

Key Changes in the 2019 Edition of the ACI Building Code (ACI 318-19)

The committee chair summarizes updates in the most recent edition

by Jack P. Moehle

ACI Committee 318, Structural Concrete Building Code, has completed the technical work for “Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19),”¹ including responses to public comments on the nearly completed document. This represents the successful completion of a 5-year cycle for the current committee members. This article introduces some of the changes so that prospective future users of the Code will know what to expect.

Before getting to the changes, I want to recognize the committee members who worked so hard to get us to this point (refer to the Acknowledgments on p. 25 listing the members). During this Code cycle, ACI Committee 318 comprised 40 Voting Members, including 11 Subcommittee Chairs, who kept the work flowing and contributed to the material in this article. As Chair, I was responsible for inviting the members to join, and I was careful to ensure that the Voting Members represented a balance among Academic/Educator (32%), Consultant (20%), Contractor (5%), Designer (22%), and Producer (15%) interests, and General interest (5%). The Voting Members were supported by a very active and well-balanced group of 72 Subcommittee Members drawn from across the United States and from the international community of ACI 318 users. Rounding out the committee were 14 Liaison Members and five Consulting Members. ACI Staff Engineer Greg Zeisler deftly managed the secretarial and administrative tasks of the committee. I have been honored to be able to work with such a talented, dedicated, and harmonious group of individuals.

The committee from the previous Code cycle devoted significant energy and time to a once-in-a-generation reorganization of the Code, resulting in ACI 318-14.² For the present Code cycle, we left the organization mainly as it was and focused instead on technical changes to improve safety, economy, and sustainability, while introducing new technologies and ideas to advance the concrete industry.

The following paragraphs introduce some of the key

changes for ACI 318-19. To help Code users identify these and other changes, they are marked within ACI 318-19 by vertical lines beside the Code and Commentary text where the changes occur.

Code and Commentary Format

One of the most apparent changes to the Code and Commentary is the widespread use of color to identify different parts of the document and to improve clarity of figures. A few figures incorporated in this write-up illustrate the improved figures. The index has been expanded as an aid to help Code users locate provisions.

Chapter 7: Structural Integrity Reinforcement for One-Way Slabs

While previous editions of the Code have contained structural integrity provisions for beams and slab-column connections, including requirements for continuity of longitudinal reinforcement and configuration requirements for transverse reinforcement, one-way cast-in-place slabs have had no similar provisions. ACI 318-19 includes a new section (Section 7.7.7) incorporating provisions, similar to those provided for beam design, to ensure that failure of a portion of a slab does not lead to disproportionate collapse. Section 4.10 provides cross-references to all the structural integrity provisions of the Code.

Chapter 8: Provisions for Two-Way Slabs

The Code has contained detailed provisions for use of the Direct Design and Equivalent Frame Methods since their introduction in the 1970s. Although these methods are still applicable to the design of two-way slabs and are still permitted by ACI 318-19, they have been largely replaced in practice by computer software based on finite element analysis methods. To reflect the change in practice, ACI Committee 318 decided it was time to remove the detailed provisions for these two design methods. The result is a

streamlined set of provisions for two-way slab design that helps clarify the fundamental requirements for strength, serviceability, and reinforcement detailing.

Tests on interior column-to-slab connections have shown that yielding of the slab flexural tension reinforcement near a column or concentrated load leads to increased local rotations and opening of inclined cracks existing within the slab. This in turn can result in a flexure-driven punching failure at a shear force less than the strength calculated by the two-way shear equations in the Code. Section 8.6.1.2 introduces a new requirement for minimum reinforcement to address this failure mode.

Since the 1956 edition, the Code has had provisions and a figure providing minimum lengths and required extensions of bars in two-way slabs. These were developed for slabs of “ordinary” proportions supporting gravity loads, and they may not be sufficient to intercept potential punching shear cracks in thick transfer slabs, podium slabs, and mat foundations. Section 8.7.4.1.3 introduces a new requirement for bar extensions to cover requirements for these thicker two-way slabs.

