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Hospital Building Safety Board
Structural and Nonstructural Regulations Committee

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Subject: Opposition to Proposed Reduction in Qualification Requirements for Post-Installed Anchors under ACI CODE-355.2-24 and ACI CODE-355.4-24

Dear Members of the Structural and Nonstructural Regulations Committee:

We urge the Committee not to adopt the proposed changes contained within the presentation titled “*Anchor Testing Requirements for Qualification of Post-installed Anchors in Concrete ACI-355.2(24) and ACI-355.4 (24)*,” presented by Dr. Roy Lobo, Ph.D., S.E. on 29 July 2026. This proposal would reduce anchorage qualification and design requirements below those contained in ACI 318-25 and referenced by IBC 2027. Such a departure is not justified by new technical evidence and would reverse the outcomes of extensive consensus-based standards development upheld in public code hearings.

1. The absence of a recent design-level earthquake in the U.S. after Northridge 1994 should not be taken as evidence that the seismic testing provisions in ACI 355-24 and ACI 318-25 documents are unnecessary

Seismic qualification was introduced after anchorage failures observed in the 1994 Northridge earthquake, which also initiated dedicated research (discussed below) shortly thereafter. Before research was able to be conducted, a testing protocol was introduced by the anchor manufacturing industry. This protocol was adapted from a small study in Ontario, Canada, in lieu of a more rigorous proposal made by the Structural Engineers Association of Southern California. This Canada-based protocol considered only a single earthquake motion imposed on Single Degree of Freedom elements. When adapted by the manufacturing community, the number of cycles at different loading levels was significantly reduced and the load levels themselves were also reduced, both with reasoning that is not discoverable today¹. The manufacturer-developed seismic testing protocol remained in place in the ACI design environment with minor changes from 1997 until the most recent testing changes were introduced in 2024 in the updated versions of ACI 355.2 and 355.4. No major American metropolitan city has experienced a design-basis earthquake since 1994. Therefore, the adequacy of the previously adopted testing protocol is not proven by field performance of in-situ anchors simply because no building in the U.S. has been subjected to a design-basis earthquake since the previous testing protocol was adopted.

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2. ACI 355.2-24, 355.4-24, and ACI 318-25 seismic testing requirements are the product of extensive research and comprehensive consensus-based committee processes

The seismic testing requirements for post-installed anchors in ACI 355.2-24, 355.4-24, and 318-25 are based on dedicated American and European research studies spanning twenty years, with an extensive peer-reviewed publication record, and many years of deliberation and balloting in ACI Committee 355 in collaboration with ACI Committee 318. The research supporting these provisions includes multiple doctoral dissertations and studies of archetype-building response to suites of ground motions, representative concrete damage states, cyclic crack behavior under reversed seismic loading, and materially different anchor performance during crack cycling. For more detailed information on the background of the newly accepted ACI 355 seismic qualification procedures, Andra Hörmann-Gast (Chair of ACI 355) and Tara Hutchinson (Professor, UCSD) provide a summary of the technical basis for the testing changes, historical context, and the principal supporting works cited in the technical record.¹ This article also summarizes the basis for the new testing protocol compared with previous testing protocols, including the earthquake motions, structural and nonstructural modeling, and resulting load and crack cycling attributes.

The final seismic testing and assessment framework in the 2024 ACI 355 standards dates to its publication in European standards in 2013; in other words, the newly adopted ACI 355 provisions trailed acceptance in European standards by 11 years. This testing framework was first formally presented to the full ACI 355 Committee in 2016, approved for implementation in ACI 355.2 and 355.4 by ACI 355 committee vote in 2021, and finalized for public comment in 2023 with consistent liaison to the ACI 318 design committee. The ACI 355.2-24, 355.4-24, and 318-25 documents were developed through the consensus-based, interest-balanced, accredited processes of ACI Committees 355 and 318 in thousands of hours of collective committee contributions and decisions. Throughout development of these standards, the ACI 355 committee comprised active membership by all major U.S. anchor manufacturers, structural engineering practitioners, researchers, and testing laboratories.

A California-based amendment for hospital construction would override multiple coordinated consensus processes that thoughtfully incorporated the state of understanding of reinforced concrete during earthquake events. Specific responses to the technical arguments made for the proposed change are provided later in this letter.

3. Cost concerns are undefined and do not justify a reduction in safety from IBC 2027

Any significant change to product qualification can impose compliance costs across an industry that includes numerous manufacturers and product families with configurations for each product. Where testing of a product is necessary, the one-time up-front cost of the new seismic testing is within the range of costs for other existing tests conducted by manufacturers. This requirement therefore cannot be categorically distinguished from other necessary testing, assessment, and design updates on a cost basis. In addition, most American manufacturers already sell European products qualified under the newer protocol. Adhesive anchor programs in particular may require little or no additional testing. The statement about “millions of dollars” of testing costs would represent several products with many configurations across the manufacturing industry, which would be true of most changes to testing requirements.

Statements regarding increased construction cost and their lack of necessity have not been demonstrated. Many designs will not require any changes compared to current practice. Where anchor design requires changes, some combination of changes to embedment, concrete strength, anchor type, and anchor configuration may be needed. In these cases, changes to anchorage represent a small fraction of total project cost. For hospitals, any marginal costs



are weighed against the continued function and restraint of critical equipment, utilities, nonstructural components, and structural elements during seismic events.

A speculative or modest overall cost increase is not an adequate basis for reducing requirements intended to address credible science-based improvements in understanding of seismic behavior and protect life safety and continuity of care.

4. The proposed changes are not substantiated by the information provided

Responses to all relevant statements provided within the presentation are provided in this section. It is worthwhile to note that similar statements and more were presented and debated in three public hearings in the 2027 International Building Code process with a proposal to make similar exceptions, with repeated opportunities for testimony, response, reconsideration, and public comment. Despite voluminous arguments available in the public record, the process upheld the ACI 318-25 requirements by a vote of 13-1 in the first Committee Action Hearing, unanimous agreement in the second Committee Action Hearing, and approximately 90% vote in the Public Comment Hearing.

Responses to slide titled "Motivation for the Study"

Statement 1:

New Crack Cycling requirement for anchor qualification will result in reduced anchors design values, added cost of anchors and is not justified due to lack of evidence that this level of qualification applies to Hospital buildings designed as using an importance factor of 1.5 intended to limit structural damage resulting in smaller crack widths in a seismic event.

Response 1:

Existing anchors are likely to experience reductions in pullout (mechanical anchors), bond (adhesive anchors), and steel capacities compared to currently published values. These failure modes may or may not govern existing designs. Changes to products or new products may also address these strength deficits.

To our knowledge, the importance factor of 1.5 does not inhibit cracking and crack cycling behavior experienced due to cycling of structural loads during earthquakes. Crack size is a secondary attribute to the crack cycling behavior. The new seismic testing protocol addresses this behavior, whereas the previous seismic testing protocol does not.

Crack sizes represent commonly observed cracks during seismic events within diaphragms, walls, and beams. Scaling of the crack cycling testing to different crack sizes would represent a new contribution that would require additional research and correlation with design scenarios. These results would then need to be organized into practical use to avoid engineering or jobsite confusion. Such work should be developed in consensus-based technical committees based on dedicated research, not proposed as an exception to those processes.

Please also see the Section 3, titled "Cost concerns are undefined and do not justify a reduction in safety from IBC 2027."



Statement 2:

Nonstructural components and equipment with anchors in concrete in hospitals are typically floor mounted to the floor slab, slab on grade, on an equipment pad, or hung from the underside of a concrete over metal deck. The research resulting in the new requirements is premised on flexure cracks with anchors installed on the underside of a reinforced concrete moment resisting frame beam, not a suitable location for post installed anchors.

Response 2:

The comment refers to the first of five major dissertations, which was published in 2006 and studied basic behavior. Significant additional work ensued. Cyclic cracking is not confined to the underside of beams or locations immediately adjacent to plastic hinges. Concrete cracks cycle wherever earthquake-induced actions repeatedly open and close them. Research extending beyond the initial beam-focused work includes full-scale shear walls and diaphragms, including concrete over metal deck. See Hörmann-Gast and Hutchinson¹ for more information and references. From this research, it has been demonstrated that the tested crack widths (0.032 in.) can occur in diaphragms, shear walls, and other anchorage regions as a result of calculated seismic stresses in tandem with preexisting temperature and shrinkage effects, long-term structural expansion and contraction, service loading, and additional “ratcheting” open of the cracks during the seismic event itself.

Responses to slide titled "Issues with crack cycling for post installed anchor qualification"

Statement 3:

Anchors for floor mounted equipment are not subject to sustained tension loads.

Statement 4:

Anchors to diagonal braces for seismic bracing of distribution systems are not subject to sustained tension.

Response 3 & 4:

The applicability of the testing protocol is not limited to sustained load situations. The protocol intentionally decouples crack cycling from load cycling, then later recombines their effects in the assessment. Simultaneously cycling both load and crack width would not be practical or broadly representative because connected elements exhibit a wide range of crack-response (based on the structural response) to load-response (based on the component response) relationships. The qualification is relevant to structural and nonstructural anchorage under both sustained and non-sustained (temporary) loading. In addition, it would add confusion to have a small subset of anchors qualified based on the presence of sustained load.

Statement 5:

Vertical hangers of brace assemblies could support tributary gravity loads and are in sustained tension, but that load is expected to be small relative to the seismic tension. System could be supported by multiple gravity supports not subject to seismic cyclic loads.

Response 5:

This statement isolates specific vertical hanger components with sustained load and no seismic loads. Please see Response 3 & 4.



Statement 6:

Location where crack cycling is expected to occur will have reinforcement. Not suitable locations for post installed anchors.

Response 6:

This statement is not substantiated. Installers do not typically locate reinforcing prior to placement of anchorage. Moreover, cracks are expected to form before seismic events due to temperature changes, shrinkage, the installation of the anchor itself, and service loading, and can be cycled and further opened or initiated during the seismic event itself. Cracks will be restrained by reinforcement and boundary conditions, then be closed during reversal of the load. Cracks will appear throughout reinforced concrete elements, including through post-installed anchors. Numerous experimental programs document such patterns under simulated inertial loads for a variety of structural components (walls, beams, beam-column connections, diaphragms, etc.).

Statement 7:

Max. crack open and tension load occur at different times.

Response 7:

This statement is not in agreement with findings reported in detail in the literature. Examples include Watkins² and Sharma et al.³. Watkins², for example, shows that there is no well-defined correlation between structure response (i.e., crack cycling), and component response (i.e., load cycling) of nonstructural components. This finding strengthens the case for de-coupling crack cycling from load cycling as discussed in Response 3 & 4. Sharma et al.³ demonstrated that cases where resonance occurs produce the worst-case scenario, which is not represented by the new testing protocol.

Statement 8:

No evidence provided from tests or past earthquake failures to show how the new protocol prevents failures from earthquakes where the current protocol does not.

Response 8:

Please see Section 1, titled "The absence of a recent design-level earthquake in the U.S. after Northridge 1994 should not be taken as evidence that the seismic testing provisions in ACI 355-24 and ACI 318-25 documents are unnecessary."

Responses to slide titled "Is Crack cycling for anchor qualification in hospital buildings necessary?"

Statement 9:

Floor diaphragms are typically concrete over metal deck and are designed essentially elastic thus limiting the crack width or crack cycling that could potentially occur

Response 9:

See Response 1.

