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Post-Installed Mechanical Anchors in Concrete— Qualification Requirements and Commentary

Reported by ACI Committee 355

ACI CODE-355.2-22



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Post-Installed Mechanical Anchors in Concrete—Qualification Requirements and Commentary

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Post-Installed Mechanical Anchors in Concrete— Qualification Requirements and Commentary

An ACI Standard

Reported by ACI Committee 355

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ACI CODE-355.2 prescribes testing programs and evaluation requirements for post-installed mechanical anchors intended for use in structural applications addressed by ACI 318 and subjected to static or seismic loads in tension, shear, or combined tension and shear. Criteria are prescribed for determining whether anchors are acceptable for use in uncracked concrete only, or in cracked as well as uncracked concrete. Performance categories for anchors are established, as are the criteria for assigning anchors to each

category. The anchor performance categories are used by ACI 318 to assign capacity reduction factors and other design parameters.

Keywords: anchors; cracked concrete; expansion anchors; fasteners; mechanical anchors; post-installed anchors; screw anchors; undercut anchors.

This Code was developed by an ANSI-approved consensus process.

ACI CODE-355.2-22 supersedes ACI 355.2R-19 and was adopted and published in September 2022.

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CODE

CHAPTER 1—GENERAL

1.1—Scope

ACI CODE-355.2 prescribes testing and evaluation requirements for post-installed mechanical anchors intended for use in concrete designed under the provisions of **ACI 318**. Criteria are prescribed to determine whether anchors are acceptable for use in uncracked concrete only, or in cracked as well as uncracked concrete. Criteria are prescribed to determine the performance category for each anchor. The anchor performance categories are used by ACI 318 to assign capacity reduction factors and other design parameters.

1.2—General

ACI CODE-355.2 describes the tests required to qualify a post-installed mechanical anchor or anchor system for use under the provisions of ACI 318.

1.3—Purpose

ACI CODE-355.2 applies to post-installed mechanical anchors (torque-controlled expansion anchors, displacement-controlled expansion anchors, undercut anchors, and screw anchors) placed into predrilled holes and anchored within the concrete by mechanical means.

1.4—Applicability

ACI CODE-355.2 applies to expansion, undercut, and screw anchors with a minimum effective embedment depth of 1-1/2 in. and with a nominal diameter of 1/4 in. or larger. Screw anchors are limited to a maximum effective embedment of $10d_a$.

COMMENTARY

CHAPTER R1—GENERAL

R1.1—Scope

ACI CODE-355.2 prescribes the testing programs required to qualify post-installed mechanical anchors for use with the design method of ACI 318-19 Chapter 17, where it is assumed that anchors have been tested either for use in uncracked concrete or for use in cracked and uncracked concrete. This testing is performed in concrete specimens controlled by the testing laboratory as a means of simulating concrete, both cracked and uncracked, that might occur in actual structures. Post-installed mechanical anchors exhibit a range of working principles, proprietary designs, and performance characteristics. ACI 318-19 Chapter 17 addresses this situation by basing capacity reduction factors for anchors on anchor performance categories. ACI CODE-355.2 is intended to develop the data required by ACI 318-19 Chapter 17 to confirm an anchor's reliability and place it in the appropriate anchor category.

ASTM E488/E488M includes some details for cracked concrete test members similar to those in this document. ASTM E488/E488M also has detailed test procedures for testing in cracked concrete.

R1.4—Applicability

The design method deemed to satisfy the anchor design requirements of ACI 318-19 Chapter 17 is based on an analysis of a database of anchors with a maximum diameter of 2 in. and an embedment depth not greater than 25 in. ACI CODE-355.2 can be used for anchors with those maximum dimensions. While ACI CODE-355.2 gives no limitations on maximum anchor diameter or embedment depth, for anchors beyond these dimensions, the testing authority should decide if the tests described herein are applicable or if alternative tests and analyses are more appropriate. The minimum diameter of 1/4 in. is based on practical considerations regarding the limit of structural anchor applications. The current database of screw anchors contains products with an embedment up to $h_{ef} = 10d_a$ due to practical limits of manufacturing and ability to install at deep embedments. This database has been shown to satisfy the design requirements of ACI 318-19 Chapter 17.



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CODE**COMMENTARY****1.5—Interpretation**

The values stated either in inch-pound units or SI units are to be separately regarded. Within the text, the SI units are shown in parentheses. The values in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems shall result in nonconformance with ACI CODE-355.2.

CODE

COMMENTARY

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_{se} = effective cross-sectional area of anchor, in.² (mm²)

c_{ac} = critical edge distance required to develop the basic strength as controlled by concrete breakout of a single post-installed anchor in tension in uncracked concrete without supplementary reinforcement to control splitting, in. (mm)

c_{min} = minimum allowable edge distance as determined from testing and given in manufacturer's data sheets, in. (mm)

d_a = outside diameter of post-installed anchor, in. (mm)

d_f = diameter of the hole in the testing fixture

d_m = diameter of carbide-tipped drill bit with diameter on low end of tolerance range for new bit, representing moderately used bit, in. (mm)

d_{max} = diameter of carbide-tipped drill bit with diameter on high end of tolerance range for new bit, representing bit as large as would be expected in use, in. (mm)

d_{min} = diameter of carbide-tipped drill bit with diameter below low end of tolerance range for new bit, representing a well-used bit, in. (mm)

$F_{5\%}$ = characteristic capacity in test series, as calculated using Eq. (A2.2), lb (N)

F_m = mean failure capacity, lb (N)

$F_{m,i}$ = mean normalized capacity in test series i , as calculated using Eq. (A1.2), lb (N)

F_{ut} = mean normalized anchor capacity in test series i as calculated using Eq. (A1.4), lb (N)

$F_{u,test,i}$ = mean anchor capacity as determined from test series i , lb (N)

f'_c = specified compressive strength of concrete, psi (MPa)

$f_{c,m,i}$ = concrete compressive strength to which test results for test series i are to be normalized using Eq. (A1.2), psi (MPa)

$f_{c,ref}$ = the concrete compressive strength of the specimen used for the confined reference tests

$f_{c,test}$ = mean concrete compressive strength as measured at time of testing

$f_{c,test,i}$ = mean concrete compressive strength measured with standard cylinders, for concrete of test series i , psi (MPa)

f_{ut} = specified ultimate tensile strength of anchor steel, psi (MPa)

$f_{u,test}$ = mean ultimate tensile strength of anchor steel as determined by test, psi (MPa)

CHAPTER R2—NOTATION AND DEFINITIONS

R2.1—Notation

$A_{se,N}$ = effective cross-sectional area of anchor in tension, in.² (mm²)

$A_{se,V}$ = effective cross-sectional area of anchor in shear, in.² (mm²)

CODE

COMMENTARY

f_y	=	specified yield strength of anchor steel, psi (MPa)
h	=	thickness of structural member, measured perpendicular to concrete surface where the anchor is installed, in. (mm)
h_{ef}	=	effective embedment depth for expansion, undercut, and screw anchors
h_{hole}	=	overall depth of the drilled hole, in. (mm)
h_{min}	=	minimum member thickness, specified by the anchor manufacturer, in. (mm)
h_{nom}	=	distance between the embedded end of the expansion, undercut, or screw anchor, and the concrete surface, in. (mm)
h_s	=	length of the embedded end of the screw anchor without full height of thread (= thread runout + length without thread), in. (mm)
h_t	=	thread pitch, in. (mm)
K	=	statistical constant (one-sided tolerance factor) used to establish 5 percent fractile with a 90 percent confidence, whose value depends on the number of tests (Appendix A2)
k	=	effectiveness factor, whose value depends on the type of anchor
k_{cr}	=	effectiveness factor for anchors tested in cracked concrete
k_m	=	mean effectiveness factor
k_{uncr}	=	effectiveness factor for anchors tested in uncracked concrete
N	=	normal force (generally tensile), lb (N)
N_1	=	minimum tension load above which variations in the load-displacement curve are acceptable, as prescribed in 6.5.1.1, lb (N)
$N_{10\%}$	=	mean load at 10 percent of ultimate load measured in tension test, lb (N)
$N_{30\%}$	=	mean load at 30 percent of ultimate load measured in tension tests, lb (N)
N_b	=	characteristic tensile capacity of an anchor with a concrete failure mode (5 percent fractile of test results), lb (N)
$N_{b,o}$	=	characteristic tensile capacity in reference tests, lb (N)
$N_{b,r}$	=	characteristic tensile capacity in reliability tests, lb (N)
N_{eq}	=	maximum tension load to be applied in the simulated seismic tension test in accordance with Table 10.5.2, Fig. 10.5.2, and Eq. (10.5.2), lb (N)
$N_{eq, reduced}$	=	reduced maximum tension load at which the anchor successfully completes the simulated seismic tension test, lb (N)
N_i	=	intermediate tension load to be applied in the simulated seismic tension test in accordance with Table 10.5.2 and Fig. 10.5.2, lb (N)
$N_{i, reduced}$	=	reduced intermediate tension load at which the anchor successfully completes the simulated seismic tension test, lb (N)