Chapter 9: Hanger Reinforcement for Beams

If a reinforced concrete beam is cast monolithically with a supporting beam and intersects one or both side faces of the supporting beam, the soffit of the supporting beam may be subject to premature failure. To avoid this type of failure, the Commentary recommends conditions under which additional transverse reinforcement, commonly referred to as hanger reinforcement, should be provided to transfer shear from the end of the supported beam (shown in Fig. R9.7.6.2.1¹).

Chapter 10: Removal of Provisions for Composite Columns

ACI 318-14 has composite column provisions that are outdated and incomplete. Consequently, those provisions are insufficient to fully design composite columns. Representatives from ACI and the American Institute of Steel Construction (AISC) met and resolved that a preferred

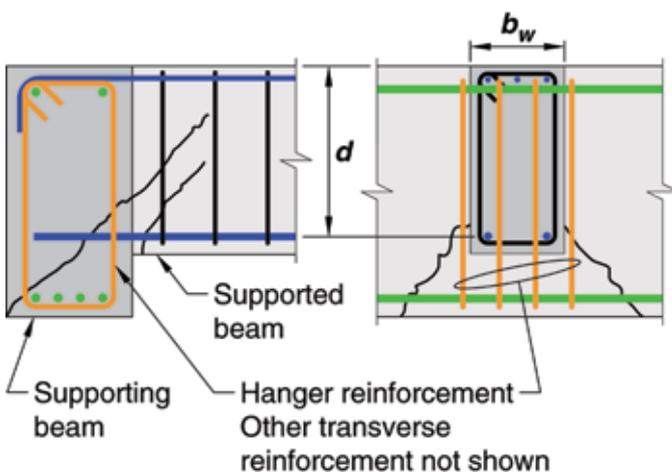


Fig. R9.7.6.2.1: Hanger reinforcement for shear transfer¹

approach was for ACI to remove the composite column provisions and refer the engineer to the more complete AISC provisions. By extension, going forward, provisions for other types of steel/concrete composite construction, such as concrete-encased steel coupling beams, are intended to be covered by AISC rather than ACI.

Chapter 11: In-Plane Shear Strength of Walls

The Code traditionally has used different equations for in-plane shear strength design of structural walls for nonseismic (Chapter 11) and seismic (Chapter 18) applications. To improve consistency in the Code, the nominal in-plane shear strength equations in Chapter 11 were modified to have the same form as the shear strength equations used in Chapter 18. Studies indicate that the former equations and the revised equations in Chapter 11 provide a comparable level of safety.

Chapters 13 and 18: Deep Foundations

This Code edition includes revisions and additions aimed at eliminating conflicting provisions in ACI 318, ASCE 7, and the International Building Code (IBC) regarding design of deep foundations for earthquake-resistant structures assigned to Seismic Design Categories (SDC) C through F. For some time, these differences have been a source of confusion for both engineers and code officials. The purpose of the Code change is to have all pertinent concrete-related design and detailing provisions for the seismic design of deep foundations in SDC C through F contained within ACI 318-19. The Code change includes provisions for both cast-in-place and precast concrete deep foundations.

The revisions and additions to the Code are taken directly from the most current relevant provisions in ASCE 7-16.³ New provisions for precast concrete piles were based on recommendations made by the PCI Piling Committee and previously adopted in the 2018 edition of the IBC.⁴

Previous editions of the Code did not include axial load limitations for deep foundations. ACI 318-19 added provisions for the allowable axial capacities for deep foundations that are consistent with the IBC allowable stress provisions. Lastly, the Code added strength design requirements that are consistent with ACI 543R-12.⁵ This Code change will allow designers of deep foundation members to use either the traditional allowable strengths that have been in the general building codes for years or the strength design method using strength reduction factors that are consistent with the rest of ACI 318-19.

Chapters 15 and 18: Beam-Column Joints

ACI 318-19 incorporates design provisions for shear strength and reinforcement detailing of beam-column joints of SDC A frames, ordinary moment frames, intermediate moment frames, and frames that are not part of the seismic force-resisting system in SDC B, C, D, E, and F. Also, existing design provisions for special moment frames were expanded to include shear strength of roof joints. The shear

strength factors incorporated in Chapter 15 are based primarily on those given in ACI 352R-02,⁶ with each connection type defined by whether the column or the beam in the direction of considered shear is continuous, as well as by confinement provided by transverse beams.

