An ACI Provisional Standard

Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary

Reported by ACI Committee 562

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CODE REQUIREMENTS FOR ASSESSMENT, REPAIR, AND REHABILITATION OF EXISTING CONCRETE STRUCTURES (ACI 562-16) AND COMMENTARY

An ACI Standard

Reported by ACI Committee 562

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SYNOPSIS

ACI 562-16 – "Code Requirements for Assessment, Repair and Rehabilitation of Existing Concrete Structures" was developed to provide design professionals involved in the assessment of existing concrete structures 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 562-16 was specifically developed to work with the International Existing Building code (IEBC) or to be adopted as a stand-alone code.

Keywords: *assessment; bond; damage; licensed design professional; durability; existing structure; evaluation; FRP; interface bond; maintenance; rehabilitation; reliability; repair; strengthening; unsafe.*

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PREFACE

This code provides minimum requirements for assessment, repair, and rehabilitation of existing structural concrete buildings, members, systems and where applicable, nonbuilding structures. This code can supplement the International Existing Building Code (IEBC 2015), supplement the code governing existing structures of a local jurisdictional authority, or act as a stand-alone code *in a locality that has not adopted an existing-building code. When this code is used as a stand-alone code, Appendix A is used in place of Chapter 4.*

This code provides 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 jurisdictional authority. Where the code has not been adopted, it provides minimum requirements for assessment, and design and construction of 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 prior to issuance of a letter of occupancy or prior to the legally defined declaration of an existing structure and for new construction within existing structures where noted herein.

Key changes from ACI 562-13 to ACI 562-16 include: revisions to definitions used in the code to bring this document into conformance with IEBC 2015 and other standards for existing structures; adding specific criteria requirements for assessment and design of repair and rehabilitation for varying levels of damage, deterioration, or faulty construction in Chapter 4 when using this code with IEBC and in Appendix A when using this code-as a stand-alone code; and re-organization and revision of Chapter 1 to address the amendments of Chapters 2 and 4. Technical changes are summarized at the end of this document.

CHAPTER 1—GENERAL REQUIREMENTS

1.1—General

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

1.1.2 Scope—This code shall apply to assessment, repair, and rehabilitation of existing concrete structures as a code supplementing the International Existing Building Code (IEBC), as part of a locally adopted code governing existing buildings or structures, or as a stand-alone code for existing concrete structures.

1.1.2C Scope*—This code defines assessment, design, construction and durability requirements for repair and rehabilitation of existing concrete structures. Throughout this code, the term "structure" means an existing building, member, system, and, where applicable, nonbuilding structures where the construction is concrete or mixed construction with concrete and other materials.*

Chapter 4 provides assessment, repair, and rehabilitation criteria if this code is used as a supplement to the IEBC for concrete members and systems.

Appendix A provides assessment, repair, and rehabilitation criteria when this code is used as a stand-alone code in a jurisdiction without a code governing existing structures.

1.1.3 The intent of this code is to safeguard the public by providing minimum structural requirements for existing structural concrete members, systems, and buildings.

1.1.3C *The intent of this code is to address the safety of existing structures through assessment requirements that demonstrate an approximation of the structural reliability using demand-capacity ratio limits of Chapter 4 or Appendix A and, if necessary as determined by the assessment, increase the structural capacity by repair or rehabilitation.*

Unless prohibited by the jurisdictional authority, if an existing structure is shown to be unsafe in accordance with 4.3 or A.3, the structure should be rehabilitated using 4.3 or A.3.

Using the demand-capacity ratio limits of 4.5.1 or A.5.1, repair of the existing structural concrete to its pre-deteriorated state is permitted based on material properties specified in the original construction (per Chapter 6), and substantiated engineering principles of the original design. Where requirements of the original building code are appreciably changed in the current building code, the licensed design professional may consider using 4.5.2 or A.5.2.

Beyond the restoration assessment requirements of 4.5.1 and 4.5.3 or A.5.1 and A.5.3, the structural reliability principles of 4.5.2 *or A.5.2 are permitted. These alternative requirements provide acceptable safety if the current building code demand exceeds the original building code demand or if the regulations of the original building code provide an unacceptable level of structural reliability.*

1.1.4 All references in this code to the licensed design professional shall be understood to mean persons who possess the knowledge, judgment and skills to interpret and properly use this code and are licensed in the jurisdiction where this code is being used. The licensed design professional is responsible for and in charge of the assessment or rehabilitation design, or both.

1.1.4C *The licensed design professional should exercise sound engineering knowledge, experience, and judgment when interpreting and applying this code.*

1.1.5 The requirements of this code are provided using strength design provisions for demands and capacities, unless otherwise noted.

1.1.5C *When this code permits the original building code regulations to be used and that code uses allowable stress design: those provisions should be substituted for strength design as noted in 4.5.3 or A.5.3; the licensed design professional is not required to use, but should consider using strength design provisions of this code as a check in the assessment of existing structures originally designed with allowable stress methods; and the licensed design professional may judge when the original building code is to be replaced by the current building code to provide structurally adequate resistance and reliability.*

1.2—Criteria for the Assessment and Design of Repair and Rehabilitation of Existing Concrete Structures

1.2.1 The "existing-building code" refers to the code adopted by a jurisdiction that regulates existing buildings or structures.

1.2.1C *The code governing existing buildings in the United States is commonly the IEBC developed by the International Code Council (ICC). The IEBC provides regulations for evaluations of damage and the limit for damage to be repaired using the original building code. If this limit is exceeded or if the licensed design professional judges the structural safety to be unacceptable based on rational engineering principles, rehabilitation is necessary in accordance with the requirements of the current building code.*

1.2.2 The "current building code" refers to the general building code adopted by a jurisdiction that presently regulates new building design and construction.

1.2.2C *The current building code establishes the design and construction regulations for new construction. Strength design regulations of the current building code include:*

a) required strengths computed 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

d) strength reduction factors, which have been established to be consistent with reliability indices used with the strength design demands

The current building code provides acceptable safety based on consistent statistical probabilities for new construction. The resulting demand-capacity ratios of the current building code provide the limits that need not be exceeded if designing new construction or assessing and designing repairs and rehabilitation of existing structures.

The general building code in the United States is usually based on the International Building Code (IBC) published by the ICC. Prior to 2015, Chapter 34 of the IBC included provisions for existing buildings. 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.

1.2.3 The "original building code" refers to the general building code applied by the jurisdictional authority to the structure in question at the time the existing structure was permitted for construction.

1.2.3C *This definition of "original building code" is consistent with the building code in effect at the time of original permitted construction per the IEBC. In assessing existing structures, the licensed design professional may need to consider changes in the codes enforced by the local jurisdictional authority for the structure from the time of the original design through the time of the completion of construction.*

Reference to design requirements of the original building code should include: demands determined using either nominal loads, load factors, and load combinations of the original building code or using allowable design loads and load combinations of the original building code; capacities determined using either strength design and reinforcement detailing provisions, and strength-reduction factors of the original building code or using allowable stress design provisions of the original building code; and construction materials. Requirements for concrete design and construction include previous versions of ACI 318, concrete codes predating ACI 318, or concrete provisions within the original building code. A structural assessment using allowable stress design provisions of the original building code should be coupled with an evaluation using current standards to increase the understanding of *structural behavior and to judge if more consistent and safe remedial recommendations are necessary using the current building code.*

1.2.4 *Design-Basis Code Criteria*

1.2.4.1 The types of design-basis code criteria used in this code are assessment criteria and design-basis criteria. The design-basis code criteria of this code shall be used to assess and design rehabilitations of existing members, systems, and structures.

1.2.4.1C *If a jurisdiction has adopted the IEBC, then the design-basis code criteria are based on the IEBC with supplemental requirements of this code for unsafe structural conditions, damage less than substantial structural damage, deterioration of concrete and reinforcement, faulty construction, serviceability issues, and durability for existing concrete. For substantial structural damage, additions, alterations, and changes in occupancy, the IEBC establishes limits to which an assessment and design of repair and rehabilitation can occur in accordance with the original building code. Above these limits, an assessment and design of the repair and rehabilitation is in accordance with the current building code. Current and original building code provisions are supplemented by this code to address existing concrete members, systems, and buildings.*

1.2.4.2 Assessment and design-basis criteria and the requirements for applying these criteria are provided in Chapter 4 and Appendix A. Chapter 4 applies if a jurisdiction has adopted the International Existing Building Code (IEBC) as the existing building code. Appendix A applies if a jurisdiction has not adopted the IEBC or if a jurisdiction has adopted this code.

1.2.4.2C *Classifying the rehabilitation category using criteria and requirements of Chapter 4 or Appendix A defines the design-basis criteria, which is used to design the repair or rehabilitation work.*

1.2.4.3 Assessment criteria shall be used to classify the rehabilitation work and to establish the design-basis criteria.

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

1.2.4.5 ACI 318-14 shall be the design basis code for new members and for connection of new members to existing structures.

1.3—Applicability of this code

1.3.1 This code is applicable when performing an assessment, repair or rehabilitation design and remedial construction of existing concrete structures including buildings and nonbuilding structures where the existing structure's construction is concrete or a mix of concrete and other materials.