Statement 10:

There is redundancy in the anchorage not all anchors resisting tension loads will also experience crack width opening



Response 10:

While we agree in principle that redundancy will benefit systems, the effect of redundancy on anchor groups has not been explored as it relates to the level of seismic demand on anchors. Design of a seismically redundant system would require assumptions about a portion of anchors that fail or a portion exposed to higher demand than others based on probabilistic analysis of crack distribution, etc. It is inappropriate to assign all anchors a lower testing requirement because of an assumed benefit of redundancy, as the behavior of groups of anchors is complex and the benefits of redundancy have not been verified or quantified.

Statement 11:

Anchors in concrete are already qualified for cracked and uncracked concrete under cyclic loads

Response 11:

The existing testing with cycling loads has been replaced by the newer testing protocol in the 2024 versions. See Section 1, titled “The absence of a recent design-level earthquake in the U.S. after Northridge 1994 should not be taken as evidence that the seismic testing provisions in ACI 355-24 and ACI 318-25 documents are unnecessary.”

Statement 12:

Anchors in concrete for NSC are designed for demands using an $I_p = 1.5$ on top of the Omega (Ω) amplification, in conjunction with 0.75% seismic reduction factor, strength reduction factor (ϕ), and the 5% fractile value for the anchor capacity

Response 12:

The factors described are design factors meant to accomplish the desired design-level safety of anchors. The fundamental tested capacity is currently unrelated to these factors.

Statement 13:

Not seen evidence from tests or past earthquake failures that show how the new protocol prevents failures from earthquakes where the current loading protocol for anchor qualification ACI 355.2 (22) and ACI 355.4 (22) does not

Statement 14:

Anchors failures have occurred where there is improper installation and lack of testing

Response 13 & 14:

Please see Section 1, titled “The absence of a recent design-level earthquake in the U.S. after Northridge 1994 should not be taken as evidence that the seismic testing provisions in ACI 355-24 and ACI 318-25 documents are unnecessary.”



Responses to Conclusions

Conclusion 1:

New anchor qualification adds additional cost of testing the anchors for each size and depth costing millions of dollars without added value for anchors in concrete not in sustained tension.

Conclusion Response 1:

This statement does not accurately represent the applicability of the testing. Please see Response 1 above to address the applicability of the testing.

The one-time cost of testing anchors for the new seismic requirements is within the range of other existing tests. Please also see Section 3, titled "Cost concerns are undefined and do not justify a reduction in safety from IBC 2027."

Conclusion 2:

Recommend to permit the anchor qualification requirement for anchors not in sustained tension or anchors with very low tension (< 0.2 times the anchor design capacity) subject to seismic cyclic loads, as acceptable, if qualified to the minimum loading protocol as required by ACI 355.2 (22) and ACI 355.4 (22).

Conclusion Response 2:

The testing applicability does not correspond to the limited range of anchorages represented by this recommendation. It applies to all ranges of loading (from fully non-sustained loads to fully sustained loads) in combination with seismic loading. Please see Response 1 above to address the applicability of the testing protocol. We are willing to review suggestions for rational changes in the anchor qualification and design process, and to coordinate with ASCE 7 on possible changes in procedures used to calculate or calibrate anchor demands. These changes should be developed following a consensus process to ensure that minimum levels of structural reliability are maintained

5. Implementation of the proposed technical changes is not clearly articulated

While we do not support the changes proposed, we also do not believe that the proposal can be properly evaluated as it is written. The proposal in Conclusion 2 provides a broad set of exceptions to ACI 318-25 requirements, but does not provide a code language proposal or describe an enforceable implementation framework. It does not define which design capacity is used to establish the proposed 0.2 threshold, for example. Without clarity on the actual implementation of the proposal, different engineers and officials will read, evaluate, and judge the requirements differently.

The proposal suggests that anchors falling within the exception would be permitted to be qualified using older versions of ACI 355.2 and 355.4; does this mean that all requirements (including those not associated with seismic testing updates) would regress to the older versions of the standards? How would different anchors on the same project be held to different standards be organized and separated?



6. Changes to qualification and design requirements should be addressed in the appropriate ACI committees

As with any code requirements, there are opportunities in seismic anchor qualification and design to further collaborate, refine, and change existing provisions. Significant code changes should be supported by research, a publication record, coordinated and robust expert deliberation, and thorough implementation processes. ACI Committees 355, 318, and their subcommittees and task groups are the appropriate forum for such changes. We warmly invite HCAI to participate in these processes to work together to improve seismic anchor design. Until a validated alternative is approved through the applicable ACI committees, the published ACI 355 and ACI 318 requirements should remain unchanged.

Requested action

For these reasons, we respectfully request that the Structural and Nonstructural Regulations Committee reject the proposed concept and retain the anchorage qualification requirements of the underlying referenced standards without a California-specific modification. The current requirements reflect the state of the art, are supported by substantial research, and have already survived rigorous review in ACI 355, ACI 318, and the 2027 IBC process.

Further research and collaboration may support future refinements, including displacement-based criteria or conditional relief. Any such amendment should be developed, validated, and balloted through the relevant ACI technical committees, where participation is open to any interested parties. Until then, creating an exception that bypasses the proper consensus process, which is aimed at protecting property and life safety, is premature. We are committed to collaborating further with all stakeholders on future efforts to improve anchorage requirements in concrete.

Respectfully submitted for your consideration,

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Member, ACI 355

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Member, ACI 355
Member, ACI 318-B

Attachments

ATT 1: Hörmann-Gast, A., and Hutchinson, T.C., “ACI Committee 355 Updates to Seismic Qualification of Post-Installed Anchors in Concrete,” Concrete International, April 2026, pp. 56–62.

ATT 2: Anchor Testing Requirements for Qualification of Post-installed Anchors in Concrete ACI-355.2(24) and ACI-355.4 (24)

ACI Committee 355 Updates to Seismic Qualification of Post-Installed Anchors in Concrete

by Andra Hörmann-Gast and Tara C. Hutchinson

ACI Committee 355, Anchorage to Concrete, has published standards to address the testing and assessment of post-installed anchors since the first version of ACI 355.2 was issued in 2001.¹ In the most recent updates to the ACI 355 prequalification standards, significant changes were made to the requirements for testing and assessment of anchors intended for use in seismic design environments (SDC C through F). These changes are reflected in ACI CODE-355.2-24, “Post-Installed Mechanical Anchors in Concrete—Qualification Requirements and Commentary,”² and ACI CODE-355.4-24, “Post-Installed Adhesive Anchors in Concrete—Qualification Requirements and Commentary.”³ Both standards are referenced in ACI CODE-318-25, “Building Code for Structural Concrete—Code Requirements and Commentary.”⁴ This article provides background for these changes, including a historical perspective on seismic qualification and design of anchorage, supporting research, and ACI Committee 355 decisions.

Historical Perspective

Testing and evaluation of post-installed anchors for compliance with U.S. building code requirements dates to the 1970s. Due to the more rigorous demands associated with construction in seismic environments, the model code organization International Conference of Building Officials (ICBO),^a which was dominant in the western United States, took the lead in issuing so-called “Acceptance Criteria” for product assessments through its Evaluation Service (ICBO

ES). The first Acceptance Criteria document, AC01,⁵ addressed post-installed expansion anchors. Reports issued under AC01 were submitted to building officials as “evidence of compliance.” Prior to 1994, post-installed anchors were assessed by ICBO ES using the average of test values divided by a global safety factor of 8 for uninspected and 4 for inspected installations. Despite the unique nature of seismic loading, no evaluation under dynamic or cyclic loading conditions was required to establish shear and tensile capacities of post-installed anchors.

The Northridge earthquake on January 17, 1994, was notable in several respects. In addition to extensive damage to steel moment frames and freeways, weaknesses were revealed in post-installed anchors used to secure nonstructural components such as sprinkler piping, mechanical and electrical equipment, and others, as noted in a report issued at the time:⁶

“Poorly constructed equipment anchorage was well tested by this earthquake. For example, an anchorage system for two rooftop chillers in a three-story shear wall department store building in Sherman Oaks failed as a result of shallow anchor-bolt embedment. Adjacent water pumps with flexible piping connections and a snubber system had failed base connections because of inadequate seismic bracing for the piping. Poorly installed anchor bolts in mechanical and electrical equipment pulled out of their holes. Electrical panels toppled over because of improperly installed and/or sized anchorage. All of the observed damage could have been easily avoided with proper anchorage and bracing.”⁶

“Serious failures of penthouse structural elements (walls and bracing) were noted at a number of facilities. Roof-mounted equipment both in and out of penthouses frequently were damaged, especially those items mounted

^aThe International Conference of Building Officials, originally established in 1922 as the Pacific Coast Building Officials Conference, began publishing the Uniform Building Code (UBC) in 1927. It merged with two other model code agencies in 1994 to form the International Code Council (ICC).

on vibration-isolating devices. The most common forms of anchorage failures involved pullout of expansion-type concrete anchor bolts.²⁶

As a direct consequence of these observed failures, evaluation reports for post-installed anchors issued by ICBO ES between the years 1995 and 1997 did not include allowable loads for earthquake loading and noted that the establishment of such allowable loads would be contingent on the implementation of appropriate testing and assessment procedures.⁷

The need for a test protocol to determine seismic capacity prompted a proposal from the newly formed Concrete Anchor Manufacturers Association (CAMA) in 1997.^b The CAMA proposal consisted of a cyclic loading test regime based roughly on procedures developed for CANDU (Canada deuterium uranium) nuclear facilities in Canada and published to this day within CSA Standard N287.3.⁸ The basis for the Canadian test procedure was a study conducted by Ontario Hydro⁹ using single-degree-of-freedom (SDOF) analyses of buildings and components subjected to the 1940 El Centro Earthquake. The protocol proposed by CAMA was adopted by ICBO ES into the 1997 versions of AC01⁵ and AC58¹⁰ and became the de facto standard for seismic qualification of post-installed anchors. In 2001, ACI 355.2 incorporated the AC01/AC58 testing procedure with two changes. The most significant change was a new requirement that the seismic tests be conducted in a 0.02 in. (0.5 mm) static crack, opened after the anchor is set in the concrete. This crack width has since been associated with serviceability conditions.¹¹ The second change was the loading level, which changed from a maximum of 40% of an uncracked static reference capacity to 50% of a static reference capacity in a 0.02 in. crack. The AC01 testing procedure was then adopted in the first version of ACI 355.4 in 2011.¹² The ACI 355.2-01/355.4-11 seismic testing procedure, which for the purposes of this article will be referred to as “C1” from this point forward, remained unchanged until the 2024 updates to ACI CODE-355.2 and ACI CODE-355.4. Table 1 and Fig. 4 compare the tensile loading protocols of the various testing documents referenced in this article.

The 2002 edition of ACI 318 was the first version of the design standard that incorporated anchor design, using the Concrete Capacity Design (CCD) methodology. In ACI 318-02,¹³ anchor qualification according to ACI 355.2-01 was required for post-installed anchors in concrete, and seismic

qualification was required for anchors used in structures assigned to ASCE/SEI 7 Seismic Design Category (SDC) C and higher. In addition, the design capacity was reduced using a 0.75 multiplier to account for conditions not anticipated or accounted for in laboratory testing, including loss of concrete section through spalling, intersecting cracks at anchor locations, and uneven load sharing of anchors under dynamic conditions. ACI 318-08¹⁴ subsequently limited the 0.75 factor to apply only to concrete-related failure modes (refer to ACI 318-25 Section 17.10.5.4 for current requirements). Parallel changes were then made in ACI 318-11¹⁵ and ASCE/SEI 7-10¹⁶ to address the treatment of different seismic anchorage design conditions. ASCE/SEI 7-10 incorporated an overstrength factor Ω_o into the provisions for anchorage as a multiplier on the design loads for nonductile connections.¹⁶ In 2011, ACI 318 incorporated seismic design provisions that designated which conditions constitute ductile connection failures, allowing ductile connections to be designed without multiplying design loads by Ω_o .

