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Assessment, Repair, and Rehabilitation of Existing Concrete Structures—Code and Commentary

Reported by ACI Committee 562

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Assessment, Repair, and Rehabilitation of Existing Concrete Structures—Code and Commentary

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ACI CODE-562-21, "Assessment, Repair and Rehabilitation of Existing Concrete Structures—Code Requirements and Commentary," was developed to provide design professionals a code for the assessment of the damage and deterioration, and the design of appropriate repair and rehabilitation strategies. The Code provides minimum requirements for assessment, repair, and rehabilitation of existing structural concrete buildings, members, systems and, where applicable, nonbuilding structures. ACI 562-19 was specifically developed to work with the International Existing Building Code (IEBC) or to be adopted as a stand-alone code.

Keywords: assessment; bond; corrosion; damage; durability; evaluation; existing structure; fiber-reinforced polymer (FRP); interface bond; licensed design professional; maintenance; rehabilitation; reliability; repair; strengthening.

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PREFACE

This code provides minimum requirements for assessment, repair, and rehabilitation of existing concrete structures, members, and systems. This code was developed by an ANSI-approved consensus process. This code can supplement the International Existing Building Code (IEBC), supplement the code governing existing structures of an authority having jurisdiction, or act as a stand-alone code in a locality that has not adopted an existing building code.

The Code is specifically written for use by a licensed design professional. This code provides minimum requirements for assessment, design and construction, or implementation of repairs and rehabilitation, including quality assurance requirements, for structural concrete in service. This code has no legal status unless it is adopted by the authority having jurisdiction. Where the code has not been adopted, it serves as a standard to provide minimum requirements for assessment, design, and construction for the repair and rehabilitation of existing structural concrete. ACI 318 provides minimum requirements for the materials, design, and detailing of structural concrete buildings and, where applicable, nonbuilding structures, and for new construction within existing structures were noted herein.

Key changes from ACI 562-19 to ACI 562-21 include:

(a) The revised code, 562-21, to be used with any existing structures code (not just IEBC).

(b) Chapters 1 and 4 have been combined. Chapter 4 was reduced to meet the goal in (a).

(c) The content of Appendix A was revised and moved into the body of ACI 562, Chapter 4.

(d) The deletion of Appendix A.

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CHAPTER 1—GENERAL REQUIREMENTS

1.1—Scope

This Code shall apply to assessment, repair, and rehabilitation of existing concrete structures as:

1. A code supplementing an existing building code, or
2. A stand-alone code for existing concrete structures when an existing building code is not adopted.

1.2—General

1.2.1 ACI 562, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures," is hereafter referred to as "this Code."

1.2.2 The *licensed design professional* is responsible for the assessment or repair and rehabilitation design, or both.

1.2.3 The requirements of this Code use strength design provisions for demands and capacities, unless otherwise noted.

1.3—Purpose

1.3.1 The purpose of this Code is to safeguard the public by providing minimum requirements for assessment, repair, and rehabilitation of existing concrete structures.

1.4—Applicability of this Code

1.4.1 This Code provides minimum requirements for assessment, repair, and rehabilitation of structural concrete components in existing structures, including buildings and non-building structures.

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R1—GENERAL REQUIREMENTS

R1.1 This Code provides assessment, design, construction, and durability requirements for repair and rehabilitation of existing concrete structures. Throughout this Code, the term "structure" means an existing building, non-building structure, member, system, or element, if the construction is concrete or mixed construction with concrete and other materials.

This Code can be used in combination with an existing building code adopted by an authority having jurisdiction. For buildings, this is anticipated to be the state or local adoption of the International Existing Building Code (IEBC) developed by the International Code Council (ICC). Other codes may be applicable to non-building structures, or to structures that are not addressed in the IEBC. The provisions of this Code are intended to be used with the IEBC and similar codes.

If an existing building code is not adopted, Chapter 4 provides requirements for use as a stand-alone code.

R1.2—General

R1.2.3 If the existing building code or this Code permits the original building code to be used and that code uses allowable stress design, the licensed design professional should consider using the strength design provisions of this Code as a check in the evaluation of existing structures originally designed with allowable stress methods. Allowable stress design methods can result in designs that have inconsistent levels of structural reliability compared with modern strength design provisions (MacGregor 1974, Ellingwood et al. 1980).

R1.4—Applicability of this code

R1.4.1 This Code focuses on buildings and non-building structures as addressed by building codes or an authority having jurisdiction.

For buildings or structures similar to buildings, members that are addressed by this Code include but are not limited to foundations, soil-supported slabs, concrete portions of composite members, and precast and prestressed concrete.

In typical U.S. practice, owners are required to maintain existing structures to prevent unsafe conditions from occur-

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ring or repair an existing structure if unsafe conditions are present. The minimum level of repair for an existing structure will typically address these unsafe or potentially unsafe conditions.

The licensed design professional can perform assessment, design, and quality assurance activities that exceed the minimum requirements of this Code. Requirements beyond the minimum stated in this Code, such as those for long-term durability, disproportionate collapse resistance, redundancy, or integrity can be considered. Exceeding the code minimum requirements is not a violation of this Code.

The Owner and the licensed design professional should agree on the intent of the repair and rehabilitation program and desired outcome at the onset of the project. The desired outcome may include consideration of the design service life of the repairs, structural reliability, serviceability considerations, and other factors. Due to the uncertain remaining service life of existing structures and the technical requirements of repair construction, quality assurance and construction observation in excess of that required by the general building code is commonly needed.

1.4.2 This Code does not apply to the repair of non-structural concrete or to aesthetic improvements, except if failure of such repairs would result in a dangerous condition.

R1.4.2 If nonstructural concrete requires repair, that repair is not required to comply with the requirements of this Code. The licensed design professional designing repairs to nonstructural concrete should consider the consequence of repair failure to determine if provisions of this Code are applicable.

1.4.3 The term "existing building code" refers to the code adopted by the authority having jurisdiction that regulates existing buildings or structures.

R1.4.3 The code commonly governing existing buildings in the United States is the IEBC, which provides limits on the extent of damage to be repaired using the original building code.

1.4.4 The term "original building code" refers to the general building code adopted by the authority having jurisdiction at the time the existing structure was permitted for construction.

R1.4.4 This description of "original building code" is consistent with the IEBC. In assessing existing structures, the licensed design professional may need to consider changes in the codes adopted by the authority having jurisdiction for the structure from the time of the original design through the time of the completion of construction. For buildings with major alterations or additions, the original building code should refer to the code in effect when the subject portion of the building was permitted, and different portions of a building may have different original building codes.

