ACI 355.4M-11

Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4M-11)

An ACI Standard

and Commentary

Reported by ACI Committee 355



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Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4M-11) and Commentary

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Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4M-11) and Commentary

An ACI Standard

Reported by ACI Committee 355

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This standard prescribes testing programs and evaluation requirements for post-installed adhesive anchors intended for use in concrete under the design provisions of ACI 318M. Testing and assessment criteria are provided for various conditions of use, including seismic loading; sustained loading; aggressive environments; reduced and elevated temperatures; and for determining whether anchors are acceptable for use in uncracked concrete only, or acceptable for service both in cracked and uncracked concrete. Criteria are provided for establishing the characteristic bond strength, reductions for adverse conditions, and the anchor category and associated job-site quality control requirements.

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Keywords: adhesive anchors; cracked concrete; fasteners; post-installed anchors; qualification procedures; uncracked concrete.

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CHAPTER 1—INTRODUCTION

1.1—Introduction

This standard prescribes testing and evaluation requirements for post-installed adhesive anchor systems intended for use in concrete under the provisions of ACI 318M. Criteria are separately prescribed to determine the suitability of adhesive anchors used in uncracked concrete only, or in both cracked and uncracked concrete. Criteria are prescribed to determine the design parameters and performance category for adhesive anchors. Included are assessments of the adhesive anchor system for bond strength, reliability, service conditions, and quality control. Special inspection (13.3) is required during anchor installation as noted in 10.22. Table 1.1 provides an overview of the scope.

R1.1 *This standard prescribes the testing programs required to qualify post-installed adhesive anchor systems for design in accordance with ACI 318M, Appendix D. Appendix D requires that anchors be tested either for use exclusively in uncracked concrete or for use in cracked and uncracked concrete conditions, whereby it is understood that the presence of cracking may occur at any time over the service life of the anchors. Test and assessment criteria are provided for various conditions, including loads (seismic and sustained), environmental with regard to humidity and temperature, and determination if anchors are acceptable for use in cracked or uncracked concrete. Refer to Cook and Konz (2001) for a review of factors that influence adhesive anchor behavior. Refer to Fuchs et al. (1995) for background on the concrete breakout design model and to Eligehausen et al. (2006) and Zamora et al. (2003) for a discussion of bond models for adhesive and grouted anchors. For a discussion of issues associated with the qualification and design of systems for post-installed reinforcing bars, refer to Spieth et al. (2001).*

1.2—Scope

This standard applies only to post-installed adhesive anchors as defined herein.

R1.2 *Adhesive anchors resist tension loads with a combination of adhesion and mechanical bond (micro-interlock). Different anchor designs and adhesive types may exhibit a range of performance characteristics. In particular, the sensitivity of adhesive anchors to variations in installation and service-condition parameters (such as hole cleaning, installation orientation, and cracked concrete characteristics) may vary widely from each system. ACI 318M addresses this situation by matching capacity reduction factors to anchor performance categories that are, in turn, established through a series of reliability tests.*

1.2.1 This standard applies to anchors with a diameter d_a of 6 mm or larger. The drilled hole shall be approximately cylindrical with a diameter $d_o \le 1.5d_a$. This standard also applies to anchors with an anchor embedment depth h_{ef} not less than four diameters ($4d_a$), or 41 mm, and an embedment depth not exceeding $20d_a$.

R1.2.1 *The minimum diameter of 6 mm is based on practical considerations regarding the limit of structural anchor applications. The upper limit on the ratio of hole diameter to anchor element diameter provides a demarcation between conditions where a single bond strength can be used to evaluate anchor strength and conditions where bond strengths at both the anchor interface and concrete interface must be determined to evaluate anchor strength. In addition, the value of 1.5d_a is based on consideration of typical practice whereby most organic adhesives are used with thin bond lines to limit both adhesive shrinkage and creep of the anchor when under load. The design method deemed to satisfy the anchor design requirements of ACI 318M, Appendix D, is based on an analysis of an anchor database with a maximum diameter of 50.8 mm. While ACI 355.4M gives no limitations on maximum anchor diameter, for anchors beyond this dimension, the testing authority should decide if the tests described in this standard are applicable or if alternative tests and analyses are more appropriate. It may also be desirable to reconsider those tests where only small, medium, and large diameters are tested when the upper diameter is much larger than 38 mm.*

A limitation on the minimum embedment length of adhesive anchors is necessary to ensure conformance with the design method deemed to satisfy the anchor design requirements of ACI 318M, Appendix D.

Table 1.1—Overview of anchor systems

Anchor type	Embedded part	Assessment criteria	
Adhesive anchor	Threaded rods, deformed reinforcing bars, or internally threaded steel sleeves with external deformations	Uncracked concrete	Table 3.1
		Cracked and uncracked concrete	Table 3.2 or Table 3.3

1.2.2 The minimum member thickness shall not be less than the value given by Eq. (10-21). Values of Δh in Eq. (10-21) shall be permitted if they are verified by tests according to Table 3.1, Test no. 14, and Table 3.2, Test no. 20, or Table 3.3, Test no. 15.

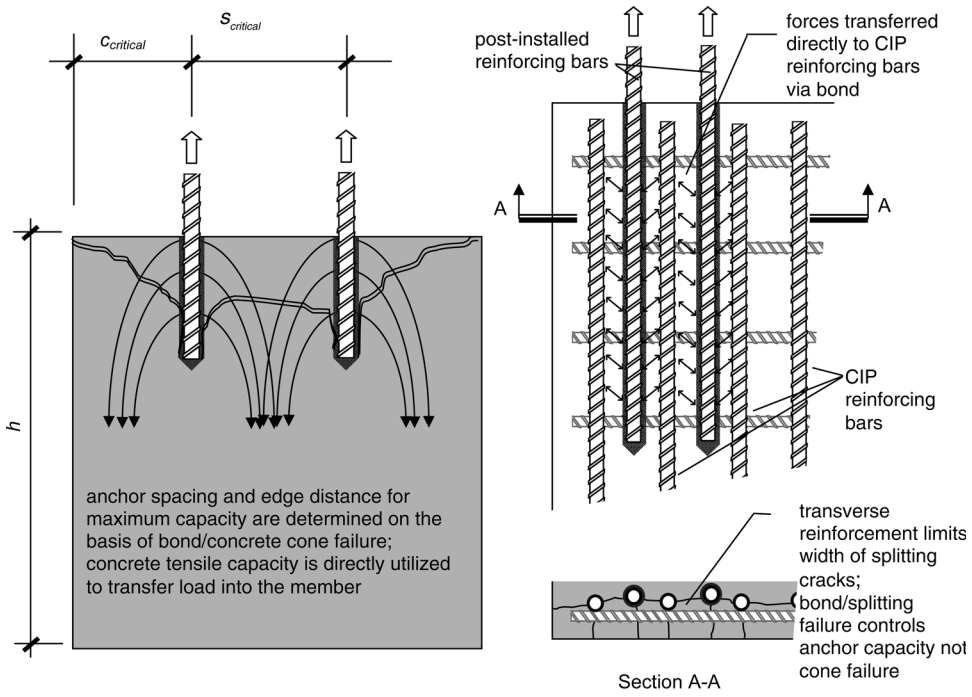
1.2.3 This standard does not address the following systems and use conditions:

1. Bulk adhesives mixed in open containers without automatically controlled metering and mixing of adhesive components.
2. Adhesives to adhere structural elements to concrete surfaces outside of a drilled hole.
3. Adhesive anchors in aggressive environments not specifically considered in this standard.
4. Adhesive anchors to resist fatigue or shock loading.

R1.2.3 *Correct proportioning (metering) and mixing of adhesive components is critical to their performance. Bulk mixing and delivery of adhesives (for example, those with paddle mixers in buckets), while appropriate for some applications, may not provide anchor performance consistent with the assumptions of this standard. These systems are not considered to provide controlled metering of adhesive components. Bulk dispensing equipment that provides automatic metering and mixing of the adhesive components is included; however, ongoing monitoring is required to check that the equipment is operating within tolerances in accordance with the Manufacturer's Printed Installation*

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(a) Reinforcing dowels designed using anchor theory as addressed by this criteria.

(b) Post-installed reinforcement designed as a lap splice (not covered by this criteria).