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COMMENTARY

N_k	= lowest characteristic tensile capacity in reference tests in uncracked concrete for concrete, steel, or pullout failures for the concrete strength of the test member, lb (N)
N_m	= minimum tension load to be applied in the simulated seismic tension test in accordance with Table 10.5.2 and Fig. 10.5.2, lb (N)
$N_{m, reduced}$	= reduced minimum tension load at which the anchor successfully completes the simulated seismic tension test, lb (N)
$N_{p, cr}$	= nominal pullout strength in tension of a single anchor in cracked concrete, lb (N)
$N_{p, eq}$	= nominal pullout strength in tension of a single anchor for load cases, including earthquake loading, in accordance with ACI 318, lb (N)
$N_{p, uncr}$	= nominal pullout strength in tension of a single anchor in uncracked concrete, lb (N)
N_{st}	= characteristic tensile steel capacity of an anchor, lb (N)
$N_{st, mean}$	= average ultimate steel capacity determined from tensile tests on full-sized anchor specimens, lb (N)
$N_{sust, con}$	= sustained load used for confined reference tests, lb (N)
N_u	= ultimate load measured in a tension test, lb (N)
$N_{u, con, mean}$	= average ultimate load determined from confined reference tests, lb (N)
N_w	= tensile load in tests of anchors located in cracks whose opening width is cycled, lb (N)
n	= number of anchors in a test series

n_t = number of threads per inch (millimeter)

CODE

COMMENTARY

s_{min}	= minimum spacing used in Table 5.1a, Test 13, and Table 5.1b, Test 16, in. (mm)
T	= applied torque in a test, ft-lb (N-m)
$T_{5\%}$	= 5 percent fractile of the ultimate torque moments, T_u , calculated in accordance with Appendix A2 , ft-lb (N-m)
T_{inst}	= specified or maximum setting torque for expansion or prestressing of an anchor, ft-lb (N-m)
T_{screw}	= specified maximum setting torque to prevent screw anchor failure during installation, ft-lb (N-m)
T_u	= mean ultimate torque moment, as measured in setting method tests, ft-lb (N-m)
V_{eq}	= maximum shear load to be applied in the simulated seismic shear test in accordance with Table 10.6.2, Fig. 10.6.2a, and either Eq. (10.6.2a) or (10.6.2b), lb (N)
$V_{eq, reduced}$	= reduced maximum shear load at which the anchor successfully completes the simulated seismic shear test, lb (N)
V_i	= intermediate shear load to be applied in the simulated seismic shear test in accordance with Table 10.6.2 and Fig. 10.6.2a, equal to $0.75V_{eq}$, lb (N)
$V_{i, reduced}$	= reduced intermediate shear load at which the anchor successfully completes the simulated seismic shear test, equal to $0.75V_{eq, reduced}$, lb (N)
V_m	= minimum shear load to be applied in the simulated seismic shear test in accordance with Table 10.6.2 and Fig. 10.6.2a, equal to $0.50V_{eq}$, lb (N)
$V_{m, reduced}$	= reduced minimum shear load at which the anchor successfully completes the simulated seismic shear test, equal to $0.50V_{eq, reduced}$, lb (N)
V_{sa}	= nominal shear strength in shear of a single anchor as governed by steel strength in accordance with ACI 318 , lb (N)
$V_{sa, eq}$	= nominal shear strength in shear of a single anchor for load cases, including earthquake loading, in accordance with ACI 318 , lb (N)
v	= sample coefficient of variation (standard deviation divided by the mean) expressed as decimal fraction or in percent
w	= crack width, in. (mm)
β	= axial stiffness of anchor in service load range, lb/in. (kN/mm)
Δw	= change in crack width, in. (mm)
$\Delta_{10\%}$	= mean displacement measured at 10 percent of ultimate load in tension test, in. (mm)
$\Delta_{30\%}$	= mean displacement measured at 30 percent of ultimate load in tension test, in. (mm)
$\psi_{c, N}$	= factor used to modify tensile strength of anchors based on presence or absence of crack in concrete

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For post-installed anchors having a reduced cross-sectional area anywhere along the anchor length, the effective cross-sectional area of the anchor should be provided by the manufacturer. For threaded bolts, ASME B1.1 defines $A_{se,N}$ or $A_{se,V}$ as

$$A_{se,N} \text{ or } A_{se,V} = \frac{\pi}{4} \left(d_o - \frac{0.9743}{n_t} \right)^2$$

Load is transferred along the length of the anchor rather than by the single deepest point of load transfer. Research (Olsen et al. 2012) has shown that the ACI 318-19 Chapter 17 design equations for mechanical anchors can be used for screw anchors with an effective embedment equal to approximately 85 percent of the nominal embedment (with minor adjustments for thread pitch and runout), which is calculated using the following equation (Fig. R2.1a and R2.1b).

$$h_{ef} = 0.85(h_{nom} - 0.5h_t - h_s)$$

The effective embedment depth for screw anchors as well as other post-installed mechanical anchors will be provided by the manufacturer.

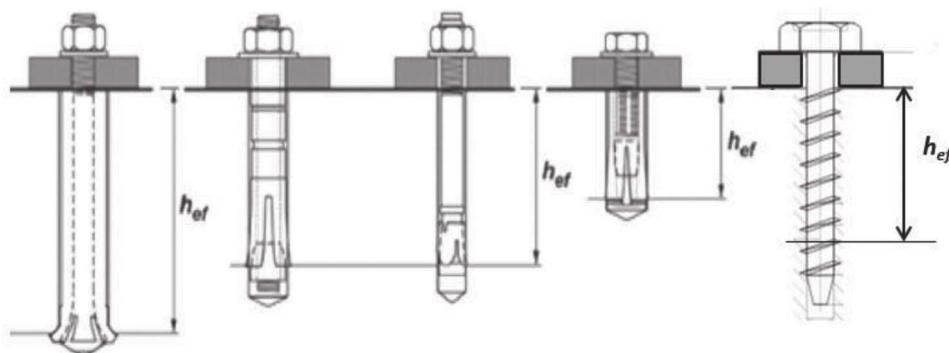


Fig. R2.1a—Effective embedment depth.

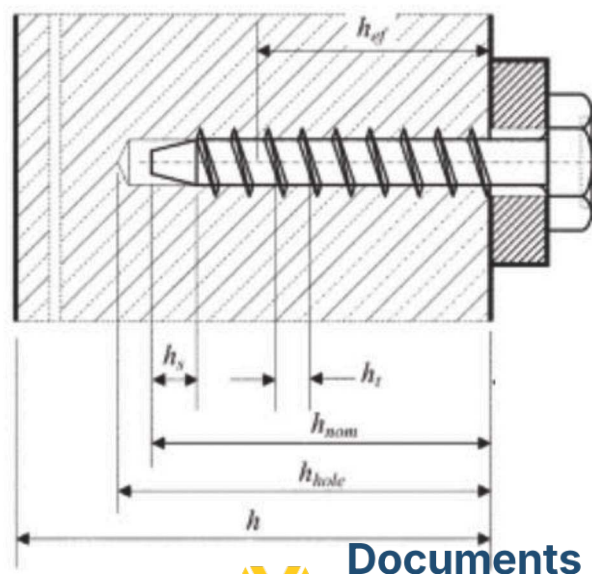


Fig. R2.1b—Effective embedment depth for screw anchors.