1.3.1C *Existing concrete structures may require an assessment, repair or rehabilitation* *design for considerations beyond the minimum requirements of this code.*

Nonbuilding concrete structures can include, but are not limited to arches, tanks, reservoirs, bins and silos, blast- and impact-resistant structures, and chimneys.

1.3.2 Considerations beyond the minimum requirements of this code, such as those for progressive collapse resistance, redundancy, or integrity provisions are permitted. The licensed design professional is permitted to require assessment, design, construction, and quality assurance activities that exceed the minimum requirements of this code. Regulations of the current building code need not be exceeded when assessing, designing repair and rehabilitation work or installing remedial work of existing structures.

1.3.3 *Foundations*

1.3.3.1 This code shall apply to the assessment and repair or rehabilitation of existing structural concrete foundation members.

1.3.3.1C *Foundation members and systems should include those constructed using plain or reinforced concrete including but not limited to spread footings, mat foundations, concrete piles, drilled piers, grade beams, pile and pier caps, and caissons embedded in the ground. The design and installation of new pilings fully embedded in the ground are regulated by the current building code. For repair of existing foundation members and systems, the provisions of this code apply if not in conflict with the code governing existing building. For the portions of concrete piling in air or water, or in soil not capable of providing adequate lateral restraint throughout the piling to prevent buckling, the provisions of this code govern.*

1.3.4 *Soil-supported slabs*

1.3.4.1 This code shall apply to the assessment and repair or rehabilitation of soil-supported structural slabs that transmit vertical loads or lateral forces from the structure to the soil.

1.3.5 *Composite members*

1.3.5.1 This code shall apply to the assessment and repair or rehabilitation of the concrete portions of composite members.

1.3.6 *Precast and prestressed concrete*

1.3.6.1 This code shall apply to the assessment and repair or rehabilitation of structural precast and prestressed concrete members, systems, and connections, and cladding transmitting lateral loads to diaphragms or bracing members.

1.3.7 *Nonstructural concrete*

1.3.7.1 This code is not intended for repair of nonstructural concrete or for aesthetic improvements, except if failure of such repairs would result in an unsafe condition.

1.3.7.1C *Where nonstructural concrete requires repair, that repair is not required to comply with or satisfy the requirements of this code. The licensed design professional designing repairs to nonstructural concrete should consider the consequence of repair failure to determine if* *there are provisions of this code that are applicable.*

1.3.8 *Seismic resistance*

1.3.8.1 Evaluation of seismic resistance and rehabilitation design shall be in accordance with the code governing existing buildings if one has been adopted or this code if a code governing existing buildings has not been adopted. If using this code for evaluation of seismic resistance and rehabilitation design, ASCE/SEI 41 shall apply.

1.3.8.1C *Provisions of ASCE/SEI 41 are supplemented by ACI 369R, which provides guidance on seismic repair and rehabilitation measures.*

1.3.8.2 If rehabilitation for seismic resistance is not required by the code governing existing buildings or this code, voluntary retrofit for seismic resistance shall be permitted. IEBC Section 403.9 shall apply if the IEBC is used with this code for voluntary retrofit of seismic resistance. When this code is used without a code governing existing buildings, the licensed design professional shall use the current building code supplemented by ASCE/SEI 41 and ASCE/SEI 7 to design seismic retrofits. New seismic retrofits shall not create structural irregularities.

1.3.8.2C *Conditions for evaluation of seismic resistance and design of retrofits are provided in ACI 369R, Chapter 3 and Appendix A2 of IEBC and ASCE/SEI 41. Critical conditions requiring engineering review are: irregular building configurations; non-ductile or strong-beam-weak-column frames; and anchorage of walls to flexible diaphragms. Significant improvements to the seismic resistance of a building can be made using repair techniques that provide less than those detailing and reinforcement methods required for new construction. As an example, providing additional reinforcement to confine concrete in flexural hinging regions will increase the energy dissipation and seismic performance even though the amount of confinement reinforcement may not satisfy the confinement requirements for new structures (Kahn 1980; Priestley et al. 1996; Harris and Stevens 1991). Visual Screening for Potential Seismic Hazards (FEMA P-154, 3rd Edition), Mitigation of Nonductile Concrete Buildings (ATC-78 Project), Seismic Performance Assessment of Buildings (ATC-58), and Quantification of Building Seismic Performance Factors (FEMA P-695 Report) Identification and Mitigation of Nonductile Concrete Buildings (ATC 78-1) address seismic assessment and resistance in existing concrete structures.*

Components of the seismic-force-resisting system that require strength and ductility should be identified. Force-controlled (nonductile) action is acceptable for some classifications of components of the seismic-force-resisting system (ASCE/SEI 41). The strength requirement of this code, Section 7.1 is applicable to these force-controlled components. ASCE/SEI 41 and ACI 369R provide information on rehabilitation for *seismic resistance. Seismic-resisting components requiring energy-dissipating capability should maintain the ability to dissipate energy after repair. Design and detailing requirements for seismic resistance of cast-in-place or precast concrete structures are addressed in ACI 318 and 369R.*

1.4—Administration

1.4.1 This code shall govern in matters pertaining to the assessment and repair or rehabilitation of existing concrete structures and, where applicable, nonbuilding structures where the construction is concrete or mixed construction with concrete and other materials, except wherever this code is in conflict with the regulations of the jurisdiction authority or code governing existing buildings. Wherever this code is in conflict with requirements in other referenced standards, this code shall govern.

1.4.2 *Approval of special systems of design or construction*—Sponsors of any repair or rehabilitation design or remedial construction system, which does not conform to this code but which has been shown to be adequate by successful use, analysis, or testing, shall have the right to present the data on which their design or construction is based to the jurisdictional authority or to a board of examiners appointed by the jurisdictional authority for review and approval. This board shall have authority to investigate the submitted data, require additional data, and formulate rules governing design-basis code criteria, design and construction of such systems to comply with the intent of this code. These rules shall be of the same force and effect as the provisions of this code if approved and disseminated by the jurisdictional authority.

1.4.2C *New methods of design, new materials, and new uses of materials for repair and rehabilitation usually undergo a period of development before being specifically covered in a code. Hence, good systems or components might be excluded from use by implication if means are not available to obtain acceptance. For systems considered under this section, specific tests, load factors, strength-reduction factors, deflection limits, and other pertinent requirements should be set by the local jurisdictional authority and should be consistent with the intent of this code. Provisions of this section do not apply to model analysis used to supplement calculations or to strength evaluation of existing structures.*

1.5—Responsibilities of the Licensed Design Professional

1.5.1 The licensed design professional for the project is responsible for 1) assessing; 2) designing, detailing, and specifying the work proposed and material requirements; 3) establishing requirements to maintain load paths for the work proposed; and 4) preparing construction documents of the work proposed and specifying a quality assurance program. Construction documents shall provide sufficient detail and clarity to indicate the location, nature and extent of the work proposed and show in detail that they will conform to the requirements of this code and the requirements of the local jurisdictional authority.

1.5.1C *During the assessment part of the investigation, the licensed design professional should request that the owner provide all available information regarding the condition of the building, plans, previous engineering reports, disclose the presence of any known hazardous materials in the work area, and any other pertinent information to the parties involved in the work. This information may require that remedial measures be taken before or during the construction process and should be considered in the scope of work.*

1.5.2 *Unsafe structural conditions*—The licensed design professional for the project shall report observations of exposed structural defects in the existing construction within the work area representing obvious unsafe structural conditions requiring immediate attention to the appropriate authorities.

1.5.2C *During repair construction, unsafe structural conditions may be uncovered and made evident. Unsafe structural conditions of uncovered circumstances of the existing construction may be observed in the work area. To protect the public safety, an observed unsafe structural condition should be reported to the contractor, owner or jurisdictional authority to mitigate the condition. Remedies may include temporary shoring or construction as part of the remedial work.*

1.5.3 *Basis of design report*

1.5.3.1 The licensed design professional for the project shall prepare a basis of design report.

The basis of design report shall include:

a) a description of the building, including age of construction, structural systems, identified original building code, and past and current uses
b) documentation of unsafe 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 demand of the original building code
e) modifications such as additions, alterations, or changes in occupancy
f) conditions and details of the proposed rehabilitation work
g) past history of concrete repairs and rehabilitations
h) assessment criteria and findings
i) design-basis code criteria and basis of rehabilitation design
j) material selection parameters

k) shoring needs

l) quality assurance and quality control (QA/QC) requirements

m) types and frequency of future inspection

n) types and frequency of future maintenance

1.5.3.1C *The basis of design report provides a summary of the assessment of the existing structure, and a summary of or reference to the construction documents used for rehabilitations. Information on some structures may be unavailable or unnecessary if strengthening is not required and should be so noted in the basis of design report. The licensed design professional should check with the jurisdictional authority to determine filing requirements of the basis of design report.*

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 or rehabilitation design that includes inspections and period of time between inspections, after completion of the repair installation. 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 1980; ACI 365.1R). Recommendations should be provided to the owner on inspection and maintenance to be undertaken during the remaining design service life of the repair material or the repaired part of the structure.