Fig. R1.1—Examples of post-installed reinforcing bars proportioned with anchor theory and with concepts of reinforcement development and splicing.

Instructions (MPII), particularly with respect to mixture ratios, leak tightness, and dwell time.

This standard is not appropriate for assessing the use of adhesives to adhere structural elements to the concrete surface. Examples include bonded steel plates or external carbon fiber reinforcement. Other standards exist for these purposes. This standard includes tests to assess the sensitivity of adhesive anchor systems to a limited range of aggressive environments, including moisture, highly alkaline fluids, and sulfur dioxide. While it is believed that these exposure environments envelop a range of possible exposures, specific environments (for example, radiation exposure and chemical production environments) may require unique assessment.

Due to the variety of possible loading conditions associated with fatigue and shock loading, this standard does not include tests for these loading variants. Fatigue and shock loading may result in reductions in bond strength, steel strength, and concrete strength, and these effects are not addressed by this standard. Caution should be exercised in the determination of whether cyclic loading should be explicitly considered. These conditions may be evaluated separately for specific systems using generally accepted principles. Fatigue is generally less of a problem for the adhesive than for the anchor element; provisions of preload in the anchor to reduce the level of stress fluctuation in the anchor element is only effective if sufficient unbonded length is provided to ensure a reasonable degree of elastic stretch.

1.2.4 Adhesive anchors shall be evaluated for sustained loading with the provisions of this standard. Qualification of adhesive anchors exclusively for short-term loads is not permitted by this standard.

R1.2.4 *While it is permissible to use adhesive anchors to resist short-term loads such as those from wind or earthquake, the sustained load tests and corresponding assessment described herein are not optional. All anchors qualified in accordance with ACI 355.4M are suitable for sustained loads within the use parameters established in the assessment (7.17 and 10.4.7).*

1.2.5 Adhesive anchor systems shall exhibit characteristic bond strengths as determined in accordance with Eq. (10-12) equal to or exceeding the minimum permissible bond strength $\tau_{k,min}$. Adhesive anchor systems that do not exhibit characteristic bond strengths equal to or exceeding the minimum permissible bond strength in accordance with 10.2, shall not be qualified according to this standard.

R1.2.5 *ACI 318M, Appendix D, provides default bond stress values for specific constellations of use parameters that may be used in place of values from an evaluation report in accordance with this standard. Because the default values are independent of the adhesive anchor system selected, they represent minimum values for the assessment of any adhesive anchor system under this standard. The minimum values and corresponding use parameters are given in Table 10.2.*

1.2.6 In general, ACI 355.4M is intended to address the assessment of adhesive anchors for cases where anchor design theory applies. It is not intended to address the assessment or design of post-installed reinforcing bars proportioned according to the concepts of development and splicing of reinforcement.

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R1.2.6 *This standard is intended to provide parameters for the design of adhesive anchors in conjunction with the provisions of ACI 318M, Appendix D. Those provisions are derived from the principles of anchor theory, whereby anchor forces are transferred to the concrete in a manner that generally precludes splitting of the concrete and where spacing, edge distance, and member thickness are explicitly considered in the evaluation of the concrete breakout capacity (Fig. R1.1(a)). It is not intended to address the assessment or design of post-installed reinforcing bars proportioned according to the concepts of development and splicing of reinforcement (Fig. R1.1(b)). While the provisions of Chapter 12 of ACI 318M may be used to establish embedment lengths for post-installed reinforcing bars in such cases, the ability of an adhesive anchor system to transfer loads to adjacent embedded bars, particularly where longer splice lengths are required, should be verified by appropriate testing. Testing for the splice length is outside the scope of this standard.*

1.3—Units of measurement

Values in this specification are stated in SI units. A companion specification in inch-pound units is also available.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1— Notation

$A_{se,N}$ = effective cross-sectional area of anchor in tension, mm^2

$A_{se,V}$ = effective cross-sectional area of anchor in shear, mm^2

c_{ac} = critical edge distance required to develop the basic concrete breakout strength of anchor in uncracked concrete without supplementary reinforcement to control splitting, mm

c_{min} = minimum anchor edge distance required to prevent splitting during anchor installation, mm, see 8.10

d_a = nominal outside diameter of post-installed anchor, mm, see Fig. 2.1

d_e = nominal diameter of bolt or threaded anchor element in a sleeved insert, mm, see Fig. 2.1

d_o = nominal diameter of drilled hole in the concrete, mm, see 2.1

F_i = test result normalized to considered concrete strength i, N

F_k = characteristic capacity for a test series, calculated according to 10.3, N

$\overline{F}_{test,i}$ = mean anchor capacity as determined from test series i, N

$\overline{F}_{test,i,f_c}$ = mean capacity for test series i, normalized to concrete strength f_c, in accordance with 10.2, N

F_y = tension force corresponding to bolt yield in accordance with Eq. (10-22), N

f_c' = specified strength of concrete, MPa

$f_{c,i}$ = mean concrete compressive strength measured with standard cylinders for concrete of batch i, MPa

$f_{c,test,x}$ = mean concrete compressive strength measured with standard cylinders of the test members used for test series x, MPa

f_t = mean ultimate tensile strength of anchor steel as determined by test, MPa

f_{uta} = specified tensile strength of anchor steel, MPa

$f_{ut,test}$ = specified ultimate tensile strength of steel anchor elements used in seismic tests, MPa

f_{ya} = specified yield strength of anchor steel, MPa

h = thickness of test member in which an anchor is installed, measured perpendicular to the concrete surface, mm, see Fig. 2.1

h_{ef} = effective embedment depth, measured from the concrete surface to the deepest point at which bond to the concrete is established, mm, see Fig. 2.1

h_{min} = minimum member thickness specified by the anchor manufacturer and verified in accordance with 9.2 and 10.7, mm

h_{sl} = slice thickness as measured immediately prior to punch testing in accordance with 8.8, mm

K = tolerance factor corresponding to a 5 percent probability of nonexceedence with a confidence of 90 percent, derived from a noncentral t-distribution for which the population standard deviation is unknown

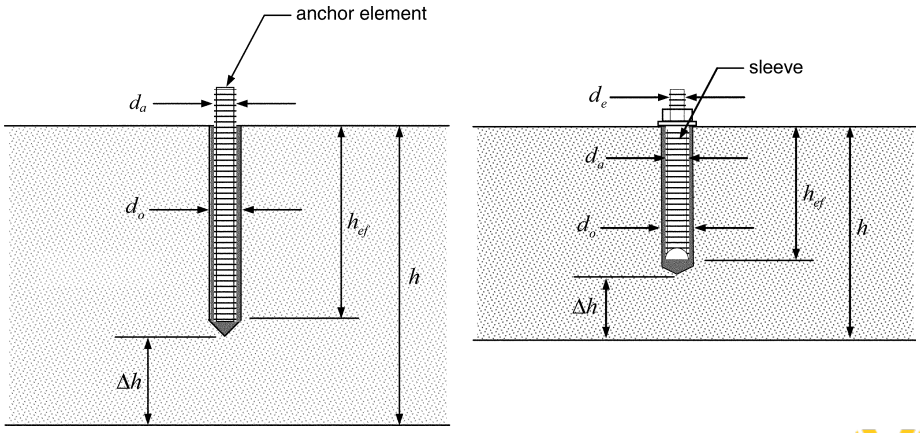


Fig. 2.1—Adhesive anchor dimensional parameters.