CODE

2.2—Definitions

anchor category—classification for an anchor that is established by the performance of the anchor in reliability tests.

anchor group—number of anchors of approximately equal effective embedment depth with each anchor spaced at less than three times its embedment depth from one or more adjacent anchors.

anchor system—similar anchors that vary only due to diameter or embedment depth; a product line of a single manufacturer.

characteristic value—5 percent fractile (value with a 95 percent probability of being exceeded, with a confidence of 90 percent).

concrete breakout failure—concrete failure mode that develops a breakout or edge failure of the test member due to setting of the anchor or to applied loads.

cracked concrete—reinforced concrete test member with a full-depth, approximately uniform, crack of a specified width according to the test procedure.

displacement-controlled expansion anchor—post-installed anchor that is set by expansion against the side of the drilled hole through movement of an internal plug in the sleeve or through movement of the sleeve over an expansion element (plug); once set, no further expansion can occur.

effective embedment depth—for expansion and undercut anchors measured from the concrete surface to the deepest point at which the anchor tension load is transferred to the concrete, in. (mm). For screw anchors, the effective embedment depth is approximated. The effective embedment depth for all mechanical anchors is provided by the manufacturer.

pullout failure—failure mode in which the anchor pulls out of the concrete without development of the full steel or concrete capacity.

pull-through failure—failure mode in which the anchor body pulls through the expansion mechanism without development of the full steel or concrete capacity.

screw anchor—post-installed anchor that is a threaded mechanical fastener placed in a predrilled hole; anchor derives its tensile holding strength from the mechanical interlock of the fastener threads with the grooves cut into concrete during installation.

setting of an anchor—process of activating the load-transfer mechanism of an anchor in a drilled hole.

COMMENTARY

R2.2—Definitions

characteristic value—used for design in [ACI 318-19](#) Chapter 17. The characteristic value is less than the average by a percentage of the average and based on the number of tests conducted, the confidence level that the code-writing body elects to use, and an accepted failure rate. The characteristic value or 5 percent fractile (value with a 95 percent probability of being exceeded, with a confidence of 90 percent) has been selected for the design of anchorages.

concrete breakout failure—includes concrete breakout under tension load, edge breakout from tension or shear, or combinations of these, as shown in Fig. 6.5.3a and 6.5.3b.

cracked concrete—to facilitate reproducibility of test results, cracked concrete tests for the prequalification of post-installed anchors are performed in line cracks with an approximately uniform crack width over the depth of the specimen.

pullout failure—occurs if the anchor does not sufficiently engage the concrete to produce a steel or concrete breakout failure. The entire anchor slips out of the drilled hole at a load lower than that corresponding to concrete breakout. While a concrete breakout may occur as part of the pullout failure, it will be at a shallower embedment depth than for a full concrete breakout failure.

pull-through failure—occurs if the anchor shank pulls through the expansion mechanism, which remains in the drilled hole. The anchor shank slips out of the drilled hole at a load lower than that corresponding to concrete breakout.

CODE

splitting failure—concrete failure mode in which the concrete fractures along a plane passing through the axis of the anchor or anchors.

statistical equivalence—statistical equivalence of two groups of test results shall be determined by two one-sided *t*-tests (TOST) in accordance with **ASTM E2935** at a significance $\alpha = 0.10$ for an assumed symmetrical equivalence limit $E = 15$ percent. For this purpose, the equivalence or nonequivalence of variances shall be established with the *F*-test or with Levene's test with $\alpha = 0.10$.

steel failure—failure mode in which the steel anchor parts fracture.

test series—group of tests having the same parameters.

torque-controlled expansion anchor—post-installed expansion anchor that is set by the expansion of one or more sleeves or other elements against the sides of the drilled hole through the application of torque, which pulls the cone(s) into the expansion sleeve(s); after setting, tensile loading can cause additional expansion (follow-up expansion).

uncracked concrete—test member that remains uncracked unless the crack is part of a failure mode.

undercut anchor—post-installed anchor that develops its holding strength from the mechanical interlock provided by undercutting of the concrete, achieved either by a special tool or by the anchor itself during installation.

COMMENTARY

statistical equivalence—the two one-sided *t*-tests (TOST) are used in place of the Student's *t*-test to establish equivalency of data sets because it appropriately associates the significance (α) with consumer risk instead of producer risk.

uncracked concrete—under ACI CODE-355.2, anchors for use in uncracked concrete are tested in concrete that is uncracked and is expected to remain so unless the anchor causes cracking as part of the failure mode.



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COMMENTARY

CHAPTER 3—REFERENCED STANDARDS

Committee documents are listed first by document number and year of publication followed by authored documents listed alphabetically.

ACI 318-19—Building Code Requirements for Structural Concrete and Commentary

American National Standards Institute

ANSI B212.15-94(R2000)—American National Standard for Cutting Tools—Carbide-Tipped Masonry Drills and Blanks for Carbide-Tipped Masonry Drills

ASTM International

ASTM A370-18—Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM C31/C31M-18—Standard Practice Making and Curing Concrete Test Specimens in the Field

ASTM C33/C33M-18—Standard Specification for Concrete Aggregates

ASTM C39/C39M-18—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C150/C150M-19—Standard Specification for Portland Cement

ASTM E488/E488M-18—Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements

ASTM E2935-17—Standard Practice for Conducting Equivalence Testing in Laboratory Applications

ASTM F606/F606M-16—Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets

International Standards Organization

ISO/IEC 17011-17—Conformity Assessment—General Requirements for Accreditation Bodies

ISO/IEC 17025-17—General Requirements for the Competence of Calibration and Testing Laboratories

ISO/ASQ/ANSI 9000:2015—Quality Management Systems – Fundamentals and Vocabulary

CODE

CHAPTER 4—SIGNIFICANCE AND USE

4.1 ACI CODE-355.2 applies to post-installed mechanical anchors intended for use in structural applications addressed by **ACI 318** and subjected to static or seismic loads in tension, shear, or combined tension and shear. Examples of applicable anchors are shown in Fig. 4.1a through 4.1d. ACI CODE-355.2 does not apply to anchors loaded in compression if the expansion mechanism is also loaded in compression, or to anchors subjected to fatigue loading. Anchors meeting the requirements herein are expected to sustain their design loads (in tension, shear, and combined tension and shear) while providing adequate stiffness. The behavior of anchors in plastic hinge zones of reinforced concrete structures is not simulated in the requirements of this document for the qualification of anchors.

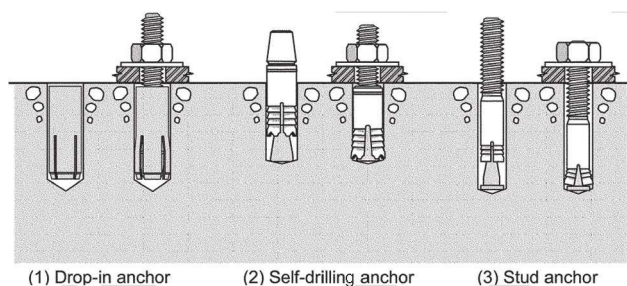


Fig. 4.1a—Examples of displacement-controlled expansion anchors.

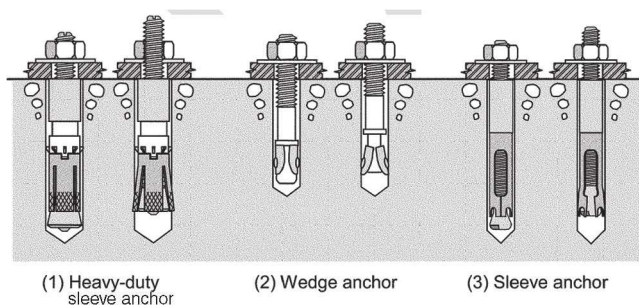


Fig. 4.1b—Examples of torque-controlled expansion anchors.

