

Significant changes to the ACI 318-08 appendixes relative to precast/prestressed concrete

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Significant changes have been made since American Concrete Institute (ACI) Committee 318 published the 2005 *Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05)*.¹ Changes to the appendixes in the new 2008 edition² are summarized in this paper. The rest of the changes were covered in a three-part series of articles in special members-only supplements.

The intent of this article is to provide a summary of significant changes affecting conventionally reinforced concrete, precast concrete, and prestressed concrete (including post-tensioned concrete). This information should be useful to building officials, design engineers, practitioners, and the academic community.

Changes to chapters 1 through 8 of ACI 318-08 were discussed in the March–April 2008 issue of the *PCI Journal* in part 1 of the aforementioned article series. Changes to chapters 9 through 20 were discussed in part 2 of this series in the supplement to the May–June 2008 issue. Changes to chapter 21 were discussed in part 3 of the article series in a supplement to the September–October 2008 issue.

ACI 318-08 will be the reference document for concrete design and construction in the 2009 edition of the

Editor's quick points

- This paper describes changes from the 2005 edition to the 2008 edition of ACI 318, *Building Code Requirements for Structural Concrete and Commentary*. Specifically, changes to the appendixes are discussed.
- ACI 318 underwent a major revision with this version.
- Changes affecting conventionally reinforced concrete and provisions affecting precast/prestressed concrete, including post-tensioned concrete, are enumerated.

International Building Code (IBC),³ which will continue to reference ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures*.⁴

All section and chapter numbers used in this paper refer to those of ACI 318-08 unless otherwise noted.

Appendix A: “Strut-and-Tie Models”

No significant changes were made to this appendix.

Appendix B: “Alternative Provisions for Reinforced and Prestressed Concrete Flexural and Compression Members”

Changes were made in section B.8.4, “Redistribution of Moments in Continuous Nonprestressed Flexural Members,” that parallel changes in section 8.4, “Redistribution of Moments in Continuous Flexural Members.” Section 8.4 was discussed in part 1 of the ACI 318-08 article series.

Appendix C: “Alternative Load and Strength Reduction Factors”

No significant changes were made to this appendix.

Appendix D: “Anchoring to Concrete”

The three significant changes in Appendix D are the following:

- new definitions of reinforcement types that cross the concrete breakout surface
- new requirements on how seismic loads are handled for anchors
- provisions that were added to the concrete breakout design of anchorages for lightweight concrete

ACI 318-05 defined an anchor group as “a number of anchors of approximately equal effective embedment depth with each anchor spaced at less than three times its embedment depth [$3h_{ef}$] from one or more adjacent anchors.” This definition considered anchors subject to tension but not anchors subject to shear. This deficiency has now been corrected. The 318-08 definition reads, “a number of anchors of approximately equal effective embedment depth with each anchor spaced at less than $3h_{ef}$ from one or more adjacent anchors when subjected to

tension, or $3c_{a1}$ from one or more adjacent anchors when subjected to shear.” The distance from the center of an anchor shaft to the edge of concrete in one direction is represented by c_{a1} . ACI 318-08 also added to the definition, “only those anchors susceptible to the particular failure mode under investigation shall be included in the group.”

An important new term, *anchor reinforcement*, is defined as “reinforcement used to transfer the full design load from the anchors into the structural member.” New sections D.5.2.9 and D.6.2.9 contain provisions concerning anchor reinforcement.

ACI 318-05 defined supplementary reinforcement as “reinforcement proportioned to tie a potential concrete failure prism to the structural member.” ACI 318-08 has revised the supplementary reinforcement definition to read, “reinforcement that acts to restrain the potential concrete breakout but is not designed to transfer the full design load from the anchors into the structural member.” The second part of the revised definition clearly indicates that supplementary reinforcement is not anchor reinforcement.

Section D.3.3 of ACI 318-05 reads, “When anchor design includes seismic loads, the additional requirements of D.3.3.1 through D.3.3.5 shall apply.” This wording has now changed to “when anchor design includes earthquake forces for structures assigned to Seismic Design Category C, D, E, or F, the additional requirements of D.3.3.1 through D.3.3.6 shall apply.” There are two differences:

- Section D.3.3.6 has been added.
- The applicability of the ACI 318-05 provision included seismic design category (SDC) B, which is no longer the case.