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k = effectiveness factor, whose value depends on the type of anchor

k_{cr} = effectiveness factor for anchors tested in cracked concrete

k_f = friction factor of threads

k_m = mean coefficient for the concrete breakout tension

k_{uncr} = effectiveness factor for anchors tested in uncracked concrete

ℓ_{side} = dimension of the side of a cube or diameter of a cylinder for conducting a freezing-and-thawing test, mm

$N_{95\%}$ = 95 percent fractile at 90 percent confidence of the induced tension force corresponding to $1.3T_{inst}$, N

$N_{95\%,slip,d}$ = 95 percent fractile at 90 percent confidence of the force corresponding to loss of adhesion between the anchor element and the adhesive for anchor diameter d, N

$\min N_{adh,i}$ = minimum value of tension load corresponding to loss of adhesion in test series i, N

N_{adh} = tension load corresponding to loss of adhesion between the adhesive and the concrete, N

$N_{adh,i,j}$ = tension load corresponding to loss of adhesion in reliability test series i, test j, N

$\overline{N}_{cure}$ =

$\overline{N}_{cure+24h}$ = mean tension capacity corresponding to the manufacturer's published minimum cure time plus 24 hours, N

N_{eq} = maximum tension load to be applied in the simulated seismic tension test, N

$N_{eq,reduced}$ = reduced maximum tension load at which the anchor successfully completes the simulated seismic tension test, N, see 10.19.1.2

N_i = intermediate tension load to be applied in the simulated seismic tension test, N

$N_{i,reduced}$ = reduced intermediate tension load at which the anchor successfully completes the simulated seismic tension test, N, see 10.19.1.2

N_k = characteristic tension capacity of an anchor, 5 percent fractile of test results, as determined in accordance with 10.3, N

$N_{k,cure}$ = characteristic tension capacity corresponding to the manufacturer's published minimum cure time, N

$N_{k,cure+24h}$ = characteristic tension capacity corresponding to the manufacturer's published minimum cure time plus 24 hours, N

$N_{k,i}$ = characteristic tension capacity of an anchor in test member i or concrete batch i, N

$N_{k,lt}$ = characteristic tension capacity at long-term elevated temperature, N

$N_{k,o,i}$ = characteristic tension capacity of an anchor in reference test series i, N

$N_{k,p,nom,cr}$ = characteristic tension capacity corresponding to service-condition tests in low- and high-strength cracked concrete, N

$N_{k,p,nom,uncr}$ = characteristic tension capacity corresponding to service-condition tests in low- and high-strength uncracked concrete, N

$N_{k,r,i}$ = characteristic tension capacity of an anchor in reliability test series i, N

$N_{k,st}$ = characteristic tension capacity at short-term elevated temperature, N

$\overline{N}_{lt}$ = mean tension capacity of an anchor at long-term elevated temperature, N

N_m = minimum tension load to be applied in the simulated seismic tension test, N

$N_{m,reduced}$ = reduced minimum tension load at which the anchor successfully completes the simulated seismic tension test, N, see 10.19.1.2

$\overline{N}_o$ = mean tension capacity of an anchor, N

$\overline{N}_{o,i}$ = mean tension capacity of an anchor in reference test series i, N

$\overline{N}_{o,i,confined}$ = mean tension capacity of anchor in confined reference tests i, N

N_{origin} = tension load corresponding to origin of load-displacement curve, N

N_p = characteristic tension pullout capacity of an anchor, 5 percent fractile of test results, as determined in accordance with 10.3, N

$\overline{N}_{r,i}$ = mean tension capacity of an anchor in reliability test series i, N

N_s = characteristic tension steel capacity of an anchor as determined in accordance with 10.3, N

$\overline{N}_{st}$ = mean tension capacity at short-term elevated temperature, N

$N_{sust,ft}$ = sustained tension load applied during freezing-and-thawing cycles, N

$N_{sust,lt}$ = sustained tension load applied at long-term test temperature, N

N_u = peak tension load measured in a tension test, N

$N_{u,i}$ = peak tension load measured in a tension test in test series i or concrete batch i, N

$\overline{N}_{u,i}$ = mean ultimate tension load measured in a tension test in test series i or concrete batch i, N

N_{u,i,f_c} = peak tension load measured in a tension test conducted in test series i or concrete batch i, normalized to concrete strength f_c, N

$N_{u,i,j}$ = peak tension load measured in a tension test in test series or concrete batch i, test j, N

N_w = tension load applied to anchor during crack width cycling, N

n = number of replicates in a test series, number of anchors in an anchor group, and exponent for determining relationship of bond stress as a function of concrete compressive strength

s_{min} = minimum anchor spacing as required to prevent splitting during anchor installation or tension loading, mm, see 8.10

T_{inst} = specified tightening torque for setting or prestressing of an anchor, according to the MPII, N-m

$t_{service}$ = intended anchor service life, in hours

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V_{eq} = maximum shear load to be applied in the simulated seismic shear test, N

$V_{eq,reduced}$ = reduced maximum shear load at which the anchor successfully completes the simulated seismic shear test, N, see 10.20.1.2

V_i = intermediate shear load to be applied in the simulated seismic shear test, N

$V_{i,reduced}$ = reduced intermediate shear load at which the anchor successfully completes the simulated seismic shear test, N, see 10.20.1.2

V_m = minimum shear load to be applied in the simulated seismic shear test, N

$V_{m,reduced}$ = reduced minimum shear load at which the anchor successfully completes the simulated seismic shear test, N, see 10.20.1.2

$\overline{V}_{o,i}$ = mean shear capacity of an anchor in reference test series i, N

V_s = characteristic shear capacity corresponding to steel failure, N

$V_{S,seis}$ = seismic shear capacity as governed by steel failure, N

α = ratio of reliability to reference tension test results calculated in accordance with 10.4.3

α_{alk} = reduction factor for alkalinity in accordance with 10.16

α_{adh} = ratio of the load at loss of adhesion to the peak load calculated in accordance with 10.4.4

α_{cat3} = additional reduction factor for Anchor Category 3 in accordance with 10.4.6.2

α_{conc} = adjustment factor for regional variations in concrete in accordance with 10.4.1.2

α_{COV} = reduction factor for larger coefficients of variation in accordance with 10.4.2

α_{dur} = reduction factor for durability tests in accordance with 10.16

α_{lt} = reduction factor for maximum long-term temperature in accordance with 10.13.1

$\alpha_{N,seis}$ = reduction factor for seismic tension loading in accordance with 10.19

α_{req} = threshold value of α given in Table 3.1, 3.2, or 3.3

$\alpha_{req,cat3}$ = α_{req} for Anchor Category 3 for corresponding reliability test in accordance with Table 10.5 or 10.6

α_{setup} = reduction factor for service-condition tests performed as confined tests in accordance with 10.4.5.1

α_{st} = reduction factor for maximum short-term temperature in accordance with 10.13.2

α_{sulf} = reduction factor for sulfur in accordance with 10.16

$\alpha_{V,seis}$ = reduction factor for seismic shear loading in accordance with 10.20

α_{ρ} = reduction factor for reliability tests in accordance with 10.4.7.1

$\alpha_{\rho,sust}$ = reduction factor for sustained load reliability test in accordance with 10.4.7.2

β = reduction factor evaluated as the minimum of α/α_{req} and α_{adh} for reliability tests and service-condition tests listed in Tables 10.3 and 10.4 in accordance with Eq. (10-12)

Δ = anchor displacement as measured in a test, mm

$\Delta_{0.3}$ = displacement at $N = 0.3N_u$, mm

$\overline{\Delta}_{lim}$ = mean displacement corresponding to loss of adhesion load N_{adh}, mm

Δ_{origin} = displacement at origin of load displacement curve, mm

$\Delta_{service}$ = extrapolated estimate of the total displacement over the anchor intended service life, mm

$\overline{\Delta}_{service}$ = mean value of the extrapolated estimate of the total displacement over the anchor intended service life, mm

$\Delta_{t=0}$ = initial displacement under sustained load, mm

Δh = concrete thickness beyond h_{ef}, mm, see 2.1

$\Delta(t)$ = displacement at time t under sustained load, mm

Δw = required change in crack width, in addition to the initial hairline crack width as measured after anchor installation, mm

ϕ = strength reduction factor for concrete failure and steel failure modes corresponding to the anchor category established in accordance with 10.4.6 and 10.5, respectively

$\nu_{test,x}$ = sample coefficient of variation for test series x equal to the sample standard deviation divided by the mean, percent

$\overline{\tau}_{dur,i}$ = minimum of mean bond stress corresponding to durability tests with test member i or concrete batch i stored in different media according to 8.8.3, MPa

τ_i = calculated bond stress corresponding to peak load in a tension test, MPa

$\overline{\tau}_i$ = mean bond stress corresponding to test series i or concrete batch i, MPa

$\tau_{k,(cr,uncr)}$ = characteristic bond stress in cracked or uncracked concrete, respectively, adjusted for variations in concrete batches and reduced in accordance with 10.4.5.3.2, MPa

$\tau_{k,i}$ = characteristic bond stress corresponding to tension tests in test member i or concrete batch i, MPa

$\tau_{k,min}$ = minimum permissible bond strength in accordance with 1.7, MPa

$\tau_{k,o,i}$ = characteristic bond stress corresponding to reference tension tests in test member i or concrete batch i, MPa

$\tau_{k,seis,(cr,uncr)}$ = seismic tension bond resistance calculated in accordance with 10.4.5.5, MPa

$\tau_{o,i}$ = bond stress corresponding to a reference tension test in test member i or concrete batch i, MPa

$\overline{\tau}_{ref,f_c}$ = mean bond stress corresponding to round-robin tests, MPa

τ_u = calculated bond stress adjusted for variations in concrete batches, MPa

$\overline{\tau}_u$ = mean bond stress, MPa

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$\bar{\tau}_{u,i}$ = mean bond stress from reliability test series in concrete batch or test member i, MPa

2.2—Definitions

adhesive—any adhesive comprised of chemical components that cure when blended together. Adhesives are formulated from organic polymers, or a combination of organic polymers and inorganic materials. Organic polymers used in adhesives can include, but are not limited to, epoxies, polyurethanes, polyesters, methyl methacrylates, and vinyl esters.