1.4.5 The term "current building code" refers to the general building code adopted by the authority having jurisdiction that regulates new building design and construction.

R1.4.5 The current building code establishes the design and construction regulations for new construction. Strength design regulations of the current building code typically include:

(a) Required strengths calculated using combinations of factored loads (strength-design demands)

(b) Design strengths (capacities) based on testing of materials, members, and systems

(c) Analytical methods used to calculate member and system capacity

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(d) Strength reduction factors that have been established to be consistent with reliability indices used with the strength-design demands

The load factors and strength reduction factors in the current building code were obtained through design code calibration procedures to achieve the targeted reliability indices that produce historically acceptable structural safety for new structures. The targeted reliability indices are generally based on past structural behavior, engineering experiences, cost and consequences of failure, and other factors. The resulting demand-to-capacity ratios for new structures provide the limits that are not to be exceeded in designing new construction, but these demand-to-capacity ratio limits need not to be the same as those for existing structures as noted in 4.5.3.

The general building code in the United States is typically based on the International Building Code (IBC) published by the ICC. Prior to 2015, Chapter 34 of the IBC included provisions for existing structures. For the design and construction of new concrete structures, the IBC and most other older general building codes often reference ACI 318, Building Code Requirements for Structural Concrete and Commentary, with exceptions and additions.

1.5—Administration

1.5.1 If provisions in this Code conflict with the regulations governing existing structures of the authority having jurisdiction, the regulations of the authority having jurisdiction shall govern.

1.5.2 If provisions in this Code conflict with requirements of standards referenced within this Code, this Code shall govern.

1.5.3 Alternative materials, design, and methods of construction shall be permitted in accordance with the existing building code or by the authority having jurisdiction.

R1.5—Administration

R1.5.3 New methods of design, new materials, and new uses of materials for repair and rehabilitation usually undergo a period of development before being permitted by a code.

Provision 1.5.3 mirrors IEBC 104.11 that permits building official approval of alternative methods, design, or materials on a project-by-project basis, provided that the alternative is demonstrated to the satisfaction of the building official to provide equivalent quality, strength, effectiveness, fire resistance, durability, and safety.

For systems considered under 1.5.3, specific tests, factored load combinations, strength reduction factors, deflection limits, and other pertinent requirements should be set by the authority having jurisdiction and should be consistent with the intent of this Code. Provision 1.5.3 does not apply to scale model testing used to supplement calculations or to strength evaluation of existing structures.

If the existing building code adopted by the authority having jurisdiction includes provisions for approval of alternative materials in new construction, the same process may be used for materials in repair applications, provided the materials conform to the provisions of this Code. Typically, the approval process requires the evaluation to be completed

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1.6—Design and construction documents

1.6.1 The basis of design shall be documented by the licensed design professional. Documentation shall identify the work area and scope of repair and rehabilitation.

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by an approved agency, and the material properties and use requirements be summarized in a written evaluation report. This process is intended to allow for use of new materials and new classes of materials that do not have approved design standards or material specifications.

R1.6—Design and construction documents

R1.6.1 The basis of design provides a summary of the assessment of the existing structure and a summary of the construction documents from original construction or prior rehabilitation used in developing the basis of design. The basis of design can be documented in a written report or included in construction documents. Information on some structures may be unavailable or unnecessary if strengthening is not required and should be so documented in the basis of design. The licensed design professional should review requirements of the authority having jurisdiction to determine the information to include in the basis of design documentation and filing requirements for the basis of design. Items that may be documented in the basis of design include:

(a) Detailed description of the structure, including age of construction, structural systems, identified original building code, and past and current uses

(b) Documentation of potentially dangerous structural conditions in the work area of the structure determined in the assessment

(c) Documentation of substantial structural damage in the work area

(d) Members and systems of the work area requiring increase in capacity beyond the demands of the original building code

(e) Conditions and details of the proposed rehabilitation work

(f) Assessment criteria and findings

(g) Design-basis code criteria and basis of rehabilitation design

(h) Shoring requirements such as loads to be resisted and spacing of shoring members

(i) Quality assurance and quality control (QA/QC) requirements

(j) Types and frequency of future inspection

(k) Types and frequency of future maintenance

(l) Recommendations to address serviceability conditions

A maintenance protocol should be provided in the basis of design, or in as-built or close-out documents. A maintenance protocol that addresses project-specific conditions provides the most effective method to ensure durability and should be established as part of the repair and rehabilitation design. The protocol should include required inspections and intervals between inspections, after completion of the repair or rehabilitation. Maintenance and frequent preventative approaches that occur early in the service life of the structure generally result in improved service life with less interruption and a lower life-cycle cost (Tuutti 1982; ACI 365.1R). Recommendations should be provided to the owner

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on inspection and maintenance to be undertaken during the remaining design service life of the repair material or the repaired part of the structure.

1.6.2 The construction documents for repair and rehabilitation shall convey the location, nature, and extent of the work, and the necessary information to perform the work in conformance with the requirements of this Code and the authority having jurisdiction. Construction documents shall require that materials used for the work conform to this Code and governing regulatory requirements at the time the work is executed.

R1.6.2 As applicable, the construction documents may consist of drawings and specifications if needed, and should indicate:

(a) Name and date of issue of the building code and supplements to which the assessment, repairs, or rehabilitation conforms

(b) Design assumptions and repair requirements including specified properties of existing and remedial materials used for the project and the strength requirements at stated ages or stages of construction

(c) Details, locations, and notes indicating repair types, materials, preparation requirements, and other pertinent information to implement the repairs, strengthening, or rehabilitation of the structure

(d) Magnitude and location of prestressing forces

(e) Anchorage details for prestressing reinforcement

(f) Reinforcement embedment, development, and lap splice lengths

(g) Type and location of mechanical or welded splices of reinforcement

(h) Shoring or bracing criteria required before, during, and at completion of the assessment, repair, or rehabilitation

(i) Quality assurance program including specific inspections, testing requirements, and acceptance criteria

ACI 563 is a reference specification that is available as a resource to users of this Code.

1.6.3 Calculations pertinent to design shall be submitted with the construction documents if required by the authority having jurisdiction.

R1.6.3 Analyses and designs should include calculations, evaluation, and design assumptions. If computer-based analyses and designs, such as finite element methods, are used, they should include input and computer-generated output.

1.6.4 Load testing and scale model testing shall be permitted to supplement calculations.

R1.6.4 Results from load tests, scale model tests, and other types of physical testing can be used to supplement analytical procedures in the evaluation of existing structures. Strength evaluation procedures are described in ACI 437R; scale model tests are described in White (1970).