Nearly a decade following the publication of ACI 355.2-01, damaging earthquakes in Haiti (2010); Maule, Chile (2010); Christchurch, New Zealand (2011); and Sendai, Japan (2012) revealed ongoing weaknesses with cast-in and post-installed anchors in concrete. Arguably, a Maximum Considered Earthquake (MCE_R -level) has not occurred near a population center in the United States or Canada since the 1906 San Francisco earthquake, and a design earthquake has not occurred since the 1994 Northridge event. However, to those involved in earthquake reconnaissance, seismic research, and code development, the need for a more representative testing protocol for the effects of earthquake forces on anchors in concrete was increasingly clear. This recognition included loads cycling on anchors, but also that the cracks intersecting anchors cycle (open and close) as the concrete itself is stressed in reversed load cycling.

Research

Shortly after the Northridge event, research was undertaken to study realistic conditions that anchors experience during earthquakes. This research led to the development of the seismic testing procedure incorporated into the 2024 versions of ACI CODE-355.2 and ACI CODE-355.4, which, for the purposes of this article, will be denoted “C2”. Mahrenholtz et al.¹¹ provides a comprehensive overview of the cited works and methodologies used to develop the C2 testing protocol, as well as a review of how the original protocol (C1) was developed. Additional studies¹⁷⁻²¹ conducted after the publication of Mahrenholtz et al. provided further support for the approach.

Early research by Hoehler²² provided insight into the basic behavior of anchors during earthquakes, including confirmation that cracks cycle in width (open-close) during earthquakes. Analysis of various reinforced concrete beam details was conducted, demonstrating that elastic cracks can reach much larger widths than the 0.02 in. (0.5 mm) used in

^bA competing proposal was made by the Structural Engineers Association of Southern California (SEAOSC). This proposal required stepwise increasing cyclic loading to failure, as is typical for other structural subassemblies. In addition, it was ostensibly intended to demonstrate the equivalence of the tested post-installed anchor and a cast-in-place anchor of equal diameter and embedment, and was judged to be more severe than the CAMA proposal. As such, although it was modified as an alternative method by ICBO ES, the authors are unaware of any reports based on this testing.

Table 1:

Comparison of tensile loading^a characteristics in various anchor seismic testing protocols, and their applicable edition time frames

Source document	CSA N287.3	AC01 AC58	ACI CODE-355.2 ACI CODE-355.4	ACI CODE-355.2 ACI CODE-355.4
Applicable editions	Unknown-present	1997-2001	2001-2022	2024
Seismic crack cycling considered?	No			Yes
Load cycling scheme	Descending amplitudes			Ascending amplitudes
Total load cycles in cycled tension test	340	140		75
Cycles at maximum load	30	10		5
Maximum cycled tension load	$0.53f_y$	$0.4\bar{N}_{seis,0^*}$	$0.5\bar{N}_{seis,1^*}$	$0.75\bar{N}_{seis,2^*}$
Cracking condition during load cycling	—	—	0.02 in. (0.5 mm)	0.032 in. (0.8 mm)

^aTable 1 compares tensile attributes of seismic testing protocols for post-installed anchors. The protocols listed also contain shear testing, which contain comparable relationships to the respective cycled tension loading protocols.

^{*}To permit comparison between different testing protocols, $\bar{N}_{seis}$ is introduced in this document to represent the average capacity determined from static reference tests, reduced as needed to pass the seismic qualification requirements. $\bar{N}_{seis,0}$ is based on tests in uncracked concrete divided by 5 and multiplied by 1.33 and 1.5. $\bar{N}_{seis,1}$ is based on a reference test in a 0.02 in. (0.5 mm) crack, while $\bar{N}_{seis,2}$ is based on a reference test in a 0.032 in. (0.8 mm) crack.

the C1 testing procedure. Hoehler concluded that 0.032 in. (0.8 mm) is an appropriate crack width for representing the range of elastic behavior in bending members. Watkins²³ studied the coincidence of crack cycling behavior with load cycling behavior, finding no correlation between the maximum and minimum crack width cycles with maximum and minimum tension load cycles.

Subsequent studies by Faraone and coauthors recorded maximum crack widths in excess of 0.032 in. (0.8 mm) within the elastic range (outside of plastic hinge regions) in shear walls of varying aspect ratio and detailing subjected to various levels of drift.¹⁷⁻²⁰ Figure 1 shows an example wall specimen from Faraone et al.¹⁸ and a diagram showing anchor locations. Crack widths recorded at various drift levels for the circled anchor in the diagram are shown at the bottom of the figure. Recent additional testing by Saenz and Pujol²¹ similarly demonstrated diaphragm crack cycling behavior with crack widths up to 0.035 in. (0.9 mm) in a full-scale study of single-bay steel-framed buildings with concrete-over-metal-deck diaphragms subjected to scaled versions of the 1940 El Centro Earthquake; refer to Fig. 2 for residual crack widths shown after various shaking runs.

Figure 3 provides a summary of the methodology used to characterize the crack cycling and load cycling protocols. To support the much-needed development of a crack cycling and (tension and shear) load cycling protocol, Wood and others^{24,25} performed building simulation of seven full-scale models of reinforced concrete building archetypes subjected to a suite of 21 earthquake motions scaled to the selected site location to determine floor response characteristics and statistics. The crack width cycling protocol was directly derived from the floor response from building simulation using all of the ground motions and finally categorizing the crack width statistics into an ascending crack width test. The anchor load

cycling protocol was developed by subjecting a large suite of anchored nonstructural components assumed as simplified SDOF elements attached sequentially at individual floors of the model buildings to the floor response, producing the equipment response and its statistical characteristics. As with the crack width cycling protocol, the anchor load cycling protocol was organized by categorizing the loads from the response statistics in ascending order.

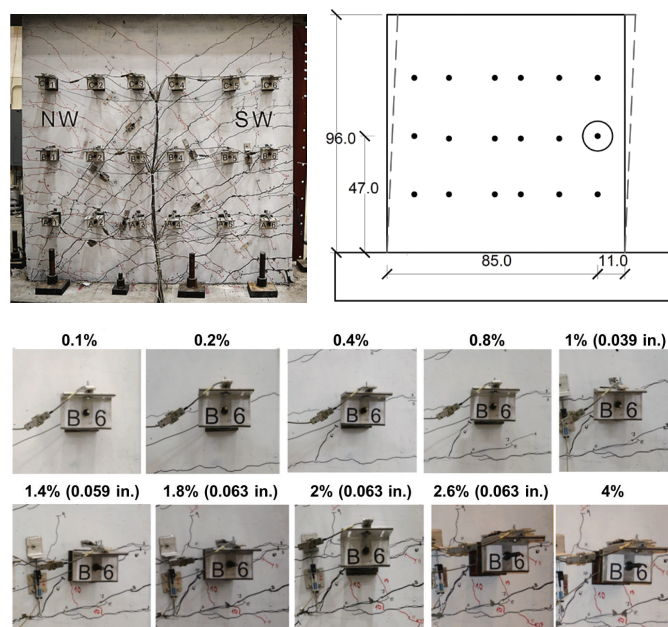


Fig. 1: Full-scale squat reinforced concrete wall tests by Faraone et al.¹⁹ documenting crack width histories; noted above are wall total drift amplitude and corresponding measured crack width at same instance (in parentheses) for anchor B6 of Wall SQ0. (Note: Units on top-right are in inches; 1 in. = 25.4 mm)

Fig. 2: (a) Full-scale shake-table testing of a hybrid steel-frame structure with concrete over metal deck diaphragms and a concrete core wall²¹; and (b) distribution of residual cracks with width annotated (in mm) after several earthquake tests in the top and bottom diaphragm slabs. Blue cracks indicate temperature/shrinkage cracks that occurred before any seismic shaking, while black cracks were produced by seismic shaking alone

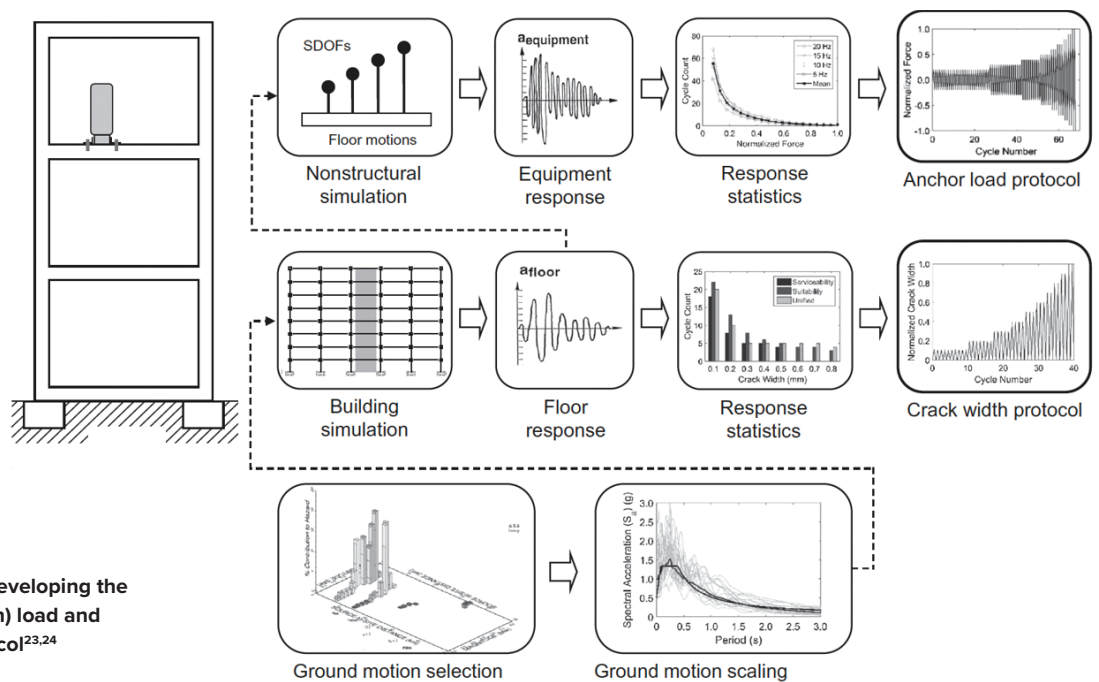
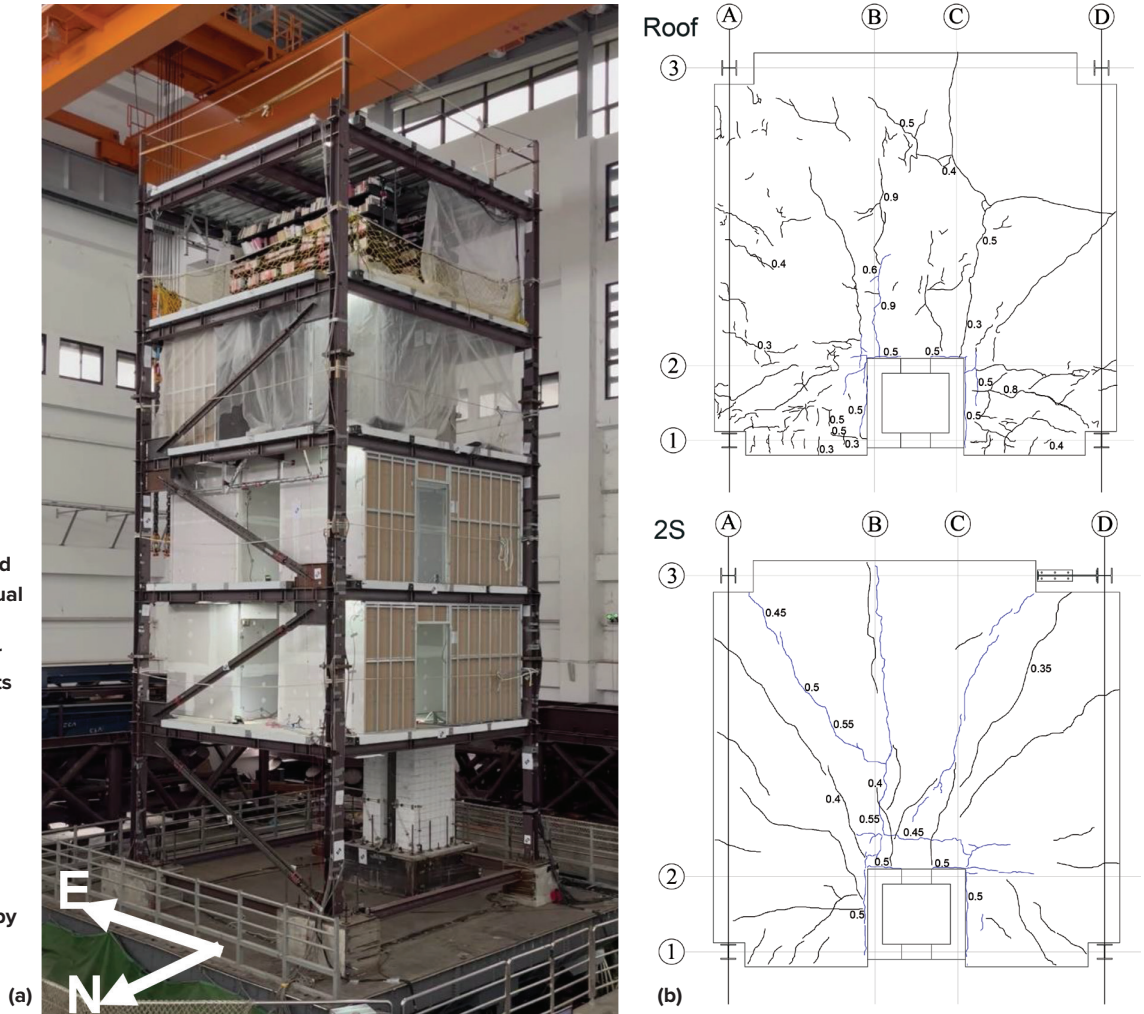