Chapter 15 also now requires consideration of the presence of opening and closing moments in corner joints. This includes consideration of moment transfer across a diagonal section through a corner joint, which is particularly critical where the joint connects a cantilever member for which no redistribution of moments is possible.

Chapter 16: Connections Between Members

The Code provisions for precast concrete bearing connections were updated to provide uniform and consistent provisions for the design forces developed by volume change effects. Prior editions of the Code contained specific provisions for restraint forces only for corbels and brackets. In 2019, Sections 16.2.2.3 and 16.2.2.4 were added to include consideration of restraint forces at all bearing connections.

Chapter 17: Anchoring to Concrete

Post-installed, concrete screw anchors are increasingly used as a viable anchoring solution, and this anchor type will now be recognized in ACI 318-19. In addition, ACI 355.2-07⁷ adds tests for concrete screw anchors to address some of the unique considerations for this anchor type.

ACI 318-19 also introduces provisions for shear lugs comprising a steel element welded to a base plate. Shear lugs are usually used at the base of columns to transfer large shear forces through bearing to a foundation element (shown in Fig. R17.11.1.a¹).

Chapter 17 and its Commentary were reorganized into the Code format followed for the 318-14 edition of the Code. To help identify the various ψ factors used for the shear and tension equations, the chapter more clearly identifies the factor type (for example, edge or thickness) to assist the Code user in their application. In addition, applicable design, specification, and inspection information has been moved to the appropriate sections of Chapter 26.

Chapter 18: Earthquake-Resistant Structures

ACI 318-19 includes several new provisions related to design of structural walls. One of the most significant

changes is a new provision (Section 18.10.3.1) that, in some cases, requires substantial amplification of earthquake shear forces for design. This new provision arose from experience gained over the last 15 years with nonlinear dynamic analysis of multiple core-wall buildings, which indicated that shear wall design forces may be amplified by inherent wall overstrength and by apparent higher-mode effects. In some cases, the design shear force will be more than double the design shear from previous Codes.

Observed behavior of structural walls in the 2010 Chile earthquake and 2010-11 Christchurch earthquakes, as well as in laboratory tests, have led to new detailing requirements for boundary elements of special structural walls. To improve concrete confinement and longitudinal bar support, Section 18.10.6.4(f) now limits the aspect ratio of hoops in the boundary element and requires that all crossties have seismic hooks at both ends (shown in Fig. R18.10.6.4a(b)¹). To avoid brittle fracture of underreinforced walls, Section 18.10.2.4 now requires some walls to satisfy minimum longitudinal reinforcement requirements.

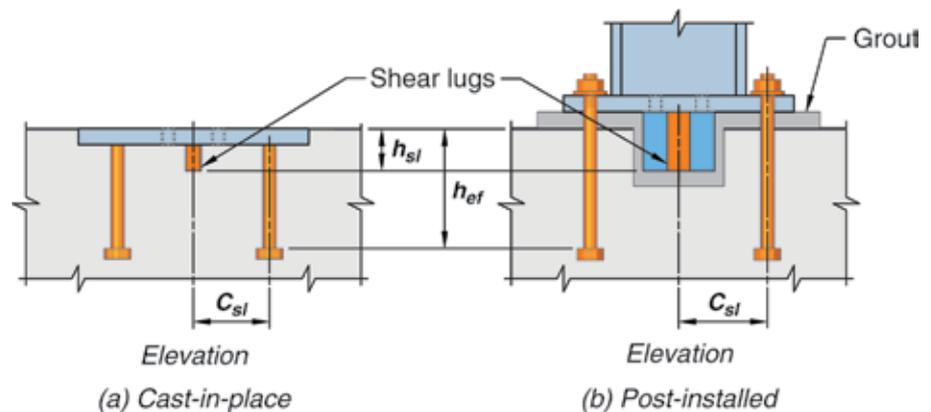
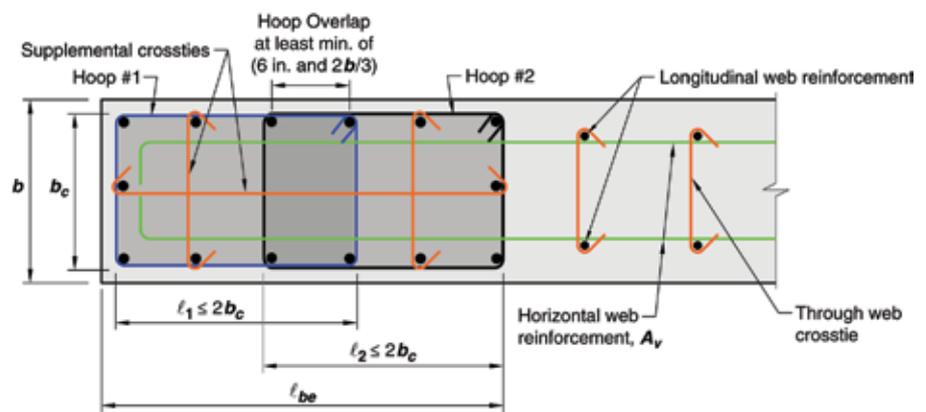