A maintenance protocol should be provided in the basis of design report, or in as-built or close-out documents. Maintenance of the repair can be incorporated in the instruction manuals from the licensed design professional, contractor, or product manufacturers. Documents and records of observations, inspections and tests should be provided to the owner as necessary for future work.

1.6—Construction documents

1.6.1 The construction documents for rehabilitation work proposed shall provide sufficient detail and clarity to 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 local jurisdictional authority. Specifications shall require that materials used for repair and rehabilitation construction satisfy this code and governing regulatory requirements at the time the work is implemented.

1.6.1C *As necessary, the construction documents should indicate:*

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

(b) Design-basis code criteria used for conditions addressed by the documents

(c) Design assumptions and construction requirements including specified

properties of existing and remedial materials used for the project and the strength requirements at stated ages or stages of the construction

(d) Details, locations and notes indicating the size, configuration, reinforcement, anchors, repair materials, preparation requirements, and other pertinent information to implement the repairs, strengthening, or rehabilitation of the structure

(e) Magnitude and location of prestressing forces

(f) Anchor details for prestressing reinforcement

(g) Development length of reinforcement and length of lap splices

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

(i) Shoring or bracing criteria necessary before, during, and at completion of the assessment, repair, or rehabilitation projects

(j) Quality assurance program including specific inspections and testing requirements

1.6.2 Calculations pertinent to design shall be filed with the construction documents if required by the jurisdictional authority. Model analysis shall be permitted to supplement calculations.

1.6.2C *Analyses and designs should include calculations, evaluation and design assumptions. If computer-based analyses and designs, such as finite element are used, they should include input, and computer-generated output.*

1.6.3 The licensed design professional shall provide the owner with copies of basis of design report, assessment reports, project documents, field reports, and other project documents produced by the licensed design professional in addition to documenting the location of the completed repairs to the extent of the licensed design professional's contractual obligations. The licensed design professional shall notify the owner if this information is filed with the jurisdictional authority.

1.6.3C *Documentation of the project and repairs that have been carried out, including structural observations, inspection reports by others, test results, and recommendations on inspection and maintenance to be undertaken during the remaining design service life of the repaired part of the concrete structure, should be provided to the owner. The extent and type of quality assurance records should include those required in the construction documents. It is good practice for the owner to keep documentation of repairs, inspections, testing, monitoring, and investigations for future reference.*

1.7—Preliminary evaluation

1.7.1 Preliminary evaluation of an existing structure shall include investigation and review of the structure, plans, construction data, reports, local jurisdictional codes, and other available documents of the existing structure. Existing in-place conditions shall be visually or otherwise investigated to verify existing geometry and structural conditions.

1.7.1C *The goal of the preliminary evaluation 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 evaluation 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 evaluation results should be updated as additional data regarding the examined structure become available.*

The licensed design professional may determine that 4.6 or A.6 applies in a preliminary assessment based on engineering judgment and without analysis if all of the following are confirmed:

- *a) historical performance of the structure and visual observation of the structural condition of members and systems indicate acceptable behavior precluding evaluation by 4.3 or A.3*
- *b) review of plans and observation of current structural conditions indicate damage or deterioration of the structure below the level requiring evaluation by 4.4 and 4.5 or A.4 and A.5*
- *c) modifications for additions, alterations, and changes in occupancy are not planned.*

Repairs are permitted that address durability and serviceability of 4.6 or A.6 without analyzing members and systems and checking the demand-capacity ratio limits of 4.3 through 4.5 or A.3 through A.5 if the structure is determined to be structurally acceptable. 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 with verifying the demand to capacity limits of 4.4 and 4.5 or A.4 and A.5.

1.7.2 The preliminary evaluation shall determine if unsafe structural conditions are present, substantial structural damage has occurred, damage less than substantial structural damage has occurred, faulty construction is present, or deterioration is present and shall report these conditions in accordance with 1.5.2 and 1.5.3.

1.7.2C *Unsafe structural conditions may require the owner install shoring, limit access, or take other measures to mitigate these conditions. Substantial structural damage refers to damage in a structure that has resulted in a significant decrease in either the gravity or lateral load resistance of a structure. The IEBC provides a definition for substantial structural damage when this code is used to supplement the IEBC. If this code stands-alone, A.4 defines substantial structural damage. The preliminary evaluation is generally the first portion of the work necessary to determine the rehabilitation category. Chapter 6 provides details for a complete assessment.*

1.7.3 For the purpose of performing a preliminary evaluation, it is permitted to assume the criteria of the original or current building code or assessment criteria of Chapter 4 or Appendix A.

1.7.3C *The assumed preliminary evaluation criteria should be substantiated or modified in accordance with the assessment details of Chapter 6.*

1.7.4 The in-place strength of the existing structure shall be determined considering in-place geometric dimensions and material properties including effects of material deterioration and other deficiencies. If material properties are not immediately available, a preliminary evaluation shall be completed using material properties as described in Chapter 6.

1.7.4C *Strength calculations should be based on in-place conditions and should include an assessment of the loss of strength due to deterioration mechanisms. 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 20-89, ATC 45-04, and ATC-78 as well as The Concrete Society Technical Report 68 (2008). When material test results are initially unavailable, historical properties based on typical values used at the time of construction can be used in 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 deterioration mechanisms that result in a change in 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. Examples of deterioration mechanisms that result in possible changes in material properties *include corrosion of steel reinforcement, thermal damage, concrete reactions such as alkali-aggregate, and freezing and thawing.*

Deficiencies to be documented include cracking, spalls, member deflection, cross-section dimensions different than specified on the original construction drawings, and construction tolerances exceeding those permitted under the original building code.

CHAPTER 2—NOTATION AND DEFINITIONS

This chapter defines notation and terminology used in this code.

2.1—Notation

c = depth of neutral axis, in.

D = dead load acting on the structure

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

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

f_c' = specified concrete compressive strength, psi

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

f_y = specified yield strength of steel reinforcement, psi

$\overline{f}_y$ = average yield strength value for steel reinforcement, psi

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

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

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

L = live load acting on the structure

n = number of sample tests

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

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 (i.e., low-probability) event computed using the probable material properties

S = snow load acting on the structure

T_g = glass transition temperature, °F

U = demand using nominal loads and factored load combinations for strength design provisions (LRFD)

U_c = demand using nominal loads of the current building code and factored load combinations of ASCE/SEI 7 for strength design provisions (LRFD)

U_o = demand using nominal loads and factored load combinations of the original building code for strength design provisions (LRFD)

U_o^* = demand using nominal loads of the original building code and factored load combinations of ASCE/SEI 7 for strength design provisions (LRFD)

U_s = demand using service loads of the original building code and 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

V_u = interface 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

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," http://terminology.concrete.org. Definitions provided here complement that resource.

2.2C *Additional repair-related definitions are provided by "ICRI Concrete Repair Terminology," http://www.icri.org/GENERAL/repairterminology.aspx.*

assessment—refer to structural assessment

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

bond—1. adhesion of applied materials to reinforcement or other surfaces against which they are placed, including friction due to shrinkage and longitudinal shear in the concrete and repair materials engaged by the bar deformations. 2. adhesion or cohesion between layers of a repair area or between a repair material and a substrate produced by adhesive or cohesive properties of the repair material or other supplemental materials throughout the service life of the repair.

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

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

Commentary: *this definition has been expanded from ACI Concrete Terminology for this code.*

compatible—the ability of two or more materials to be placed in contact or in sufficiently close proximity to interact with no significant detrimental results.

composite construction—a type of construction using members produced by combining different materials (for example, concrete and structural steel); members produced by combining cast-in-place and precast concrete, or cast-in-place concrete elements constructed in separate placements but so interconnected that the combined components act together as a single member and respond to loads as a unit.

connector steel—steel elements, such as reinforcing bars, shapes, or plates, embedded in concrete or connected to embedded elements to facilitate concrete member connectivity. The purpose of connector steel is to transfer load, restrain movement, and provide stability.

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

Commentary—an example of a contact critical application is the addition of a confinement jacket around a column.

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—changes in the capacity of an existing structure resulting from events, such as loads and displacements.

Commentary: deterioration from aging and faulty construction should not be considered as damage.

dangerous—any concrete building, structure, or portion thereof that meets any of the conditions described below shall be deemed dangerous:

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 nominal loads.
3. Unsafe structural condition has been determined in the building or structure.

Commentary: this definition has been modified from the IEBC. Potentially dangerous conditions of an existing member or system include the following: unsafe structural conditions, instability, falling hazards, or noncompliance with fire resistance ratings.

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

demand-capacity ratio—ratio of nominal demand to capacity.

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 (of a building, component, or material)—the period of time after installation or repair during which the performance satisfies the specified requirements if routinely maintained but without being subjected to an overload or extreme event**.**

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

effective area of concrete—cross-sectional area of a concrete member that resists axial, shear, or flexural stresses.

effective area of reinforcement—cross-sectional area of reinforcement assumed to resist axial, shear, or flexural stresses.

equivalent cover—a system to supplement insufficient concrete cover to improve durability or fire protection to that equivalent to the minimum cover specified in the design basis code.