Fig. 3: Methodology for developing the anchor (shear and tension) load and crack width cycling protocol^{23,24}

Implementation

Prior to 2013, Europe did not require seismic qualification of post-installed anchors. In the European implementation of seismic testing and design in 2013 through ETAG 001,²⁶ two tiers were incorporated based on peak ground acceleration (PGA): one using the existing U.S. C1 testing protocol and the second using the new C2 testing protocol. Although PGA tiers in Europe and SDC as used in ASCE/SEI 7 cannot be directly compared, effective translations show that the analogous dividing line between C1 and C2 testing in Europe occurs within the U.S. equivalent of SDC B; that is, the European design framework requires C1 for the equivalent of SDC A and a portion of SDC B, whereas C2 is required for the equivalent of SDC C and beyond.²⁷ In ACI CODE-318, seismic qualification of post-installed anchors is not required for SDC A and B, so a corresponding C1 tier to the European approach is not applicable in the current U.S. framework.

In 2016, an ACI Committee 355 Task Group dedicated to

updating seismic qualification was formed to evaluate the state of the art in seismic qualification and the applicability of the C2 testing protocol. The ACI Committee 355 effort was mirrored in the same time frame by CAMA, which produced an Acceptance Criteria document published in 2020,²⁸ incorporating both the C1 and C2 testing protocols as “ASPC 1” and “ASPC 2,” respectively, to allow future reference to one or both of the protocols. Code requirements for anchor qualification corresponding to the seismic testing protocols were not adopted into ASCE/SEI 7-22.²⁹ Recognizing the pivotal role of ACI in this subject area, ACI Committee 355 established seismic qualification requirements for anchors based on the available research and consistent with the design provisions in ACI CODE-318 Chapter 17. The decision to implement the C2 seismic testing protocol was taken in April 2021.

Throughout the development process of the ACI 355 standards, correspondence between ACI Committee 355 and

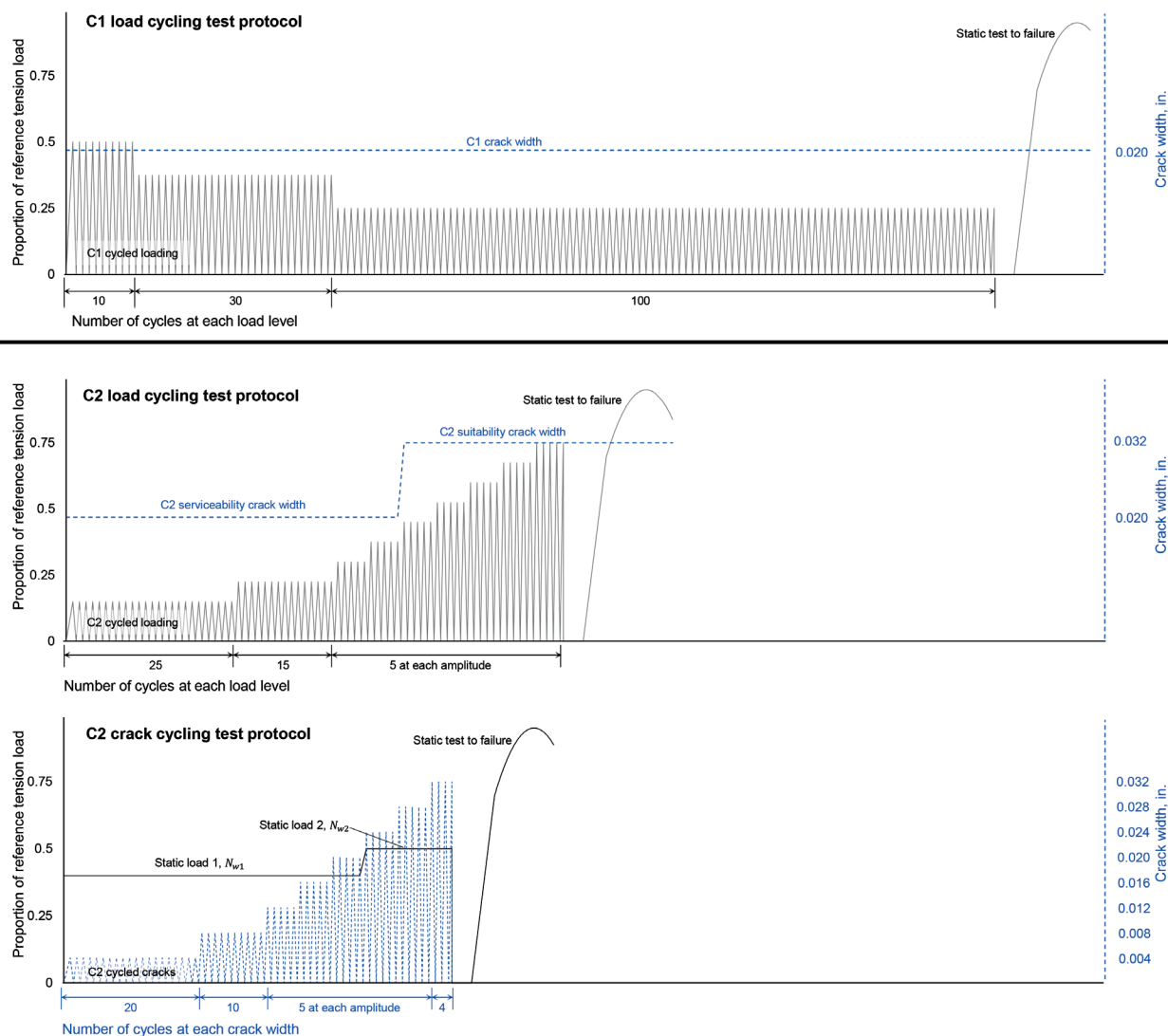


Fig. 4: C1 load cycling protocol (top), C2 load cycling protocol (middle), and C2 crack cycling protocol (bottom)

ACI Subcommittee 318-B was maintained. After deliberation from 2016 through 2020, development of the required revisions to ACI CODE-355.2 and ACI CODE-355.4 occurred between 2021 and 2023 with public review from November 2023 to January 2024. The publication-ready versions of the documents were completed in March 2024, after which publication was held until November 2024 to better align with the publication date of ACI CODE-318-25. The revised standards were adopted by ACI Committee 318 for the 318-25 version^c and published as ACI CODE-355.2-24 and ACI CODE-355.4-24.

Table 1 and Fig. 4 compare the features and the associated timeline of various seismic testing protocols discussed throughout this article.

Summary Remarks

Prior editions of the ACI 355 standards for testing and assessment of post-installed anchors provided a pathway for seismic qualification that was based on a limited understanding of both load and crack cycling behavior.

The 2024 editions of the ACI CODE-355.2 and ACI CODE-355.4 codes represent a significant advancement in the state of the art, supported by numerous dissertations and a comprehensive publication record. The new testing protocol reproduces the conditions that anchors experience during earthquakes, including crack cycling behavior. The anchor loading and crack cycling requirements are derived from rigorous analysis of a large suite of archetype buildings of various periods, characteristics across a range of earthquake hazards, and a site hazard representative of the most seismically active region of the western United States. The updated seismic testing requirements provide nominal anchor capacities for post-installed anchors appropriate for use with the Chapter 17 design provisions of ACI CODE-318-25.

The relevant technical committees in ACI have sought to use all available information to provide designers with state-of-the-art testing and design provisions for anchors in concrete. As with all areas of the Code, there are opportunities to improve the anchor qualification and design, including more representative treatment of seismic loading and displacement demands on anchors. Continued participation of both academics and design professionals in technical committees will be essential to encoding further findings that represent the best knowledge of anchor behavior during earthquakes.

^cThe incorporation by reference of ACI CODE-355.2-24 and ACI CODE-355.4-24 into ACI CODE-318-25 occurred in the same manner as all reference documents through the Public Comment process, where a single commenter requests that updates to all referenced standards be considered. This is to minimize the number of ballots on dozens of reference updates and to allow recently published and updated documents to be considered.