Fig. R17.11.1a: Examples of attachments with shear lugs¹ (elevation views only)



(b) Overlapping hoops with supplemental 135-degree crossties and 135-degree crossties supporting distributed web longitudinal reinforcement
 Fig. R18.10.6.4a: Configurations of boundary transverse reinforcement and web crossties¹ (portion (b) only)

Since the 1994 Northridge earthquake, extensive research has been carried out on the seismic behavior and design requirements for precast concrete diaphragms. The 2016 edition of ASCE 7 incorporated new provisions that called for significant increases in seismic design forces, and it established new requirements for the design and detailing of precast concrete diaphragms, particularly the connections between precast elements. To provide design guidance, Joint ACI-ASCE Committee 550, Precast Concrete Structures, developed two new ACI standards: ACI 550.5-18⁸ and ACI 550.4-18.⁹ ACI 318-19 adopts by reference both of the ACI Committee 550 standards.

Chapter 19: Materials and Durability

While the IBC has included provisions for the use of shotcrete over several Code cycles, there has been no explicit mention of shotcrete in previous editions of ACI 318. Working with the American Shotcrete Association and ACI Committee 506, Shotcreting, ACI Committee 318 has introduced and updated Code provisions to reflect current practice. The updated provisions are located in several places throughout the Code. Cross-references are provided in Commentary Section R4.2.1.1.

ACI 318-19 added a new approach for establishing λ , the modification factor to reflect the reduced mechanical properties of lightweight concrete. This change adds a means of establishing λ based on unit weight of lightweight concrete. This approach will make it easier for a designer to specify a unit weight and determine a value of λ to use during the design process. The method for establishing λ by specifying splitting tensile strength was removed from the Code.

Until now, the Code has been silent on alkali-aggregate reaction. ACI 318-19 adds provisions for preventing alkali-silica reaction (ASR). The approach taken is to identify concrete that will be exposed to water in service. As such exposure is identified, the Licensed Design Professional (LDP) is required to investigate and determine appropriate action for aggregates susceptible to ASR. Aggregate susceptible to alkali-carbonate reaction is banned by the Code.

Chapter 20: High-Strength Reinforcement

A major thrust of the 2019 Code cycle was to expand permissible applications of high-strength reinforcement. Table 20.2.2.4(a) now permits the use of Grade 100 reinforcement to resist moments and axial forces from gravity and wind load combinations. The use of higher-grade reinforcement raised concerns about serviceability (cracking and deflections), which were addressed through a series of changes for slab and beam minimum reinforcement, effective moment of inertia, and requirements for deflection calculations for two-way slabs. Strength and ductility concerns were addressed by introducing new requirements for mechanical properties of reinforcing bars, adjusting the method for calculating the strength reduction factor for moment and combined moment and axial load, revising development length provisions, and limiting the value of f_y that can be used for calculating the

