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An ACI Standard

Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4M-19) and Commentary

Reported by ACI Committee 355

ACI 355.4M-19

American Concrete Institute
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First Printing
August 2021
ISBN: 978-1-64195-154-8

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ACI 355.4M-19

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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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ACI 355.4M-19 supersedes ACI 355.4M-11, and was adopted and published August 2021.

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 $d_o \leq 1.5d_a$. 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 $20d_a$.

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

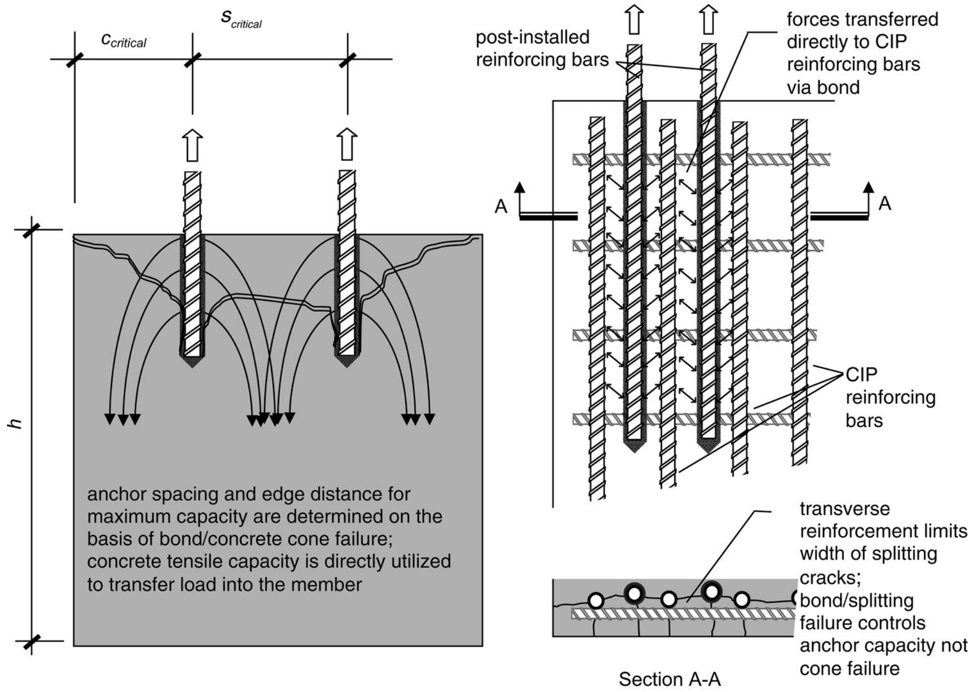
R1.2.1 *The minimum diameter of 6 mm is based on practical considerations regarding the limit of structural anchor applications. The upper limit on the ratio of hole diameter to anchor element diameter provides a demarcation between conditions where a single bond strength can be used to evaluate anchor 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.

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.
5. Injection-type adhesive anchor systems for horizontal and upwardly inclined installations that do not employ a piston plug or similar device to provide back pressure during the adhesive injection process.



(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.

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 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.

Void-free injection of adhesive is critical for the performance of adhesive anchors, particularly for cases involving sustained tension load. This standard includes several criteria for assessing the effectiveness of the adhesive anchor injection system. Nevertheless, the injection of adhesive into horizontal and upwardly inclined holes presents special challenges. The collapse of a tunnel ceiling in Boston, Massachusetts, in 2006 highlights this issue. NTSB (2006) documented improper installation of the adhesive based on observation of failed anchors and anchors adjacent to the collapsed section. Subsequent laboratory investigations confirmed these findings; see Ocel and Hartmann (2007). The piston plug was developed to minimize injected air voids (see Fig. 2.2). Laboratory investigations (Silva 2016) indicate that injection of adhesive with only an extension tube—that is, without the use of a device such as a piston plug to provide back pressure during the injection process—does not result in a sufficient degree of reliability in the installation process. The use of a piston plug during the injection process consistently results in good installation. For small hole diameters (6.35 to 9.55 mm), the same