References

1. ACI Committee 355, "Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-01) and Commentary (ACI 355.2R-01)," American Concrete Institute, Farmington Hills, MI, 2001, 29 pp.
2. ACI Committee 355, "Post-Installed Mechanical Anchors in Concrete—Qualification Requirements and Commentary (ACI CODE-355.2-24)," American Concrete Institute, Farmington Hills, MI, 2024, 118 pp.
3. ACI Committee 355, "Post-Installed Adhesive Anchors in Concrete—Qualification Requirements and Commentary (ACI CODE-355.4-24)," American Concrete Institute, Farmington Hills, MI, 2024, 127 pp.
4. ACI Committee 318, "Building Code for Structural Concrete—Code Requirements and Commentary (ACI CODE-318-25)," American Concrete Institute, Farmington Hills, MI, 2025, 702 pp.
5. AC01, "Acceptance Criteria for Expansion Anchors in Concrete and Masonry Elements," ICC Evaluation Service, LLC, Brea, CA, 1997, 10 pp.
6. EQE International, "The January 17, 1994 Northridge, CA Earthquake: An EQE Summary Report," ABS Group, Spring, TX, Mar. 1994, https://www.lafire.com/famous_fires/1994-0117_NorthridgeEarthquake/quake/00_EQE_contents.htm. (accessed Mar. 13, 2026)
7. Silva, J.F., "Test Methods for Seismic Qualification of Post-Installed Anchors," International Symposium on Connections between Steel and Concrete," R. Eligehausen, ed., RILEM Publications SARL, V. 1, 2001, pp. 551-563.
8. CSA N287.3:25, "Design Requirements for Concrete Containment Structures for Nuclear Power Plants," CSA Group, Toronto, ON, Canada, 2025, 76 pp.
9. Tang, J.H.K., and Deans, J.J., "Test Criteria and Method for Seismic Qualification of Concrete Expansion Anchors," *Proceedings of the Fourth Canadian Conference on Earthquake Engineering*, University of British Columbia, Vancouver, BC, Canada, 1983, pp. 58-69.
10. AC58, "Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements," ICC Evaluation Service, LLC, Brea, CA, 1997.
11. Mahrenholtz, P.; Wood, R.L.; Eligehausen, R.; Hutchinson, T.C.; and Hoehler, M.S., "Development and Validation of European Guidelines for Seismic Qualification of Post-Installed Anchors," *Engineering Structures*, V. 148, Oct. 2017, pp. 497-508. doi: 10.1016/j.engstruct.2017.06.048
12. ACI Committee 355, "Qualification of Post-Installed Adhesive Anchors in Concrete and Commentary (ACI 355.4-11)," American Concrete Institute, Farmington Hills, MI, 2011, 55 pp.
13. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)," American Concrete Institute, Farmington Hills, MI, 2002, 443 pp.
14. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary," American Concrete Institute, Farmington Hills, MI, 2008, 473 pp.
15. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary," American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.
16. ASCE/SEI 7-10, "Minimum Design Loads for Buildings and Other Structures," American Society of Civil Engineers, Reston, VA, 2010, 608 pp.

17. Faraone, G., "Behavior of Post-Installed Anchors in Reinforced Concrete Shear Walls of Different Aspect Ratios Subjected to Simulated Seismic Loads," PhD dissertation, University of California San Diego, San Diego, CA, 2021, 583 pp.

18. Faraone, G.; Hutchinson, T.C.; Piccinin, R.; and Silva, J.F., "Seismic Performance of Varying Aspect Ratio Full-Scale Concrete Walls," *ACI Structural Journal*, V. 119, No. 6, Nov. 2022, pp. 19-34. doi: 10.14359/51737173

19. Faraone, G.; Hutchinson, T.C.; Piccinin, R.; and Silva, J.F., "Anchor Performance in Cyclically Loaded Shear Walls," *ACI Structural Journal*, V. 119, No. 6, Nov. 2022, pp. 35-51. doi: 10.14359/51737174

20. Faraone, G.; Hutchinson, T.C.; Piccinin, R.; and Silva, J.F., "Simulated Seismic Damage Evolution in Concrete Shear Walls," *ACI Structural Journal*, V. 120, No. 2, Mar.-Apr. 2023, pp. 143-156. doi: 10.14359/51737235

21. Saenz, A., and Pujol, S., "Cracking Observed in a Test Structure," internal report, University of Canterbury, Christchurch, New Zealand, 2025, 46 pp.

22. Hoehler, M., "Behavior and Testing of Fastenings to Concrete for Use in Seismic Applications," PhD dissertation, University of Stuttgart, Stuttgart, Germany, 2006, 261 pp.

23. Watkins, D., "Seismic Behavior and Modeling of Anchored Nonstructural Components Considering the Influence of Cyclic Cracks," PhD dissertation, University of California San Diego, San Diego, CA, 2011.

24. Wood, R.L., and Hutchinson, T.C., "Crack Protocols for Anchored Components and Systems," *ACI Structural Journal*, V. 110, No. 3, May-June 2013, pp. 391-401. doi: 10.14359/51685597

25. Wood, R.; Hutchinson, T.; and Hoehler, M., "Cyclic Load and Crack Protocols for Anchored Nonstructural Components and Systems," Structural Systems Research Project (SSRP) 2009/12, University of California San Diego, San Diego, CA, 2010.

26. ETAG 001 Committee, "ETAG 001: Guideline for European Technical Approval of Metal Anchors for Use in Concrete — Annex E: Assessment of Metal Anchors Under Seismic Actions," European

Organisation for Technical Approvals, Brussels, Belgium, Apr. 2013.

27. Mahrenholtz, P., and Olsen, J., "Brief Comparison of US and European Regulations for the Qualification and Design of Seismic Anchors," *Proceedings of the Fourth International Symposium on Life-Cycle Civil Engineering (IALCCE 2014)*, Tokyo, Japan, 2014, pp. 267-274.

28. AC510, "Acceptance Criteria for Qualification of Post-Installed Adhesive Anchors in Concrete," ICC Evaluation Service, LLC, Brea, CA, June 2020.

29. ASCE/SEI 7-22, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures," American Society of Civil Engineers, Reston, VA, 2022, 1072 pp.

Received and reviewed under Institute publication policies.

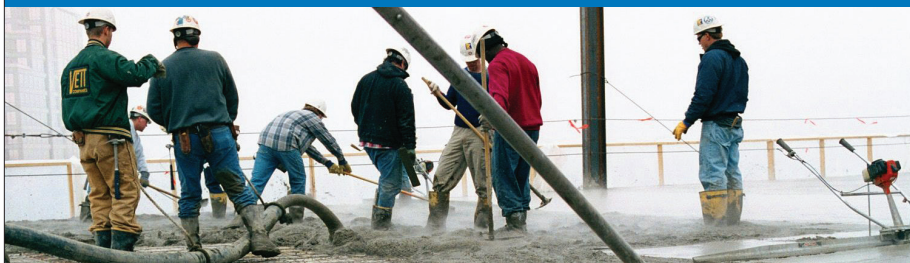


Andra Hörmann-Gast is Chair of ACI Committee 355, Anchorage to Concrete. She has nearly three decades of experience in evaluation, inspection, and design of post-installed anchors in concrete and has served on numerous global committees dedicated to anchorage throughout her career. She has also been involved in conformity assessment in both Europe and the United States.



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Attachment 2

Anchor Testing Requirements for Qualification of Post-installed Anchors in Concrete ACI-355.2(24) and ACI-355.4 (24)

By

Roy Lobo, Ph.D., S.E.

To HBSB – SNSR Committee

7/29/2026

Outline of Presentation

- Background
- New Crack Cycling requirement for anchor qualification
- Application of new qualification requirements for post installed anchors in concrete for anchorage of nonstructural components
- Issues with new crack cycling anchor qualification
- Recommendations

Code Requirement for Anchors in Concrete

- Requirement in ASCE 7

13.4.2.3 Post-Installed Anchors in Concrete and Masonry Post-installed anchors in concrete shall be prequalified for seismic applications in accordance with ACI 355.2 or other approved qualification procedures. Post-installed anchors in masonry shall be prequalified for seismic applications in accordance with approved qualification procedures.

- Requirement in 2025 CBC

1617A.1.19 ASCE 7, Section 13.4 Replace ASCE 7, Sections 13.4.2.3, with the following:

13.4.2.3 Prequalified post-installed anchors and specialty inserts in concrete and masonry.

Post-installed anchors, post-installed reinforcing bars and specialty inserts in concrete that are pre-qualified for seismic applications in accordance with ACI 355.2, ACI 355.4, ICC-ES AC193, ICC-ES AC232, ICC-ES AC308 or ICC-ES AC446 shall be permitted. Post-installed anchors in masonry shall be pre-qualified for seismic applications in accordance with ICC-ES AC01, AC58 or AC106. ||

What prompted this issue?

- ACI 318-25 now adopts ACI 355.2 (24) and ACI 355.4 (24) by reference, and ACI 318-25 is adopted by the 2027 IBC
- ACI 355.2 (24) and ACI 355.4 (24) now have a new testing protocol for anchor qualification that requires good performance of anchors under repeated crack width cycling under sustained tension loads.

Why was Crack Cycling Investigated?

- Concrete cracks
- Cracks open and close during a cyclic event (wind or seismic)
- Reliability of anchors when subject to extreme events like earthquakes
- Current crack cycling requirements (≤ 0.3 mm) and large number of cycles (1000) in ACI 355 not intended to represent seismic conditions
- Crack closure and compressive stress can significantly affect anchor performance
- Other

Background for testing parameters

Behavior and Testing of Anchors in Simulated Seismic Cracks

by Matthew S. Hoehler and Rolf Eligehausen

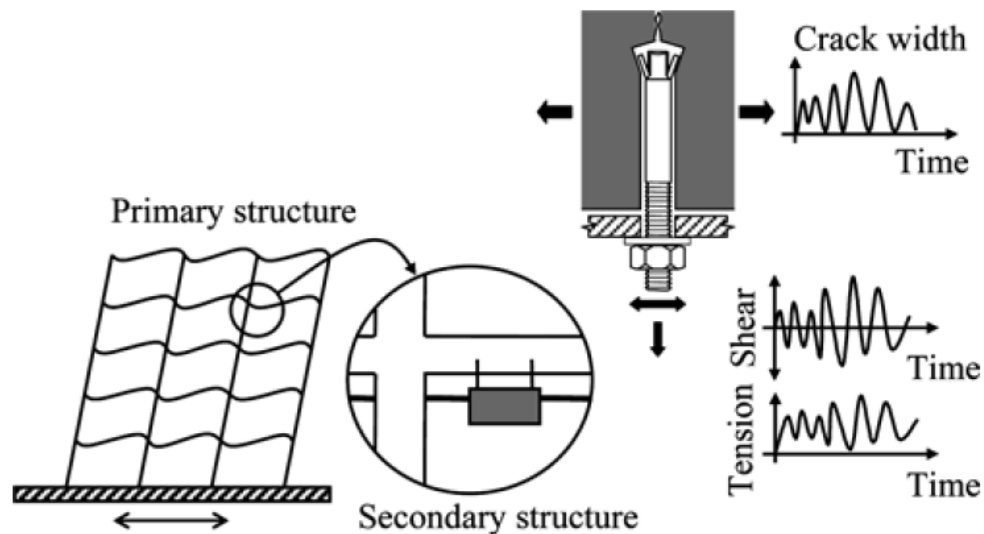


Fig. 1—Actions acting on nonstructural anchorage under earthquake loading.

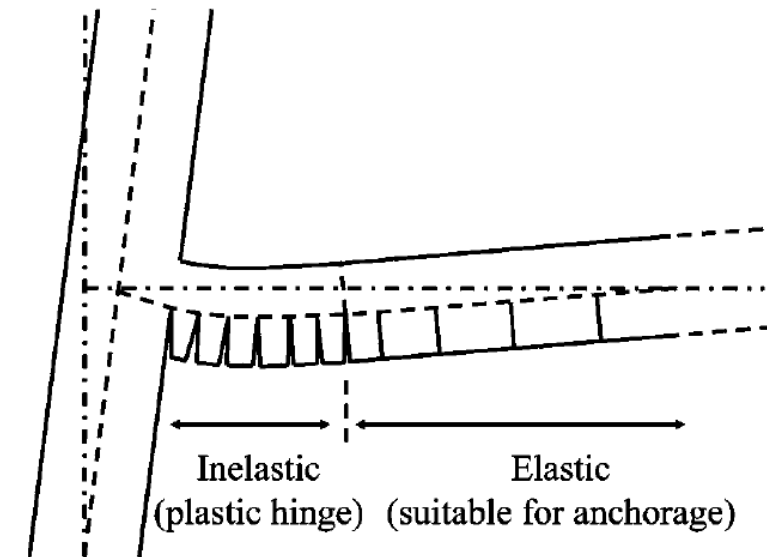


Fig. 2—Idealization of cracking in beam caused by transverse motion of building.

