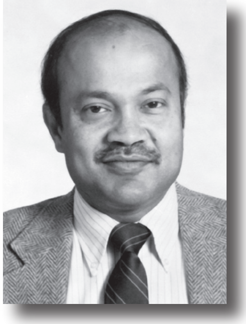
Significant Changes in the 2005 ACI Code, Including Changes Affecting Precast/Prestressed Concrete — Part 2



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Significant changes made since the publication of the 2002 ACI 318 Building Code, which are reflected in the 2005 edition of the Code, were summarized in Part 1 of this article (September-October 2004 PCI JOURNAL). In addition to changes impacting conventionally reinforced concrete, provisions affecting precast/prestressed concrete, including post-tensioned concrete, were enumerated. Changes in Appendix D, Anchoring to Concrete, not discussed earlier, are discussed in this Part 2 article.

The 2005 edition of the American Concrete Institute's Building Code Requirements for Structural Concrete (ACI 318-05) has been out for several months. The significant changes from the previous edition of the ACI Code (ACI 318-02) were summarized in Part 1 of this article, published in the September-October 2004 issue of the PCI JOURNAL, except that changes in Appendix D, Anchoring to Concrete, were not included.

The intent of this article is to provide a summary of significant changes in Appendix D, Anchoring to Concrete, from ACI 318-02 to ACI 318-05.

ACI 318-05 will be the reference document for concrete design and construction in the 2006 edition of the *International Building Code*,[1] Supplement No. 1 to the 2005 edition of the *ASCE 7 Standard Minimum Design Loads for Buildings and Other Structures*,[2] and the second (2006) edition of the NFPA 5000 *Building Construction and Safety Code*,[3] issued by the National Fire Protection Association. All section numbers refer to the 2005 Code, unless otherwise noted. In the paragraphs that follow, strike-out marks, wherever used, indicate deletion of ACI 318-02 text, and underlining indicates addition of new text.

CHANGE OF NOTATION

Perhaps the most important change in ACI 318-05 is a thorough clean-up of the notation used in the Code, as discussed in Part 1 of this article. The notation changes in Appendix D of the Code are extensive and are vitally important if one is to follow the changes in that appendix from ACI 318-02 to ACI 318-05. Table 1 presents a comprehensive list of the changes. It should be evident that the ACI 318-05 notation is more descriptive. The subscripts *c* for concrete and *a* for anchor have been added in several cases. Also, to illustrate the pattern, factors Ψ_1 and Ψ_5 have been replaced by $\Psi_{ec,N}$ and $\Psi_{ec,V}$, respectively, where *ec*, *N*, and *V* stand for eccentricity, normal force (tension), and shear, respectively. The factor $\Psi_{ec,N}$ is used to modify the tensile strength of anchors based on eccentricity of applied loads, and $\Psi_{ec,V}$ is used to modify the shear strength of anchors based on eccentricity of applied loads.

CONCRETE BREAKOUT STRENGTH OF ANCHOR IN TENSION

In Section D.5.2.1, the equations for the nominal concrete breakout strength, N_{cb} or N_{cbg}, of a single anchor or a group of anchors in tension have been changed as follows:

$$N_{cb} = \frac{A_N}{A_{No}} \Psi_2 \Psi_3 N_b$$

has been replaced by:

$$N_{cb} = \frac{A_{NC}}{A_{NCo}} \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b \qquad \text{(D-4)}$$

and

$$N_{cbg} = \frac{A_N}{A_{No}} \Psi_1 \Psi_2 \Psi_3 N_b$$

has been replaced by:

$$N_{cbg} = \frac{A_{NC}}{A_{NCo}} \Psi_{ec,N} \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b \qquad \text{(D-5)}$$

Apart from a change of notation, a new modification factor $\Psi_{cp,N}$ has been added to each equation for reasons that need to be explained. Appendix D of ACI 318-02 assumed that anchors with an edge distance equal to $1.5h_{ef}$ or greater developed the basic concrete breakout strength in tension. Test experience has since shown that many torque-controlled and displacement-controlled expansion anchors and some undercut anchors require an edge distance greater than $1.5h_{ef}$ to meet this requirement in uncracked concrete without supplementary reinforcement to control splitting.

These types of anchors introduce splitting tensile stresses in the concrete during installation that are increased during load application and may cause a premature splitting failure. The $\Psi_{cp,N}$ factor is a new modification factor for these types of anchors to prevent splitting failure where supplementary reinforcement to prevent splitting is not present.