Evaluation—refer to structural evaluation

existing structure—structure for which a legal certificate of occupancy has been issued. For structures that are not covered by a certificate of occupancy, existing structures are those that are 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, geometry, size or location of concrete members, reinforcement or connections.

glass transition temperature—midpoint in transition over which a polymer resin changes from a glassy state to a viscoelastic state as measured pursuant to ASTM D4065. T_g – 27°F is the glass transition temperature minus 27°F.

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

Interface reinforcement—existing or supplemental reinforcement that is properly anchored on both sides of an interface; post-installed reinforcement such as adhesive anchors or mechanical anchors, or other mechanical connections providing 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.

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

Commentary: An example of a jurisdictional authority is the local building official.

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).

Commentary: this definition is adopted from ACI Concrete Terminology.

nominal load—magnitude of load specified by the design-basis code before application of any factor.

nonstructural concrete—any element made of plain or reinforced concrete that is not required to transfer gravity load, 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 owner is the party in legal possession of the structure.

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

Commentary: this definition is adapted from ACI Concrete Terminology – "the process of repairing or modifying a structure to a desired useful condition." The definition is specific for concrete rehabilitation and is inclusive of the IEBC definition – "Any work, as described by the categories of work defined herein, undertaken in an existing building." Herein, concrete rehabilitations include: repair to restore original capacity; strengthening to increase the capacity to the current building code requirements; seismic retrofits per ASCE/SEI 41; and modifications addressing additions, alterations, and change of occupancy.

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.

Commentary: the definition of repair from ACI Concrete Terminology is "to replace or correct deteriorated, damaged, or faulty materials, components, or elements of a structure." The *definition of repair from IEBC is "The reconstruction or renewal of any part of any part of an existing building for the purpose of its maintenance or to correct damage." The definition herein is adapted from the IEBC and is specific for repair of materials, components, or elements of existing concrete structures where structural repair or durability is addressed. Faulty materials, components, or elements of a structure are interpreted to be faulty construction resulting from errors or omissions in design or construction.*

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 or increasing the capacity of a structure.

Commentary: this definition is adapted from ACI Concrete Terminology – "increasing the load-carrying capacity of a structural component beyond its current capacity or restoring a damaged structural component to its original design capacity." Herein, the definition addresses increasing the capacity to include enhancements such as ductility of existing concrete members. Repairs to nonstructural members, whose failure would cause or result in unsafe structural conditions are considered structural repairs.

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

retrofit—modification of an existing member, system, or structure to increase its strength, ductility, or both as a means of improving the seismic performance of the structure.

Commentary: typically used to refer to seismic modifications to increase resistance in an existing structure per ASCE/SEI 41. The definition is adapted from ASCE/SEI 41 – "Improving the seismic performance of structural or nonstructural components of a building."

serviceability—structural performance under service loads.

shoring—props or posts of timber or other material in compression used for the temporary support of excavations, formwork, or unsafe structures; the process of erecting shores.

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

Commentary: The term specialty engineer is used in Chapter 9. In this code, the specialty engineer will typically be a licensed design professional that is retained by the contractor to design specific types of components such as precast or shoring members.

stability, global—stability of the overall existing structure with respect to uplift, overturning, sway instability, or sliding failure.

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

strengthening—process of increasing the load-resistance 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.

structural 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: This definition with specific details for existing concrete is adapted from ASCE/SEI 11 – "Systematic collection and analysis of data, evaluation, and recommendations regarding the portions of an existing structure which would be affected by its proposed use." Herein, 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 plans, construction records, original, current, and code governing existing buildings, and historical events

b) evaluation of an existing structure, member or system of the work area (see commentary for structural evaluation)

c) detail findings and conclusions of the investigation and evaluation include:
   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 or mechanism of damage, distress and deterioration
   iii. identify faulty construction limitations
   iv. appraise test results to determine cause of failure and predict future performance.

d) determine repair and rehabilitation concepts, strategies, alternates 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 include:*
   i. *work area limits and limitations of information collected and evaluated*
   ii. *assessment criteria and work of the evaluation such as calculations, tests and analyses*
   iii. *details of findings (conclusions) and recommendations*
   iv. *safety issue requirements (recommendation for any temporary shoring etc.)*

A structural assessment is the processes of acquiring knowledge of the existing structure used for the purpose of judging the 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.

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

Commentary: This definition is adapted from ASCE/SEI 11 – "The process of determining the structural adequacy of the structure or component for its intended use and/or performance. Evaluation by its nature implies the use of personal and subjective judgment by those functioning in the capacity of experts." An evaluation should determine, to the best of the license design professional's knowledge, the level of quality (structural adequacy, serviceability, or durability) of an existing structure based upon a measured criteria and the judgment of the licensed design professional. An evaluation may require professional judgment to gage structural adequacy. Structural analyses may be required to determine possible ranges of existing structure 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 appraisal requires determining capacity and demand, which may vary widely depending on the acquired information, tests, models, and analyses; determining the demand-capacity ratios; and judging structural reliability limits, which 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, strength of material properties or structural capacity of existing members or systems or for presence of contaminants.*

b) *Analysis of test results to establish reinforcement, 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-capacity ratios to appraise structural adequacy, ascertain classifications, and judge the need for repair and rehabilitation*
   ii. *determination of maintenance requirements necessary for the service life of the structure*

substantial structural damage—Except when using Appendix A, substantial structural damage per the IEBC shall be - A condition where one or both of the following apply:

1. In any story, the vertical elements of the lateral force resisting system have suffered damage such that the lateral load-carrying capacity of the structure in any horizontal direction has been reduced by more than 33 percent from its predamage condition.

2. The capacity of any vertical gravity load-carrying component, or any group of such components, that supports more than 30 percent of the total area of the structure's floor(s) and roof(s) has been reduced more than 20 percent from its predamage condition and the remaining capacity of such affected elements, with respect to all dead and live loads, is less than 75 percent of that required by this code for new buildings of similar structure, purpose and location.

When using this code as a stand-alone code, substantial structural damage shall be as defined in A.4.

Commentary: the definition of substantial structural damage is from IEBC and has been modified as noted in A.4 when using this code as a stand-alone code.

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

undercutting—concrete removal above or below reinforcement to allow for existing reinforcement to be encapsulated in repair material.

unsafe structural condition—structural state of an individual structural member, structural system, or structure with instability, potential collapse of overhead components or pieces (falling hazards), noncompliance with fire resistance ratings or demand to capacity ratio limits above acceptable limits defined in this code.

Commentary: this definition is adapted from the IEBC and modified for strength design to be consistent with concrete requirements.

CHAPTER 3—REFERENCED STANDARDS

***C** Both current, past 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.*

American Concrete Institute

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

ACI 318-14 Building Code Requirements for Structural Concrete and Commentary

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 360-10 Specification for Structural Steel Buildings

American Welding Society

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 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)

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, Deforme4d, for Concrete (Withdrawn)

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 A1064/A1064M-14 Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

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

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

American Society of Civil Engineers

ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures

ASCE/SEI 37-14 Design Loads on Structures during Construction

ASCE/SEI 41-13 Seismic Evaluation and Retrofit of Existing Buildings

International Code *Council*

IEBC 2015 International Existing Building Code

CHAPTER 4—CRITERIA WHEN USING THIS CODE WITH THE INTERNATIONAL EXISTING BUILDING CODE (IEBC)

4.1—General

4.1.1 This chapter applies if a jurisdiction has adopted the International Existing Building Code as the existing building code. When this chapter is used, Appendix A does not apply.

4.1.1C *Appendix A is used when this code is used for existing concrete structures as a stand-alone code without the IEBC.*

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

4.1.2C *Structures constructed under previously adopted codes or before the adoption of a building code may not satisfy all current building code requirements. This code and the IEBC contain specific requirements that determine if existing structures should be rehabilitated or retrofitted to satisfy the requirements of the current building code. Local ordinances may also require that a structure be rehabilitated to satisfy the current codes. These requirements should be reviewed at the start of a project.*

An evaluation and remediation of unsafe seismic resistance is excluded from IEBC. The licensed design professional should determine if seismic evaluation and retrofits are necessary using ASCE/SEI 41. Provisions of ASCE/SEI 41 may or may not be applicable to nonbuildings. Section 4.3.2 provides minimum assessment criteria for seismic safety provisions.

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

4.1.4 Alternately, this code in conjunction with the IEBC shall be used to determine the rehabilitation category of work as shown in Table 4.1.4.

4.1.4C *Unless the local jurisdiction provides more restrictive requirements, this Chapter with the IEBC should be used to determine the assessment and design-basis criteria based on the rehabilitation category of Table 4.1.4.*

Table 4.1.4—Design-Basis Code Criteria References for Rehabilitation Categories

Rehabilitation Category	Design-Basis Code Criteria Reference
Unsafe structural conditions for gravity and wind loads	4.3.2
Unsafe structural conditions for seismic forces in regions of high seismicity	4.3.3
Substantial structural damage, definition	IEBC Chapter 2
Substantial structural damage to vertical elements of the lateral-force-resisting system	IEBC Section 404.2 or 606.2.2
Substantial structural damage to vertical elements of the gravity-load-resisting system	IEBC Section 404.3 or 606.2.3
Damage less than substantial structural damage with strengthening	4.5
Damage less than substantial structural damage without strengthening	4.6
Deterioration and faulty construction with strengthening	4.5
Deterioration and faulty construction without strengthening	4.6
Additions	IEBC Section 402 or 1103
Alterations	IEBC Section 403; Sections 503 and 707; Sections 504 and 807; or Sections 505 and 907
Changes in Occupancy	IEBC Section 407 or 1007

4.1.5 This code shall be used to design repairs of existing structures. ACI 318-14 shall be used to design new members and connections between new members and existing construction.