Crack width and cycling

- Extensive numerical studies of crack width in reinforced concrete bending members designed according to Eurocode indicate that the maximum crack width that can be expected to occur at steel yield in unfavorably designed flexural members is approximately 0.8 mm (0.03 in.). This value was determined for frame members subjected primarily to axial and bending deformation and is not valid for shear cracking. (Hoehler et. al.)

Crack Cycling Loading Setup

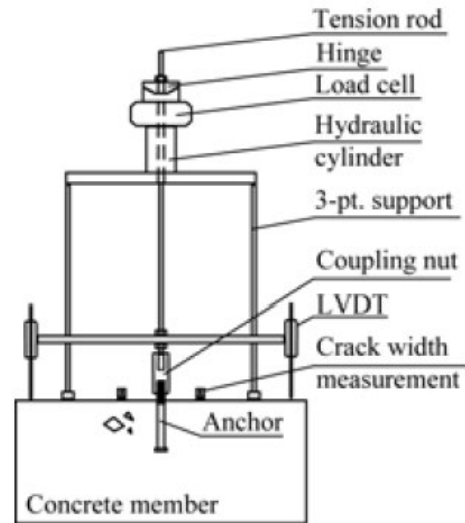


Fig. 7—Anchor loading setup for seismic crack cycling tests.

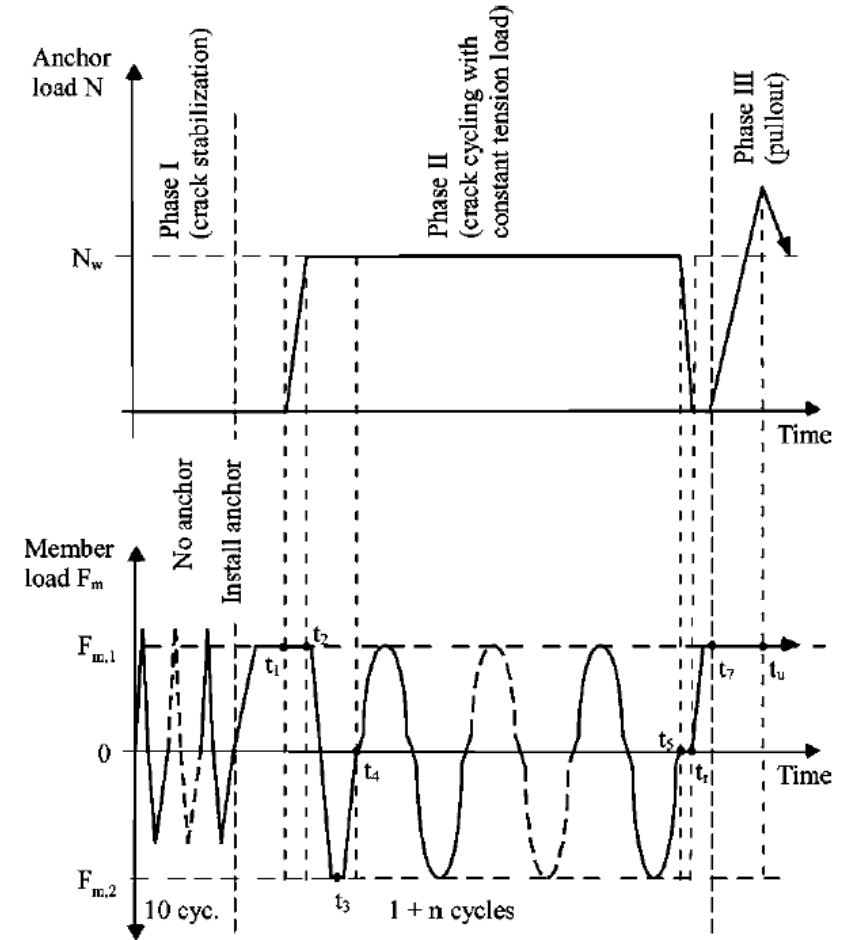


Fig. 8—Schematic loading time-histories for anchor and anchorage component.

Failure Modes

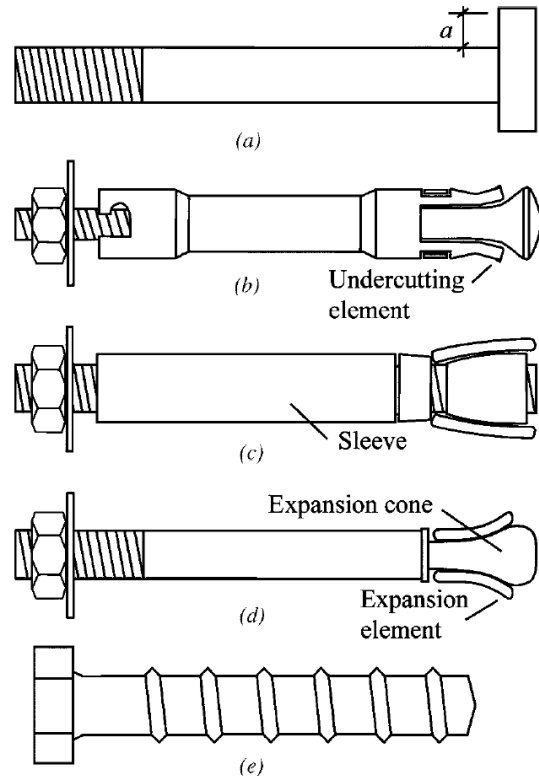


Fig. 3—Investigated anchor types: (a) headed stud; (b) undercut anchor; (c) expansion anchor (sleeve-type); (d) expansion anchor (bolt-type); and (e) screw anchor.

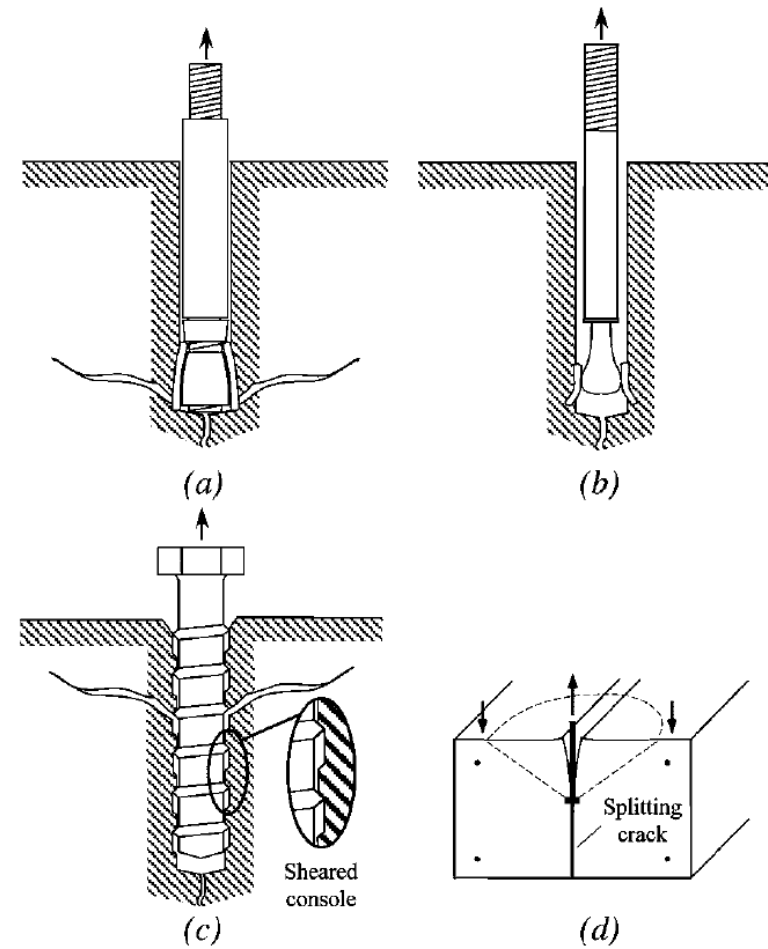


Fig. 10—Failure modes: (a) concrete cone breakout; (b) pull-through; (c) pullout/concrete cone; and (d) splitting.

Pull through failure of Mechanical Anchors

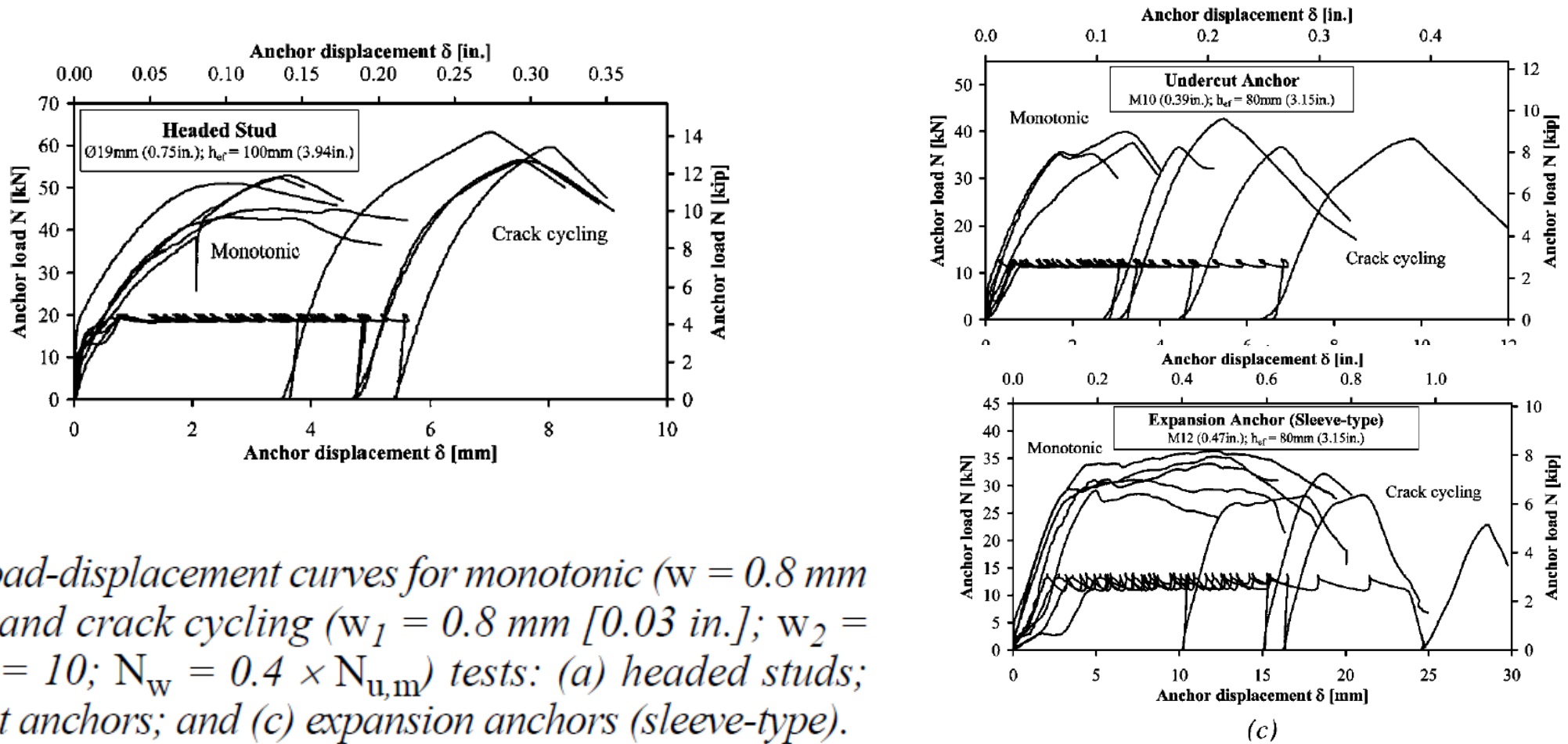


Fig. 12—Load-displacement curves for monotonic ($w = 0.8\text{ mm}$ [0.03 in.]) and crack cycling ($w_1 = 0.8\text{ mm}$ [0.03 in.]; $w_2 = 0.0\text{ mm}$; $n = 10$; $N_w = 0.4 \times N_{u,m}$) tests: (a) headed studs; (b) undercut anchors; and (c) expansion anchors (sleeve-type).