The change in the SDC matters for section D.3.3.1 only because subsequent ACI 318-05 language restricted the applicability of sections D.3.3.2 through D.3.3.5 to structures assigned SDC C, D, E, or F.

Section D.3.3.2 of ACI 318-08 specifically requires that “pullout strength N_p and steel strength of the anchor in shear V_{sa} shall be based on the results of the ACI 355.2 Simulated Seismic Tests.” This specific requirement was not part of ACI 318-05.

Section D.3.3.3 has undergone an important change. While the section in ACI 318-05 required that “the design strength of anchors shall be taken as $0.75\phi N_n$ and $0.75\phi V_n$,” the ACI 318-08 section requires that “the anchor design strength associated with concrete failure

modes shall be taken as $0.75\phi N_n$ and $0.75\phi V_n$.” The variables ϕ , N_n , and V_n represent the strength reduction factor, the nominal strength in tension, and the nominal shear strength, respectively. By making the seismic reduction apply only to concrete failure modes, it is significantly more difficult to meet the requirements of section D.3.3.4 when anchors subjected to seismic forces in structures assigned to SDC C, D, E, or F have to be governed by the strength of a ductile steel element.

Section D.3.3.4 of ACI 318-05 waived the ductile anchor failure requirement if section D.3.3.5 could be satisfied. The same section in ACI 318-08 waives the ductile failure requirement if either section D.3.3.5 or section D.3.3.6 can be satisfied.

The 2006 IBC section 1908.1.16 modified ACI 318-05 section D.3.3.5 to read, “Instead of D.3.3.4 . . . specified in D.3.3.3, or the minimum design strength of the anchors shall be at least 2.5 times the factored forces transmitted by the attachment.” The 2006 IBC includes the text of ACI 318-05 section D.3.3.5 with the addition of “or the minimum design strength of the anchors shall be at least 2.5 times the factored forces transmitted by the attachment.” In other words, ductile anchor failure was declared unnecessary if the anchorage was overdesigned for concrete breakout.

This concept has been adopted into section D.3.3.6 of ACI 318-08 with the wording, “as an alternative to D.3.3.4 [ductile anchor failure] and D.3.3.5 [yielding in the attachment], it shall be permitted to take the design strength of the anchors as 0.4 times the design strength determined in accordance with D.3.3.3.” For anchors of stud-bearing walls, the 0.4 factor may be taken as 0.5. Because ACI 318 is a material standard, the committee did not feel comfortable modifying the design load, as the 2006 IBC had done. It was decided instead, in effect, to modify the strength reduction factor. A 0.4 multiplier on ϕ is equivalent to a 2.5 multiplier on the design load.

Section D.3.4 concerning anchors embedded in light-weight concrete is different—but mostly in appearance, not really in substance.

An important sentence has been added to section D.4.2.1: “Where anchor reinforcement is provided in accordance with D.5.2.9 and D.6.2.9, calculation of the concrete breakout strength in accordance with D.5.2 and D.6.2 is not required.” This sentence was added because anchor reinforcement is reinforcement that carries all of the design load when breakout failure occurs.

The commentary concerning supplementary reinforcement has changed in section RD.4.4. Important new points are, “An explicit design of supplementary