***adhesive**—it is not intended that adhesives be restricted to those listed in this standard and the listing of a specific adhesive does not imply any preference. The suitability of a specific adhesive for anchoring applications may also be dictated by health and safety requirements as contained, for example, in the product Material Safety Data Sheet (MSDS). This standard does not address issues such as adhesive toxicity, safe disposal of adhesive compounds, or conformance with sustainable building requirements as applicable.*

adhesive anchor—a post-installed anchor, inserted into hardened concrete with an anchor hole diameter not greater than 1.5 times the anchor diameter, that transfers loads to the concrete by bond between the anchor and the adhesive and bond between the adhesive and the concrete.

***adhesive anchor**—evaluation of the tension resistance of grouted anchors installed in hole diameters greater than 1.5d_a requires separate consideration of bond stresses developed along the anchor element/grout interface, as well as between the grout and the concrete. Because these anchors may demonstrate tension behavior that does not conform to the design method deemed to satisfy the anchor design requirements of ACI 318M, Appendix D, they are not considered in this standard.*

adhesive anchor system—for the purposes of this standard, the adhesive anchor system is comprised of the following components:

- Anchor
- Proprietary adhesive compounds in combination with a mixing and delivery system where different mixing and delivery systems are provided for the same adhesive anchor system, it shall be verified through testing that the mixing and delivery systems yield equivalent performance of the installed anchor
- Accessories for cleaning the drilled hole, including brushes, air nozzles, and other items needed to complete the cleaning process
- Printed instructions for the adhesive anchor installation including hole preparation, injection, and cure for all environmental conditions permitted in the qualification.

***adhesive anchor system**—this standard addresses the testing and assessment of adhesive anchor systems, whereby all components of the system (for example, the anchor itself and all accessories and instructions necessary for the installation in the drilled hole) are included in the assessment. Instructions for use as provided by the manufacturer, should include specific instructions for all conditions of installation to be included in the evaluation, including installation in water-saturated concrete, water-filled holes, overhead installation, and other adverse installation conditions.*

aggressive environment—any anchor environmental exposure that may be characterized as equivalent to that produced by exposure of the adhesive compound to an alkaline environment and a high sulfur dioxide concentration.

***aggressive environment** —testing of adhesive compounds as used in adhesive anchor applications to resist chemical exposure is limited in this standard to alkalinity, which is mandatory, and sulfur dioxide, which is optional. As both of these tests involve exposure to water, evaluation of the adhesive for susceptibility to hydrolyzation is included as well. ACI Committee 355 believes alkalinity is the most common aggressive chemical exposure condition. This standard considers the effects of alkalinity and sulfur dioxide separately, and the α_{dur} factor is taken as the condition representing the greatest reduction in strength.*

anchor—a steel element post-installed into a hardened concrete member and used to transmit applied loads. Steel elements for adhesive anchors may include threaded rods, deformed reinforcing bars, or internally threaded steel sleeves with external deformations.

***anchor**—the term "anchor," as used herein, refers to the steel component bonded to the concrete with adhesive. The bond model used in ACI 318M is appropriate for steels only because the use of non-steel elements may influence the bond stress distribution and may involve failure modes not considered in the model.*

anchor category—an assigned rating that corresponds to a specific strength reduction factor ϕ for concrete failure modes associated with anchors in tension. The anchor category is established by performance of the anchor in reliability tests.

***anchor category**—assignment of the anchor category is intended to represent sensitivity of the anchor system (for example, variations in installation conditions). It is used to determine the strength reduction factor in ACI 318M, Appendix D.*

anchor installation—unless otherwise noted, the process defined by the MPII for the subject anchor.

***anchor installation**—anchor installation parameters shall include, but are not limited to, ambient air and concrete temperature at the time of installation, concrete type and strength, presence of moisture or water in the drilled hole at installation time, hole drilling method, hole diameter, hole cleaning and preparation requirements, adhesive material conditioning, mixing and placement, anchor element installation and retention, gel and cure time restrictions, and installer safety requirements. It is assumed that all aspects of anchor installation are described in the MPII for all installation conditions, including installation direction and concrete temperature.*

bulk adhesives—two-component adhesives supplied in industrial quantities in either barrels or 4 to 19 L cans. They are delivered with a bulk dispensing machine whereby metering and mixing of the components are automatically controlled during dispensing through a metering manifold and disposable mixing nozzle.

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***bulk adhesives**—the use of bulk adhesive in conjunction with automatic mixing and metering equipment that ensures the correct proportioning and mixing of the adhesive components is permitted in conjunction with the standard. Such equipment is considered part of the adhesive anchor system. The use of bulk adhesive components metered, mixed, and delivered manually (that is, poured) is not addressed by this standard.*

capsule anchor systems—adhesives for anchor applications packaged in glass or foil capsules. Capsule diameter corresponds approximately to nominal anchor diameter. The quantity of resin, hardener, and aggregate component in each capsule is suitable for a single anchor application. Component mixing is achieved during anchor installation. The capsule is fragmented and becomes part of the hardened resin matrix.

***capsule anchor systems**—unlike cartridge and bulk adhesive anchor systems, capsule anchor systems are designed to deliver a finite quantity of adhesive into the drilled hole. Their use, therefore, is generally limited to discrete embedment depths for each anchor diameter corresponding to complete filling of the annular gap with cured adhesive. For deeper embedments, use of multiple capsules may be specified by the manufacturer. The drilling action during setting of spin-set capsule anchors is critical to the correct mixing and curing of adhesive. Unlike cartridge systems, the characteristics of the tool used for setting of the anchor, such as horsepower, torque, and rpm, is an integral part of the anchor system. Capsule anchors that are set with hammering action only, hammer-set may have other parameters that are critical in this regard.*

cartridge systems—two-component adhesives for anchor applications packaged in cartridges for use with either manually- or power-driven dispensers. Metering and mixing of the components is automatically controlled as the adhesive is dispensed through a manifold and disposable mixing nozzle.

***cartridge systems**—cartridge systems may employ different types of injection equipment depending on, for example, the anchor size and hole depth. Each injection system used with the adhesive anchor system should be evaluated as part of the anchor qualification in accordance with this standard.*

characteristic value—the 5 percent fractile, that is, value with a 95 percent probability of being exceeded with a confidence of 90 percent. Refer to **five percent fractile**.

***characteristic value**—the characteristic value is used for design in ACI 318M, Appendix D. 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 has been selected for anchorage design.*

closed crack—condition of a crack in an unloaded test member. Refer to **hairline crack**.

***closed crack**—crack closure in cracked concrete test members is facilitated by tension forces in the test member of the longitudinal reinforcing steel. Following unloading of the test member, a residual crack width approximately 0.05 mm will typically remain. The residual crack width associated with a closed crack may be influenced by the presence of anchors installed in the crack path and by the crack width cycling history of the test member.*

concrete batch—a mixture of specific amounts of cement, aggregate, water, and admixtures prepared and placed at a specific time and cured in a specific manner.