Basic Concrete Breakout Strength of Post-Installed Anchors

In Section D.5.2.2, the basic concrete breakout strength of a single anchor in tension in cracked concrete is given as follows:

$$N_b = k_c \sqrt{f'_c}\, h_{ef}^{1.5}$$

where

$k_c = 24$ for cast-in anchors, and

$k_c = 17$ for post-installed anchors

ACI 318-05 has added: "The volume of k_c for post-installed anchors shall be permitted to be increased above 17 based on ACI 355.2 product-specific tests, but shall in no case exceed 24." The following has been removed from RD.5.2.2: "When using k [now k_c] values from ACI 355.2 product approval reports, Ψ_3 [now Ψ_c] shall be taken as 1.0 because the published test results of the ACI 355.2 product approval tests provide specific k values for cracked or uncracked concrete." The intent is to clarify the design of post-installed anchors in cracked and uncracked concrete in the body of the Code rather than in the Commentary.

Anchor Close to Three or More Edges

Section D.5.2.3 now states that where anchors are located less than $1.5h_{ef}$ from three or more edges, the value of h_{ef} used in Eqs. (D-4) through (D-11) must be the greater of $c_{a,max}/1.5$ and one-third of the maximum spacing between anchors within the group; in ACI 318-02, it was just $c_{a,max}/1.5$.

The limit on h_{ef} of at least one-third of the maximum spacing between anchors within the group prevents the designer from using a calculated strength based on individual breakout prisms for a group anchor configuration. Code Fig. RD.5.2.3, reproduced here as Fig. 1, is useful in understanding the requirement of Section D.5.2.3. To visualize the requirement, move the concrete breakout surface, which originates at the actual h_{ef}, in a direction parallel to the applied tension toward the surface of the concrete.

The value of h_{ef} used in Eqs. (D-4) to (D-11) is determined when either (a) the outer boundaries of the failure surface first intersects a free edge, or (b) the intersection of the breakout surface between anchors within the group first intersects the surface of the concrete. Point A in Fig. 1 defines the intersection of the transported failure surface with the concrete surface and determines the value of h_{ef} to be used in the computation of anchor breakout strength.

In Fig. 1, the actual h_{ef} is 5.5 in., but three edges are within $1.5h_{ef}$, or 8.25 in., from the end anchor. Therefore, the limiting value of h_{ef} (h'_{ef} in the figure) is the larger of $c_{a,max}/1.5$ and one-third of the maximum spacing for an anchor group. This gives h'_{ef} = max (6/1.5, 9/3) = 4 in., which is to be used for the value of h_{ef} in Eqs. (D-4) to (D-11), including the calculation of A_{NC}; $A_{NC} = [(6 + 4)(5 + 9 + 1.5(4)] = 200\ \text{in.}^2$. Note that by ACI 318-02, h'_{ef} would also have been equal to 6/1.5 = 4 in. The new modification does not make any difference in this particular example until the spacing between the anchors exceeds (6/1.5)(3) = 12 in.

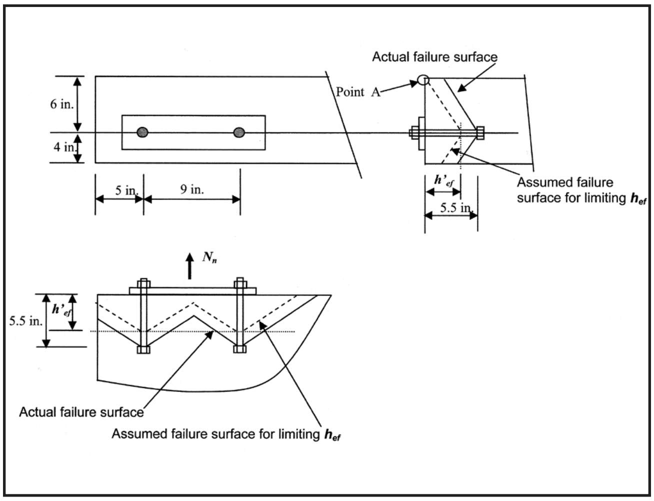

Fig. 1. Anchor in tension close to three or more edges (ACI Code Fig. RD.5.2.3).

Table 1. ACI 318 Appendix D Notation Changes from the 2002 to 2005 Editions.