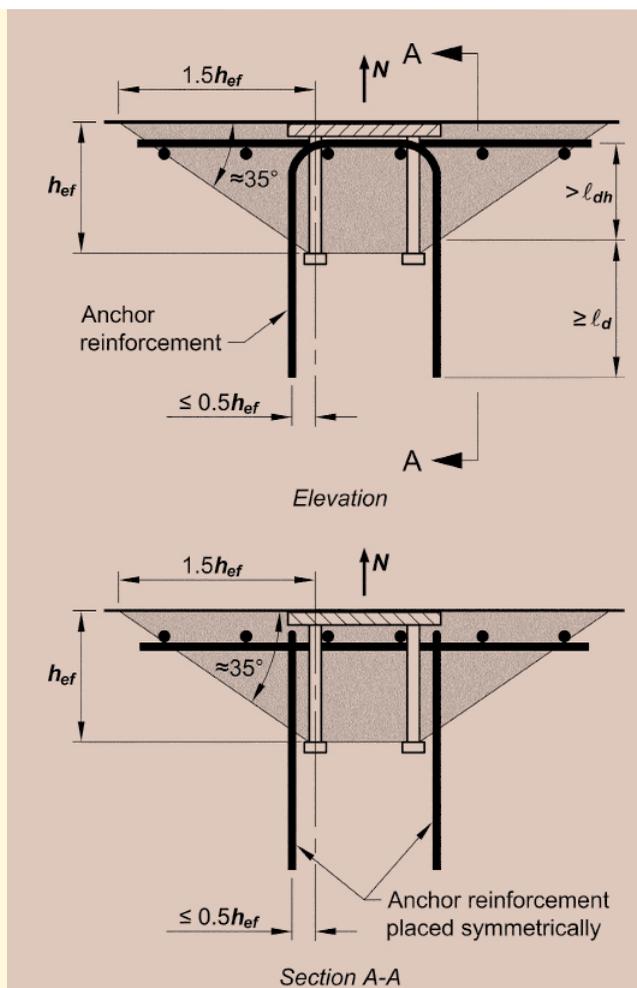


Figure 1. Anchor reinforcement for tension.

Source: Reprinted by permission from *Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary (ACI 318R-08)* (Farmington Hills, MI: ACI, 2008), p. 426, Fig. RD.5.2.9.

reinforcement is not required. However, the arrangement of supplementary reinforcement should generally conform to that of the anchor reinforcement shown in Fig. RD.5.2.9 and RD.6.2.9 (b). Full development is not required [of the supplemental reinforcement].”

The descriptions of conditions A and B in section D.4.4 were editorially modified for greater clarity. The descriptions now read, “Condition A applies where supplementary reinforcement is present except for pullout and pryout strengths. Condition B applies where supplementary reinforcement is not present, and for pullout or pryout strength.”

A distinction is now made between the effective cross-sectional area of anchor in tension $A_{se,N}$ and the effective cross-sectional area of anchor in shear $A_{se,V}$. In ACI 315-05, there was only the effective cross-sectional area of anchor A_{se} . The change is reflected in ACI 318-08 Eq. (D-3), (D-19), and (D-20).

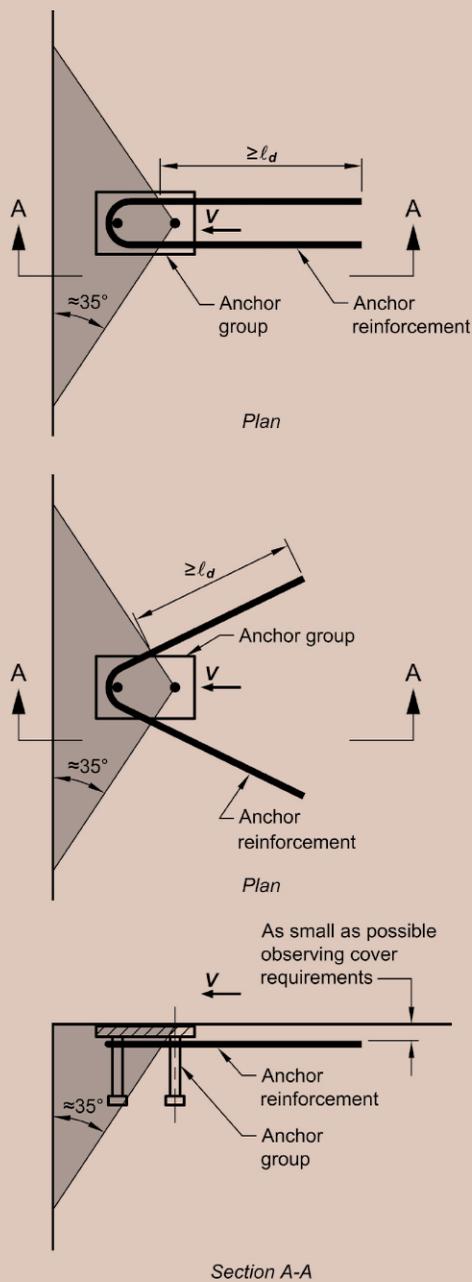


Figure 2. Hairpin anchor reinforcement for shear.
Source: Reprinted by permission from *Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary (ACI 318R-08)* (Farmington Hills, MI: ACI, 2008), p. 435, Fig. RD.6.2.9(a).

