorage devices. One hairpin bar or stirrup shall be placed between each anchorage device and one on each side of the group. The hairpin bars or stirrups shall be placed with the legs extending into the slab perpendicular to the edge. The center portion of the hairpin bars or stirrups shall be placed perpendicular to the plane of the slab from $\boldsymbol{3h/8}$ to $\boldsymbol{h/2}$ ahead of the anchorage devices.

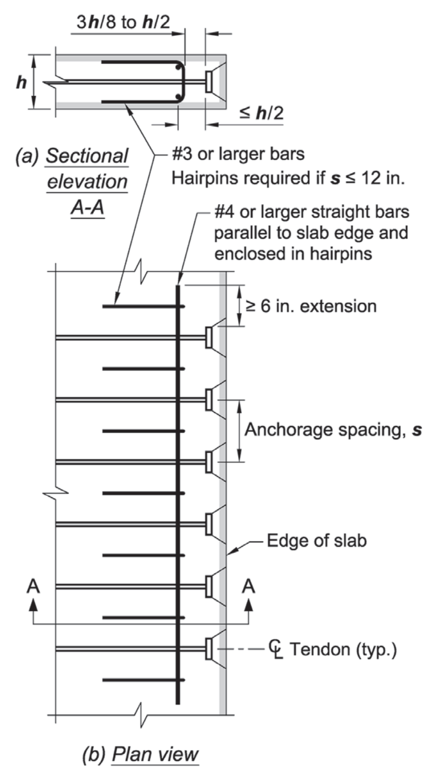

Fig. R25.9.4.4.6—Anchorage zone reinforcement for groups of 1/2 in. or smaller diameter tendons in slabs.

Fig. 1—Section 25.9.4.4.6 in ACI 318-14.[1] Authorized reprint from ACI 318-14.

range in which the bursting steel must be placed for slabs 8 in. (203 mm) and smaller.

In the second option, two sets of No. 4 bars or larger are required. This option can be used for any slab regardless of its thickness. The first set of bars must be placed immediately in front and as close as possible to the bearing face of the anchor, not to exceed a distance of 4 in. (102 mm), as shown in Fig. 2a, 2b, 3a, and 3e. Backup bars, when placed directly against the anchors, increase safety by containment of the concrete if there are unexpected concrete consolidation issues. The bursting steel, typically hairpins in slabs, are required to be placed at a distance between 3/8h to h/2 enclosed by another set of No. 4 bars in accordance with Section 25.7.1.2. The LDP must determine the bursting steel reinforcement size based on Section 25.9.4.3. The depth of the bursting steel reinforcement, either hairpins or stirrups, is equal to the slab depth less top and bottom cover.

It should be noted that headed stud shear reinforcement is commonly used as bursting reinforcement in anchorage zones. While not currently addressed in the Code, if headed shear studs are used, regardless of the slab thickness, only one