Notation		ACI 318-05 Description
ACI 318-05	ACI 318-02	
A_{brg}	same	Bearing area of the head of stud or anchor bolt, in.², Appendix D.
A_{Nc}	A_N	Projected concrete failure area of ~~an~~ a single anchor or group of anchors, for calculation of strength in tension, in.², ~~as defined in~~ see D.5.2.1. ~~A_N shall not be taken greater than nA_{No}. See Fig. RD.5.2.1(b)~~, Appendix D.
A_{Nco}	A_{No}	Projected concrete failure area of ~~one~~ a single anchor, for calculation of strength in tension ~~when~~ if not limited by edge distance or spacing, in.², ~~as defined in~~ see D.5.2.1 ~~Fig. RD.5.2.1(a)~~, Appendix D.
A_{se}	same	Effective cross-sectional area of anchor, in.², Appendix D
A_{Vc}	A_V	Projected concrete failure area of ~~an~~ a single anchor or group of anchors, for calculation of strength in shear, in.², ~~as defined in~~ see D.6.2.1 and ~~A_V shall not be taken greater than nA_{Vo}. See~~ Fig. RD.6.2(b), Appendix D.
A_{Vco}	A_{Vo}	Projected concrete failure area of ~~one~~ a single anchor, for calculation of strength in shear, ~~when~~ if not limited by corner influences, spacing, or member thickness, in.², ~~as defined in~~ see D.6.2.1 ~~and see Fig. RD.6.2(a)~~, Appendix D.
	c	~~Distance from center of an anchor shaft to the edge of concrete, in., Appendix D.~~
c_{ac}		Critical edge distance required to develop the basic concrete breakout strength of a post-installed anchor in uncracked concrete without supplementary reinforcement to control splitting, in., see D.8.6, Appendix D.
$c_{a,max}$	c_{max}	~~The largest edge~~ maximum distance from center of an anchor shaft to the edge of concrete, in., Appendix D.
$c_{a,min}$	c_{min}	~~The smallest edge~~ minimum distance from center of an anchor shaft to the edge of concrete, in., Appendix D.
c_{a1}	c_1	Distance from the center of an anchor shaft to the edge of concrete in one direction, in.; ~~where~~ If shear ~~force~~ is applied to anchor, ~~c_1~~ c_{a1} is taken in the direction of the applied shear ~~force~~. If tension is applied to the anchor, c_{a1} is the minimum edge distance ~~See Fig. RD.6.2(a)~~, Appendix D.
c_{a2}	c_2	Distance from center of an anchor shaft to the edge of concrete in the direction ~~orthogonal~~ perpendicular to ~~c_1~~ c_{a1}, in., Appendix D.
d_o	same	Outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt, in., see ~~See also~~ D.8.4, Appendix D.
d'_o	same	Value substituted for d_o when an oversized anchor is used, in., see ~~See~~ D.8.4, Appendix D.
e_h	same	Distance from the inner surface of the shaft of a J- or L-bolt to the outer tip of the J- or L-bolt, in., Appendix D.
e'_N	same	~~Eccentricity of normal force on a group of anchors; the~~ distance between ~~the~~ resultant tension load on a group of anchors loaded in tension and the centroid of the group of anchors loaded in tension, in.; e'_N is always positive~~. See Fig. RD.5.2(b) and (c)~~, Appendix D.
e'_V	same	~~Eccentricity of shear force on a group of anchors; the~~ distance between ~~the~~ resultant shear load on a group of anchors loaded in shear in the same direction ~~point of shear force application~~ and the centroid of the group of anchors loaded in ~~resisting~~ shear in the same direction ~~of the applied shear~~, in.; e'_V is always positive, Appendix D.
f'_c	same	Specified compressive strength of concrete, psi, Chapters 4, 5, 8-12, 14, ~~15,18-22~~ 18, 19, 21 22, Appendices A-D.
$\sqrt{f'_c}$	same	Square root of specified compressive strength of concrete, psi, Chapters 8, 9, 11, 12, 18, 19, 21, 22, Appendix D.
f_r	same	Modulus of rupture of concrete, psi, ~~See~~ see 9.5.2.3, Chapters 9, 14, 18, ~~Appendices~~ Appendix B~~, D~~.
	f_t	~~Calculated concrete tensile stress in a region of a member, psi, Appendix D.~~
f_{uta}	f_{ut}	Specified tensile strength of anchor steel, psi, Appendix D.
	f_{utsl}	~~Specified tensile strength of anchor sleeve, psi, Appendix D.~~
f_{ya}	f_y	Specified yield strength of anchor steel, psi, Appendix D.
h_a	h	Thickness of member in which an anchor is ~~anchored~~ located, measured parallel to anchor axis, in., Appendix D.
h_{ef}	same	Effective ~~anchor~~ embedment depth of anchor, in., see ~~See~~ D.8.5 ~~and Fig. RD.1~~, Appendix D
k_c	k	Coefficient for basic concrete breakout strength in tension, Appendix D.
k_{cp}	same	Coefficient for pryout strength, Appendix D.
ℓ_e	ℓ	Load bearing length of anchor for shear, ~~not to exceed $8d_o$~~, in., see D.6.2.2, Appendix D. ~~= h_{ef} for anchors with a constant stiffness over the full length of the embedded section, such as headed studs or post-installed anchors with one tubular shell over the full length of the embedment depth, Appendix D.~~ = $2d_o$ for torque controlled expansion anchors with a distance sleeve-separated from the expansion sleeve, Appendix D
n	n	~~Number of anchors in a group, Appendix D.~~ Number of items, such as strength tests, bars, ~~or~~ wires, monostrand anchorage devices, anchors, or shearhead arms ~~being spliced or developed along the plane of splitting~~, Chapters 5, 11, 12, 18, Appendix D.
N_b	same	Basic concrete breakout strength in tension of a single anchor in cracked concrete, ~~as defined in D.5.2.2,~~ lb, see D.5.2.2, Appendix D.