COMMENTARY

CHAPTER R4—SIGNIFICANCE AND USE

R4.1 ACI 318 Chapter 17 requires an anchor that is to be used under seismic loading to be qualified under a simulated seismic loading cycle. Experience shows that plastic hinge regions in reinforced concrete structures subjected to earthquake loading typically develop crack widths well in excess of the crack widths anticipated by ACI CODE-355.2.

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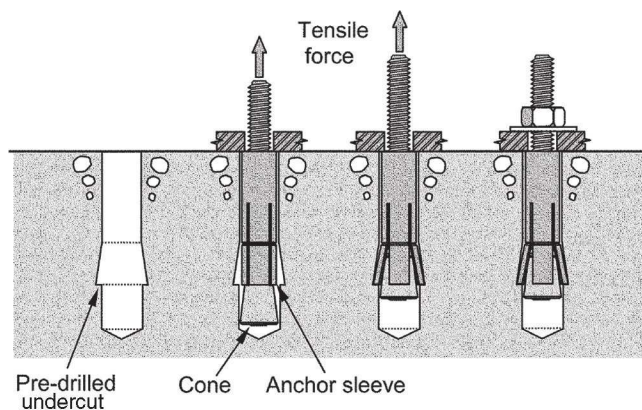


Fig. 4.1c(a)—Type 1 undercut anchor. Load-controlled anchor installed by tensioning anchor, causing sleeve to expand into predrilled undercut.

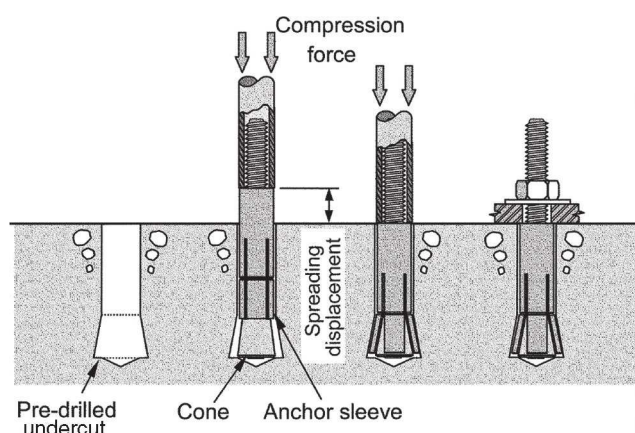


Fig. 4.1c(b)—Type 2 undercut anchor. Displacement-controlled anchor set in predrilled undercut by hammering sleeve over cone.

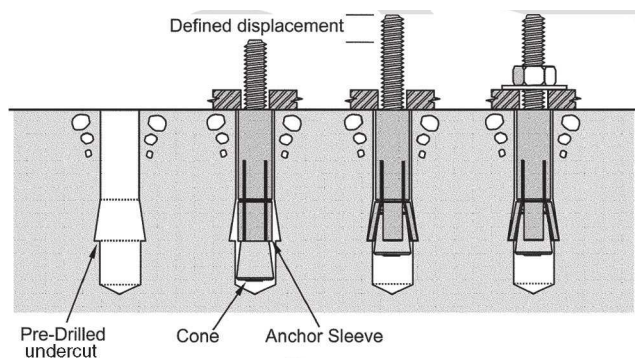


Fig. 4.1c(c)—Type 3 undercut anchor. Displacement-controlled anchor installed in predrilled undercut and set by defined displacement, causing expansion sleeve to expand into undercut.

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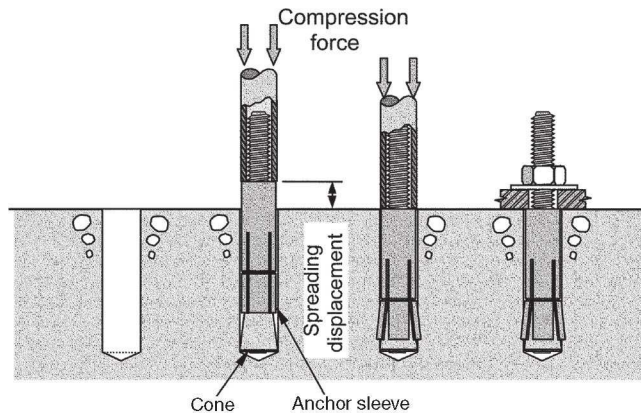


Fig. 4.1c(d)—Type 4 undercut anchor. Displacement-controlled anchor that cuts its own undercut while set by hammering sleeve over cone.

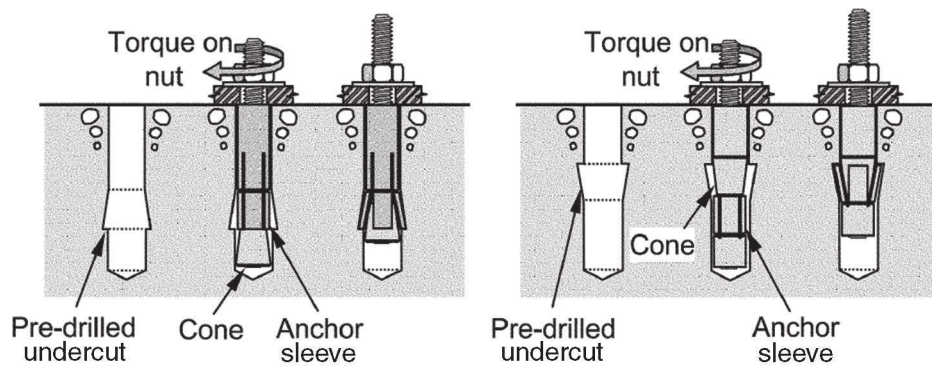


Fig. 4.1c(e)—Type 5 undercut anchor. Torque-controlled anchor set into predrilled undercut by application of torque forcing sleeve over cone (two examples shown).

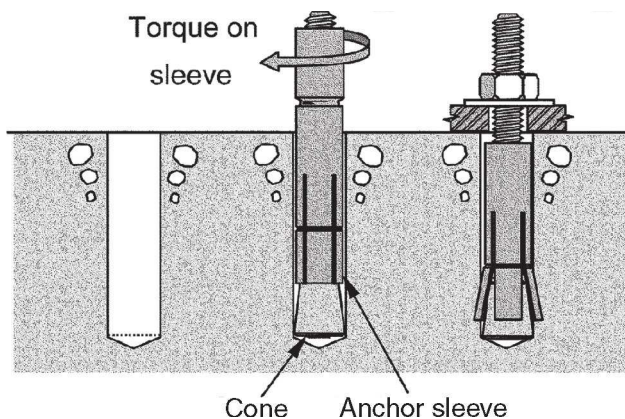


Fig. 4.1c(f)—Type 6 undercut anchor. Torque-controlled anchor that cuts its own undercut by application of setting torque that forces sleeve over cone.

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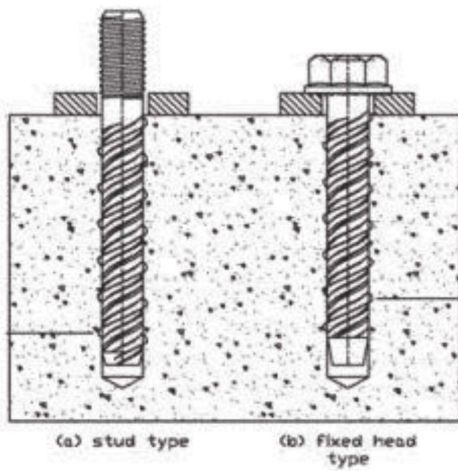


Fig. 4.1d—Examples of stud type and headed screw anchors.

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COMMENTARY

CHAPTER 5—GENERAL REQUIREMENTS

CHAPTER R5—GENERAL REQUIREMENTS

5.1—Testing sequence

Perform four types of tests in the following sequence:

1. Identification tests to evaluate the anchor's compliance with the critical characteristics ([Chapter 7](#))
2. Reference tests to establish baseline performance against which subsequent tests are to be compared ([Chapter 8](#))
3. Reliability tests to confirm the reliability of the anchor under adverse installation procedures and long-term use ([Chapter 9](#))
4. Service-condition tests to evaluate the performance of the anchor under expected service conditions ([Chapter 10](#)). When service-condition tests are performed by both the testing agency and the manufacturer, a complete test series of the minimum number of required tests are to be performed by one of the organizations, and not split between them.