1.7—Assessment, design, and construction requirements if used with an existing building code

1.7.1 If this Code is used in conjunction with an existing building code, assessment, repair, and rehabilitation shall be in accordance with the existing building code and the provisions of 1.7.

R1.7—Assessment, design, and construction requirements if used with an existing building code

R1.7.1 The provisions of this Code are intended to be used in combination with the existing building code. The existing building code provides criteria for evaluation, when required, and criteria for repair or rehabilitation, when required. These existing building code criteria are supplemented by 1.7.2 through 1.7.9.

The code governing existing buildings in the United States is commonly the IEBC. The IEBC provides limits regarding the extent of damage that can be repaired using the original building code.

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1.7.2 In all cases, assessment, repair, and rehabilitation shall be permitted to conform to the requirements of the *current building code*.

1.7.3 Loads shall be as specified in the existing building code. Load combinations and strength reduction factors shall be in accordance with Chapter 5.

1.7.4 Evaluation and assessment of the existing structure shall be performed as required by the existing building code.

1.7.5 Design of repairs and rehabilitation shall be in accordance with Chapters 7 and 8.

1.7.5.1 Repairs that do not change the strength, stiffness, or ductility of the seismic-force-resisting system are permitted for structures in all Seismic Design Categories.

1.7.5.2 For structures assigned to Seismic Design Category A in accordance with ASCE/SEI 7, repair and rehabilitation of the lateral-force-resisting system shall be permitted in accordance with this Code.

1.7.5.3 This Code shall not be used for repair or rehabilitation of elements of seismic force-resisting systems that result in a change in the strength, stiffness, or ductility of those elements from their pre-damage condition for structures in Seismic Design Categories B through F in accordance with ASCE/SEI 7.

1.7.6 This Code is not to be used for strengthening of elements of seismic-force-resisting systems.

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R1.7.2 The current building code is always permitted as the design-basis code because it provides an acceptable level of safety. Use of the current building code may, however, result in an overly conservative assessment of an older structure. Therefore, the choice to use this option should be given careful consideration. The licensed design professional should review the benefits and drawbacks of using the current building code with the Owner at the start of the project.

R1.7.4 The requirements of the existing building code should be followed to determine the required extent of evaluation and assessment of the existing structure. If the existing building code permits repair to the pre-damage condition without requiring assessment or evaluation, such repair is permitted by this Code. If the existing building code does not provide specific assessment requirements, 1.8 and Chapter 6 can be used for assessment of existing structures.

R1.7.5.1 The licensed design professional should evaluate any required repairs to the seismic-force-resisting system of a structure and determine how the repairs will affect the performance of the structure under design loadings. Changes in the strength, stiffness, or ductility of the structure may results in unintended distribution of load during seismic loading. Repairs to the seismic-force-resisting system can be designed using this Code if the repairs do not affect the strength, stiffness, or ductility of the structure. Seismic performance evaluation of existing structures is described in FEMA P-58 and FEMA P-695.

R1.7.5.2 Repairs to the lateral-force-resisting system of a structure that result in a change in the strength, stiffness, or ductility of those elements are only permitted in structures in Seismic Design Category A in accordance with ASCE/SEI 7.

R1.7.5.3 This Code is not permitted for seismic force-resisting systems because changes in strength, stiffness, or ductility introduced during rehabilitation can adversely affect the overall seismic resistance of the structure. For this reason, repair and rehabilitation of the seismic force-resisting system is beyond the scope of this Code. Other standards, such as "Seismic Evaluation and Retrofit of Existing Buildings," (ASCE 41) address repair and strengthening of seismic force-resisting systems.

R1.7.6 Evaluation and strengthening of the seismic-force-resisting system should be performed in accordance with the requirements of the existing building code and standards.

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1.7.6.1 Voluntary strengthening shall be permitted, subject to the limitations of the existing building code and Chapter 5.

1.7.7 Design of new elements shall be in accordance with the requirements of the *existing building code*.

1.7.7.1 Detailing of new elements and connection of new elements to the existing structure shall be in accordance with the current building code.

1.7.8 All work shall conform to the requirements of Chapters 9 and 10.

1.8—Assessment, design, and construction requirements if not used with an existing building code

1.8.1 If this Code is used as a stand-alone code, preliminary assessment, assessment, repair, and rehabilitation shall be in accordance with 1.8.2 through 1.8.12.

1.8.2 In all cases, it shall be permitted to conform to the requirements of the current building code.

1.8.3 The *design-basis code* shall be determined in accordance with Chapter 4 based upon the results of the preliminary assessment and assessment.

1.8.4 *Preliminary assessment and assessment*

1.8.4.1 Preliminary assessment of an existing structure shall be conducted within the *work area*. The preliminary assessment shall include investigation and review of the structure, construction documents, reports, local jurisdictional codes, and other available documents. Existing in-place conditions shall be visually or otherwise investigated to establish existing geometry and structural conditions.

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such as ASCE 41, which was specifically developed for seismic evaluation of existing structures.

R1.8—Assessment, design, and construction requirements if not used with an existing building code

R1.8.1 Section 1.8 provides similar information to 1.7 but is applicable if this Code is used as a stand-alone code. Chapter 4 provides criteria for evaluation, if required, and design criteria for repair or rehabilitation, if required. The criteria in Chapter 4 are supplemented by the requirements of 1.8.2 through 1.8.12.

R1.8.2 As stated in R1.7.2, it is always permitted to use the current building code as the *design-basis code*. However, this may result in an overly conservative assessment of an older structure. The licensed design professional should review benefits and drawbacks of using the current building code with the Owner at the start of the project.

R1.8.4 *Preliminary assessment and assessment*

R1.8.4.1 The goal of the preliminary assessment is to examine available information about the structure within the work area, and to make an initial determination of its adequacy to withstand in-place environmental conditions and design loads. The results of the preliminary assessment should be used to make decisions regarding the current in-place condition, need for additional information, work items necessary as part of the assessment, possible rehabilitation design and construction work to consider, and if there is a need for temporary shoring for safety of the existing structure. The preliminary assessment results should be updated as additional data regarding the examined structure become available.

The licensed design professional may determine that 4.6 applies in a preliminary assessment based on engineering judgment and without analysis if the following are confirmed:

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(a) Historical performance of the structure and visual observation of the structural condition of members and systems indicate acceptable behavior precluding assessment by 4.3.

(b) Review of construction documents and observation of current structural conditions indicate damage or deterioration of the structure below the level requiring assessment by 4.4 and 4.5.