4.1.6 The detailing of the existing reinforcement need not comply with ACI 318-14 if the following conditions are satisfied:

a) The structure is in seismic design categories A, B, or C and deterioration is addressed;
b) The repaired structure shall have capacity equal to or greater than demand per 5.2.2 using the original building code;
c) No unsafe structural conditions were determined to be present;
d) The structure has demonstrated historical structural reliability.

4.1.6C *The licensed design professional should determine if structural distress as identified by observations, testing or measurements is proportional to that predicted based on historical data of the loads the structure has experienced and if this demonstrates statically acceptable past performance. Where the structural performance indicates adequate behavior based on historical data, such as acceptable resistance of previous loads which equal or exceed the loads that would be predicted for the remaining life of the structure, the licensed design professional may judge the structure to have demonstrated historical structural reliability. ACI 224.1R-07, ACI 437R-03 and ACI 437.1R-07 provide guidance in judging acceptable performance.*

4.2—Compliance Method

4.2.1 The assessment and repair and rehabilitation design shall be performed in accordance with the prescriptive method, the work area method, or the performance method of the IEBC. The compliance method selected and the design basis code shall be used consistently for all assessment and rehabilitation design, excluding other options.

4.3—Unsafe structural conditions

4.3.1 A structural assessment shall be performed to determine if unsafe structural conditions are present.

4.3.2 For gravity and wind loads, unsafe structural conditions include instability, potential collapse of overhead components or pieces (falling hazards), or structures where the demand-capacity ratio is more than 1.5, as shown in Eq. (4.3.2).\

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

In Eq. (4.3.2), the strength design demand (U_c) shall be determined for current building code nominal dead, live, snow and wind loads, excluding earthquake using factored load combinations of ASCE/SEI 7 and the strength reduction factors (ϕ) of 5.3 or 5.4 shall apply.

If the demand-capacity ratio exceeds 1.5 for structures, the design-basis criteria shall be the current building code. Unsafe structural conditions shall be reported in accordance with 1.5.2.

If the demand-capacity ratio does not exceed 1.5 for structures, 4.4 through 4.9 shall be used to determine the design-basis criteria.

4.3.2C *In assessing unsafe structural conditions the strength design demand of Eq. (4.3.2) combines current building code nominal gravity loads (dead, live and snow) and lateral wind forces, excluding seismic forces, using the factored load combinations of ASCE/SEI 7. A demand to capacity ratio greater than 1.5, calculated using Equation 4.3.2, represents a condition with limited to no margin of safety against failure.*

In the assessment of unsafe structural conditions, the licensed design professional should determine if it may be appropriate to include structural redundancies, alternate load paths, primary and secondary supporting elements, redistribution of loads, collapse mechanisms, reduced live loads, measured displacements (listing, leaning and tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth pressures, self-straining loads, ice, and floods. References for unsafe structural conditions include: commentary to Chapter 1 of ASCE/SEI 7-10, Galambos, T.V., Ellingwood, B.R., MacGregor, J.G., and Cornell, C.A., 1982, "Probability Based Load Criteria: Assessment of

Current Design Practice," *Galambos, T.V., Ellingwood, B.R., MacGregor, J.G., and Cornell, C.A., 1982,"Probability Based Load Criteria: Load Factors and Load Combinations," and* Ellingwood, B. R., and Ang, A. H-S., 1972, *"A Probability Study of Safety Criteria for Design." These references provide target reliability indexes, basic probability theory and concepts for an evaluation using the specific details of the demand as it relates to the capacity with the strength reduction factors of Chapter 5 for concrete structures.*

4.3.3 Assessment criteria for unsafe structural conditions of seismic resistance is limited to structures in seismic design category D, E, and F of ASCE/SEI 7 and shall be determined using ASCE/SEI 41 and this code. The design-basis criteria for rehabilitation design and construction of unsafe structures shall be this code and ASCE/SEI 41.

4.3.3C *Compliance with ASCE/SEI 41 for Structural Performance Level, Collapse Prevention using an applicable Earthquake Hazard Level should be as determined by the local jurisdictional authority for the assessment of unsafe structural conditions. Assessment of unsafe structural conditions for seismic resistance is not required for structures in regions of low or moderate seismicity. If no requirements for unsafe structural conditions are provided by the local jurisdictional authority, the licensed design professional should refer to ATC 78, the IEBC and ASCE 41 appendices for guidance.*

4.4—Substantial Structural Damage

4.4.1 Substantial structural damage shall be assessed and rehabilitated as referenced in Table 4.1.4.

4.5—Conditions of Deterioration, Faulty Construction or Damage Less than Substantial Structural Damage

4.5.1 If a structure has damage less than substantial structural damage, deterioration, or contains faulty construction, and there is a reason to question the capacity of the structure, it shall be assessed by checking the demand-capacity ratio using the original building code demand (U_o) with nominal loads, factored load combinations and capacities of the original building code to determine if it exceeds 1.0, as shown in Eq. (4.5.1).

$$U_o / \varnothing R_{cn} > 1.0 \qquad (4.5.1)$$

In Equation 4.5.1, strength reduction factors (ϕ) of original building code shall be used. If the demand-capacity ratio exceeds 1.0, then that member or system strength shall be restored using the original building code. If the demand-capacity ratio does not exceed 1.0, then strengthening is not required.

Repairs shall be permitted that restore a member or system to the capacity of the original building code based on material properties of the original construction.

4.5.1C *Most existing concrete structures with damage less than substantial structural damage, deterioration, or containing faulty construction, will provide acceptable safety if restored to the strength of the original building code.*

The demand-capacity ratio limit of 1.0 as provided in this section allows strengthening that restores the structural reliability of the existing structure to the level prior to damage and deterioration, or as intended in the original building code.

Historical performance is often an acceptable indicator of adequate safety if the structure has been subjected to known loads.

If the capacity of the structure is not in question, such as indicated by the commentary provisions of 1.7.1C, assessment checks are not required.

4.5.2 Alternative assessment criteria for deterioration, faulty construction, or damage less than substantial structural damage shall be permitted. The selected alternative assessment criterion shall substantiate acceptable structural safety using engineering principles for existing structures.

4.5.2C *An alternative assessment criterion may be use of the current building code and ASCE/SEI 41. The references of 4.3.2C should be considered in the selection of an applicable assessment criteria.*

Beyond using the current building code, the assessment criteria should address if the demand or capacity of the original structure or member is significantly inconsistent with current standards and results in unacceptable structural safety. An increase in load intensity, added loads, change in load factors, strength-reduction factors or load combinations, modification of analytical procedures, or changes in the determined capacity between the original and current building codes [such as a change from ASD to strength design] or the benefits received versus the costs incurred should lead the licensed design professional to question the applicability of using the original building code for assessment of an existing structure. Engineering principles used to determine acceptable structural safety are to use either a probabilistic evaluation of loads and capacities to show adequate structural reliability indices or an evaluation procedure using demand-capacity ratios that is derived from the basic engineering principles as presented in current standards.

An assessment criterion for a structure that has damage less than substantial structural damage, deterioration, or faulty construction excluding seismic forces that is based on the demand-capacity ratios of IEBC is the following:

a) If the current building code demand (U_c) exceeds the original building code *demand* (U_o^*) *increased by 5 percent* $(U_c > 1.05U_o^*)$, *check the demand-capacity ratio using the current building code demand (U_c) to determine if it exceeds 1.1, as shown in Eq. (4.5.2a).*

$$U_c / \varnothing R_{cn} > 1.1 \qquad (4.5.2a)$$

If the demand-capacity ratio exceeds 1.1, then that system or member should be strengthened using the current building code demand. If the demand-capacity ratio does not exceed 1.1, then no strengthening is required.

b) If the current building code demand (U_c) does not exceed the original building code demand (U_o^*) *increased by 5 percent* $(U_c \leq 1.05U_o^*)$, *check the demand-capacity ratio using the original building code demand* (U_o^*) *to determine if it exceeds 1.05, as shown in Eq. (4.5.2b).*

$$U_o^* / \varnothing R_{cn} > 1.05 \qquad (4.5.2b)$$

If the demand-capacity ratio exceeds 1.05, then that system or member strength should be restored using the original building code demand. If the demand-capacity ratio does not exceed 1.05, then strengthening is not required.

Strength reduction factors (ϕ) of sections 5.3 or 5.4 in Eq. (4.5.2a) and (4.5.2b) apply. If the original building code demand is used, the repair design should be supplemented for existing members or systems by this code.