Commentary section RD.5.1.2 reproduces an equation from American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) B1.1, *Unified Inch Screw Threads (UN and UNR Thread Form)*⁵ for $A_{se,N}$ of threaded bolts. Commentary section RD.6.1.2 reproduces an equation from ANSI/ASME B1.1 for $A_{se,V}$ for threaded bolts. The two equations are identical. The difference in the value obtained from the two equations is evident for postinstalled mechanical anchors, particularly torque-controlled expansion anchors

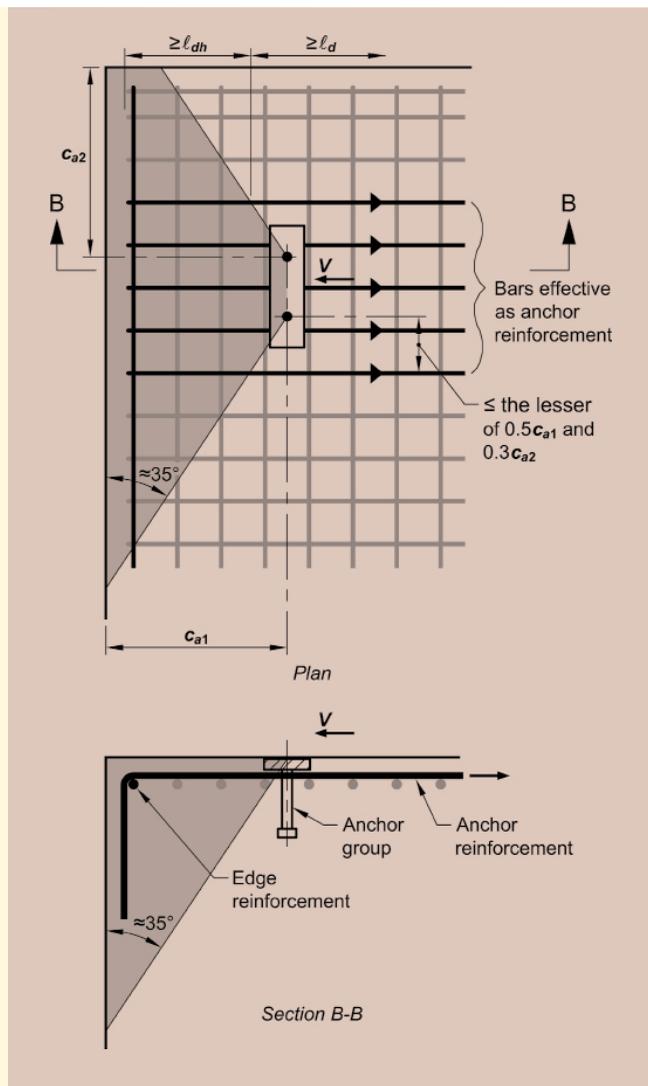


Figure 3. Edge reinforcement and anchor reinforcement for shear.
Source: Reprinted by permission from *Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary (ACI 318R-08)* (Farmington Hills, MI: ACI, 2008), p. 435, Fig. RD.6.2.9(b).

with a tapered conical shape at the bottom. Approved postinstalled anchors give both effective areas in the product approval. In most cases, the areas provided are the same as those given by the equations in the ACI 318-08 commentary.

In Eq. (D-7) for basic concrete breakout strength, a lightweight concrete factor λ was introduced.

An important new section, D.5.2.9, has been added to ACI 318-08. This section reads, “Where anchor reinforcement is developed in accordance with Chapter 12 on both sides of the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining ϕN_n . A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement.”

An important new commentary section RD.5.2.9 states that “for conditions where the factored tensile force exceeds the concrete breakout strength of the anchor(s) or where the breakout strength is not evaluated, the nominal strength can be that of anchor reinforcement.” The commentary includes Fig. RD.5.2.9, which is helpful and is reproduced in this paper as **Fig. 1**.