N_{cb}	same	Nominal concrete breakout strength in tension of a single anchor, ~~as defined in D.5.2.1,~~ lb, see D.5.2.1, Appendix D.
N_{cbg}	same	Nominal concrete breakout strength in tension of a group of anchors, ~~as defined in D.5.2.1,~~ lb, see D.5.2.1, Appendix D.
N_n	same	Nominal strength in tension, lb, Appendix D.
N_p	same	Pullout strength in tension of a single anchor in cracked concrete, ~~as defined in D.5.3.4 or D.5.3.5,~~ lb, see D.5.3.4 and D.5.3.5, Appendix D
N_{pn}	same	Nominal pullout strength in tension of a single anchor, as defined in D.5.3.1, lb, see D.5.3.1, Appendix D.
N_{sa}	N_s	Nominal strength of a single anchor or group of anchors in tension as governed by the steel strength, ~~as defined in D.5.1.1 or D.5.1.2,~~ lb, see D.5.1.1 and D.5.1.2, Appendix D.
N_{sb}	same	Side-face blowout strength of a single anchor, lb, Appendix D.
N_{sbg}	same	Side-face blowout strength of a group of anchors, lb, Appendix D.
N_{ua}	N_u	Factored tensile force ~~load~~ applied to anchor or group of anchors, lb, Appendix D.
s	same	~~Anchor center to center spacing, in., Appendix D.~~ Center-to-center spacing of items, such as longitudinal reinforcement, transverse reinforcement, prestressing tendons, wires, or anchors, ~~spacing of shear or torsion transverse reinforcement in direction parallel ot longitudinal reinforcement,~~ in., Chapters ~~11,~~ 10-12, 17-~~18~~, 21, Appendix D.
	s_o	~~Spacing of the outer anchors along the edge in a group, in., Appendix D.~~
s_s	s	Sample standard deviation, psi, Chapter 5, Appendix D.
	t	~~Thickness of washer or plate, in., Appendix D.~~
V_b	same	Basic concrete breakout strength in shear of a single anchor in cracked concrete, ~~as defined in D.6.2.2 or D.6.2.3,~~ lb, see D.6.2.2 and D.6.2.3, Appendix D.
V_{cb}	same	Nominal concrete breakout strength in shear of a single anchor, ~~as defined in D.6.2.1,~~ lb, see D.6.2.1, Appendix D.
V_{cbg}	same	Nominal concrete breakout strength in shear of a group of anchors, ~~as defined in D.6.2.1,~~ lb, see D.6.2.1, Appendix D.
V_{cp}	same	Nominal concrete pryout strength of a single anchor, ~~as defined in D.6.3,~~ lb, see D.6.3, Appendix D.
V_{cpg}		Nominal concrete pryout strength of a group of anchors, lb, see D.6.3, Appendix D.
V_n	same	Nominal shear strength, lb, Chapters 8, 10, 11, 21, 22, Appendix~~ces C,~~ D.
V_{sa}	V_s	Nominal strength in shear of a single anchor or group of anchors as governed by the steel strength, ~~as defined in D.6.1.1 or D.6.1.2,~~ lb, see D.6.1.1 and D.6.1.2, Appendix D.
V_{ua}	V_u	Factored shear force ~~load~~ applied to a single anchor or group of anchors, lb, Appendix D.
ϕ	same	Strength reduction factor, see 9.3, Chapters 8-11, 13, 14, ~~17-19, 21, 22,~~ 17-22, Appendices A, B, C, D.
$\psi_{c,N}$	ψ_3	~~Modification factor, for strength in tension, to account for cracking, as defined in D.5.2.6 and D.5.2.7, Appendix D.~~ Factor used to modify tensile strength of anchors based on presence or absence of cracks in concrete, see D.5.2.6, Appendix D.
$\psi_{c,P}$	ψ_4	~~Modification factor, for pullout strength, to account for cracking, as defined in D.5.3.1 and D.5.3.6, Appendix D.~~ Factor used to modify pullout strength of anchors based on presence or absence of cracks in concrete, see D.5.3.6, Appendix D.
$\psi_{c,V}$	ψ_7	~~Modification factor, for strength in shear, to account for cracking, as defined in D.6.2.7, Appendix D.~~ Factor used to modify shear strength of anchors based on presence or absence of cracks in concrete and presence or absence of supplementary reinforcement, see D.6.2.7 for anchors in shear, Appendix D.
$\psi_{cp,N}$		Factor used to modify tensile strength of post-installed anchors intended for use in uncracked concrete without supplementary reinforcement, see D.5.2.7, Appendix D.
$\psi_{ec,N}$	ψ_1	~~Modification factor, for strength in tension, to account for anchor groups loaded eccentrically, as defined in D.5.2.4, Appendix D.~~ Factor used to modify tensile strength of anchors based on eccentricity of applied loads, see D.5.2.4, Appendix D.
$\psi_{ec,V}$	ψ_5	~~Modification factor, for strength in shear, to account for anchor groups loaded eccentrically, as defined in D.6.2.5, Appendix D.~~ Factor used to modify shear strength of anchors based on eccentricity of applied loads, see D.6.2.5, Appendix D.
$\psi_{ed,N}$	ψ_2	~~Modification factor, for strength in tension, to account for edge distances smaller than **1.5**h_{ef}, as defined in D.5.2.5, Appendix D.~~ Factor used to modify tensile strength of anchors based on proximity to edges of concrete member, see D.5.2.5, Appendix D.
$\psi_{ed,V}$	ψ_6	~~Modification factor, for strength in shear, to account for edge distances smaller than **1.5**c_1, as defined in D.6.2.6, Appendix D.~~ Factor used to modify shear strength of anchors based on proximity to edges of concrete member, see D.6.2.6, Appendix D.

