An ACI Standard

Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-19) and Commentary

Reported by ACI Committee 355



American Concrete Institute Always advancing



Qualification of Post-Installed Mechanical Anchorsin Concrete (ACI 355.2-19) and Commentary

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at http://concrete.org/Publications/ DocumentErrata.aspx. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided "as is" without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, through electronic subscription, or reprint, and may be obtained by contacting ACI.

ACI codes, specifications, and practices are made available in the ACI Collection of Concrete Codes, Specifications, and Practices. The online subscription to the ACI Collection is always updated, and includes current and historical versions of ACI's codes and specifications (in both inch-pound and SI units) plus new titles as they are published. The ACI Collection is also available as an eight-volume set of books and a USB drive.

American Concrete Institute 38800 Country Club Drive Farmington Hills, MI 48331 Phone: +1.248.848.3700 Fax: +1.248.848.3701

www.concrete.org

ACI 355.2-19

Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-19) and Commentary

An ACI Standard

Reported by Joint ACI Committee 355

Lee W. Mattis, Chair

Monzer M. Allam Neal S. Anderson Jacques A. Bertrand T. J. Bland Peter J. Carrato Harry A. Chambers Ronald A. Cook

Edwin G. Burdette Robert W. Cannon Neil M. Hawkins

Rolf Eligehausen Werner A. F. Fuchs Branko Galunic Brian C. Gerber Herman L. Graves, III Andra Hoermann-Gast Brent E. Hungerford

Consulting Members

Paul R. Hollenbach Donald F. Meinheit Conrad Paulson

Amy S. Kolczak Thomas A. Kolden Anthony J. Lamanna Nam-Ho Lee Robert R. McGlohn Giovanni Muciaccia Jake Olsen

Dan R. Stoppenhagen Harry Wiewel Richard E. Wollmershauser

John E. Pearson Milton Rodriguez John F. Silva Patrick J. E. Sullivan J. Bret Turley Curtis R. Yokoyama Jian Zhao

ACI 355.2 prescribes testing programs and evaluation requirements for post-installed mechanical anchors intended for use in concrete under the design provisions of ACI 318. Criteria are prescribed for determining whether anchors are acceptable for use in uncracked concrete only, or in cracked as well as uncracked

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

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.



ACI 355.2R-19 supersedes 355.2-07, became effective April 8, 2019, and was published June 2019.

Copyright © 2019, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless vright proprietors.

CONTENTS

CHAPTER 1—SCOPE, p. 5

CHAPTER 2—DEFINITIONS AND NOTATION, p. 7

2.1—Definitions, p. 7 2.2—Notation, p. 8

CHAPTER 3—SIGNIFICANCE AND USE, p. 13

CHAPTER 4—GENERAL REQUIREMENTS, p. 16

4.1—Testing sequence, p. 16

4.2—Test samples, p. 25

4.3—Testing by independent testing and evaluation agency and by manufacturer, p. 26

4.4—Changes to product, p. 26

CHAPTER 5—REQUIREMENTS FOR TEST SPECIMENS, INSTALLING ANCHORS, AND CONDUCTING TESTS, p. 29

5.1—Concrete for test members, p. 29

5.2—Anchor installation, p. 30

5.3—Test methods, p. 37

5.4—Tests in cracked concrete, p. 37

5.5—General requirements for anchor behavior, p. 38

CHAPTER 6—REQUIREMENTS FOR ANCHOR IDENTIFICATION, p. 45

6.1—Determination of critical characteristics of anchors, p. 45

6.2—Specification of critical characteristics of anchors, p.45

6.3—Verification of conformance to drawings and specifications, p. 45

CHAPTER 7—REFERENCE TESTS, p. 48

7.1—Purpose, p. 48

7.2—Reference tension tests for single anchors without spacing and edge effects (Table 4.1a, Tests 1 through 3, or Table 4.1b, Tests 1 through 5), p. 48

7.3—Required calculations using results of reference tests, p. 49

CHAPTER 8-RELIABILITY TESTS, p. 52

8.1—Purpose, p. 52

8.2—Reliability tests using reduced installation effort (Table 4.1a, Test 4, and Table 4.1b, Test 6), p. 52

8.3—Reliability in low-strength concrete with large drill bit (Table 4.1a, Test 5, and Table 4.1b, Test 7), p. 53

8.4—Reliability in high-strength concrete with small drill bit (Table 4.1a, Test 6, and Table 4.1b, Test 8), p. 53

8.5—Reliability under repeated load (Table 4.1a, Test 7, and Table 4.1b, Test 10 for screw anchors), p. 54

8.6—Reliability in cracked concrete where crack width is cycled (Table 4.1b, Test 9), p. 55

8.7—Reliability of screw anchors for brittle failure (Table 4.1a, Test 8, and Table 4.1b, Test 11), p. 58

8.8—Reliability tests of screw anchors to setting method (Table 4.1a, Tests 9, 10, and 11, or Table 4.1b, Tests 12, 13, and 14), p. 64