(c) Modifications for additions, alterations, and changes in occupancy are not planned.

If the structure is determined to be structurally acceptable, repairs are permitted that address durability and serviceability of 4.6 without analyzing members and systems and without checking the demand-to-capacity ratio limits of 4.3 through 4.5. Structural performance should be considered acceptable if past and present performance has been satisfactory and observations do not indicate structural distress beyond levels expected.

The extent of damage or deterioration should be limited, and the licensed design professional should not have a concern about the capacity of the structure if repairs are completed using the provisions of 4.6 without verifying the demand-to-capacity limits of 4.4 and 4.5.

1.8.4.2 The preliminary assessment shall determine if visible potentially dangerous structural conditions are present.

R1.8.4.2 Potentially dangerous structural conditions may require the Owner to install shoring, limit access, or take other measures to mitigate these conditions.

1.8.4.3 In performing a preliminary assessment, it shall be permitted to use the original or current building code for assessment criteria.

R1.8.4.3 The assumed preliminary assessment criteria should be substantiated or modified in accordance with the assessment details of Chapter 6.

1.8.4.4 If required, the in-place strength of the existing structure shall be determined considering in-place geometry and material properties including effects of material deterioration and other deficiencies. If material properties are not available, a preliminary assessment is permitted using material properties in accordance with 6.3.2.

R1.8.4.4 If required as a part of the preliminary assessment, strength calculations should be based on in-place conditions and should include an assessment of the loss of strength due to deterioration. Guidelines for assessing in-place conditions include ACI 201.2R, ACI 214.4R, ACI 228.1R, ACI 228.2R, ACI 364.1R, ACI 437.1R, FEMA P-58, FEMA P-154, FEMA 306, FEMA 307, ASCE/SEI 11, ASCE/SEI 41, ATC-20, ATC-45, ATC-78 and The Concrete Society *Technical Report 68* (2008). If material test results are initially unavailable, historical properties based on typical values used at the time of construction can be used in a preliminary evaluation. If available, material properties from construction documents can also be used in a preliminary evaluation.

The assessment of existing structures should initially focus on critical gravity-load-resisting members such as columns, walls, and members that are expected to have limited ductility, followed by an assessment of the lateral-load-resisting system.

Assessing fire damage and other forms of deterioration that affect material properties (such as compressive strength or modulus of elasticity) should include an evaluation of the effect of the damage on the material properties and the impact of the damage on the performance of the existing structure.

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Examples of deterioration mechanisms that result in possible changes in material properties or structural performance include corrosion of steel reinforcement, thermal damage, chemical reactions such as alkali-aggregate, and freezing-and-thawing damage.

Conditions to be documented include cracking, spalls, member deflection, cross-section dimensions that are different than specified on the original construction drawings, and construction deviating from tolerances permitted under the original design criteria.

1.8.4.5 A structural assessment in accordance with Chapter 6 shall be performed if a member or structure exhibits damage, displacements, deterioration, structural deficiencies, or performance that is unexpected or inconsistent with available design and construction documents or code requirements in effect at the time of construction.

R1.8.4.5 The preliminary assessment is generally the first portion of the work necessary to determine the rehabilitation category. Based upon preliminary assessment results, a structural assessment may be required to determine the extent of damage or if potentially dangerous structural conditions are present. However, in some cases, the licensed design professional may deem that a structural assessment is not required based on judgment in accordance with 1.8.4.1 through 1.8.4.4.

1.8.5 Loads shall be as specified in the design-basis code. Load combinations and strength reduction factors shall be in accordance with Chapter 5.

1.8.6 Design of repairs and rehabilitation shall be in accordance with Chapters 7 and 8.

1.8.6.1 Repairs that do not change the strength, stiffness, or ductility of the seismic-force-resisting system are permitted for structures in all Seismic Design Categories.

R1.8.6.1 Refer to R1.7.5.1.

1.8.6.2 For structures assigned to Seismic Design Category A in accordance with ASCE/SEI 7, repair and rehabilitation of the lateral-force-resisting system shall be permitted in accordance with this Code.

R1.8.6.2 Refer to R1.7.5.2.

1.8.6.3 Use of this Code is not permitted for repair or rehabilitation of elements of seismic force-resisting systems that result in a change in the strength, stiffness, or ductility of those elements from their pre-damage condition for structures in Seismic Design Categories B through F.

R1.8.6.3 Refer to R1.7.5.3.

1.8.7 Retrofit of elements of seismic-force-resisting systems shall be performed in accordance with ASCE/SEI 41.

1.8.8 Design of new elements shall be in accordance with the *design-basis code.*

1.8.8.1 Detailing of new elements and connection of new elements to the existing structure shall be in accordance with the current building code.

1.8.9 Voluntary strengthening shall be permitted, subject to the limitations of Chapters 4 and 5.

1.8.10 All work shall conform to the requirements of Chapters 9 and 10.

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CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

This chapter defines notation and terminology used in this Code.

c = depth of neutral axis, mm

D = effect of service dead load

d_t = distance from extreme compression fiber to centroid of extreme tension reinforcement, mm

$\overline{f_c}$ = average core strength modified to account for the diameter and moisture condition of the core, MPa

f_c' = specified concrete compressive strength, MPa

f_{ceq} = equivalent specified concrete strength used for evaluation, MPa

f_y = specified yield strength of steel reinforcement, MPa

$\overline{f_y}$ = average yield strength value for steel reinforcement, MPa

f_{yeq} = equivalent yield strength of steel reinforcement used for evaluation, MPa

k_c = coefficient of variation modification factor for concrete testing sample size

k_s = coefficient of variation modification factor for steel testing sample size

L = effect of service live load

ℓ_t = span of member under load test and taken as the smaller of: (a) distance between centers of supports; and (b) clear distance between supports plus thickness h of member; for a cantilever, it shall be taken as twice the distance from face of support to cantilever end, mm

n = number of specimens tested

R_a = service load capacity of structural member, system, or connection including effects of damage, deterioration of concrete and reinforcement, and faulty construction determined using allowable stresses according to the original building code

R_{cn} = current in-place nominal capacity of structural member, system, or connection including the effects of damage, deterioration of concrete and reinforcement, and faulty construction

R_{ex} = nominal resistance of the structure during an extraordinary (that is, low-probability) event calculated using the probable material properties

R_n = nominal capacity of structural member, system, or connection excluding the effects of damage, deterioration of concrete and reinforcement, and faulty construction