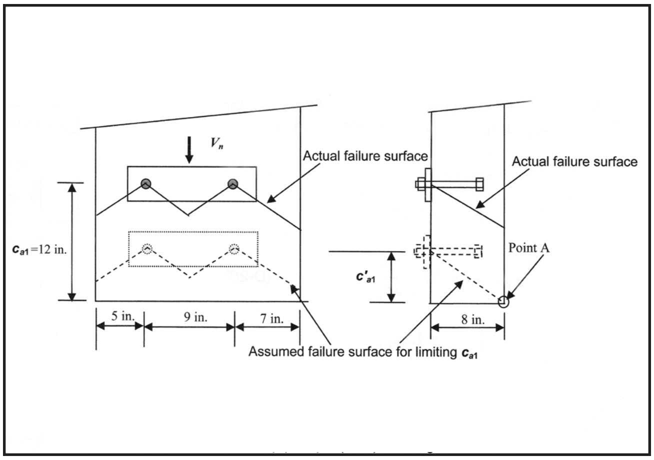

Fig. 2. Anchor in shear close to three or more edges (ACI Code Fig. RD.6.2.4).

Modification Factor for Anchor Groups Loaded Eccentrically in Tension

Fig. RD.5.2.4, showing the definition of e'_N for a group of anchors, has been significantly modified.