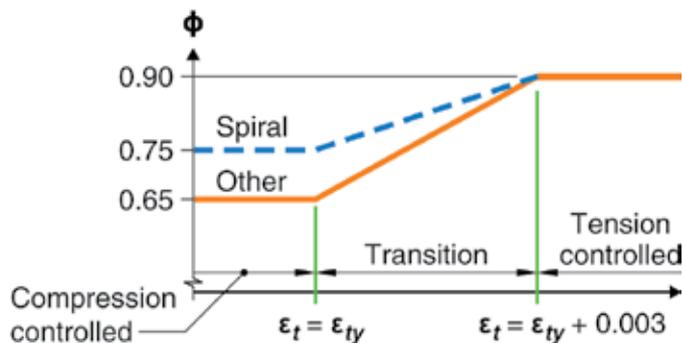


Fig. R21.2.2b: Variation of ϕ with net tensile strain in extreme tension reinforcement, ϵ_t ¹

maximum axial compressive strength $P_{n,max}$ of columns. It is likely that Grade 100 reinforcement will be used mostly for vertical bars of shear walls and columns, though it might also be used for heavily loaded floor systems.

Substantial new research funded by the Pankow Foundation, ACI Foundation, and others has demonstrated acceptable performance of members of special seismic systems reinforced with ASTM A706 Grade 80 reinforcement and ASTM A706-equivalent Grade 100 reinforcement. Recognizing this, ACI 318-19 now permits special moment frames with ASTM A706 Grade 80 reinforcement and special structural walls with ASTM A706 Grade 80 and ASTM A706-equivalent Grade 100 reinforcement. The provisions allow the use of the higher grades to resist moments, axial forces, and shear. To accommodate these higher grades, additional restrictions on hoop spacing, beam-column joint dimensions, and lap splice locations have been added that will contribute to more reliable performance of special structural systems.

Chapter 21: Strength Reduction Factors

The introduction of higher-strength reinforcement required an adjustment to the strength reduction factor for moment and combined moment and axial force. In the new Code, compression-controlled failure is defined for net tensile strain $\epsilon_t \leq \epsilon_{ty}$ and tension-controlled failure is defined for $\epsilon_t \geq \epsilon_{ty} + 0.003$, where ϵ_{ty} is the nominal yield strain of the deformed reinforcement. Concurrent with this change, the Code also requires that sections of nonprestressed beams and slabs with $P_u < 0.10 f'_c A_g$ shall be tension-controlled, such that the strength reduction factor is always 0.9 (shown in Fig. R21.2.2b¹).

Chapter 22: New Sectional Shear Strength Equations

ACI 318-19 introduces a new set of simplified equations for one-way shear strength, applicable to nonprestressed beams, slabs, and walls loaded out-of-plane. The equations include a size effect for sections that do not have minimum shear reinforcement. The size effect is also applicable to two-way shear and to strut capacity for strut-and-tie models without a minimum grid of reinforcement. The size effect factor is not applicable to isolated and combined footings.

Chapter 23: Strut-and-Tie Method

The committee approved 12 changes related to the strut-and-tie method (STM) for design of discontinuity regions (D-regions). The requirements for distributed reinforcement in deep beams were expanded to include most other discontinuity regions, although distributed reinforcement is not required where it is impractical and unnecessary—in pile caps, for example. Recent research showing inclined struts are

weakened by diagonal tension rather than bottle-shape behavior warranted changes in the strut efficiency factors and a shear stress check in unreinforced D-regions. Other noteworthy changes include new requirements for ties extending from bend regions of reinforcing bars (curved-bar nodes), increases in allowable node and strut stresses based on confinement at bearing areas, and new requirements for design and detailing of D-regions that may experience bar yielding or

Acknowledgments

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concrete crushing in an earthquake. Collectively, the STM changes for ACI 318-19 will make the method more versatile, while improving safety and serviceability.

Chapter 24: Serviceability

A new method for calculating the effective moment of inertia I_e has been introduced to improve accuracy for members with low reinforcement ratios and to better reflect effects of construction loads on cracking of “green” concrete.