S = effect of service snow load

T_g = glass transition temperature, °C

U = required strength or demand using nominal loads and factored load combinations for strength design provisions

U_c = required strength or demand using nominal loads of the current building code and factored load combinations of ASCE/SEI 7 for strength design

COMMENTARY

R2—NOTATION AND DEFINITIONS

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U_o = required strength or demand using nominal loads and factored load combinations of the original building code for strength design

U_{o*} = required strength or demand using nominal loads of the original building code and factored load combinations of ASCE/SEI 7 for strength design

U_s = demand using service loads of the original building code and allowable stress load combinations of the original building code

V = coefficient of variation (a dimensionless quantity equal to the sample standard deviation divided by the mean) determined from testing of concrete or steel samples from structures

v_{ni} = nominal interface shear stress capacity

v_u = resultant interface stress demand from the transfer of tension and shear

ε_t = net tensile strain in the extreme tension reinforcement at nominal strength

ε_y = yield strain of steel reinforcement

ϕ = strength reduction factor

ϕ_{ex} = strength reduction factor used to check strength of the structure without external reinforcement after an extraordinary event

ϕ_o = strength reduction factor from the original building code used in the design of an existing structure

2.2—Definitions

assessment—the process of investigating by systematically collecting information that affects the performance of an existing structure; evaluating the collected information to make informed decisions regarding the need for repair or rehabilitation; detailing of findings as conclusions and reporting recommendations for the examined structural concrete work area (member, system, or structure).

COMMENTARY

R2.2—Definitions

For consistent application of this Code, it is necessary that terms be defined if they have particular meanings in the Code. The definitions given are for use in application of this Code only and do not always correspond to ordinary usage. A glossary of common terms relating to cement manufacturing, concrete design and construction, and research in concrete is contained in "ACI Concrete Terminology" (CT) available on the ACI website.

This definition with specific details for existing concrete is adapted from ACI 364 and ASCE/SEI 11.

An assessment is the process of acquiring knowledge of the existing structure for the purpose of judging its future performance. The results of the investigation and evaluation are used to make decisions on the appropriate course of action regarding the future use of the structure and the suitability of the structure to continue in service.

Assessments should be limited to the work area and may include:

(a) Investigation of the in-place condition of the existing structure by:

i. Collection and review of field data for the structure, such as geometry, material strengths, conditions, symptoms of distress, extent of damage, measurement of displacements, environmental factors, and reinforcement sizes and placement

ii. Collection of background data, such as construction plans, construction records, original code, current code, and existing building codes and historical events

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(b) Evaluation of an existing structure, member, or system of the work area (refer to Commentary for "evaluation")

(c) Findings and conclusions of the investigation and evaluation:

i. Define the existing structure, member, or system rehabilitation category using the assessment criteria of this Code

ii. Identify the work area, scope of work, and likely cause of damage, distress, and deterioration

iii. Identify extents of possible faulty construction

iv. Evaluate test results to determine cause of failure and estimate likely future performance

(d) Determine repair and rehabilitation concepts, strategies, alternatives, and recommendations

i. Develop cost-impact or economic study as necessary to appraise remedial work and maintenance

ii. Describe repair and rehabilitation work recommendations

(e) Report conclusions and recommendations:

i. Work area limits and limitations of information collected and evaluated

ii. Assessment criteria and results of the evaluation such as calculations, tests, and analyses

iii. Details of findings (conclusions) and recommendations

iv. Safety issue requirements (for example, recommendation for any temporary shoring)

assessment criteria—codes, standards, loads, demands, capacities, strength reduction factors, materials, material properties, connections, and details used in the evaluation.

authority having jurisdiction—person or entity that has legal control over the applicable building code and permitting procedures for a structure.

An example of an authority having jurisdiction is the local building official.

bond—(1) mechanism for transfer of forces to reinforcing bars embedded in concrete through a combination of adhesion, friction, and interlock of the bar deformations; (2) adhesion between layers of a repair area or between a repair material and a substrate produced by adhesive properties of the repair material or other supplemental materials.

bond-critical application—strengthening or repair system that relies on load transfer from the substrate to the system material through shear and tension transfer at the interface; strengthening or repair system for which bond rather than mechanical attachment is used as the primary load transfer mechanism.

capacity—the strength, stiffness, ductility, or energy dissipation of a material, member, or system as determined by analysis or testing.

compatible—the ability of two or more materials in contact to function together with no significant detrimental effect on the intended service life.

condition assessment—a process of reviewing information gathered about the current condition of a structure or its components, its service environment and general circumstances, whereby its adequacy for future service may be

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established against specified performance requirements for a defined set of loadings or environmental exposures, or both.

connector steel—steel elements, such as reinforcing bars, shapes, or plates, embedded in concrete or connected to embedded elements to transfer load, restrain movement, or provide stability.

contact-critical application—strengthening or repair system that relies on load transfer from the substrate to the system material through bearing perpendicular to the interface.

construction documents—written and graphic documents and specifications prepared or assembled that describe the location, design, materials, and physical characteristics of the elements of a project necessary for obtaining a building permit and for construction of the project.

damage—a decrease in the capacity of an existing member or structure resulting from unexpected events, such as excessive loads and displacements, or from deterioration.

dangerous—designation applied to any building, structure, or portion thereof that meets any of the following conditions:

1. The building or structure has collapsed, has partially collapsed, has moved off its foundation, or lacks the necessary support of the ground.

2. There exists a significant risk of collapse, detachment, or dislodgement of any portion, member, appurtenance, or ornamentation of the concrete building or structure under actual loads already in effect; or under snow, wind, rain, flood, earthquake, or other environmental loads when such loads are imminent.

demand—the force, deformation, energy input, and chemical or physical attack imposed on a material, member, or system that has to be resisted.

design-basis code—legally adopted code requirements under which the assessments, repairs, and rehabilitations are designed and constructed.

design-basis criteria—codes, standards, loads, displacement limits, material properties, connections, details, and protections used in the design of mandated or voluntary work.

design service life—the period of time after installation or repair of a building, component, or material during which the performance is required to satisfy the specified requirements if routinely maintained but without being subjected to an overload or extreme event.

deterioration—(1) physical manifestation of failure of a material (for example, cracking, delamination, flaking, pitting, scaling, and spalling) caused by environmental or internal autogenous influences; (2) decomposition of material during either testing or exposure to service conditions.

durability—ability of a material or structure to resist weathering action, chemical attack, abrasion, and other service conditions and maintain serviceability over a specified time or design service life.

COMMENTARY

An example of a contact-critical application is the addition of a confinement jacket around a column.