Modification Factor Based on Presence or Absence of Cracks in Concrete

ACI 318-05 has added the following requirements:

1. Where the value of k_c used in Eq. (D-7) is taken from the ACI 355.2 product evaluation report for post-installed anchors qualified for use in cracked and uncracked concrete, the values of k_c and $\Psi_{c,N}$ shall be based on the ACI 355.2 product evaluation report.
2. Where the value of k_c used in Eq. (D-7) is taken from the ACI 355.2 product evaluation report for post-installed anchors qualified for use only in uncracked concrete, $\Psi_{c,N}$ shall be taken as 1.0.

The intent once again is to clarify the design of post-installed anchors used in cracked and uncracked concrete in the body of the Code.

Modification Factor for Post-Installed Anchors

As noted earlier, ACI 318-05 has introduced a modification factor for post-installed anchors designed for uncracked concrete in accordance with Section D.5.2.6 without supplementary reinforcement to control splitting. This modification factor is given by:

$$\Psi_{cp,N} = 1.0 \text{ if } c_{a,min} \geq c_{ac} \quad \text{(D-12)}$$

or

$$\Psi_{cp,N} = \frac{c_{a,min}}{c_{ac}} \geq \frac{1.5h_{ef}}{c_{ac}} \text{ if } c_{a,min} < c_{ac} \quad \text{(D-13)}$$

where the critical edge distance, c_{ac}, is defined in Section D.8.6 (equal to $2.5h_{ef}$ for undercut anchors and $4h_{ef}$ for torque-controlled anchors and displacement-controlled anchors).

For all other cases, including cast-in anchors, $\Psi_{cp,N}$ is to be taken equal to 1.0.

The new modification factor, $\Psi_{cp,N}$, has been explained earlier. Section RD.5.2.7 points out that the presence of supplementary reinforcement to control splitting does not affect the selection of Condition A or B in Sections D.4.4 and D.4.5.

STEEL STRENGTH OF ANCHOR IN SHEAR

In Section D.6.1.2(b), Eq. (D-20) for cast-in headed bolt and hooked bolt anchors is now applicable also to post-installed anchors where sleeves do not extend through the shear plane. Section D.6.1.2(c) now requires "that for post-installed anchors where sleeves extend through the shear plane, V_{sa} shall be based on the results of tests performed and evaluated according to ACI 355.2. Alternatively, Eq. (D-20) shall be permitted to be used." Eq. (D-19) in Section D.6.1.2(c) of ACI 318-02 has been deleted. These changes have been made to require testing if the contribution of post-installed anchor sleeves to shear strength is to be taken into account.

CONCRETE BREAKOUT STRENGTH IN SHEAR

Section D.6.2.1(c) now states: "For shear force parallel to an edge, V_{cb} or V_{cbg} shall be permitted to be twice the value of the shear force determined from Eq. (D-21) or (D-22), respectively, with the shear force assumed to act perpendicular to the edge and with $\Psi_{ed,V}$ taken equal to 1.0." This modification is intended to clarify how to evaluate the shear breakout strength when anchors are loaded parallel to an edge.

Section RD.6.2.1 has been modified as follows:

"~~The assumption shown in the upper right example of Fig. RD.6.2.1(b), with the case for two anchors perpendicular to the edge, is a conservative interpretation of the distribution of the shear force on an elastic basis.~~ When using Eq. (D-22) for anchor groups loaded in shear, both assumptions for load distribution illustrated in examples on the right side of Fig. RD.6.2.1(b) should be considered because the anchors nearest the edge could fail first or the whole group could fail as a unit with the failure surface originating from the anchors farthest from the edge. If the anchors are welded to a common plate, when the anchor nearest the front edge begins to form a failure cone, shear load would be transferred to the stiffer and stronger rear anchor. For this reason, anchors welded to a common plate do not need to consider the failure mode shown in the upper right figure of Fig. RD.6.2.1(b). ~~For cases where nominal strength is not controlled by ductile steel elements, D.3.1 requires that load effects be determined by elastic analysis.~~"

…

"The case of shear force parallel to an edge is shown in Fig. RD.6.2.1(c). A special case can arise with shear force parallel to the edge near a corner. In the example of a single anchor near a corner (see Fig. RD.6.2.1(d)), the provisions for shear in the direction of the load should be checked in addition to the provisions for shear in the direction parallel to the edge. ~~where the edge distance to the side c_2 is 40 percent or more of the distance c_1 in the direction of the load, the shear strength parallel to that edge can be computed directly from Eq. (D-20) and (D-21) using c_1 in the direction of the load.~~"

These changes are intended to provide guidance for computing the nominal concrete breakout strength in shear for anchor groups and for anchors that are loaded parallel to an edge.