Test requirements are summarized in Tables 5.1a and 5.1b. Determine the acceptability of the anchor using the criteria prescribed in Chapters 7 through 10. Determine the anchor category (an index of the anchor's sensitivity to conditions of installation and use) using the criteria prescribed in [Chapter 11](#). Report the lowest anchor category by diameter as prescribed in [Chapter 12](#). For anchors with multiple embedment depths, refer to Table 5.1c.

R5.1—Testing sequence

ACI CODE-355.2 follows a four-step procedure (covering four types of tests) to check the suitability of the anchor for structural purposes (within the use limits established by [ACI 318](#)) and to establish a performance category for the anchor that can be used with the design approach established by ACI 318. The four test types are: identification, reference, reliability, and service-condition tests. Flowcharts giving the testing sequences are presented in Fig. R5.1a through R5.1f.

Identification tests are required to determine if the anchor complies with fabrication requirements and to establish a baseline for quality assurance.

Reference tests serve two functions: 1) they establish the characteristic resistance to be used in the design of single anchors with large edge distances and spacings; and 2) they are intended to be compared with results of the reliability tests. For the reference tests, anchors should be installed according to the manufacturer's printed installation instructions (MPII).

Reliability tests serve two functions: 1) to establish the anchor categories used in ACI 318; and 2) to check the reliability of the anchor under sustained loads and variable loads. The anchor should be capable of safe and effective behavior under normal and adverse conditions, both during installation and in service. Factors included are sensitivity to variations of:

- (a) Installation conditions in concrete
- (b) Reduced drill bit diameter resulting from worn drill bits
- (c) Sustained and variable loads on the anchor
- (d) Crack width (for anchors being tested for use in cracked and uncracked concrete)
- (e) Crack width associated with long-term and variable loading of the structure (for anchors for use in cracked and uncracked concrete)

To reduce the scope of the required test program, the effects of these factors on anchor performance are combined in the required tests using the most severe combination of conditions.

The procedures prescribed for checking the reliability of an anchor and assigning an anchor category to it consider possible on-site deviations from the MPII procedure. This document, however, does not cover gross installation errors, which are prevented by appropriate training and site inspection. Such gross errors include, but are not limited to, drill bits of the wrong diameter; inappropriate drilling methods; improper setting tools; inappropriate setting methods; and failure to clean, dry, or otherwise prepare the drilled hole as required by the MPII.

To represent normal conditions, the repeated load test (Table 5.1a, Test 7) and the test in which the crack width is cycled (Table 5.1b, Test 9) are performed with a drill bit of diameter d_m .



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Table 5.1a—Test program for evaluating anchor systems for use in uncracked concrete

Test number	Reference	Purpose	Description	Concrete strength	Member thickness	Drill bit diameter	Minimum sample size*
Reference tests							
1	8.2.1	Reference test in uncracked low-strength concrete	Tension – single anchor with no edge influence	Low	$\geq h_{min}$	d_m	5
2	8.2.1	Reference test in uncracked high-strength concrete	Tension – single anchor with no edge influence	High	$\geq h_{min}$	d_m	5
3	8.2.2	Reference test for screw anchors – confined test in uncracked high-strength concrete	Confined tension – single anchor away from edges	High	$\geq h_{min}$	d_m	5 ^{†‡}
Reliability tests							
4	9.2	Sensitivity to reduced installation effort	Tension – single anchor with no edge influence	Varies with anchor	$\geq h_{min}$	$d_m^{\S}$	5
5	9.3	Sensitivity to large hole diameter	Tension – single anchor with no edge influence	Low	$\geq h_{min}$	d_{max}	5
6	9.4	Sensitivity to small hole diameter	Tension – single anchor with no edge influence	High	$\geq h_{min}$	d_{min}	5
7	9.5	Reliability under repeated load	Repeated tension – single anchor with no edge influence, residual capacity	Low	$\geq h_{min}$	d_m	5 [#]
8	9.7	Reliability of screw anchors against brittle failure	Embrittlement test – single anchor away from edges	High	$\geq h_{min}$	d_m	5 ^{†‡}
9	9.8.2	Reliability of screw anchors if set with impact screwdriver	Setting test – single anchor away from edges	Low	$\geq h_{min}$	d_{max}	15
10	9.8.3	Reliability of screw anchors if set with a torque wrench in low-strength concrete	Setting test – single anchor away from edges	Low	$\geq h_{min}$	d_{max}	10
11	9.8.4	Reliability of screw anchors if set with a torque wrench in high-strength concrete	Setting test – single anchor away from edges	High	$\geq h_{min}$	d_{min}	10
Service-condition tests							
12	10.2	Verification of full concrete capacity in corner with two edges located at $1.5h_{ef}$	Tension – single anchor with two edges located at $1.5h_{ef}$	Low	h_{min}	d_m	4
13	10.3	Minimum spacing and edge distance to preclude splitting on installation	High installation tension (torque or direct) – two anchors near edge	Low	h_{min}	d_m	5
14	10.4	Shear capacity of anchor steel	Shear – single anchor with no edge influence	Low	$\geq h_{min}$	d_m	5
15	10.7	Torque test (optional)	Effect of torque on anchor tension force	High	$\geq h_{min}$	d_m	5

*Minimum sample size for each anchor diameter, unless otherwise noted.

[†]Tests are not required if the conditions in 9.7.1.1 are fulfilled.[‡]Perform tests to match those required in 9.7.2.1 or 9.7.2.2.[§]Drilling diameters for undercuts are specified in Table 6.2.3.4.[#]Tests are not required for each anchor diameter. Test smallest, middle, and largest anchor diameter. For screw anchors, test all diameters.^{||}Test all diameters at minimum embedment, h_{ef} .

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COMMENTARY

Table 5.1b—Test program for evaluating anchor systems for use in cracked and uncracked concrete

Test No.	Reference	Purpose	Description	Crack opening width, in. (mm)	Concrete strength	Member thickness	Drill bit diameter	Minimum sample size* <i>n</i>
Reference tests								
1	8.2.1	Reference test in uncracked low-strength concrete	Tension – single anchor with no edge influence	—	Low	$\geq h_{min}$	d_m	5
2	8.2.1	Reference test in uncracked high-strength concrete	Tension – single anchor with no edge influence	—	High	$\geq h_{min}$	d_m	5
3	8.2.1	Reference test in cracked low-strength concrete	Tension – single anchor with no edge influence	0.012 (0.3)	Low	$\geq h_{min}$	d_m	5
4	8.2.1	Reference test in cracked high-strength concrete	Tension – single anchor with no edge influence	0.012 (0.3)	High	$\geq h_{min}$	d_m	5
5	8.2.2	Reference test for screw anchors – Confined test in uncracked high-strength concrete	Confined tension – single anchor away from edges	—	High	$\geq h_{min}$	d_m	5 ^{†‡}
Reliability tests								
6	9.2	Sensitivity to reduced installation effort	Tension – single anchor with no edge influence	0.012 (0.3)	Varies with anchor type	$\geq h_{min}$	$d_m^{\S}$	5
7	9.3	Sensitivity to crack width and large hole diameter	Tension – single anchor with no edge influence	0.020 (0.5)	Low	$\geq h_{min}$	d_{max}	5
8	9.4	Sensitivity to crack width and small hole diameter	Tension-single anchor with no edge influence	0.020 (0.5)	High	$\geq h_{min}$	d_{min}	5
9	9.6	Tests in cracks whose opening width is cycled	Sustained tension – single anchor with no edge influence, residual capacity	0.004 to 0.012 (0.1 to 0.3)	Low	$\geq h_{min}$	$d_{max}^{\#}$	5
10	9.5	Reliability of screw anchors under repeated load	Repeated tension – single anchor away from edges, residual capacity	—	Low	$\geq h_{min}$	d_m	5
11	9.7	Reliability of screw anchors against brittle failure	Embrittlement test – single anchor away from edges	—	High	$\geq h_{min}$	d_m	5 ^{†‡}
12	9.8.2	Reliability of screw anchors if set with impact screwdriver	Setting test – single anchor away from edges	—	Low	$\geq h_{min}$	d_{max}	15
13	9.8.3	Reliability of screw anchors if set with a torque wrench in low-strength concrete	Setting test – single anchor away from edges	—	Low	$\geq h_{min}$	d_{max}	10
14	9.8.4	Reliability of screw anchors if set with a torque wrench in high-strength concrete	Setting test – single anchor away from edges	—	High	$\geq h_{min}$	d_{min}	10
Service-condition tests								
15	10.2	Verification of full concrete capacity in corner with two edges located at $1.5h_{ef}$	Tension-single anchor with two edges located at $1.5h_{ef}$	—	Low	h_{min}	d_m	4
16	10.3	Minimum spacing and edge distance to preclude splitting on installation	High installation tension (torque or direct) – two anchors near edge	—	Low	h_{min}	d_m	5
17	10.4	Shear capacity of anchor steel	Shear-single anchor with no edge influence	0.012 (0.3)	Low	$\geq h_{min}$	d_m	5
18**	10.5	Seismic tension	Pulsating tension, single anchor, with no edge influence	0.020 (0.5)	Low	$\geq h_{min}$	d_m	5
19**	10.6	Seismic shear	Alternating shear, single anchor, with no edge influence	0.020 (0.5)	Low	$\geq h_{min}$	d_m	5
20**	10.7	Torque test (optional)	Effect of torque on anchor tension force	—	High	$\geq h_{min}$	d_m	5