This definition has been adopted from the IEBC.

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equivalent concrete cover—a system to supplement insufficient concrete cover to provide durability or fire protection equivalent to the specified minimum cover.

evaluation—the process of determining and judging the adequacy of a structure, member, or system for its current intended use or performance objective.

existing structure—(1) when used in conjunction with an existing building code, a building erected prior to the date of adoption of the appropriate code, or one for which a legal building permit has been issued; (2) when not used in conjunction with an existing building code, building for which a legal certificate of occupancy has been issued; for structure not covered by a certificate of occupancy, a structure that is complete and permitted for use or otherwise legally defined as an existing structure or building

factored load—product of the nominal load and load factor.

faulty construction—deficient construction resulting from errors or omissions in design or improper construction causing displacement of supporting portions of the structure or resulting in deficient materials, incorrect geometry or location of members, improper reinforcement, or connection

COMMENTARY

This definition is adapted from ASCE/SEI 11. In a structural evaluation, the licensed design professional should determine the structural adequacy, serviceability, and durability of an existing structure based upon compiled data and other knowledge. An evaluation may require professional judgment to gauge structural adequacy. Structural analyses and member capacity calculations may be required to determine possible ranges of existing structural capacities and variations in demands. The goal of the evaluation process is to appraise the in-place condition to determine adequacy for current or proposed future use. Structural evaluation requires determining capacity and demand, which may vary widely depending on the acquired information, test results, computational models, and analyses. Determining the demand-to-capacity ratios; and judging structural reliability limits may be open to interpretation based on project requirements, structural experience, knowledge, and past performance.

Evaluation activities may include:

(a) Tests to confirm reinforcement location and orientation, strength of materials or structural capacity of existing members or systems, or the presence of contaminants

(b) Analysis of test results to establish statistical equivalent material properties, limits of faulty construction, and structural capacity

(c) Screening of observations and tests for mechanisms and causes of damage, distress, and deterioration

(d) Establishing the assessment criteria

(e) Calculating demand loadings, serviceability limits, lateral displacements, and durability requirements

(f) Analysis of the structure to determine the capacity of the structure to withstand current or future load demands and comply with serviceability limits

i. Determination of demand-to-capacity ratios to appraise structural adequacy and judge the need for repair and rehabilitation

ii. Determination of maintenance requirements necessary for the service life of the structure

Definition 1 is consistent with the IEBC. Definition 2 is different from the IEBC definition of an existing building.

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detailing that reduce capacity of or have an adverse effect on long-term durability or serviceability.

in-place condition—current condition of an existing structure, system, member, or connection including component sizes and geometry, material properties, faulty construction, deterioration, and damage.

interface reinforcement—(1) existing or supplemental reinforcement that is properly anchored on both sides of an interface; (2) post-installed reinforcement such as adhesive anchors or mechanical anchors, or other mechanical connections that provides a method of force transfer across an interface.

interface shear stress—shear stress resulting from transfer of forces at bonded interfaces between repair material and existing substrate used to achieve composite behavior.

licensed design professional—(1) an engineer or architect who is licensed to practice structural design as defined by the statutory requirements of the professional licensing laws of a state or jurisdiction; (2) the engineer or architect, licensed as described, who is responsible for the structural design of a particular project (also historically engineer of record).

nominal load—magnitude of load specified by the applicable code before application of any load factor.

nonstructural concrete—any element or portion thereof made of plain or reinforced concrete that is not required to transfer gravity load (other than self-weight), lateral load, or both, along a load path of a structural system to the ground.

owner—corporation, association, partnership, individual, or public body or authority with whom the contractor enters into an agreement and for whom the work is provided; the party in legal possession of the structure.

potentially dangerous—(1) structural state of existing concrete within a work area for an individual structural member, structural system, or structure that meets the definition of dangerous or unsafe, is unstable, has potential of collapse of overhead components or pieces (falling hazards), has been determined to have demand-to-capacity ratio exceeding the limit of 4.3.2, or has potentially hazardous resistance for seismic events; (2) a limit state of unacceptably low margin of safety against collapse without supplemental resistance.

rehabilitation—repairing or modifying an existing structure to a desired useful condition.

repair—the reconstruction or renewal of concrete parts of an existing structure for the purpose of its maintenance or to correct deterioration, damage, or faulty construction of members or systems of a structure.

repair reinforcement—reinforcement used to provide additional strength, ductility, confinement, or any combination of the three, to the repaired member.

repair, structural—restoring a damaged or deteriorated structure to its original capacity or increasing the capacity of a structure.

COMMENTARY

Potentially dangerous conditions of an existing concrete member, system, or structure include conditions that may be defined as dangerous or unsafe in the IEBC. These conditions may be overtly dangerous or unsafe depending on the circumstances or load probability between the time of determination and repair.

Concrete rehabilitation includes: repair to restore original capacity; strengthening to increase the capacity to the current building code requirements; seismic retrofits in accordance with ASCE/SEI 41; and modifications addressing additions, alterations, and change of occupancy.

The definition is adapted from the IEBC and is specific for repair of materials, components, or elements of existing concrete structures. Faulty materials, components, or elements of a structure are considered to be faulty construction resulting from errors or omissions in design or construction.

The definition addresses increasing the capacity to include enhancements such as ductility of existing concrete members. Repairs to nonstructural members, whose failure

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repair system—the combination of existing and new components, which may include existing reinforcement, repair materials, supplementary reinforcement, and supplemental structural members.

serviceability—structural performance under service conditions.

shoring—temporary support of excavations, formwork, members during repairs, or potentially dangerous structures; the process of erecting shores.

specialty engineer—a licensed design professional retained to design a delegated portion of the project.

stability, global—stability of the overall existing structure with respect to vertical support, uplift, overturning, lateral instability, or sliding.

stability, local—the stability of an individual member or part of an individual member.

strengthening—increasing the capacity of an existing structure or a portion thereof.

structural analysis—process of using engineering mechanics to determine internal demands on, and capacities of, a structure, member, or system.

structural concrete—plain or reinforced concrete in a member that is part of a structural system required to transfer gravity loads, lateral loads, or both, along a load path to the ground.

substantial structural damage— (1) level of damage as defined in the *existing building code*; (2) if this Code is used as a stand-alone code, substantial structural damage shall be as defined in Chapter 4.

temporary bracing—non-permanent supplemental members added to an existing structure to prevent local or global instability during assessment and repair construction.

undercutting—concrete removal around the reinforcement circumference to allow for existing reinforcement to be encapsulated in repair material.

work area—that portion or portions of a structure consisting of all areas indicated in the construction documents or identified by the owner and licensed design professional for assessment; it excludes portions of the structure where incidental work entailed by the intended work must be performed and portions of the structure where work not initially intended by the owner is required by this Code.