***concrete batch**—a concrete batch is one mixture of concrete from which test members are made. It represents a single mixture so that variations from different batches can be eliminated in the testing. Batch control requirements are provided in 4.4.*

concrete breakout failure—failure of the anchor in an unconfined tension test, characterized by the formation of a conical fracture surface originating at or near the embedded end of the anchor element and projecting to the surface of the concrete test member.

***concrete breakout failure**—the concrete breakout surface is associated with concrete breakout failure mode. The design method deemed to satisfy the anchor design requirements of ACI 318M, Appendix D, idealizes the shape and dimensions of the concrete breakout surface to establish spacing and edge distance effects associated with concrete breakout, edge breakout, and pryout failure modes. Adhesive anchors may exhibit concrete breakout failure before attainment of the maximum bond stress achievable for the adhesive in question. Sometimes concrete breakout surface formation is observable in the test and in other cases it may not reach the concrete surface before the associated fracture process in the concrete precipitates a bond failure. Care should be taken in the characterization of failure modes based on test observations.*

cracked concrete—for the purposes of this standard, a test member with a uniform crack width over the depth of the concrete test member.

***cracked concrete**—for purposes of this test program, cracked concrete refers to an idealized crack with parallel walls, and not the wedge-shaped crack opening expected in bending. Parallel crack openings are used because they represent the most critical condition for the anchor response to loading.*

cure time—the elapsed time from after mixing the adhesive material components until the adhesive material in the drilled hole achieves mechanical properties that correspond to those established with the test conducts described in this standard and are consistent with final design.

***cure time**—cure time is influenced by concrete and ambient temperature. For adhesive placement in deep embedments and/or large-diameter holes, rapid cure brought on by high concrete temperatures may result in voids, incomplete embedment of the anchor, and loss of bond. Retarded cure associated with low temperatures may likewise result in loss of adhesive in nondownhole applications. The manufacturer should specify proper procedures for permissible installation temperatures as required ensuring correct anchor placement and attainment of maximum bond strength. Refer to **gel time**.*

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dry concrete—concrete that, at the time of adhesive anchor installation, is 21 days and older and has not been exposed to water for the preceding 14 days.

dry concrete—*the term "dry concrete" as used herein is relevant to the establishment of anchor performance in connection with reliability tests.*

elevated concrete temperature—interior temperature of concrete within vicinity of anchor location. Short-term elevated concrete temperatures occur over brief intervals, for example, as a result of diurnal cycling. Long-term concrete temperatures are roughly constant over significant periods of time.

elevated concrete temperature—*elevated concrete temperatures arise from a number of factors, including sun exposure, proximity to operating machinery, or containment of liquids or gasses at elevated temperature.*

To establish design bond strengths, two classes of elevated concrete temperature are identified:

1. *Where elevated concrete temperatures are transient or part of a regular cycle of heating and cooling, such as day-night temperature rise and fall, they are considered short-term elevated temperatures for the purposes of this standard; and*
2. *Where concrete temperatures may remain elevated over weeks or months, they should be considered long-term elevated temperatures.*

Concrete temperature as an installation parameter is addressed separately in 8.6 and 8.7.

five percent fractile—a value corresponding to a 5 percent probability of nonexceedence with a confidence of 90 percent based on a Gaussian distribution for which the population standard deviation is unknown. Refer to **characteristic value**.

five percent fractile—*this section intentionally left blank.*

gel time—the elapsed time after mixing adhesive material components to onset of significant chemical reaction as characterized by an increase in viscosity.

gel time—*mechanical disturbance of the chemical reaction after the gel time has elapsed and before the attainment of full cure as defined by the cure time is likely to result in impairment of adhesive material mechanical properties.*

hairline crack—a crack in an unloaded test member resulting from tension loading of the member.

hairline crack—*hairline cracks in test members used for anchor testing in cracks are typically 0.05 mm. The residual crack width associated with a hairline crack may be influenced by the presence of anchors installed in the crack path and the crack width cycling history of the test member.*

Independent Testing and Evaluation Agency (ITEA)—a laboratory accredited in conformance with requirements in Chapter 12 having responsibility for testing and assessment of an anchor product in accordance with the criteria in this standard.

Independent Testing and Evaluation Agency (ITEA)—*laboratories engaged in testing and evaluation of adhesive anchor systems must be familiar with the test procedures and reference standards described in this standard as applicable and have demonstrated conformance with the procedures and policies set forth in ISO 17020 and ISO 17025. The testing agency and evaluation agency may be separate organizations.*

load at loss of adhesion—load corresponding to the loss of adhesion between adhesive and concrete in a tension test (10.4.4.1).

load at loss of adhesion—*loss of adhesion is typically identified as an abrupt change in the load-slip response of an adhesive anchor in a tension test and marks the transition from resistance associated primarily with adhesion, or chemical bond, to frictional resistance or micro-keying.*

Manufacturer's Printed Installation Instructions (MPII)—published instructions for correct anchor installation under all covered installation conditions as supplied in product packaging by the manufacturer of the adhesive anchor system. The MPII shall include information on storage conditions, shelf life, and all restrictions on installation conditions (10.22.1).

Manufacturer's Printed Installation Instructions (MPII)—*for the purposes of this standard, the MPII is the sole source of instruction for the installation of the adhesive anchor system. It must be included in packaging for the adhesive anchor system and cannot be supplied in the form of supplementary documentation or verbal instruction. The format, text, pictograms, photos, or other graphic devices used to convey the installation procedures should be legible, self-explanatory, and understandable for persons having a secondary school or higher education level. It is the responsibility of the ITEA to evaluate the MPII and assess its suitability prior to beginning the test program.*

primary testing laboratory—ITEA with primary responsibility for testing and assessment of an anchor product in accordance with this standard.

primary testing laboratory—*while it is permissible for multiple ITEAs to be engaged in the assessment of a single adhesive anchor system, one laboratory is responsible for the coordination and overall assessment of the system.*

pullout failure—a failure mode characterized by the withdrawal of the anchor element from the concrete without rupture of the embedded part—for example, the threaded rod or reinforcing bar—and without formation of a full-depth conical breakout surface. The formation of limited-depth conical breakout surfaces shall also be considered as pullout failures.

pullout failure—*visual assessment of pullout failure is difficult in many cases. This standard compares the predicted concrete breakout strength with the maximum bond strength, as based on the characteristic limiting bond stress, to determine pullout failure.*

saturated concrete—concrete that, at the time of adhesive anchor installation, has been exposed to water over a sufficient length of time to have the maximum possible amount of absorbed water into the concrete pore structure to a depth equal to the anchor embedment depth.

saturated concrete—*the term "saturated concrete" as used herein is relevant to the establishment of anchor performance in connection with reliability tests.*

shelf life—recommended time that adhesive materials may be stored before degradation may begin. Shelf life shall

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be determined by appropriate testing, indicated on the adhesive anchor system packaging, with required storage conditions described in the MPII.

shelf life*—influenced by storage conditions. The MPII should clearly state the storage requirements associated with predicted shelf life for the adhesive.*

small, intermediate, and large diameters—the smallest, intermediate, and largest diameters are to be determined from the manufacturer's published or production anchor diameters of the tested anchor system. The intermediate diameter shall be taken as least 3 mm larger than the smallest diameter and the diameter most closely representing the arithmetic mean of the smallest and largest diameters.

small, intermediate, and large diameters*—this section intentionally left blank.*

splitting failure—a concrete failure mode characterized by the formation of a planar crack in the concrete parallel to and extending through the axis of the anchor or anchors.

standard temperature—23°C ± 4°C.

statistically equivalent—two groups of test results shall be considered statistically equivalent if there are no significant differences between the means and the standard deviations of the two groups. Such statistical equivalence shall be demonstrated using a one-sided Student's *t*-Test at a confidence level of 90 percent.

steel failure—a failure mode characterized by fracture of the anchor element.

test member—a concrete element in which anchors are installed and tested.

test member*—this section intentionally left blank.*

test series—a group of identical anchors tested under identical conditions. Identical conditions include anchor diameter, length, embedment, spacing, edge distance, hole diameter and depth, concrete density/weight, test member thickness, and concrete compressive strength.

uncracked concrete—for purposes of this standard, a concrete test member that is uncracked at the beginning of the test.