Chapter 25: Reinforcement Details

Ongoing research has provided data adequate to extend the ACI 318-14 provisions for development length for deformed bars, standard hooks, and headed deformed bars in tension considering higher concrete compressive strengths and higher-strength reinforcement. The provisions for development of deformed bars are similar to those in past Codes, but with an additional factor $\psi_g \geq 1.0$ and a requirement for transverse reinforcement when higher grades of reinforcement are used. The provisions for standard hooks and headed deformed bars are substantially different from those of past Codes and better represent the effects of bar diameter, concrete compressive strength, spacing between reinforcement, and level of confining reinforcement on required lengths.

Section 25.9.4 was updated to clarify requirements for anchorage zone reinforcement for unbonded monostrand tendon anchorages in slab edges. Analysis of test data has shown that for slab edge anchors to perform reliably, horizontal bars oriented parallel to the slab edge and located in close proximity to the anchorage devices (known as “back-up bars”) must be provided. This change clarifies these requirements for slabs of varying thickness.

Chapter 26: Construction Documents and Inspection

Provisions to allow the use of alternative cements and recycled aggregates were added. Both of these materials are drawing a lot of attention as a means of making concrete more

sustainable. While allowing use of these materials, the Code includes warnings to the LDP to review the design and durability properties of these materials before allowing their use.

Requirements for “qualified” technicians were changed to “certified.” Additionally, all referenced ACI certification programs are now listed in the Commentary References with a URL to allow users to determine what is covered in each program.

The inspection provisions were enhanced to reflect all requirements currently in the IBC. The committee’s expectation is that the IBC will reference ACI 318 for concrete inspection.

Multiple changes were made to the construction provisions to reflect other changes made throughout the Code during this Code cycle.

Chapter 27: Strength Evaluation of Existing Structures

ACI 437.2-13¹⁰ was developed to be a standard for load testing of existing concrete structures. Changes were made to Chapter 27 to modify the test load magnitude and acceptance criteria of the Code to be consistent with the requirements in ACI 437.2-13. The proposal also allows for cyclic load testing of structures using ACI 437.2 criteria for load testing.

Appendix A: Design Verification Using Nonlinear Response History Analysis

Not so long ago, the use of nonlinear dynamic analysis methods for design of earthquake-resistant buildings was an academic issue. Today, the biggest and most iconic buildings on the West Coast of the United States, and many other seismic regions of the world, are being designed by these methods. For the first time, ACI 318-19 includes provisions for application of these methods to concrete buildings, including the enabling clause of Section 4.4.6.7, requirements for nonlinear analysis in Section 6.8, and complete provisions for earthquake-resistant design in Appendix A. The provisions are intended to be fully compatible with Chapter 16 of ASCE 7-16, which contains requirements on seismic hazard, selection of earthquake ground motions, load combinations, and independent peer review.

References

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5. ACI Committee 543, "Guide to Design, Manufacture, and Installation of Concrete Piles (ACI 543R-12)," American Concrete Institute, Farmington Hills, MI, 2012, 64 pp.

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Selected for reader interest by the editors.



Jack P. Moehle, F.A.C.I., is the Ed and Diane Wilson Presidential Professor of Structural Engineering in the Department of Civil and Environmental Engineering at the University of California, Berkeley, Berkeley, CA, where he has taught since 1980. He has served on the ACI Board of Direction and Technical Activities Committee. He was the Chair of ACI

Committee 318, Structural Concrete Building Code, during the most recent Code cycle. He is a member of ACI Committees 133, Disaster Reconnaissance, and 369, Seismic Repair and Rehabilitation; and Joint ACI-ASCE Committee 352, Joints and Connections in Monolithic Concrete Structures. Moehle received the 1998 ACI Alfred E. Lindau Award, 2001 ACI Delmar L. Bloem Distinguished Service Award, 2007 ACI Chester Paul Siess Award for Excellence in Structural Research, 2008 ACI Foundation Concrete Research Council Arthur J. Boase Award, and 2019 ACI Joe W. Kelly Award. His research interests include structural engineering with an emphasis on reinforced concrete and earthquake engineering. Moehle is a licensed civil engineer in California.



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