*Minimum sample size for each anchor diameter, unless otherwise noted.

[†]Tests are not required if the conditions in 9.7.1.1 are fulfilled.

[‡]Perform tests to match those required in 9.7.2.1 or 9.7.2.2.

[§]Drilling diameters for undercuts are specified in Table 6.2.3.4.

[#]Test of undercut anchors use d_m .

^{||}Test all diameters at minimum embedment, h_{ef} .

**These tests are optional and only apply to anchors that have been tested in accordance with Table 5.1b, Test Numbers 1-17.



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Table 5.1c—Required embedment depths for test program

Embedment depth to be tested for given diameter	Test number for embedment depths		
	Shallow	Deep*	All
Table 5.1a	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	3, 4, 5, 6, 7, 8, 12, 13	1, 2
Table 5.1b	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	5, 6, 7, 8, 9, 10, 11, 15, 16, 18, 19	1, 2, 3, 4

*For Tests 13 and 16 at deep embedment, these tests are not required if the distance $h_{min} - h_{ef}$ equals or exceeds this value for an anchor at shallow embedment.

Test 7 of Table 5.1a specifies that only the smallest, middle, and largest diameter anchors are to be tested. For a given anchor system, the manufacturer usually offers several diameters—for example, 1/4, 3/8, 1/2, 5/8, 3/4, 1, and 1-1/4 in. (6, 10, 13, 16, 19, 25, and 32 mm). In this example, the smallest (1/4 in. [6 mm]), middle (5/8 in. [16 mm]), and largest (1-1/4 in. [32 mm]) would be tested.

The selected combination of conditions is intended to minimize the test program while maintaining an acceptable level of safety of the entire connection. The observed anchor capacities from the reliability tests can be lower than from the reference tests, provided that the reduction is limited and well defined. This is addressed by the category calculation that compares the ratio of the reliability result to the reference result for each reliability test to determine the anchor category. Refer to [Chapter 11](#), which describes the establishment of anchor categories. The higher categories result in lower ϕ factors used to determine design values per [ACI 318](#) provisions.

The requirements in this document differ from the requirements of [ASTM E488/E488M](#) for minimum sample sizes based on coefficient of variation of test data. The minimum number of tests in this document, as given in Tables 5.1a and 5.1b, is considered to be sufficient. The sample size of four for Test 12 of Table 5.1a and Test 15 of Table 5.1b (the corner test) is because a typical test specimen block has four corners. Concrete test blocks are to be fabricated at a thickness of concrete for which the anchor is qualified. Thus, the testing agency needs only one slab for these tests.

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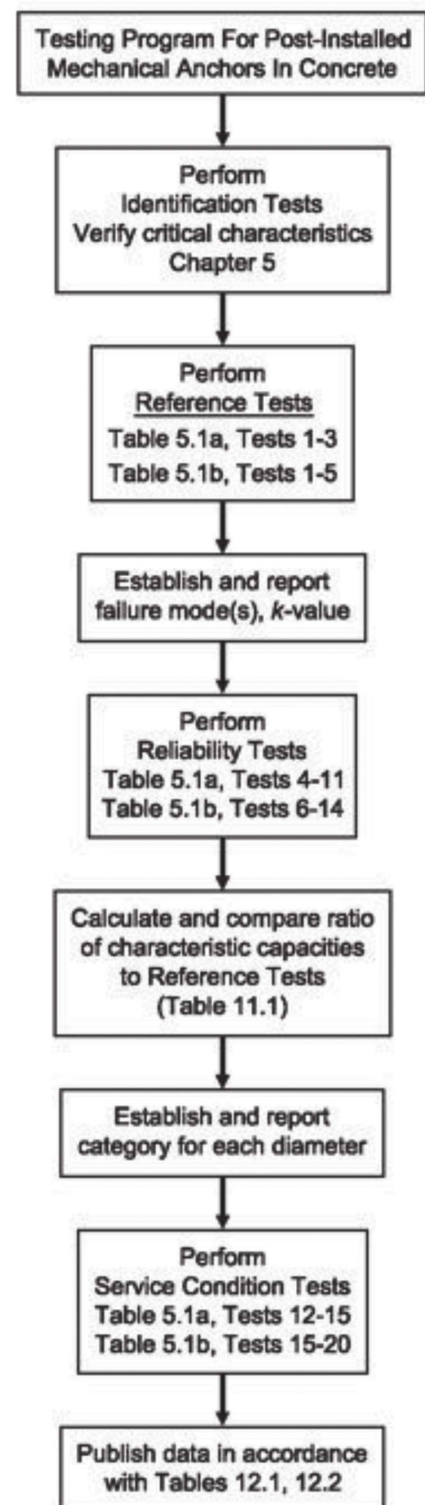


Fig. R5.1a—Flowchart for overall testing program.

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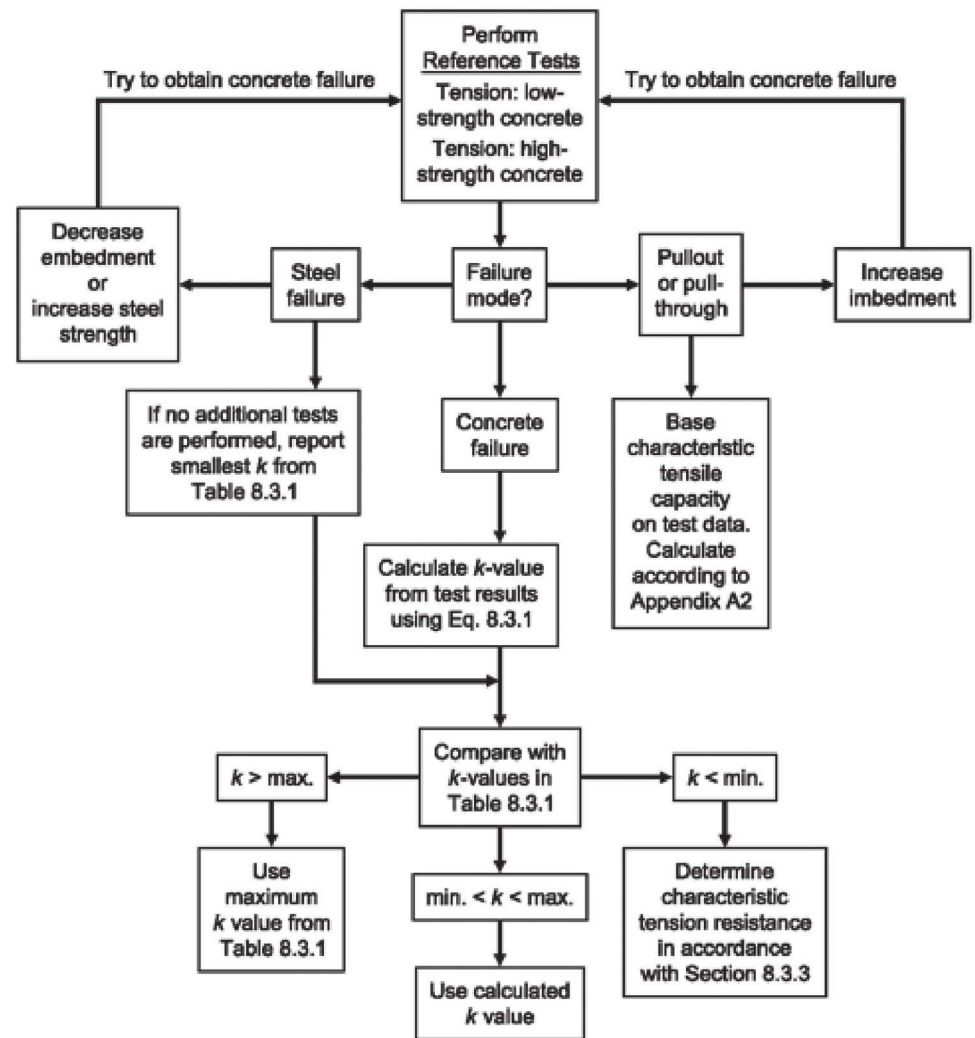