In this assessment criterion, the current building code strength design demand (U_c) combines current building code nominal gravity loads (dead, live, and snow) and lateral wind loads excluding earthquake loads using the factored load combinations of ASCE/SEI 7. The original building code strength design demand (U_o^*) *combines original building code nominal gravity loads (dead, live, and snow) and lateral wind loads excluding earthquake loads using the factored load combinations of ASCE/SEI 7. Consideration should be given as to if it may be appropriate to include ASCE/SEI 41 seismic provisions, redistribution of loads, reduced live loads, measured displacements (listing, leaning, and tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth pressures, self-straining loads, ice, and floods.*

The use of structure-specific data is acceptable, if substantiated by the licensed design professional. For these assessment *criteria, the demand-capacity ratio provisions of part (1) may be used in the assessment regardless of the whether the current building code demand does or does not exceed the original building code demand increased by 5 percent.*

4.5.3 If the concrete design regulations of the original building code only used allowable stress design and design service loads, the demand - capacity ratio shall be based on service load demand (U_S) and resistance calculated using allowable stresses (R_a) as shown in Eq. (4.5.3).

$$U_s / R_a > 1.0 \qquad (4.5.3)$$

If the demand-capacity ratio exceeds 1.0, then that member or system strength shall be restored using the original building code. If the demand-capacity ratio does not exceed 1.0, then strengthening is not required. Repairs shall be permitted that restore the member or system to its pre-damage or pre-deteriorated state. Repair of existing structural concrete is permitted based on material properties of the original construction.

4.5.3C *Before 1963 the "Building Code Requirements for Reinforced Concrete" (ACI 318-63), the design of reinforced concrete structures was based upon allowable stress, or working stress, design principles. Original building code demands should include nominal gravity loads (dead, live, and snow) and lateral wind forces including seismic forces using the load combinations of original building code. Displacements (listing, leaning, and tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth pressures, self-straining loads, ice, and floods should be considered.*

Using allowable stress design is inconsistent with the reliability principles of current strength design provisions. To adequately address safety, consideration should be given to verification using 4.5.2 and a check of seismic resistance using ASCE/SEI 41.

4.5.4 Existing structures other than those to be strengthened per 4.3 through 4.5 shall use 4.6 through 4.9 to determine the design-basis criteria.

4.6—Conditions of Deterioration, Faulty Construction, or Damage Less than Substantial Structural Damage without Strengthening

4.6.1 If no damage or less than substantial structural damage is present, structures damaged, deteriorated, or containing faulty construction that do not require strengthening in accordance with 4.5 shall use Chapters 7 through 10 of this code as the design-basis criteria.

4.6.2 *Deflections*

4.6.2.1 The effects of floor levelness, vibrations, and deflections on the performance of the existing structure shall be assessed. Deflections exceeding those allowed by the original building code shall be permitted provided those deflections do not adversely affect structural performance.

4.6.2.1C *The effect of floor levelness, vibrations, and deflections on the structural performance should be investigated by the licensed design professional to determine if the performance of the structure is acceptable to the owner and users of the structure. Acceptable performance criteria will need to be established for an individual structure based upon the intended use of the structure.*

4.7—Additions

4.7.1 The existing structure shall be assessed and rehabilitated in accordance with structural requirements of the IEBC per Table 4.1.4 for Additions.

4.8—Alterations

4.8.1 The existing structure shall be assessed and rehabilitated in accordance with structural requirements of the IEBC per Table 4.1.4 according to Alteration level 1, 2, or 3.

4.8.1C *Alterations in this section exclude the remedial work of 4.3 through 4.6.*

4.9—Change of Occupancy

4.9.1 The existing structure shall be assessed and rehabilitated in accordance with structural requirements of the IEBC per Table 4.1.4 for Changes of occupancy.

CHAPTER 5—LOADS, FACTORED LOAD COMBINATIONS, AND STRENGTH-REDUCTION FACTORS

5.1—General

5.1.1 Applicable loads used in the assessment of the existing structure and the design of rehabilitation shall be determined to verify code compliance.

5.1.2 If this code is part of the design-basis code for the assessment or rehabilitation design, the load factors, load combinations and strength-reduction factors in this Chapter shall be used.

5.1.2C *Load factors, load combinations, and strength-reduction factors are intended to achieve acceptable levels of safety against failure based on the accuracy of the strength prediction model and on maximum expected loads during the service life of the rehabilitated structure.*

In some instances, a building may need to be upgraded to satisfy current building code requirements in accordance with the provisions of Chapters 4 and 6 or Appendix A and Chapter 6. Applicable loads are determined in accordance with the existing-building code and standards such as ASCE/SEI 7, ASCE/SEI 37, and ASCE/SEI 41.

5.1.3 It shall not be permitted to use load factors and load combinations from the original building code with strength-reduction factors from this Chapter. It shall not be permitted to use load factors and load combinations from this Chapter with strength-reduction factors from the original building code.

5.1.3C *Mixing of load factors and load combinations from one code with strength-reduction factors from a different code may result in an inconsistent level of reliability and safety. Sections 4.5.2 and A.5.2 use nominal load from the original codes with factored load combinations and strength-reduction factors from this code.*

5.1.4 Loads during the construction period shall be in accordance with the design basis code. If the building is unoccupied during the construction period, it shall be permitted to determine loads in accordance with ASCE/SEI 37. If portions of the building are restricted to construction-only access during the construction period, it shall be permitted to determine loads on only those portions in accordance with ASCE/SEI 37.

5.1.4C *These provisions permit the less stringent loads in ASCE/SEI 37 to be applied for the construction-access only case.*

5.1.5 When assessing an existing structure, consideration shall be given to effects caused by loads or imposed deformations that the structure is subjected to, if required by the jurisdictional authority, even if such effects may not have been specified in the original building code.

5.1.5C *Examples of such loads include vibration or impact loads. Examples of such imposed deformations include unequal settlement* *of supports, and listing, leaning and tilting, and those due to prestressing, shrinkage, temperature changes, creep.*

5.2—Load factors and load combinations

5.2.1 Design of rehabilitation shall account for existing loads and deformations of the structure; the effects of load redistribution due to damage, deterioration, or load removal; and the sequencing of load application, including construction and shoring loads, during the rehabilitation process.

5.2.2 Rehabilitation design shall confirm that structural members and connections have design strengths at all sections at least equal to the required strengths calculated for factored loads and forces in such combinations as stipulated in this code. Structural evaluation shall consider whether the design strengths of such members and connections at all sections are sufficient.

5.2.2C *The basic requirement for strength design or assessment is expressed as:*
design strength (for example, capacity)≥ required strength (for example, demand)

$$\phi\,(R_n) \geq U$$

The design strength is the nominal strength multiplied by the strength-reduction factor ϕ.

5.2.3 Required strength U shall equal or exceed the effects of factored load combinations as specified in the design-basis code.

5.2.3C *The required strength U is expressed in terms of factored loads, which are the product of specified nominal loads multiplied by load factors.*

5.2.4 Required strength $\boldsymbol{U}$ shall include internal load effects due to reactions induced by prestressing with a load factor of 1.0.

5.2.5 For post-tensioned anchorage zone design or evaluation, a load factor of 1.2 shall be applied to the maximum prestressing jacking force.

5.2.5C *The load factor of 1.2 applied to the maximum tendon jacking force results in a design load that exceeds the typical prestressing yield strength. This compares well with the maximum attainable jacking force, which is limited by the anchor efficiency factor. For jacking loads less than the maximum tendon jacking force, or for jacking loads applied to nonmetallic prestressing tendons, design of the anchorage for 1.2 times the anticipated jacking force is appropriate given that the jacking load is controlled better than typical dead loads.*

5.3—Strength reduction factors for rehabilitation design

5.3.1 Design strength provided by a member, its connections to other members, and its cross sections, in terms of flexure, axial load, shear, and torsion, shall be taken as the nominal strength calculated in accordance with requirements and assumptions of this code, multiplied by the strength-reduction factors ϕ in 5.3.2 and 5.3.4.

5.3.2 The strength-reduction factor ϕ shall be as follows:

Tension-controlled sections (steel tensile strain at failure exceeding $2.5\varepsilon_y$ where ε_y is the yield strain)..0.90

Compression-controlled sections (tensile strain at failure not exceeding ε_y)

(a) Members with spiral reinforcement...................0.75

(b) Other reinforced members...........................0.65

For sections in which the net tensile strain in the extreme tension steel at nominal strength, ε_t, is between the limits for compression-controlled and tension-controlled sections, linear interpolations of ϕ shall be permitted.