Pull through failure of Mechanical Anchors

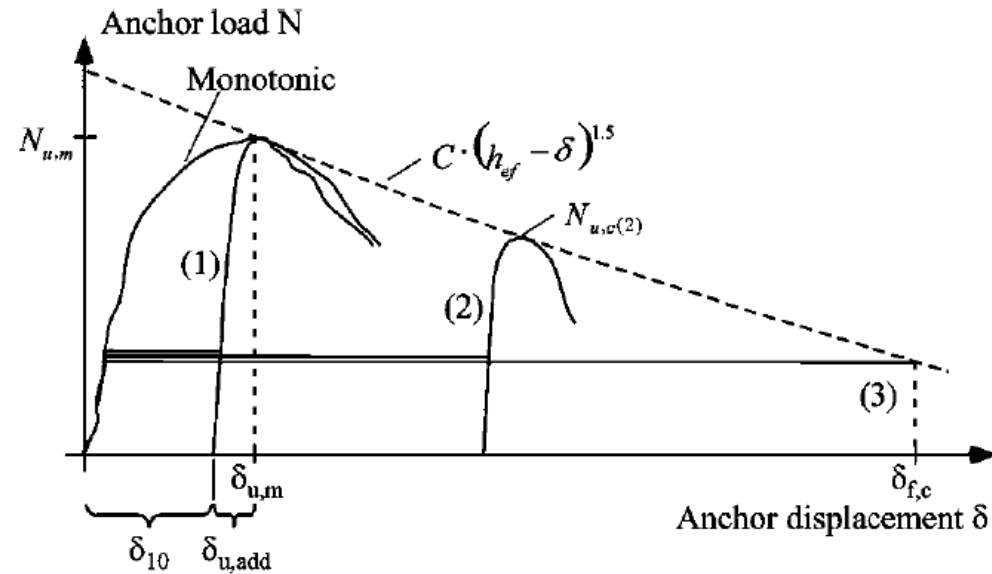


Fig. 13—Schematic load-displacement curves for crack cycling tests in case of concrete cone breakout.

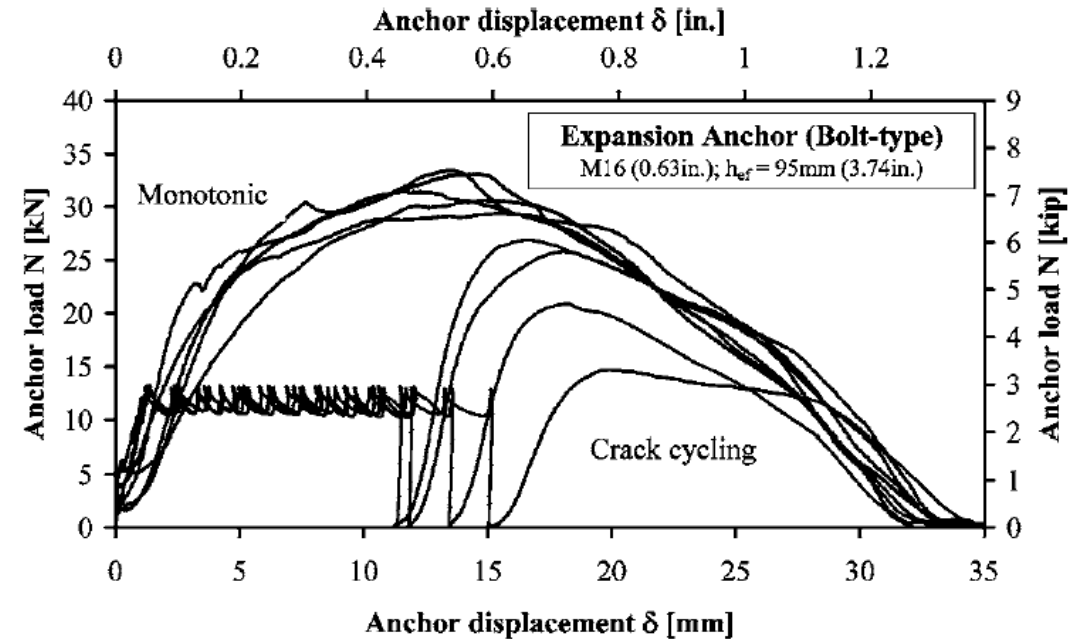


Fig. 14—Load-displacement curves for monotonic ($w = 0.8 \text{ mm}$ [0.03 in.]) and crack cycling ($w_1 = 0.8 \text{ mm}$ [0.03 in.]; $w_2 = 0.0 \text{ mm}$; $n = 10$; $N_w = 0.4 \times N_{u,m}$) tests for pull-through ($\delta_{10} \approx \delta_{u,m}$).

Displacement Conditions during Crack Cycling

Table 3—Displacement conditions during crack cycling for concrete cone breakout

Condition	Description	Residual strength
(1) $\delta_{10} < \delta_{u,m}$	Displacement during crack cycling is less than that at ultimate load in monotonic reference tests	$N_{u,c} \geq N_{u,m}$
(2) $\delta_{u,m} \leq \delta_{10} < \delta_{f,c}$	Displacement during crack cycling equals or exceeds that at ultimate load in monotonic reference tests but does not reduce effective anchorage depth enough to result in concrete cone breakout at applied constant tension load	$N_{u,c} < N_{u,m}$
(3) $\delta_{10} = \delta_{f,c}$	Displacement during crack cycling reduces effective anchorage depth enough to result in concrete cone breakout at applied constant tension load	Not applicable

Acceptance Criteria

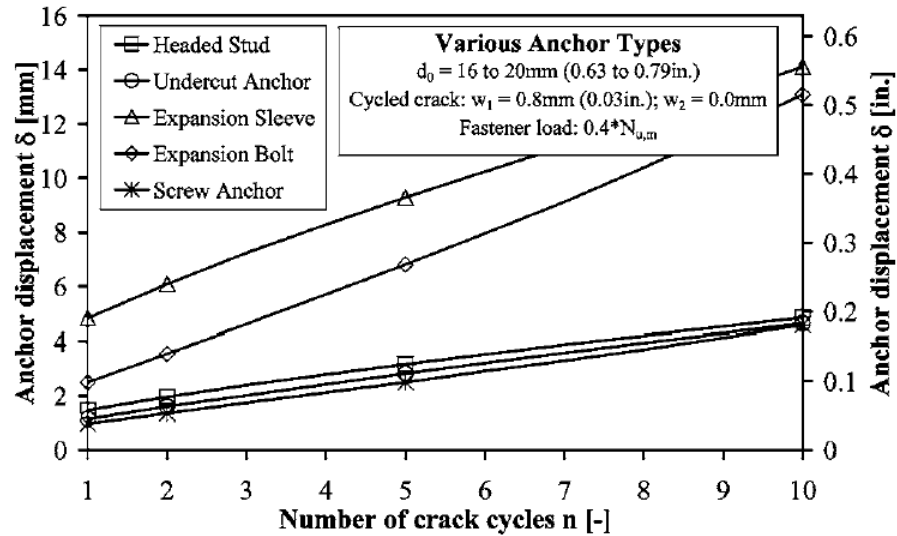


Fig. 17—Anchor displacement as function of number of crack cycles for investigated anchors.

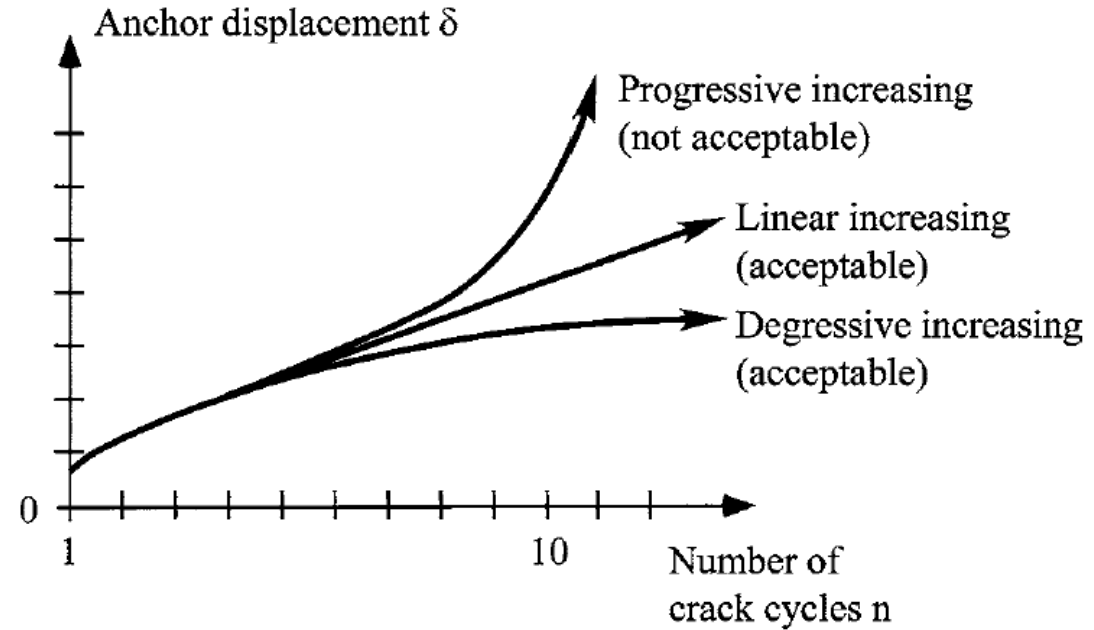


Fig. 18—Schematic anchor displacement for small number of crack cycles (<100) of relatively large amplitude, $w_1 - w_2 \geq 0.5\text{ mm}$ (0.02 in.).