Fig. R5.1b—Flowchart for reference tests.

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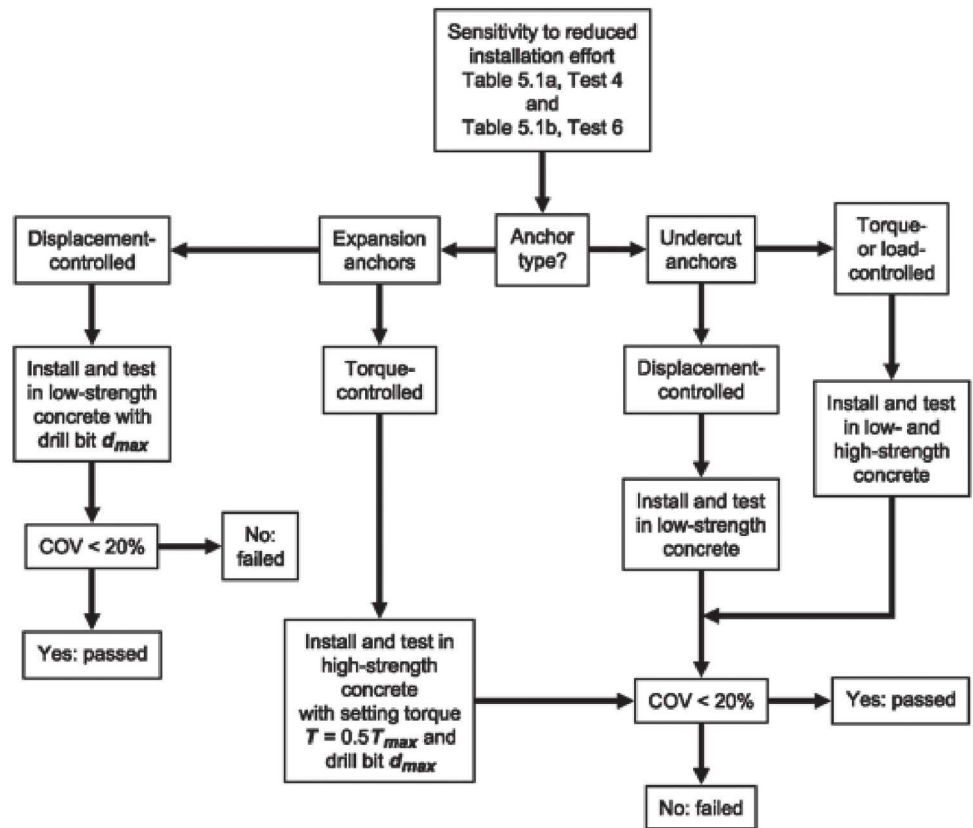


Fig. R5.1c—Flowchart for reliability tests with reduced installation effort.

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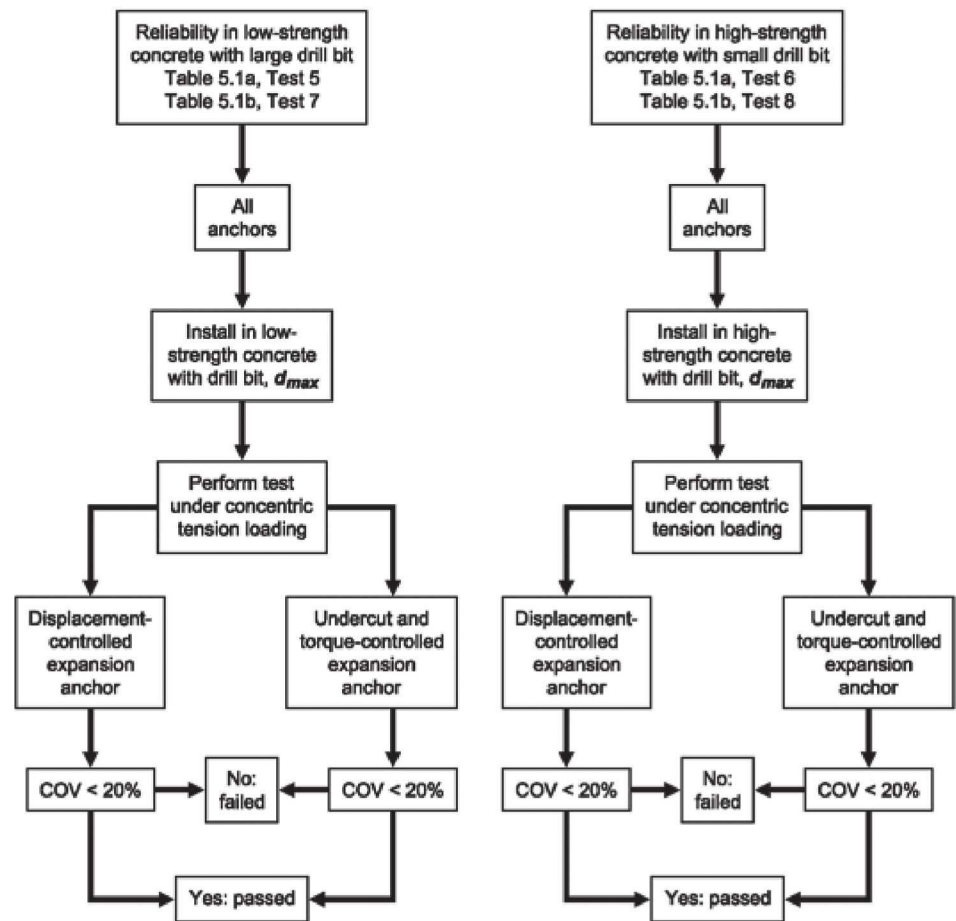


Fig. R5.1d—Flowchart for reliability test for sensitivity to large and small holes.