CHAPTER 3—GENERAL REQUIREMENTS

3.1—Test organization

3.1.1 Qualification of an anchor system in accordance with ACI 355.4M evaluates the anchor system under four types of tests:

1. Identification tests to evaluate anchor compliance with manufacturer's specifications (Chapter 5)
2. Reference tests to obtain baseline values for the evaluation of reliability and service-condition test results (Chapter 6)
3. Reliability tests to assess anchor sensitivity to adverse installation conditions and long-term loading (Chapter 7)
4. Service-condition tests to establish anchor performance under expected service conditions (Chapter 8)

R3.1.1 *The classification of test types in this standard is identical to that established in ACI 355.2 (ACI Committee 355 2007).*

3.1.2 In addition, the following supplemental service-condition tests (3.1.2.1 through 3.1.2.3) are included (Chapter 9).

3.1.2.1 Mandatory round-robin tests for adhesive anchors shall be performed to establish the effects of regional variations in concrete on anchor behavior (9.1).

R3.1.2.1 *Round-robin tests were introduced in ACI 355.4M to avoid undue influence of regional concrete composition on anchor tension strength. Round-robin tests followed extensive, but inconclusive, investigations to determine the precise nature of concrete composition influence on adhesive anchor performance. Theories regarding this effect include variations in concrete porosity, as reflected in the concrete density, and aggregate hardness. Limited experimental evidence indicates these effects may lessen as the concrete age increases.*

Round-robin tests are performed in regional concretes to establish and compare a nominal bond strength for generally expected anchor performance against the tested anchor bond strength. Based on round-robin tests (establishing a bond strength above or below the ITEA value) the reported bond strength is adjusted up or down. Refer to 9.1 and 10.4.1 for further methodology.

3.1.2.2 Supplemental assessment tests for multiple anchor element types (refer to 3.4).

3.1.2.3 Supplemental assessment tests for alternate drilling methods (refer to 3.5).

3.2—Variables and options

R3.2 *Optional tests are specified in ACI 355.4M. Omission of optional tests will result in limitations being placed on use of the adhesive anchor system.*

3.2.1 The assessment of a given anchor system in accordance with ACI 355.4M includes consideration of the following system variables and optional installation and use conditions:

1. *Presence of water during anchor installation*—Installation procedures, including hole cleaning procedures, are as specified in the MPII. Hole cleaning procedures typically include vacuuming, evacuation with forced air, and brushing. Quantification of the number, order, and duration of cleaning operations and description of equipment used is required. The default installation condition for verification of the hole cleaning procedure is dry concrete. Verification in water-saturated concrete is mandatory. Options include installation in water-filled holes and in submerged concrete (7.6 through 7.8 and 7.10 through 7.12).
2. *Drilling method*—The default drilling method uses a rotary hammer drill with carbide bit. Optional drilling methods for assessment includes core drilling and rock drilling (3.5).
3. *Installation direction*—Installation direction is the orientation of the axis of the anchor relative to gravity. Unless otherwise noted, the installation direction is vertically down. Optional installation directions for assessment extenuation are horizontal and vertical (7.18).
4. *Installation temperature*—The default concrete temperature range during anchor installation is 10 to 27°C. Options include installation at lower concrete temperatures (8.6).

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5. *Embedment depth and anchor diameter*—The anchor diameters and associated embedment depth range are specified by the manufacturer within the ranges permitted by this standard (refer to Chapter 1).
6. *Anchor element type*—Anchor element types used in the anchorage system include different steel material types such as carbon and stainless steels, different tensile strengths of the steel, and different anchor elements such as threaded rods, reinforcing bars, and internally threaded inserts (3.4).
7. *Environmental use conditions*—Default conditions are dry and wet environments with service temperatures ranging from –40°C to the maximum long- and short-term service temperatures corresponding to the temperature categories given in Table 8.1.
8. *Chemical exposure*—The default exposure condition is high alkalinity in a wet environment. The optional exposure condition is sulfur dioxide (8.8).
9. *Concrete condition*—Options include uncracked concrete or uncracked and cracked concrete.
10. *Loading*—Default loading conditions are static loading including sustained loads. Qualification for seismic loading is optional in conjunction with qualification for cracked concrete (8.12 and 8.13).
11. *Member thickness*—The default minimum member thickness is $h_{ef,min} + \Delta h$. Refer to 1.2.1 for $h_{ef,min}$ and 10.7 for Δh. For smaller values of Δh, tests shall be conducted to verify that holes may be drilled and anchors installed without concrete spalling on the backside of the member for specific ratios of h_{ef}/h.

3.2.2 Limitations on conditions of use as a function of which optional tests are performed are described in 10.22.1.

3.3—Test requirements

R3.3 *This standard makes a fundamental distinction between anchors qualified for use exclusively in concrete that is expected to remain uncracked over the service life of the anchorage and anchors qualified for use in concrete that may be cracked or uncracked over the service life of the anchorage.*

Table 3.1 addresses qualification for use in uncracked concrete only, while Table 3.2 addresses cracked concrete qualification as well as qualification for seismic loading. Note that qualification for seismic loading can only be conducted in the context of qualification for cracked concrete. Table 3.3 provides an abbreviated test program for anchors to be qualified for use in cracked concrete, but without the option to achieve qualification for seismic loading.

3.3.1 Test requirements for adhesive anchors assessed to resist static loads in uncracked concrete conditions are defined in Table 3.1.

3.3.2 Test requirements for adhesive anchors assessed to resist static loads in both cracked and uncracked concrete conditions are defined in Tables 3.2 and 3.3. The reduced test program in Table 3.3 is associated with a predefined and conservative value for the ratio of characteristic limiting bond stresses in uncracked and cracked concrete. For optimization of the predicted strength of anchors in cracked concrete conditions, the entire test program outlined in Table 3.2 must be conducted.

3.3.3 Test requirements for adhesive anchors to be assessed to resist seismic loads are defined in Table 3.2. Tables 3.1 and 3.3 may not be used to assess anchors to resist seismic loads.

3.4—Assessment for multiple anchor element types for adhesive anchors

R3.4 *When tests are performed on one type of anchor material such as carbon steel-threaded rod and the qualification is intended to include other types of threaded rod, such as stainless steel or hot-dip galvanized rod, then the testing and assessment of the adhesive anchor system is conducted for the primary rod type (usually carbon steel) and supplementary tests are conducted using the second rod type in accordance with Table 3.4. This abbreviated testing and assessment is primarily intended to address change in the torque-tension relationship associated with different rod materials, coatings, and thread types (ANSI/ASME B1.1 1989).*

If the additional testing performed using Table 3.4 indicates significant differences between the bond stresses of the two anchor elements, then repeat the entire test program for the anchor element.

3.4.1 When the assessment encompasses multiple anchor element material types such as carbon and stainless steel, the entire assessment shall be permitted to be performed with one anchor type; however, the other anchor element types shall be subjected to additional tests in accordance with Table 3.4.

3.5—Assessment for alternate drilling methods

R3.5 *Hammer drilling and rock drilling are assumed to produce similar hole wall characteristics from the standpoint of bond strength development. Drilling with diamond core bits, dry or wet, produces a smoother hole wall with a layer of drilling slurry or dust that can impair bond development.*

3.5.1 Qualification of anchors using drilling methods other than carbide bit rotary-hammer must meet the requirements noted in 3.5.1.1 and 3.5.1.2.

3.5.1.1 Perform supplemental tests in accordance with Table 3.5 using the alternate drilling method. Install anchors in accordance with the MPII.

3.5.1.2 Results of supplemental testing required in Table 3.5 must be compared to corresponding tests conducted using a carbide rotary-hammer bit. If the comparison does not indicate statistical equivalence in test results between carbide rotary-hammer drilling and the alternative drilling method, then the alternative drilling method must be qualified using the test requirements of 3.3.