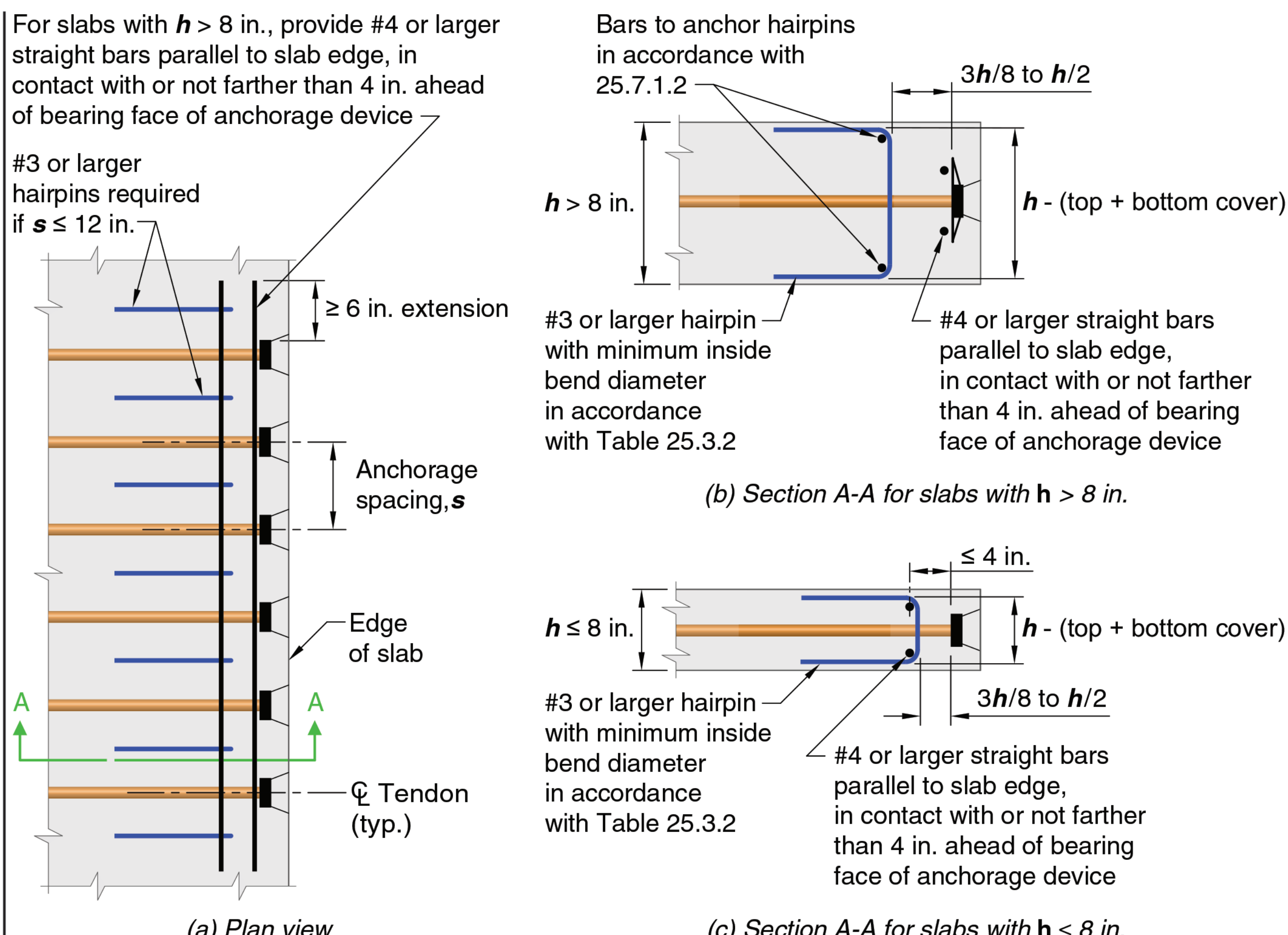

Fig. R25.9.4.4.6*—Anchorage zone reinforcement for groups of 1/2 in. or smaller diameter tendons in slabs (other reinforcement not shown).*

1. Backup bars closer to the anchorage
2. Safer to prevent blow-outs
3. Hairpin depth = Slab depth minus cover

Fig. 2—Updates to Section 25.9.4.4.6 in ACI 318-19.[2] Authorized reprint from ACI 318-19. (Note: 1 in. = 25.4 mm.)