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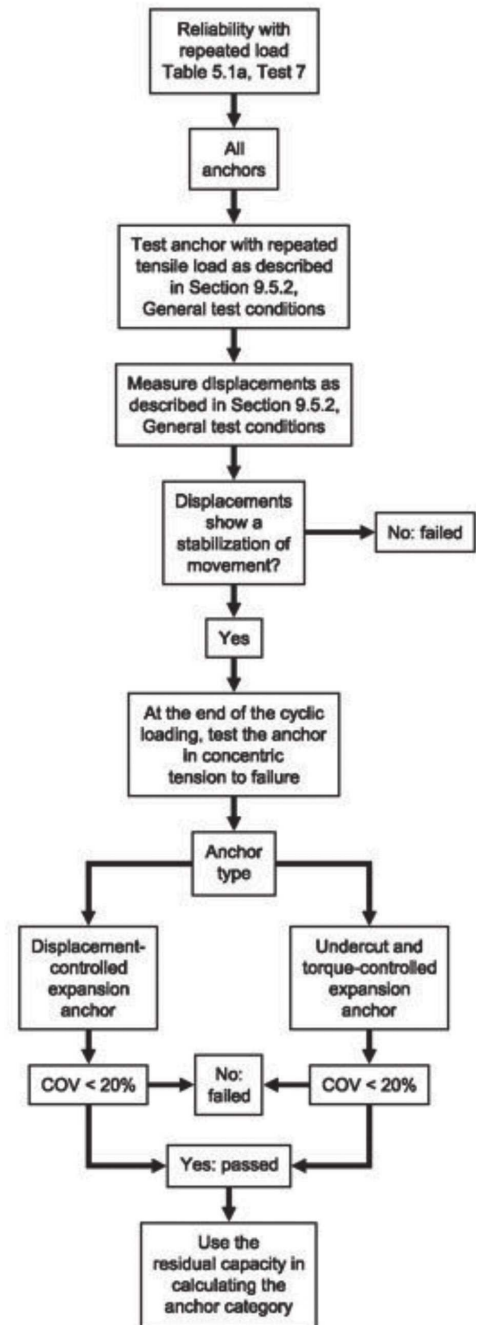


Fig. R5.1e—Flowchart for reliability tests with repeated loads.

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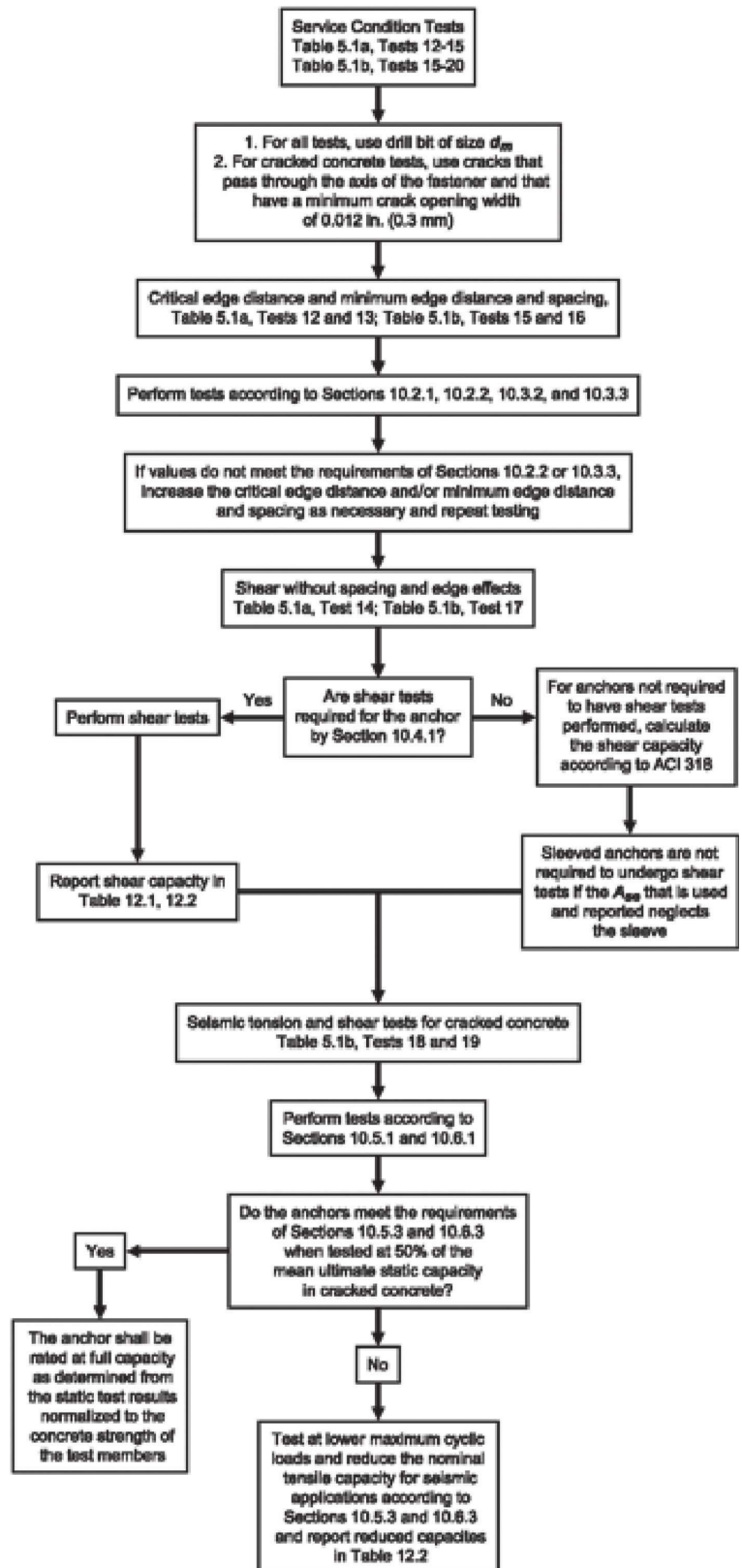


Fig. R5.1f—Flowchart for service-conditions tests.

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5.2—Test samples

For anchors in production, the testing agency shall randomly select anchors to be used in this qualification program from the manufacturing or distribution facility and verify that the samples are representative of the production of the manufacturer as supplied to the marketplace.

To test newly developed anchors that are not in production, use samples produced by the expected production methods. After production has begun, perform identification and reference tests to verify that the constituent materials have not changed and that the performance of the production anchors is statistically equivalent to that of the anchors originally tested.

5.2.1 If internally threaded anchors are supplied without fastening items, such as bolts, the manufacturer shall specify the bolts to be used. To achieve concrete breakout failure for comparison with Eq. (8.3.1), it shall be permitted to use bolts of higher strength than those specified, provided that those bolts do not change the functioning, setting, or follow-up expansion of the anchors.

5.2.2 For anchor systems supplied with different materials, pretensioning application mechanisms, or coatings, or that are manufactured with different production methods, perform the torque tests in accordance with 10.7. If the results do not meet the requirements of 10.7.3 and 10.7.4.2, perform the complete test program for each anchor material, coating, production method, or pretensioning application mechanism.

5.2.3 The sample sizes given in Tables 5.1a and 5.1b are the minimum required to satisfy the requirements of this standard. At the discretion of the independent testing and evaluation agency or manufacturer, the sample size shall be permitted to be increased.

5.3—Testing by independent testing and evaluation agency and by manufacturer

The minimum number of reference, reliability, and service-condition tests given in Tables 5.1a and 5.1b shall be performed by the independent testing and evaluation agency (ITEA) (Chapter 13). At the discretion of the ITEA, test data resulting from tests conducted by the manufacturer shall be permitted to be considered in the evaluation. Such tests shall be conducted with anchors sampled in accordance with 5.2, they shall be witnessed by the ITEA, and the results shall be shown to be statistically equivalent to those of the ITEA.

COMMENTARY

R5.2—Test samples

Prototypes can be used for testing if the anchor samples are prepared in the same manner as expected for production. Identification and reference tests are performed on the production samples, and their performance is compared statistically with the results of the tested prototypes to determine if additional tests need to be performed.

R5.2.2 Torque tests may be performed to demonstrate equivalency as described in this section.

R5.2.3 The minimum sample sizes for each test is given in Tables 5.1a and 5.1b. The sample size is permitted to be increased. There are two primary reasons for increasing the sample size. First, if the coefficient of variation is greater than allowed in the requirements sections of each of the tests, then adding additional test samples may bring the coefficient of variation to an acceptable level. The trade-off is cost of testing versus attempting to reduce the coefficient of variation. The second reason is that the calculation of the k-factor is dependent on sample size. Increasing the sample size might possibly increase the k-factor.

R5.3—Testing by the independent testing and evaluation agency and by the manufacturer

The testing program should be performed under the guidance and direction of a single qualified ITEA with experience in anchor testing. The primary testing laboratory may have specific tests performed by other qualified laboratories, but the primary laboratory retains overall responsibility for the testing and evaluation of the anchor system. Tests performed in the manufacturer's laboratory should be considered for improvement of the statistical accuracy of a test series and should be shown to belong to the same data compilation by establishing statistical equivalency of the mean, with the