There are, however, two exceptions: 1) testing for shear capacity of the anchor element need not be repeated. Additional testing for shear capacity of the anchor element is not required and may be omitted (Table 3.1, Test 12; Table 3.2, Test 16; or Table 3.3, Test 13); and 2) testing using a carbide rotary-hammer drill shall also be valid for percussive drilling, like pneumatic rock drilling, without supplementary tests. Testing using percussive drilling

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Table 3.1—Test program for evaluating adhesive anchor systems in uncracked concrete

Testing				Assessment				
Test no.	Test reference	Purpose	Test parameters	α_{req}	Load and displacement	f_c*	h_{ef}†	Minimum sample size n_{min}
Reference tests								
1a	Chapter 6	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	—	—	low	min max	Five per concrete batch
1b	Chapter 6	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	—	—	high	min	Five per concrete batch
Reliability tests								
2a	7.5	Sensitivity to hole cleaning, dry substrate	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‡
2b	7.6	Sensitivity to hole cleaning, installation in water-saturated concrete	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‡
2c	7.7	Sensitivity to hole cleaning, installation in a water-filled hole§	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‡
2d	7.8	Sensitivity to hole cleaning, installation in submerged concrete§	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‖
2e	7.9	Sensitivity to mixing effort	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five#
2f**	7.10	Sensitivity to installation in water-saturated concrete	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‡
2g	7.11	Sensitivity to installation in a water-filled hole§	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‡
2h	7.12	Sensitivity to installation in submerged concrete§	Tension, confined, single anchor away from edges	10.4.6	10.4.2 10.4.4	low	max	Five‖
3	7.16	Sensitivity to freezing/thawing conditions	Sustained tension, residual capacity, confined test	0.90	10.4.2 10.4.4 10.10	high	min††	Five#
4	7.17	Sensitivity to sustained load	Sustained tension, residual capacity, confined test	0.90	10.4.2 10.4.4 10.11	low	min††	Five#
5	7.18	Sensitivity to installation direction§	Tension, confined, single anchor away from edges	0.90	10.4.2 10.4.4 10.12	low	max	Five#
6	7.19	Torque test‡‡	Application of torque, confined, single anchor away from edges	—	10.8	high	min	Five‖
Service-condition tests								
7a	8.4	Tension in low-strength concrete	Tension, unconfined, single anchor away from edges§§	—	10.4.2 10.4.4 10.4.5	low	min max	Five‖
7b	8.4	Tension in high-strength concrete‖‖	Tension, unconfined, single anchor away from edges§§	—	10.4.2 10.4.4 10.4.5	high	min	Five‖
8a	8.5	Tension at elevated temperatures	Tension, confined, single anchor away from edges	—	10.4.2 10.4.4 10.13	low	min	Five#
8b	8.6	Tension at decreased installation temperature§	Tension, confined single anchor away from edges	—	10.4.2 10.4.4 10.14	low	min	Five#
8c	8.7	Curing time at standard installation temperature	Tension, confined single anchor away from edges	—	10.4.2 10.4.4 10.15	low	min	Five#
9a	8.8	Resistance to alkalinity	Slice tests	—	10.16	low	—	Ten#
9b	8.8	Resistance to sulfur§	Slice tests	—	10.16	low	—	Ten#
10	8.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges##	—	10.17	low	min max	Four‖
11	8.10	Minimum spacing and edge distance to preclude splitting	High installation tension (torque or unconfined tension), two anchors near an edge##	—	10.18	low	min	Five‖
12	8.11	Shear capacity of steel element having a non-uniform cross section***	Shear, single anchor away from edges	—	10.6	low	min	Five‖
13	9.1	Round-robin tests for regional concrete variation	Tension, confined and unconfined single anchor away from edges	—	10.4.1	low†††	$7d_a$	Five#
14	9.2	Minimum member thickness§	Installation tests##	—	10.7	low	max	Ten‖

*For definition of high- and low-strength concrete, refer to 4.3.4.
†Where MPII specifies multiple embedment depths for single anchor diameter, test anchor at minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \le 5.0$ (4.7.2).
‡Test small, medium, and large diameters.
§Optional test.
‖Test all diameters.
#Test the nominal M12 diameter or the smallest nominal diameter if it is larger than M12. For overhead and horizontal orientations, test the largest diameter for which recognition is sought. For tests conducted in accordance with 9.1, tests shall be performed with a nominal M12 anchor only.
**Test 2f may be omitted if Test 2g is performed.
††Refer to 4.7.2.2.
‡‡Refer to 3.4 for multiple anchor element types.
§§Alternatively, tests may be performed as confined tests.
‖‖Tests are optional if test results of Test 1b can be shown to be statistically equivalent to or greater than the results of Test 1a. If Test 7b is not performed, limit the calculated anchor tension resistance to $f_c' = 17$ MPa regardless of the in-place concrete strength.
##Use minimum member thickness h_{min} for these tests.
***Test is required only for anchors having a cross-sectional area, within five anchor diameters of the shear failure plane, that is less than that of a threaded bolt having the same nominal diameter as the anchor.
†††Test in concrete having a measured compressive strength of 21 ± 3.5 MPa at the time of testing.

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Table 3.2—Test program for evaluating adhesive anchor systems for cracked and uncracked concrete

Testing				Crack width Δ_w, mm	Assessment		f_c*	h_{ef}†	Minimum sample size n_{min}
Test no.	Test reference	Purpose	Test parameters		α_{req}	Load and displacement			
Reference tests									
1a	Chapter 6	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	—	—	—	low	min max	Five per concrete batch
1b	Chapter 6	Reference tension in low-strength, cracked concrete	Tension, confined, single anchor away from edges	0.3	—	—	low	min	Five per concrete batch
1c	Chapter 6	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	—	—	—	high	min	Five per concrete batch
1d	Chapter 6	Reference tension in high-strength, cracked concrete‡	Tension, confined, single anchor away from edges	0.3	—	—	high	min	Five per concrete batch
Reliability tests									
2a	7.5	Sensitivity to hole cleaning, dry substrate	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five§
2b	7.6	Sensitivity to hole cleaning, installation in water-saturated concrete	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five§
2c	7.7	Sensitivity to hole cleaning, installation in a water-filled hole‖	Tension, confined, single anchor away from edges	—	10.4.6	10.4.4 10.4.4	low	max	Five§
2d	7.8	Sensitivity to hole cleaning, installation in submerged concrete‖	Tension, confined, single anchor away from edges	—	10.4.6	10.4.4	low	max	Five#
2e	7.9	Sensitivity to mixing effort	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five**
2f††	7.10	Sensitivity to installation in water-saturated concrete	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five§
2g	7.11	Sensitivity to installation in a water-filled hole‖	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five§
2h	7.12	Sensitivity to installation in submerged concrete‖	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five#
3	7.13	Sensitivity to crack width in low-strength concrete	Tension, confined, single anchor away from edges	0.5	0.80	10.4.4 10.4.4	low	min	Five§
4	7.14	Sensitivity to crack width in high-strength concrete‡	Tension, confined, single anchor away from edges	0.5	0.80	10.4.2 10.4.4	high	min	Five§
5	7.15	Sensitivity to crack width cycling	Sustained tension, single anchor away from edges, residual capacity, confined test	0.1 to 0.3	0.90	10.4.2 10.4.4 10.9	low	min	Five #
6	7.16	Sensitivity to freezing/thawing conditions	Sustained tension, residual capacity, confined test	—	0.90	10.4.2 10.4.4 10.10	high	min‡‡	Five**
7	7.17	Sensitivity to sustained load	Sustained tension, residual capacity, confined test	—	0.90	10.4.2 10.4.4 10.11	low	min‡‡	Five**
8	7.18	Sensitivity to installation direction‖	Tension, confined, single anchor away from edges	—	0.90	10.4.2 10.4.4 10.12	low	max	Five**
9	7.19	Torque test§§	Application of torque, confined, single anchor away from edges	—	—	10.8	high	min	Five#
Service-condition tests									
11a	8.4	Tension in low-strength concrete	Tension, unconfined, single anchor away from edges	—	—	10.4.2 10.4.4 10.4.5	low	min max	Five#
11b	8.4	Tension in high-strength concrete‡	Tension, unconfined, single anchor away from edges	—	—	10.4.2 10.4.4 10.4.5	high	min	Five#
11c	8.4	Tension in low-strength, cracked concrete	Tension, unconfined, single anchor away from edges	0.3	—	10.4.2 10.4.4 10.4.5	low	min	Five#
11d	8.4	Tension in high-strength, cracked concrete‡	Tension, unconfined, single anchor away from edges	0.3	—	10.4.2 10.4.4 10.4.5	high	min	Five#
12a	8.5	Tension at elevated temperatures	Tension, confined single anchor away from edges	—	—	10.4.2 10.4.4 10.13	low	min	Five**
12b	8.6	Tension at decreased installation temperature‖	Tension, confined single anchor away from edges	—	—	10.4.2 10.4.4 10.14	low	min	Five**
12c	8.7	Curing time at standard installation temperature	Tension, confined single anchor away from edges	—	—	10.4.2 10.4.4 10.15	low	min	Five**

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Table 3.2—Test program for evaluating adhesive anchor systems for cracked and uncracked concrete (cont.)