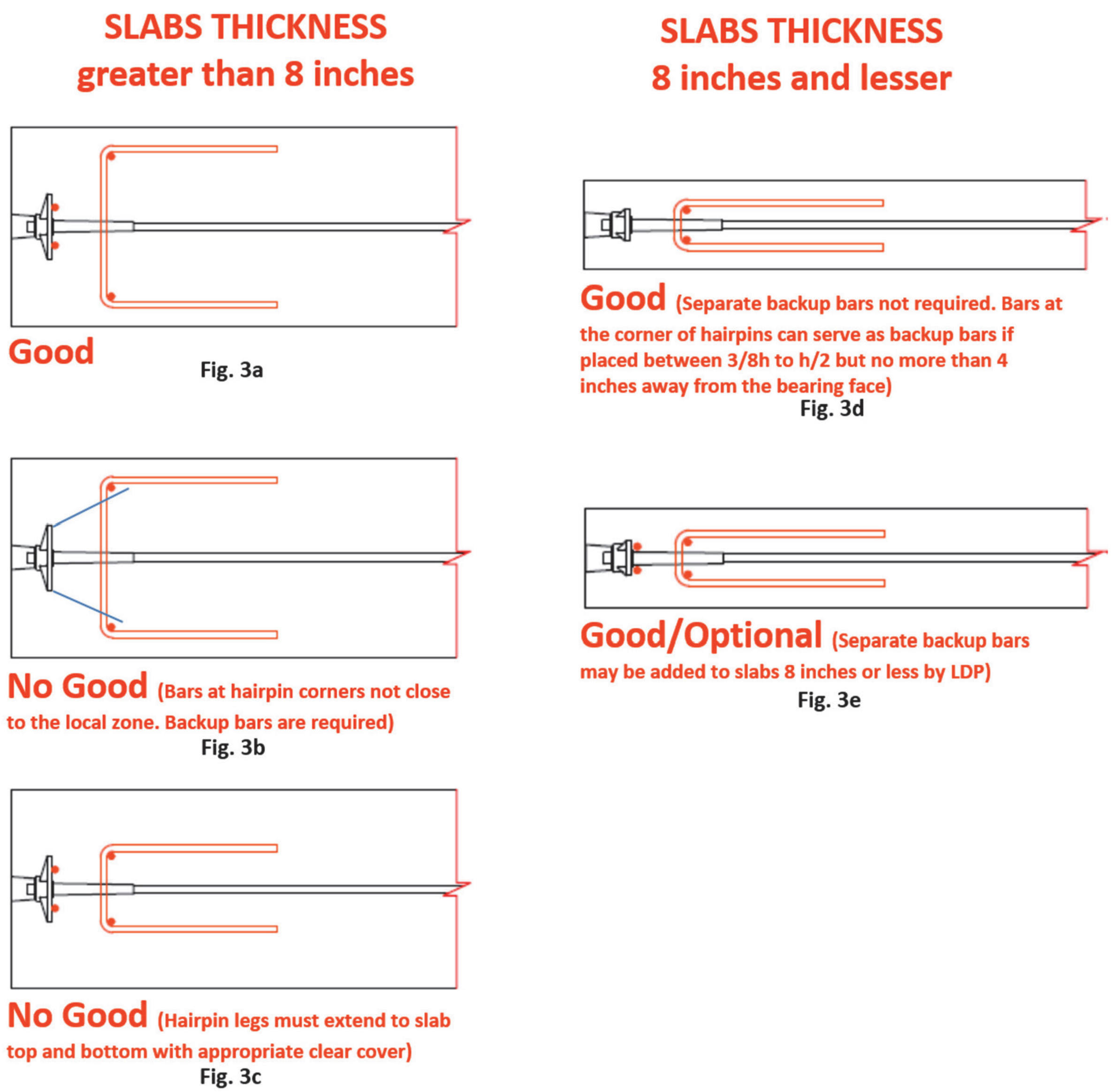

Fig. 3—Proper placement of backup bars and hairpins per ACI 318-19 code change. (Note: 1 in. = 25.4 mm.)

layer of backup bars are required, preferably placed close to or touching the anchors. The studs must be placed vertically and within 3/8h to h/2 from the anchor. The height of the studs is equal to the slab depth, less top and bottom cover.

11. Modify 2% loss of prestress limitation—26.10.2(g) and R26.10.2(g)

This provision, which has been in the Code for many years, is intended to cover loss of prestressing force primarily due to broken tendons.

- **Reason for Change:** To permit some leeway to the licensed design professional in evaluating the amount of prestressed reinforcement that may break during construction and does not have to be replaced.
- **318-14:** Code specifies that the loss of prestressing force in a member due to broken tendons cannot exceed 2% of the specified design prestressing force.
- **318-19:** The Code now permits the LDP to allow for more than 2% loss of the prestressing force for broken tendons without requiring replacement if acceptable to the LDP. **CAUTION!** In making this evaluation, the LDP should account for the field-measured elongations of the unbroken tendons and how they compare to the required elongations based on friction calculations to determine a "realistic as-built force" in the member.

Table 2—Location of bursting reinforcement for slabs 8 in. thick and smaller (refer to Fig. 2c). Note: 1 in. = 25.4 mm.

Slab thickness *h*, in.	Closest location of hairpin (based on 0.375*h*), in.	Farthest location of hairpin (based on 0.5*h* and center of backup bar not exceeding 4 in. from the anchor bearing face), in.
5	1.88	2.50
5.5	2.06	2.75
6	2.25	3.00
6.5	2.44	3.25
7	2.63	3.38 (for No. 3 hairpin) or 3.25 (for No. 4 hairpin)
7.5	2.81	3.38 (for No. 3 hairpin) or 3.25 (for No. 4 hairpin)
8	3.00	3.38 (for No. 3 hairpin) or 3.25 (for No. 4 hairpin)

Other related changes for the sake of completeness.

12. Extensions of Flexural Reinforcement in Thick Two-way Slabs (Podiums)—R8.7.4.1.3:

To address potential punching shear strength deficiency caused by lack of flexural reinforcement intercepting critical shear cracks for standard reinforcement extensions.

13. Depth Effect on Two-way Slab Shear Strength (currently changes for non-prestressed slabs)—22.6.5.2, R22.6.5.2, 22.6.6.1, R22.6.6.1, 22.6.6.2, and R22.6.6.2 (2019)

Two-way slab shear provisions updated, including of requirements for stacking (piggybacking of headed shear studs).

14. Added structural integrity provisions for cast-in-place nonprestressed one-way slabs—New Provision 7.7.7 (2019): Similar to integrity provisions for beams

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Asit N Baxi, *PhD, President, Baxi Engineering Inc. He has over 25 years' experience as a structural engineer in the area of prestressed concrete; he is recognized as an industry expert on post-tensioned buildings. He owns and runs a full-service post-tensioned concrete specialty engineering firm with specialization in the analysis and design, construction, repair, and forensics of different types of post-tensioned concrete structures utilizing any type of post-tensioning systems.*

He is a member of PTI Committees DC-20, Building Design; DC-110, Building Information Modeling; and TAB-120, Technical Advisory Board; ACI Subcommittees 301-I, Post-Tensioned Concrete, and 318-G, Precast and Prestressed Concrete; and Joint ACI-ASCE Committee 423, Prestressed Concrete.

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