The variable d_o , which represents the outside diameter or shaft diameter of a headed stud, headed bolt, or hooked bolt of ACI 318-05, has been replaced with d_a in ACI 318-08. This change is reflected in Eq. (D-16) for pull-out strength in tension and in section D.8.3.

The lightweight concrete factor λ is introduced in Eq. (D-17) for the concrete side-face blowout strength of a single anchor in tension and in Eq. (D-18) for the concrete side-face blowout strength of a group of anchors in tension.

A new modification factor $\psi_{h,v}$ has been added to Eq. (D-21) and (D-22) for concrete breakout strength of anchors in shear. The factor is defined by Eq. (D-29) and is for anchors located in a concrete member in which $h_a < 1.5c_{a1}$ and h_a is the thickness of the member in which an anchor is located, measured parallel to anchor axis.

The lightweight concrete factor λ is also introduced into Eq. (D-24) and (D-25) for the basic concrete breakout strength in shear.

Paralleling section D.5.2.9, another important new section, D.6.2.9, has been added to ACI 318-08. It reads, “Where anchor reinforcement is either developed in accordance with Chapter 12 on both sides of the breakout surface, or encloses the anchor and is developed beyond the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining ϕV_n . A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement.” New commentary section RD.6.2.9 explains the provision. It includes Fig. RD. 6.2.9(a) and RD.6.2.9(b), which are reproduced in this paper as **Fig. 2** and **3**, respectively.

Summary and conclusion

Significant and substantial changes have been made in appendix D of ACI 318-08. The other appendixes had no or only minor changes. Changes to appendix D in ACI 318-08 have been summarized and discussed in this paper on significant changes from ACI 318-05 to ACI 318-08.

The changes to appendix D are few in number but are quite substantive in nature. Anchor design strength associated with steel failure is no longer to be reduced by an additional 0.75 factor. Also, there are new provisions that clearly define the role of anchor reinforcement, which is designed to carry the entire anchorage load once breakout failure in tension or shear occurs.

References

1. American Concrete Institute (ACI) Committee 318. 2005. *Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05)*. Farmington Hills, MI: ACI.
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Notation

- A_{se} = effective cross-sectional area of anchor (ACI 318-05)
- $A_{se,N}$ = effective cross-sectional area of anchor in tension
- $A_{se,V}$ = effective cross-sectional area of anchor in shear
- c_{a1} = distance from the center of an anchor shaft to the edge of concrete in one direction (if shear is applied to the anchor, c_{a1} is the maximum edge distance)
- c_{a2} = distance from the center of an anchor shaft to the edge of concrete in the direction perpendicular to c_{a1} , in.
- d_o = outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt (ACI 318-05)

d_a = outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt

h_a = thickness of member in which an anchor is located, measured parallel to anchor axis

h_{ef} = effective embedment depth of anchor

ℓ_d = development length in tension of deformed bar, deformed wire, plain and deformed welded-wire reinforcement, or pretensioned strand, in.

ℓ_{dh} = development length in tension of deformed bar or deformed wire with a standard hook, measured from critical section to outside end of hook (straight embedment length between critical section and start of hook [point of tangency] plus inside radius of bend and one bar diameter), in.

N = tensile force

N_n = nominal strength in tension

N_p = pullout strength in tension of a single anchor in cracked concrete

V = shear force

V_n = nominal shear strength

V_{sa} = nominal strength in shear of a single anchor or group of anchors as governed by the steel strength

λ = lightweight concrete factor

ϕ = strength reduction factor

$\psi_{h,V}$ = factor used to modify shear strength of anchors located in concrete members with $h_a < 1.5c_{a1}$

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in the appendixes of the 2008 edition are summarized in this article. In addition to changes affecting conventionally reinforced concrete, provisions affecting precast/prestressed concrete, including post-tensioned concrete, are enumerated.

Keywords

ACI 318, code, structural concrete.

Synopsis

Significant changes were made since American Concrete Institute (ACI) Committee 318 published the 2005 *Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05)*. The changes

Reader comments

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