Anchor Close to Three or More Edges

Section D.6.2.4 now states: "Where anchors are influenced by three or more edges, the value of c_{a1} used in Eqs. (D-23) through (D-28) shall not exceed the greatest of: $c_{a2}/1.5$ in either direction, $h_a/1.5$, and one-third of the maximum spacing between anchors within the group." In ACI 318-02, it was: "…edge distance c_1 [now c_{a1}] shall be limited to h[now h_a]/1.5."

The changes have been made so that the overly conservative concrete breakout strengths in shear given by ACI 318-02 for anchors influenced by three or four edges would be more in accordance with test results. The limit on c_{a1} of at least one-third of the maximum spacing between anchors within the group keeps the calculated strength from being based on individual breakout prisms for a group anchor configuration.

Fig. RD.6.2.4, reproduced here as Fig. 2, is useful in understanding the requirement of Section D.6.2.4. To visualize the requirement, move the concrete breakout surface originating at the actual c_{a1} in the direction of the applied shear toward the surface of the concrete.

The value of c_{a1} to be used in Eqs. (D-21) to (D-28) is determined when either (a) the outer boundaries of the failure surface first intersect a free edge, or (b) the intersection of the breakout surface between anchors within the group first intersects the surface of the concrete. Point A in Fig. 1 defines the intersection of the transported failure surface with the concrete surface, and determines the value of c_{a1} to be used in the computation of anchor breakout strength.

In Fig. 2, the actual c_{a1} is 12 in., but two orthogonal edges are within $1.5c_{a1}$ or 18 in. from the anchor group; c_{a2} = the larger of 5 and 7 in. = 7 in., and h_a = 8 in. Therefore, the limiting value of c_{a1} (c'_{a1} in the figure) is the largest of $c_{a2,max}/1.5$, $h_a/1.5$, and one-third of the maximum spacing for an anchor group. This gives c_{a1} = max (7/1.5, 8/1.5, 9/3) = 5.33 in., which is to be used for the value of c_{a1} in Eq. (D-21) to (D-28), including the calculation of A_{Vc}; $A_{Vc} = (5 + 9 + 7)(1.5)(5.33) = 168$ in.^{2}, which is the cross-sectional area of the member.

Note that by ACI 318-02, c'_{a1} would also have been equal to 8/1.5 = 5.33 in. The new modifications do not make any difference in this particular example until the spacing between the anchors exceeds (8/1.5)(3) = 16 in. and/or the larger orthogonal edge distance c_{a2} exceeds 8 in.

CONCRETE PRYOUT STRENGTH IN SHEAR

In Section D.6.3.1, a new equation has been added for the pryout strength of a group of anchors in shear:

$$V_{cpg} = k_{cp}N_{cpg}$$

where N_{cpg} is given by Eq. (D-5).

CRITICAL EDGE DISTANCE FOR POST-INSTALLED ANCHORS

A new Section D.8.6 has been added, requiring that the critical edge distance, c_{ac} (see "Modification Factor for Post-Installed Anchors," above), unless determined from tension tests in accordance with ACI 355.2, shall not be taken less than:

$2.5h_{ef}$ for undercut anchors
$4h_{ef}$ for torque-controlled anchors
$4h_{ef}$ for displacement-controlled anchors

CONCLUDING REMARKS

ACI 318 Appendix D, Anchoring to Concrete, which was first included in ACI 318-02 and introduced the Concrete Capacity Design (CCD) method of anchor design, has been modified in a number of ways in ACI 318-05. These changes have been discussed in this article.

Further changes to Appendix D of ACI 318-02 have been suggested.[4,5] ACI Committee 318 will consider these changes for possible inclusion in ACI 318-08.

PCI has sponsored an extensive research program, conducted by Wiss, Janney, Elstner Associates, Inc. (WJE), to study design criteria for headed stud groups loaded in shear[5,6] as well as subject to the combined effects of shear and tension. The Sixth Edition of the *PCI Design Handbook*,[7] while using Appendix D of ACI 318-02 for stud groups in tension, has chosen to use shear provisions culminating from this research. Further results from this investigation have just been published.[8]

In view of the above, it appears likely that Appendix D will undergo further significant modifications in ACI 318-08 and beyond.

REFERENCES

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