CHAPTER 9—SERVICE-CONDITION TESTS, p. 68

9.1—Purpose, p. 68

9.2—Service-condition tension test with single anchor and with two edges (corner) (Table 4.1a, Test 12, and Table 4.1b, Test 15), p. 68

9.3—Service-condition test at minimum edge distance and minimum spacing (Table 4.1a, Test 13, and Table 4.1b, Test 16), p. 69

9.4—Service-condition shear test for single anchors without spacing and edge effects (Table 4.1a, Test 14, and Table 4.1b, Test 17), p. 71°

9.5—Service-condition, simulated seismic tension tests (Table 4.1b, Test 18), p. 71

9.6—Service condition, simulated seismic shear tests (Table 4.1b, Test 19), p. 73

9.7—Torque tests (Table 4.1a, Test 15, and Table 4.1b, Test 20) – Optional, p. 76

CHAPTER 10—ESTABLISHING ANCHOR CATEGORIES, p. 78

CHAPTER 11—PRESENTING ANCHOR DATA, p. 79

11.1—Data analysis, p. 79

11.2—Format of data sheet, p. 79

11.3—General requirements, p. 79

11.4—Contents of evaluation report, p. 79

CHAPTER 12—REQUIREMENTS FOR INDEPENDENT TESTING AND EVALUATION AGENCY, p. 80

CHAPTER 13—REFERENCES, p. 81

Authored documents, p. 81



MANDATORY APPENDIXES: APPENDIX A1—REQUIREMENTS FOR NORMALIZATION OF RESULTS, p. 82

A1.1-Normalization of capacities to take account of concrete and steel strengths, p. 82

- A1.2—Concrete breakout or splitting failure, p. 82
- A1.3—Pullout and pull-through failure, p. 82
- A1.4—Steel failure, p. 82

APPENDIX A2—REQUIREMENTS FOR ESTABLISHING CHARACTERISTIC CAPACITIES, p. 83

- A2.1—Scope, p. 83 A2.2—Procedure, p. 83

APPENDIX A3—REQUIREMENTS FOR TEST

MEMBERS, p. 84

- A3.1-Tests in uncracked concrete, p. 84
- A3.2—Tests in cracked concrete, p. 84
- A3.3—Casting and curing of test members, p. 85

EXAMPLE OF EVALUATION OF A WEDGE-TYPE ANCHOR IN UNCRACKED CONCRETE, p. 86

- E1—Anchor specifications, p. 86
- E2—Test results, p. 87
- E4-Establishing anchor category, p. 91
- E5-Report of anchor data, p. 91



PAGE LEFT INTENTIONALLY BLANK

CHAPTER 1—SCOPE

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

1.4 ACI 355.2 applies to expansion, undercut, and screw anchors with a minimum effective embedment depth of 1-1/2 in. (40 mm) and with a nominal diameter of 1/4 in. (6 mm) or larger. Screw anchors are limited to a maximum effective embedment of $10d_a$ (refer to R1.4).

1.5 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

COMMENTARY

CHAPTER R1—SCOPE

R1.1 ACI 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 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.

Procedures for making and controlling cracks in test members have been published. Also, 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 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. (50 mm) and an embedment depth not greater than 25 in. (635 mm). ACI 355.2 can be used for anchors with those maximum dimensions. While ACI 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. (6 mm) 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. Additional research for deeper embedments would be required to further expand the scope of ACI 355.2 for screw anchors.

This is a preview. Click here to purchase the full publication.

COMMENTARY

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 355.2.





CHAPTER 2—DEFINITIONS AND NOTATION

2.1—Definitions

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

2.1.2 *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.

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

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

2.1.5 *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.

2.1.6 *cracked concrete*—concrete test member with a single, full-depth, approximately uniform width crack.

2.1.7 *displacement-controlled expansion anchor*—postinstalled 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.

2.1.8 *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.

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

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

COMMENTARY

CHAPTER R2—DEFINITIONS AND NOTATION

R2.1—Definitions

R2.1.4 *characteristic value*—The characteristic value is 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.

R2.1.5 concrete breakout failure—Concrete breakout failure includes concrete breakout under tension load, edge breakout from tension or shear, or combinations of these, as shown in Fig. 5.5.3a and 5.5.3b.

R2.1.8 *pullout failure*—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.

R2.1.9 *pull-through 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.

2.1.11 *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.

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

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

2.1.14 *statistical equivalence*—statistical equivalence of two groups of test results shall be determined by two one-sided *t*-test (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 $\alpha = 0.10$.

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

2.1.16 *test series*—group of tests having the same parameters.

2.1.17 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).

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

2.1.19 *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.

2.2—Notation

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

R2.1.12 *statistical equivalence*—The two one-sided t-Test (TOST) is 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.

COMMENTARY

R2.1.18 *uncracked concrete*—Under ACI 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.

R2.2—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)

For post-installed anchors having a reduced crosssectional area anywhere along the anchor length, the effective cross-sectional area of the anchor should be provided



= critical edge distance required to develop the basic strength as controlled by concrete breakout of a single post-installed anchor in tension in