Shear and torsion, and interface shear 0.75

Bearing on concrete (except for post-tensioned anchorage zones and strut-and-tie models)......................... 0.65

Post-tensioned anchorage zones 0.85

Strut-and-tie models and struts, ties, nodal zones, and bearing areas in such models 0.75

5.3.2.C *For a steel yield strength of 60 ksi, the steel tensile strains corresponding to the tension- and compression-controlled limits are 0.005 and 0.002, respectively. Because the compressive strain in the concrete at nominal strength is typically assumed to be 0.003, the net tensile strain limits for compression-controlled members may also be stated in terms of the ratio* c/d_t, *where* c *is the depth of the neutral axis at nominal strength, and* d_t *is the distance from the extreme compression fiber to the centroid of extreme tension reinforcement. The* c/d_t *limits for tension- and compression-controlled sections are 0.375 and 0.6, respectively. The 0.6 limit for compression-controlled sections applies to sections reinforced with Grade 60 steel and to prestressed sections. For other grades of steel,* c/d_t *should change with* ε_y, *where* $c/d_t = 0.003/(0.003+\varepsilon_y)$, *where* ε_y *is the yield strain of the steel reinforcement.*

5.3.3 Computation of development lengths do not require a ϕ-factor.

5.3.4 For flexure, compression, shear, and bearing of structural plain concrete, ϕ shall be 0.60.

5.4—Strength-reduction factors for assessment

5.4.1 If the required structural element dimensions and location of reinforcement are determined in accordance with Chapter 6, and material properties are determined in accordance with 6.4, it shall be permitted to increase ϕ from those specified in 5.3, but ϕ shall not exceed:

Tension-controlled section 1.0

Compression-controlled sections:

Members with spiral reinforcement.......................... 0.9

Other reinforced members...... 0.8

Shear and/or torsion, interface shear....................................... 0.8

Bearing on concrete................ 0.8

Strut-and-tie models and struts, ties, nodal zones, and bearing areas in such models.............. 0.8

5.4.1C *Strength-reduction factors given in 5.4.1 are larger than those in 5.3.1. These increased values are justified by the improved reliability due to the use of accurate field-obtained material properties, actual in-place dimensions, and well-understood methods of analysis. They have been deemed appropriate for use in ACI 318-14, Chapter 27, and have had a lengthy history of satisfactory performance.*

5.4.2 If an evaluation of members with no observed deterioration is based on historical material properties as given in Tables 6.3.1a through 6.3.1c, the ϕ-factors not exceeding those in 5.3 shall apply.

5.4.3 For flexure, compression, shear, and bearing of structural plain concrete, ϕ shall be 0.60.

5.4.3C *The resistance factor for assessment of plain concrete is the same as that specified for design in 5.3.4. Material properties for plain concrete determined in accordance with 6.3.5 may increase its nominal resistance, but the strength-reduction factor remains unchanged because plain concrete failures are usually brittle.*

5.5—Additional load combinations for structures rehabilitated with external reinforcing systems

5.5.1 For rehabilitation achieved with unprotected external reinforcing systems that are susceptible to damage by fire, vandalism or collision, the required strength of the structure without rehabilitation shall equal or exceed the effects of the load combinations specified in 5.5.2, and 5.5.3.

5.5.1C *For rehabilitation achieved with external reinforcing systems, such as externally bonded fiber-reinforced polymer, externally bonded steel plates, or external post-tensioning systems, the unrehabilitated structure requires a minimum strength without the participation of the external reinforcing system. Section 7.9 gives requirements for protected and unprotected external reinforcing systems with respect to fire and elevated temperatures.*

5.5.2 The required strength of the structure without external reinforcement shall satisfy Eq. (5.5.2)

$$\phi R_n \geq 1.1D + 0.75L + 0.2S \quad (5.5.2)$$

where *D, L* and *S* are the effects due to the specified dead, live and snow loads, respectively, calculated for the rehabilitated structure, ϕ is the strength-reduction factor in 5.3 or 5.4, as applicable, and R_n is the nominal strength.

5.5.2C *This load combination is intended to minimize the risk of overload or damage to the unstrengthened structure in the case where, during normal operating conditions, the external reinforcement is damaged. Such damage may not be detected immediately and so the structure (or structural component) may remain in service until the damage is identified. This combination also provides a desirable upper limit on the additional strength that can be utilized using external reinforcing systems.*

5.5.2.1 If the applied live load has a high likelihood of being sustained the live load factor in Eq. 5.5.2 shall be increased from 0.75 to 1.0.

5.5.2.1C *Examples include library stack areas, heavy storage areas, warehouses, and other occupancies with a live load exceeding 100 lb/ft^2.*

5.5.3 The required strength of the structure without external reinforcement after an extraordinary event shall satisfy Eq. (5.5.3).

$$\phi_{ex} R_{ex} \geq 1.2D + 0.5L + 0.2S \quad (5.5.3)$$

where ϕ_{ex} = 1.0; R_{ex} is the nominal resistance of the structure computed using the probable material properties after the extraordinary event; and *S* is the specified snow load. For cases where the design live load acting on the member to be strengthened has a high likelihood of being present for a sustained period of time, a live load factor of 1.0 shall be used in place of 0.5 in Eq. (5.5.3).

5.5.3C *This load combination is intended to minimize the risk of overload or damage to a strengthened structure when the external reinforcement is damaged by an extraordinary event such as fire, impact, or blast. Wind and earthquake forces are not considered extraordinary events for this load combination, as they are unlikely to result in damage that specifically affects the capacity of the unprotected external reinforcing systems. The minimum limit of Eq. (5.5.3) should allow the structure to maintain sufficient structural strength until the damaged rehabilitation system has been repaired. Guidance concerning probable material properties during the extraordinary event may be obtained from ACI 216.1.*

5.5.3.1 If the applied live load has a high likelihood of being sustained, the live load factor in Eq. 5.5.3 shall be increased from 0.50 to 1.0.

5.5.3.1C *Refer to 5.5.2.1C*

CHAPTER 6—ASSESSMENT, EVALUATION, AND ANALYSIS

6.1—Structural assessment

6.1.1 A structural assessment shall be performed before rehabilitation of an existing structure. The structural assessment shall comprise 1) an investigation to establish the in-place condition of the structure in the work area, including environment, geometry, material strengths, reinforcing-steel sizes and placement, and signs of distress; 2) an evaluation to define the causes of distress, goals of the rehabilitation, and criteria for selection of rehabilitation solution(s); and 3) appropriate rehabilitation strategies.

6.2—Investigation and structural evaluation

6.2.1 An investigation and structural evaluation shall be performed if an existing structure 1) exhibits signs of damage, displacement, deterioration, structural deficiency, or behavior that is inconsistent with available design and construction documents or code requirements in effect at the time of construction, or 2) preliminary evaluation indicates strengthening is required.

6.2.1C *Field investigations in support of the structural evaluation may include visual observations, destructive testing, and nondestructive testing (NDT). Areas of known deterioration and distress in the structural members should be identified, inspected, and recorded as to the type, location, and degree of severity. Procedures are referenced in ACI 201.1R, ACI 228.1R, ACI 228.2R, ACI 364.1R, ACI 437R, ASCE/SEI 11, ASCE/SEI 41 and FEMA P-154. The affected structural members are not only members with obvious signs of distress but also contiguous members and connections in the structural system.*

The data gathered to determine the existing capacity should include the effects of material degradation, such as loss of concrete strength from chemical attack; freezing and thawing; and loss of steel area due to corrosion or other causes, or misplaced reinforcement; and effects of damaging events, such as earthquakes or fire. The effect of deterioration on the ductility of the member should be considered in the evaluation. The strength or serviceability of a member or structure may be compromised by spalling, excessive cracking, large deflections, or other forms of damage or degradation. Seismic evaluation references for undamaged buildings include FEMA P-58, FEMA P-154 and ASCE/SEI 41 and for damaged buildings include ATC 20, FEMA 306 and FEMA 307.

6.2.2 An investigation and structural evaluation shall be performed when there is a reason to question the capacity of the structure and insufficient information is available to determine if an existing structure is capable of resisting design demands.

6.2.3 Where repairs are required to an individual member in a structure, it shall be determined if similar members throughout the structure also require evaluation.

6.2.3C *If there is no evidence of damage, distress or deterioration of similar members elsewhere in a structure to those that required repair, there is no need to perform an evaluation of similar members unless unsafe conditions are present. Unsafe conditions may be a concern if there are significant variances from the original design intent such as lower-strength concrete or insufficient reinforcement. In addition, if the similar members are in an environment that could foster deterioration, then repairs with strengthening or durability enhancements may be required, as opposed to a similar member in a less severe environment.*

6.2.4 An investigation shall document conditions as necessary to perform a structural evaluation.

6.2.4C *Conditions which may need to be documented include (a) through (g):*

(a) The physical condition of the structural members to examine the extent and location of degradation or distress.

(b) The adequacy of continuous load paths through the primary and secondary structural members to provide for life safety and structural integrity.

(c) As-built information required to determine appropriate strength reduction factors in accordance with Chapter 5.

(d) Structural members' orientation, displacements, construction deviations, and physical dimensions.

(e) Properties of materials and components from available drawings, specifications, and other documents; or by testing of existing materials.

(f) Additional considerations, such as proximity to adjacent buildings, load-bearing partition walls, and other limitations for rehabilitation.

(g) Information needed to assess lateral-force-resisting systems, span lengths, support conditions, building use and type, and architectural features.

The construction documents may not represent as-built conditions. Therefore, the licensed design professional is encouraged to research and verify that the material properties obtained from record documents are accurate. Material testing may be required to verify these values.

6.2.5 If an analysis is performed, the structural evaluation shall document the requirements of 6.2.4 and (a) through (c). The analysis shall be performed in accordance with 6.5.

a) As-measured structural member dimensions.
b) The presence and effect of alterations to the structural system.

c) Loads, occupancy, or usage different from the original design.