Test Protocol New Anchor Qualification

- ACI 355.2 & 355.4 (24) – Crack cycling tests

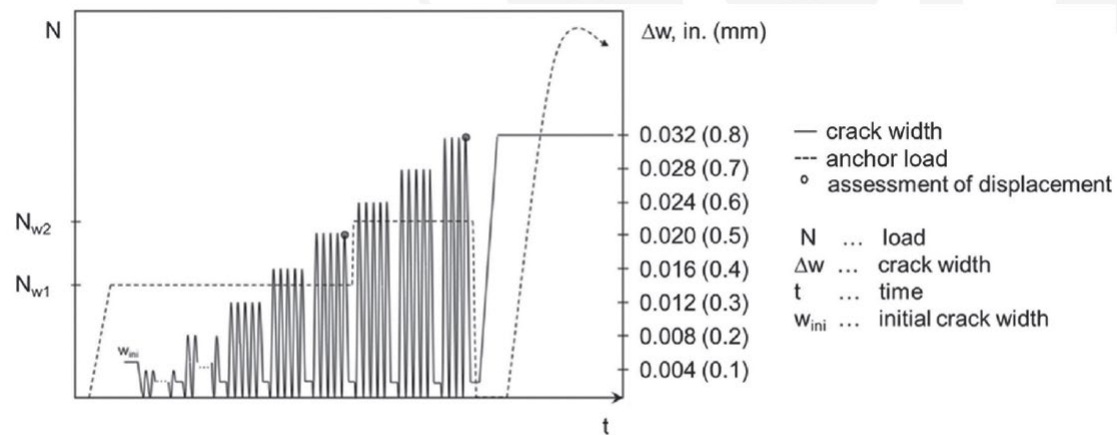


Fig. 8.14.2—Required crack widths and load levels for crack cycling test.

$$N_{w1} = 0.4 \bar{N}_{u,1e} \left(\frac{f_{c,test}}{f_{c,test,1e}} \right)^n \quad (1b) \quad (8.14.5)$$

$$N_{w2} = 0.5 \bar{N}_{u,1e} \left(\frac{f_{c,test}}{f_{c,test,1e}} \right)^n \quad (1b) \quad (8.14.6)$$

Table 8.14.2—Required crack widths and load levels for crack cycling test

Anchor load	Number of cycles	Crack width Δw, in.
N _{w1}	20	0.004
N _{w1}	10	0.008
N _{w1}	5	0.012
N _{w1}	5	0.016
N _{w1}	5	0.020
N _{w2}	5	0.024
N _{w2}	5	0.028
N _{w2}	4	0.032
Sum	59	—

Test Protocol New Anchor Qualification

- ACI 355.2 & 355.4 (24) – Seismic Cycling Tension Test

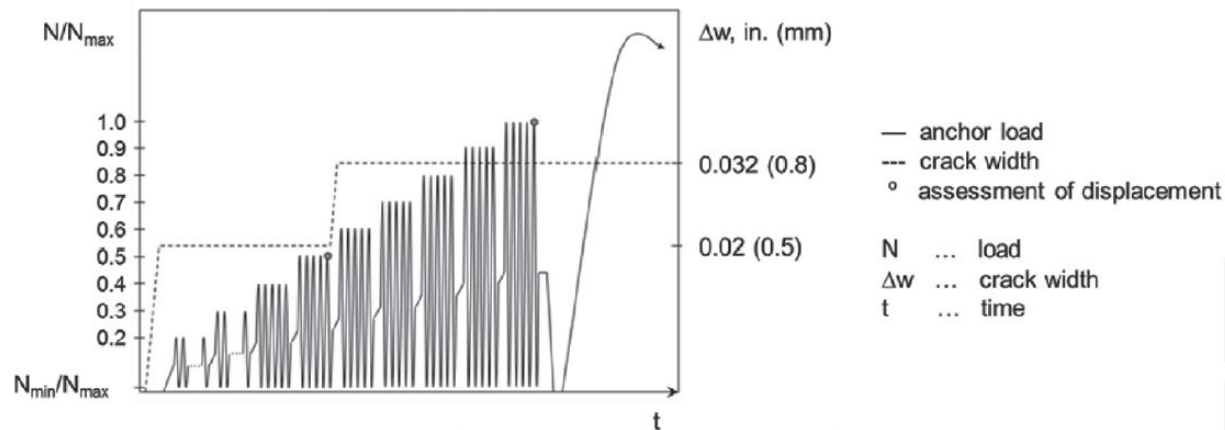


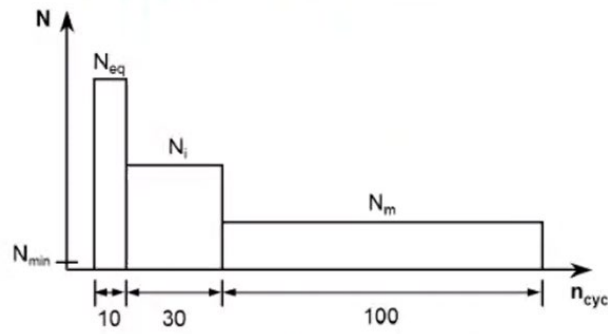
Fig. 8.12.2—Required load history for seismic cyclic tension test.

Table 8.12.2—Required load history for seismic cyclic tension test

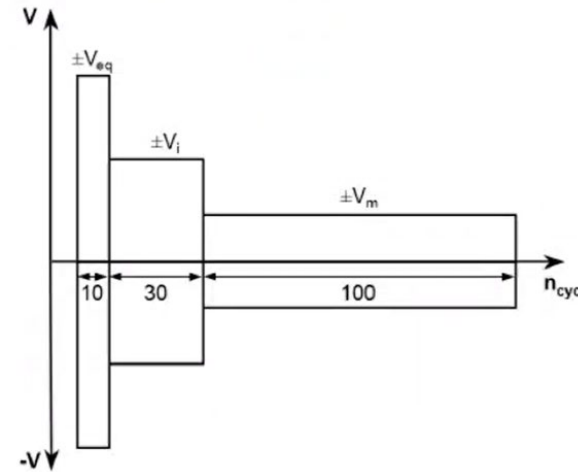
Load level N/N_{max}	Number of cycles	Crack width Δw , in.
0.2	25	0.020
0.3	15	0.020
0.4	5	0.020
0.5	5	0.020
0.6	5	0.032
0.7	5	0.032
0.8	5	0.032
0.9	5	0.032
1.0	5	0.032
Sum	75	—

Test Protocol Current Anchor Qualification

- ACI 355.2 & 355.4 (22) – Seismic Cycling Tension Test



$$\begin{aligned} N_{eq} &= 0.5 N_{u,m,ref} \\ N_i &= 0.375 N_{u,m,ref} \\ N_m &= 0.25 N_{u,m,ref} \end{aligned}$$



$$\begin{aligned} V_{eq} &= 0.5 V_{u,m,ref} \\ V_i &= 0.375 V_{u,m,ref} \\ V_m &= 0.25 V_{u,m,ref} \end{aligned}$$

What is Different in the new qualification requirement?

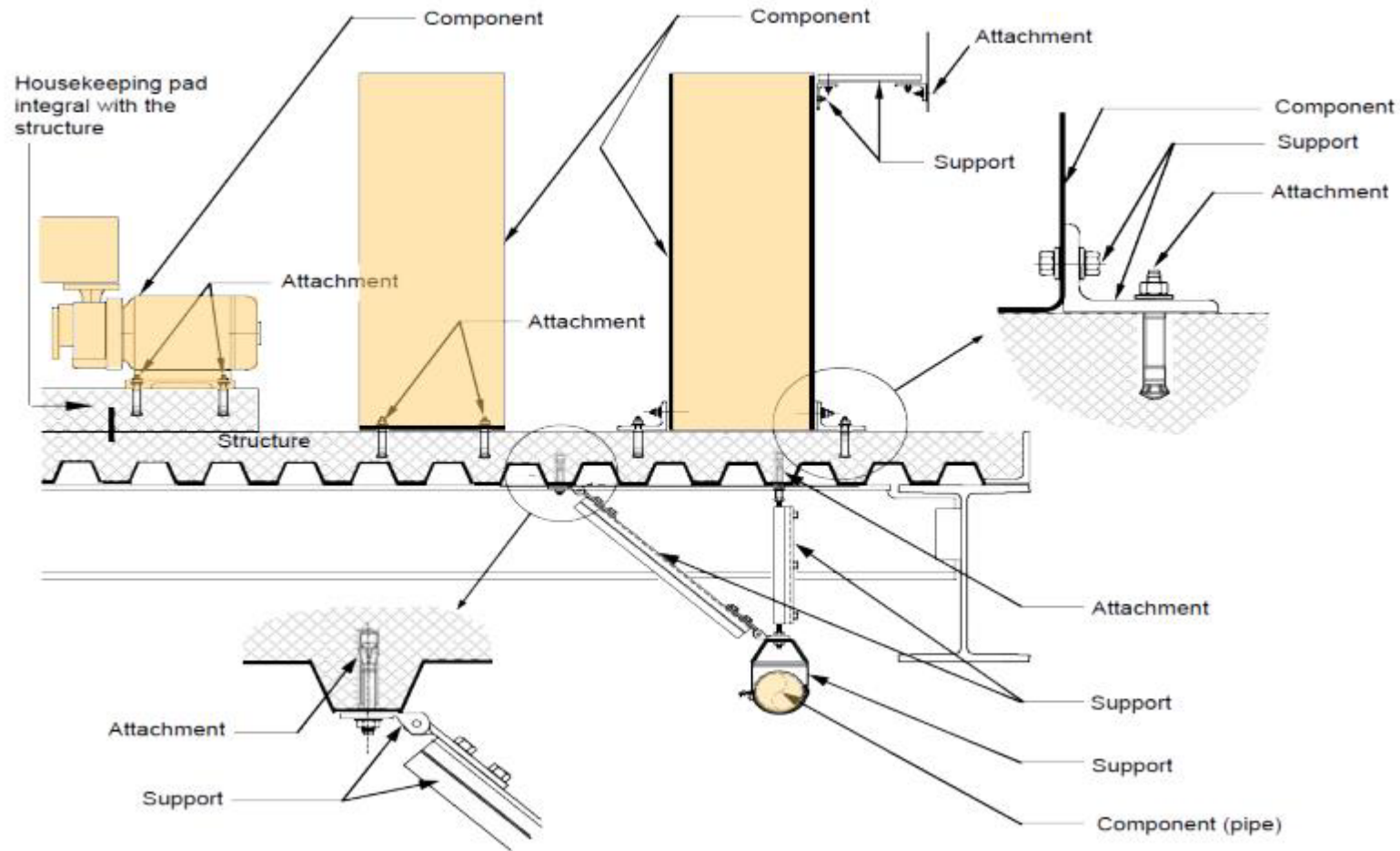
- Crack Protocol: Cycle counting is performed on curvature histories, going from smallest to largest
- Load Protocol: Cycle counting is performed on the oscillating SDOF systems, the input motions of these are affected by the nonlinear behavior of the building
- Integration of a unified protocol to simultaneously consider serviceability and suitability of anchor
- Based on current science and latest FEA tools

Is the loading protocol for anchor qualification reasonable?

- Thoughts?



Typical Anchorage of Nonstructural Components in Concrete



Issues with crack cycling

- Anchors for floor mounted equipment are not subject to sustained tension loads.
- Anchors to diagonal braces for seismic bracing of distribution systems are not subject to sustained tension.
- Vertical hangers of brace assemblies could support tributary gravity loads and are in sustained tension, but that load is expected to be small relative to the seismic tension. System could be supported by multiple gravity supports not subject to seismic cyclic loads.
- Location where crack cycling is expected to occur will have reinforcement. Not ideal locations for post installed anchors.
- Max. crack open and tension load occur at different times.
- No evidence provided from tests or past earthquake failures to show how the new protocol prevents failures from earthquakes where the current protocol does not.

Is the new test protocol for anchor qualification necessary for Hospital Buildings?

- New anchor qualification adds additional cost of testing the anchors for each size and depth costing millions of dollars.
- Recommend to permit the anchor qualification requirement for anchors not in sustained tension or anchors with very low tension < 0.2 Anchor Design Capacity that are subject to seismic loads to be qualified to the previous loading protocol.
- Thoughts?