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would cause or result in potentially dangerous structural conditions, are considered structural repairs.

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CHAPTER 3—REFERENCED STANDARDS

American Concrete Institute

ACI 216.1-14—Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

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

ACI 369.1-17—Standard Requirements for Seismic Evaluation and Retrofit of Existing Concrete Buildings

ACI 437.2-13—Code Requirements for Load Testing of Existing Concrete Structures and Commentary

ACI 440.6-08—Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement

ACI 440.8-13—Specification for Carbon and Glass Fiber-Reinforced Polymer (FRP) Materials Made by Wet Layup for External Strengthening of Concrete and Masonry Structures

American Institute of Steel Construction

ANSI/AISC 360-16—Specification for Structural Steel Buildings

American Society of Civil Engineers

ASCE/SEI 7—Minimum Design Loads for Buildings and Other Structures

ASCE/SEI 37—Design Loads on Structures during Construction

ASCE/SEI 41—Seismic Evaluation and Retrofit of Existing Buildings

American Welding Society

AWS D1.4/D1.4M:2011—Structural Welding Code—Reinforcing Steel

ASTM International

ASTM A15—Specification for Billet-Steel Bars for Concrete Reinforcement (withdrawn 1969)

ASTM A16—Specification for Rail-Steel Bars of Concrete Reinforcement (withdrawn 1969)

ASTM A61—Specification for Deformed Rail Steel Bars for Concrete Reinforcement with 60,000 psi Minimum Yield Strength (withdrawn 1969)

ASTM A160—Specification for Axle-Steel Bars for Concrete Reinforcement (withdrawn 1969)

ASTM A185/A185M-18—Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete (withdrawn 2013)

ASTM A370-14—Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM A408—Specification for Special Large Size Deformed Billet-Steel Bars for Concrete Reinforcement (withdrawn 1968)

ASTM A431—Specification for High-Strength Deformed Billet-Steel Bars for Concrete Reinforcement with 75,000 psi Minimum Yield Strength (withdrawn 1968)

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R3—REFERENCED STANDARDS

Both current and withdrawn standards are referenced. Standards that are referenced in the design-basis code are applicable for the assessment of existing structures. These standards may have been withdrawn by the developing organization; however, they provide information on the materials used at the time of original construction. Refer to 4.3.3 and Chapter 6.

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ASTM A432—Specification for Deformed Billet Steel Bars for Concrete Reinforcement with 60,000 psi Minimum Yield Point (withdrawn 1968)

ASTM A497/A497M—Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete (withdrawn 2013)

ASTM A615/A615M-14—Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A616/A616M-96a—Standard Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement (withdrawn 1999)

ASTM A617/A617M-96a—Standard Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement (withdrawn 1999)

ASTM A706/A706M-14—Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A955/A955M-15—Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement

ASTM A1061/A1061M-09—Standard Test Methods for Testing Multi-Wire Steel Strand

ASTM C42/C42M-13—Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C823/C823M-12—Standard Practice for Examination and Sampling of Hardened Concrete in Constructions

ASTM C1580-15—Standard Test Method for Water-Soluble Sulfate in Soil

ASTM C1583/C1583M-13—Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

ASTM D516-16—Standard Test Method for Sulfate Ion in Water

ASTM D4065-12—Standard Practice for Plastics: Dynamic Mechanical Properties: Determination and Report of Procedures

ASTM D4130-15—Standard Test Method for Sulfate Ion in Brackish Water, Seawater, and Brines

ASTM E329-14a—Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection

BSI Group

BS EN 1504-10:2017—Products and systems for the protection and repair of concrete structures. Definition, requirements, quality control and evaluation of conformity. Site application of products and systems and quality control of the works

International Code Council

IBC—International Building Code

IEBC—International Existing Building Code

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CHAPTER 4—CRITERIA AS A STAND-ALONE CODE FOR ASSESSMENT, REPAIR, AND REHABILITATION OF EXISTING STRUCTURES

4.1—General

4.1.1 This Chapter applies for the assessment and for repair and rehabilitation of existing structures and their components if this Code is used as a stand-alone code.

4.1.2 The design-basis code for the project shall be based on requirements set forth in this Chapter.

4.1.3 Assessment results shall be used to classify the work and to establish the design-basis criteria.

4.1.4 Design-basis criteria shall be used to establish the applicable building code for repair and rehabilitation design.

4.2—Criteria for the assessment, repair, and rehabilitation design of existing concrete structures

4.2.1 The design-basis criteria of the project shall be determined based upon the results of the preliminary assessment as described in 1.8 or the detailed assessment as described in Chapter 6, if performed, using the requirements in this Chapter. The design-basis criteria shall be used consistently for all assessment, repair, and rehabilitation design in the work area or areas of the structure.

4.2.1.1 It shall be permitted to use the current building code as the design-basis code for all damage states, deterioration, and faulty construction.

4.2.2 Assessment criteria, design-basis criteria, and the requirements for applying these criteria are provided in 4.3 through 4.9.

4.2.3 The current building code shall be used to detail new members and connections between new concrete members and existing construction. If the original building code is used as the design-basis criteria for repairs, new or supplemental elements built integrally with the existing concrete

COMMENTARY

R4—CRITERIA AS A STAND-ALONE CODE FOR ASSESSMENT, REPAIR, AND REHABILITATION OF EXISTING STRUCTURES

R4.1—General

R4.1.1 The assessment, repair, and rehabilitation design criteria and associated demand-to-capacity ratios used in this Chapter were developed to be consistent with the performance-based procedures presented in 1.3.1.3 of ASCE/SEI 7-16. The licensed design professional for the project should evaluate the applicability of this Chapter to non-building structures (for example, environmental engineering structures such as those addressed in ACI 350 - Code Requirements for Environmental Engineering Concrete Structures and Commentary) as these structures may be designed with procedures that are not compatible with the performance-based procedures of ASCE/SEI 7.

R4.2—Criteria for the assessment, repair, and rehabilitation design of existing concrete structures

R4.2.1 Structures constructed under previously adopted codes or before the adoption of a building code may not satisfy all current building code requirements. This Chapter contains specific requirements that determine if existing structures should be repaired or rehabilitated to satisfy the requirements of the original or the current building code, whichever serves as the design-basis code. Local ordinances may also require that a structure be rehabilitated to satisfy the current code.