Testing				Crack width Δ_w, mm	Assessment		f_c*	h_{ef}†	Minimum sample size n_{min}
Test no.	Test reference	Purpose	Test parameters		α_{req}	Load and displacement			
13a	8.8	Resistance to alkalinity	Slice tests	—	—	10.16	low	—	Ten**
13b	8.8	Resistance to sulfur‖	Slice tests	—	—	10.16	low	—	Ten**
14	8.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges##	—	—	10.17	low	min max	Four#
15	8.10	Minimum spacing and edge distance to preclude splitting	High installation tension (torque or unconfined tension) two anchors near an edge##	—	—	10.18	low	min	Five#
16	8.11	Shear capacity of anchor element having a non-uniform cross section	Shear, single anchor away from edges***	—	—	10.6	low	min	Five#
17	8.12	Seismic tension‖	Pulsating tension, single anchor away from edges	0.5	—	10.4.2 10.4.4 10.19	low	min max	Five#
18	8.13	Seismic shear‖	Alternating shear, single anchor away from edges	0.5	—	10.20	low	min	Five§
19	9.1	Round-robin tests for regional concrete variation	Tension, confined and unconfined single anchor away from edges	—	—	10.4.1	low†††	$7d_a$	Five**
20	9.2	Minimum member thickness‖	Installation tests##	—	—	10.7	low	max	Ten#

*For definition of high- and low-strength concrete, refer to 4.3.4.
†Where MPII specify multiple embedment depths for single anchor diameter, test anchor at minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \le 5.0$ (4.7.2).
‡Tests are optional if test results of Test 1c can be shown to be statistically equivalent to or greater than results of Test 1a. If any of Tests 1d, 4, 11b, and 11d are not performed, limit calculated anchor tension resistance to $f'_c = 17$ MPa.
§Test small, medium, and large diameters.
‖Optional test.
#Test all diameters.
**Test the nominal M12 diameter or the smallest nominal diameter if it is larger than M12. For overhead and horizontal orientations, test the largest diameter for which recognition is sought. For tests conducted in accordance with Section 9.1, tests shall be performed with a nominal M12 anchor only.
†††Test 2f may be omitted if Test 2g is performed.
‡‡Refer to Section 4.7.2.2.
§§Refer to Section 3.4 for multiple anchor element types.
##Use minimum member thickness h_{min} for these tests.
***Test is required only for anchors having a cross-sectional area, within five anchor diameters of the shear failure plane, that is less than that of a threaded bolt having the same nominal diameter as the anchor.
†††Test in concrete having a measured compressive strength of 21 MPa ± 3.5 MPa at the time of testing.

Table 3.3—Reduced test program for evaluating adhesive anchor systems in cracked and uncracked concrete

Testing				Crack width Δ_w, mm	Assessment		f_c*	h_{ef}†	Minimum sample size n_{min}
Test no.	Test reference	Purpose	Test parameters		α_{req}	Load and displacement			
Reference tests									
1a	Chapter 6	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	—	—	—	low	min max	Five per concrete batch
1b	Chapter 6	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	—	—	—	high	min	Five per concrete batch
Reliability tests									
2a	7.5	Sensitivity to hole cleaning, dry substrate	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‡
2b	7.6	Sensitivity to hole cleaning, installation in water-saturated concrete	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‡
2c	7.7	Sensitivity to hole cleaning, installation in a water-filled hole§	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‡
2d	7.8	Sensitivity to hole cleaning, installation in submerged concrete§	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‖
2e	7.9	Sensitivity to mixing effort	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five#
2f**	7.10	Sensitivity to installation in water-saturated concrete	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‡
2g	7.11	Sensitivity to installation in a water-filled hole§	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‡
2h	7.12	Sensitivity to installation in submerged concrete§	Tension, confined, single anchor away from edges	—	10.4.6	10.4.2 10.4.4	low	max	Five‖

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Table 3.3—Reduced test program for evaluating adhesive anchor systems in cracked and uncracked concrete (cont.)

Testing				Crack width Δ_w, mm	Assessment		f_c*	h_{ef}†	Minimum sample size n_{min}
Test no.	Test reference	Purpose	Test parameters		α_{req}	Load and displacement			
3	7.15	Sensitivity to crack width cycling	Sustained tension, single anchor away from edges, residual capacity, confined test	0.1 to 0.3	0.90	10.4.2 10.4.4 10.9	low	min	Five‖
4	7.16	Sensitivity to freezing/thawing conditions	Sustained tension, residual capacity, confined test	—	0.90	10.4.2 10.4.4 10.10	high	min††	Five#
5	7.17	Sensitivity to sustained load	Sustained tension, residual capacity, confined test	—	0.90	10.4.2 10.4.4 10.11	low	min††	Five#
6	7.18	Sensitivity to installation direction§	Tension, confined, single anchor away from edges	-—	0.90	10.4.2 10.4.4 10.12	low	max	Five#
7	7.19	Torque test‡‡	Application of torque, confined, single anchor away from edges	—	—	10.8	high	min	Five‖
Service-condition tests									
8a	8.4	Tension in low-strength concrete	Tension, unconfined, single anchor away from edges	—	—	10.4.2 10.4.4 10.5	low	min max	Five‖
8b	8.4	Tension in high-strength concrete§§	Tension, unconfined, single anchor away from edges	—	—	10.4.2 10.4.4 10.5	high	min	Five‖
9a	8.5	Tension at elevated temperatures	Tension, confined single anchor away from edges	—	—	10.4.2 10.4.4 10.13	low	min	Five#
9b	8.6	Tension at decreased installation temperature§	Tension, confined single anchor away from edges	—	—	10.4.2 10.4.4 10.14	low	min	Five#
9c	8.7	Curing time at standard installation temperature	Tension, confined single anchor away from edges	—	—	10.4.2 10.4.4 10.15	low	min	Five#
10a	8.8	Resistance to alkalinity	Slice tests	—	—	10.16	low	-	Ten#
10b	8.8	Resistance to sulfur§	Slice tests	—	—	10.16	low	-	Ten#
11	8.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges##	—	—	10.17	low	min max	Four‖
12	8.10	Minimum spacing and edge distance to preclude splitting	High installation tension (torque or unconfined tension), two anchors near an edge##	—	—	10.18	low	min	Five‖
13	8.11	Shear capacity of anchor element having a non-uniform cross section	Shear, single anchor away from edges***	—	—	10.6	low	min	Five‖
14	9.1	Round-robin tests for regional concrete variation	Tension, confined and unconfined single anchor away from edges	—	—	10.4.1	low†††	$7d_a$	Five#
15	9.2	Minimum member thickness§	Installation tests##	—	—	10.7	low	max	Ten‖

*For definition of high- and low-strength concrete, refer to 4.3.4.
†Where MPII specify multiple embedment depths for single anchor diameter, test anchor at minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \le 5.0$ (4.7.2).
‡Test small, medium, and large diameters.
§Optional test.
‖Test all diameters.
#Test nominal M12 diameter or smallest nominal diameter if it is larger than M12. For overhead and horizontal orientations, test largest diameter for which recognition is sought. For tests conducted in accordance with 9.1, tests shall be performed with nominal M12 anchor only.
**Test 2f may be omitted if Test 2g is performed.
††Refer to 4.7.2.2.
‡‡Refer to 3.4 for multiple anchor element types.
§§Tests are optional if test results of Test 1b can be shown to be statistically equivalent to or greater than results of Test 1a. If Test 8b is not performed, limit calculated anchor tension resistance to $f_c' = 17$ MPa.
##Use minimum member thickness h_{min} for these tests.
***Test is required only for anchors having cross-sectional area within five anchor diameters of the shear failure plane that is less than that of threaded bolt having same nominal diameter as anchor.
†††Test in concrete having measured compressive strength of 21 ± 3.5 MPa at time of testing.

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