R4.2.1.1 Most current building codes, such as those based on the IBC, provide acceptable safety based on consistent statistical probabilities. If the current building code is used, the resulting demand-to-capacity ratios provide limits that should not be exceeded if assessing and designing remedial construction.

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structure shall be designed using either the original building code or the current building code.

4.2.4 Detailing of the existing reinforcement within the work area need not comply with the current building code if the original building code is the design-basis criteria, and both of the following conditions are satisfied:

(a) The damage or deterioration to existing reinforcement is addressed; and

(b) The repaired work area has capacity equal to or greater than demand in accordance with 5.2.2 if using the original building code requirements or satisfies the requirements of 4.5.3 if using allowable stress design.

4.3—Potentially dangerous structural conditions

4.3.1 If there is a reason for the licensed design professional to question the capacity of the structure or if potentially dangerous structural conditions are observed as a part of the preliminary assessment, an assessment shall be performed in the work area.

4.3.2 For gravity, fluid, soil, and wind loads, potentially dangerous structural conditions exist in members or structures if the demand-to-capacity ratio is greater than 1.5, as given in Eq. (4.3.2).

$$U_c/\phi R_{cn} > 1.5 \qquad (4.3.2)$$

In Eq. (4.3.2), U_c is the strength-design demand determined by using the nominal gravity, fluid, soil, and wind loads identified in the current building code and the factored load combinations of ASCE/SEI 7, excluding seismic, flood, and tsunami forces; and ϕR_{cn} is the current in-place nominal capacity adjusted by the strength reduction factor (ϕ) in 5.3 or 5.4.

COMMENTARY

R4.2.4 The licensed design professional should review conditions related to anchorage of the existing reinforcing steel. Cracking near the ends of the existing reinforcing steel should be reviewed to determine if the cracking is indicative of potential reinforcement anchorage failure. Research has shown that development length equations from previous versions of ACI 318 may be unconservative for top reinforcing steel bars (Feldman and Cairns 2017). Changes in ACI 318 have increased the development length of reinforcing steel.

If the basis of design is the current building code, the licensed design professional should consider the following:

(a) Assessing demand-to-capacity ratios for the existing reinforcing steel using current development length provisions.

(b) Confinement details of the reinforcement if assessing seismic resistance.

The licensed design professional should determine if structural behavior indicates adequate performance. ACI 224.1R, ACI 437R, and ACI 437.1R provide guidance in judging acceptable performance.

R4.3—Potentially dangerous structural conditions

R4.3.1 Structural assessments are required if damage, deterioration, structural deficiencies, or behavior are observed during the preliminary assessment that are unexpected or inconsistent with available construction documents. The structural assessment should be performed in accordance with 1.8 or Chapter 6, or both. Results of the assessment should also be reviewed to identify the presence of potentially dangerous structural conditions, which could include any instability, the potential for collapse of overhead components or pieces (falling debris hazards), or an unacceptable risk of collapse under service load conditions.

R4.3.2 Demand-to-capacity ratios are used to quantify the adequacy of the member or structure. The threshold demand-to-capacity ratios determine when different levels of intervention may be required. This Chapter provides how the applicable demands and capacities are determined. Demands may be determined based upon factored loads associated with *current building codes* (U_c as defined in 4.3.2) or factored loads used for the original design (U_o as defined in 4.5.2) of the structure. The calculated capacity of the structure will vary depending upon the condition of the structure and extent of evaluation used to confirm as-built properties of the structure.

In assessing potentially dangerous structural conditions, the strength-design demand of Eq. (4.3.2) combines current building code nominal gravity loads (dead, live, and snow) with lateral loads from fluid, soil, and wind (excluding seismic, flood, and tsunami forces) using factored load combinations of ASCE/SEI 7-16. The demand-to-capacity

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4.3.2.1 If the demand-to-capacity ratio given by Eq. (4.3.2) exceeds 1.5 for a member or members in the work area, the design-basis criteria shall be the current building code.

4.3.2.2 Assessment and repair shall be limited to the members, elements, and connections identified to be *potentially dangerous* and their load paths to the supporting ground.

4.3.2.3 For structures without potentially dangerous structural conditions and if the demand-to-capacity ratio is 1.5 or less, the design-basis criteria shall be determined in accordance with 4.4 through 4.9.

4.3.3 Assessment criteria for seismic resistance, unless addressed by the authority having jurisdiction, are limited to conditions associated with Structural Performance Level, Collapse Prevention of structures in Seismic Design Category D, E, and F of ASCE/SEI 7 using Earthquake Hazard Level, BSE-1E and shall be determined using ASCE/SEI 41 and this Code. The design-basis criteria to address seismic conditions in concrete structures shall be this Code and ASCE/SEI 41.

4.4—Substantial structural damage

4.4.1 If there is a reason for the licensed design professional to question the capacity of the structure based upon the results of the preliminary assessment, an assessment shall be performed in the work area to determine if substantial structural damage is present. Substantial structural damage in the work area shall be assessed using current building

COMMENTARY

ratio for unsafe conditions was developed consistent with the performance-based procedures contained in 1.3.1.3 of ASCE/SEI 7-16. A demand-to-capacity ratio greater than 1.5, calculated using Eq. (4.3.2), represents a condition with limited to no margin of safety against failure for ASCE/SEI 7 loads (Stevens and Kesner 2016a; Stevens et al. 2019).

In the assessment of potentially dangerous structural conditions, the licensed design professional should determine if it may be appropriate to include structural redundancies, alternative load paths, primary and secondary supporting elements, redistribution of loads, collapse mechanisms, reduced live loads, measured displacements (sagging, listing, leaning, and tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth and fluid pressures, self-straining loads, ice, and floods. References for potentially dangerous structural conditions include: commentary to Chapter 1 of ASCE/SEI 7-10, Galambos et al. (1982), Ellingwood et al. (1982), and Ellingwood and Ang (1972). These references provide target reliability indices, basic probability theory, and concepts for an evaluation.

R4.3.3 Compliance with ASCE/SEI 41 for Structural Performance Level, Collapse Prevention using an applicable Earthquake Hazard Level BSE-1E should be reviewed and approved by the authority having jurisdiction for the assessment of potentially hazardous seismic conditions of concrete structures. Assessment of seismic conditions for concrete structures is not required, but may be considered, for structures in regions of low or moderate seismicity. If no requirements for seismic structural conditions are provided by the authority having jurisdiction, the licensed design professional should refer to ATC-78, the IEBC, and ASCE/SEI 41 appendices for guidance.

R4.4—Substantial structural damage

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