6.3—Material properties

6.3.1 Material properties shall be obtained from available drawings, specifications, and other documents. If such documents do not provide sufficient information to characterize the material properties, such properties shall be obtained from the historical data provided in Tables 6.3.1a through 6.3.1c, or in accordance with 6.4, or both.

Table 6.3.1a—Default compressive strength of structural concrete, psi

Time frame	Footings	Beams	Slabs	Columns	Walls
1900-1919	1000	2000	1500	1500	1000
1920-1949	1500	2000	2000	2000	2000
1950-1969	2500	3000	3000	3000	2500
1970-present	3000	3000	3000	3000	3000

Note: Adopted from ASCE/SEI 41-06.

Table 6.3.1b—Default tensile and yield strength properties for steel reinforcing bars for various periods*

		Structural†	Intermediate†	Hard†				
	Grade	33	40	50	60	65	70	75
	Minimum yield, psi	33,000	40,000	50,000	60,000	65,000	70,000	75,000
Year	**Minimum tensile, psi**	55,000	70,000	80,000	90,000	75,000	80,000	100,000
1911-1959		X	X	X	—	X	—	—
1959-1966		X	X	X	X	X	X	X
1966-1972		—	X	X	X	X	X	—
1972-1974		—	X	X	X	X	X	—
1974-1987		—	X	X	X	X	X	—
1987-Present		—	X	X	X	X	X	—

Note: Adopted from ASCE/SEI 41-06.
*An entry of "X" indicates the grade was available in those years.
†The terms "structural," "intermediate," and "hard" became obsolete in 1968.

Table 6.3.1c—Default tensile and yield strength properties of steel reinforcement for various ASTM specifications and periods*

				Structural†	Intermediate†	Hard†				
		Grade		33	40	50	60	65	70	75
		Minimum yield, **psi**		33,000	40,000	50,000	60,000	65,000	70,000	75,000
ASTM Designation‡	**Steel type**	**Year range**	**Minimum tensile, psi**	55,000	70,000	80,000	90,000	75,000	80,000	100,000
A15	Billet	1911-1966		X	X	X	—	—		
A16	Rail§	1913-1966		—	—	X	—	—		
A61	Rail	1963-1966		—	—	—	X	—		
A160	Axle	1936-1964		X	X	X	—	—		
A160	Axle	1965-1966		X	X	X	X	—		
A185	WWF	1936-present		—	—	—	—	X		
A408	Billet	1957-1966		X	X	X	—	—		
A431	Billet	1959-1966		—	—	—	—	—		X
A432	Billet	1959-1966		—	—	—	X	—		—
A497	WWF	1964-present		—	—	—	—	—	X	—
A615	Billet	1968-1972		—	X	—		—	—	X
A615	Billet	1974-1986		—	X	—	X	—		—
A615	Billet	1987-present		—	X	—	X	—		X
A616-96‖	Rail	1968-present		—	—	—	X	—		—
A617	Axle	1968-present		—	X	—	—	—		—
A706#	Low-alloy	1974-present		—	—	—	X	—	X	—
A955	Stainless	1996-present		—	X	—	X	—		X

Note: Adopted from ASCE/SEI 41-06.
*An entry of “X” indicates the grade was available in those years.
†The terms structural, intermediate, and hard became obsolete in 1968.
‡ASTM steel is marked with the letter W.
§Rail bars are marked with the letter R.
‖Bars marked with “s!” (ASTM A616-96) have supplementary requirements for bend tests.
#ASTM A706 has a minimum tensile strength of 80 ksi, but not less than 1.25 times the actual yield strength.

***6.3.1C** Material properties required for seismic evaluation and rehabilitation are discussed in ASCE/SEI 41. Where the as-built conditions and properties of historical buildings require evaluation and rehabilitation, care should be taken to minimize the impact of design and investigation procedures (U.S. Department of the Interior 1995). Material properties include all physical and chemical properties of the concrete and reinforcement, and includes all references to ASTM standards and other methods of determining physical and chemical properties.*

6.3.2 Concrete compressive strength and steel reinforcement yield strength shall be determined for the structure if a structural evaluation is required. If tests are used to determine material properties, test methods shall be in accordance with 6.3.5.

***6.3.2C** Additional factors and characteristics affecting materials that may be required to be evaluated include:*

a) Ductility of the member based on the stress-strain curves of the material.

b) Presence of corrosion of embedded steel reinforcement, including carbonation, chloride intrusion, and corrosion-induced spalling.

c) Presence of other degradation, such as alkali-silica reaction, sulfate attack, or delayed ettringite formation.

d) Degradation due to cyclic freezing and thawing.

e) Internal cracking (especially adjacent to and under previous repairs).

f) Degradation of stiffness and strength due to bar slip in cracked sections and joints damaged in seismic events.

Other tests for material properties, including petrographic examination, are often used. These tests can be highly variable and dependent on the structure, member type(s), and distress mechanism.

Chloride penetration can cause steel reinforcement corrosion, which can lead to cracking and spalling. The depth of a spall will affect the effective area of concrete section. Concrete degradation will affect its compressive strength.

6.3.3 Nominal material properties shall be determined by (a), (b) or (c):

a) Historical material properties in accordance with Tables 6.3.1a through 6.3.1c.

b) Available drawings, specifications, and previous testing documentation.

c) Physical testing in accordance with 6.4.

***6.3.3C** The construction documents may not represent as-built conditions. Therefore, the evaluation of material properties should verify, using material testing as required, that the material properties obtained from record documents are representative.*

6.3.4 The material properties provided in the original construction test reports or material test reports shall be permitted to be used unless known deterioration that can affect performance has occurred.

6.3.4C *If the results of material testing from original construction are available, these results may be used in the analysis. Additional testing could be required to confirm these material test results if degradation has occurred.*

6.3.5 If material properties are determined by in-place testing in accordance with 6.4, the locations and numbers of material samples shall be defined to characterize the materials. The number of samples shall be determined during evaluation.

6.3.5C *Review of available records from the original construction may be used to guide testing. Evaluation, historical research, and documentation of the geometry, material properties, and detailing used in the construction are invaluable and may be used to reduce the amount of required in-place testing. The data gathered to determine strength should include the effects of material degradation, such as loss of concrete strength from chemical attack and loss of steel area due to corrosion. The impact of deterioration on the expected strength and ductility of the section also should be considered in the evaluation.*

The minimum number of tests is influenced by the data available from the original construction, the type of structural system, the desired accuracy, and the quality and condition of the in-place materials. The focus of the prescribed material testing should be on the principal structural members and specific properties needed for analysis. The licensed design professional should determine the appropriate number and type of testing needed to evaluate the existing conditions.

Care should be taken in selecting the location for sampling concrete. Core drilling should minimize damage of the existing reinforcement and should generally occur at locations where the coring will least affect the member strength.

6.3.6 If historic data are not given in either Table 6.3.1b or 6.3.1c, the historic default value for yield strength, f_y shall be taken as 27,000 psi.

6.3.6C *Additional guidance regarding the use of the historic lower bound default value is given in 6.4.4.1C*

6.4—Test methods to quantify material and member properties

6.4.1 *General*

6.4.1.1 Destructive and nondestructive test methods used to obtain in-place mechanical properties of materials and member properties shall be in accordance with this section. Compressive strength of sound concrete shall be determined by taking and testing core samples or by a combination of cores and by the use of site specific nondestructive testing. Steel reinforcement properties shall be determined by removal of reinforcement samples and destructive testing.

6.4.2 *Core sampling of concrete for testing*

6.4.2.1 It shall be permitted to determine the compressive strength of sound concrete by taking cores from the members being evaluated. Steel reinforcement shall be located before locating the cores to be extracted.

6.4.2.1C *NDT may be used to locate existing reinforcement and to avoid damage to reinforcement during coring. Guidelines for core sampling and evaluating core strength data are given in ACI 214.4R.*

6.4.3 Concrete

6.4.3.1 The cores shall be selected and removed in accordance with ASTM C42 and ASTM C823. The equivalent specified concrete strength f_{ceq} shall be calculated by:

$$f_{ceq} = 0.9\overline{f}_c\left[1 - 1.28\sqrt{\frac{(k_cV)^2}{n} + 0.0015}\right] \qquad (6.4.3.1)$$

where $\overline{f}_c$ is the average core strength, as modified to account for the diameter, length to diameter ratio and moisture condition of the core; V is the coefficient of variation of the core strengths (a dimensionless quantity equal to the sample standard deviation divided by the mean); n is the number of cores taken, and k_c is the coefficient of variation modification factor, as obtained from Table 6.4.3.1.

Table 6.4.3.1—Coefficient of variation modification factor k_c

n	k_c
2	2.4
3	1.47
4	1.28
5	1.20
6	1.15
8	1.10
10	1.08
12	1.06
16	1.05
20	1.03
25 or more	1.02

6.4.3.1C *The equivalent specified strength determined using this procedure can be used in strength equations with the strength reduction factors from Chapter 5. The strength value obtained using this procedure is an estimate of the 13 percent fractile of the in-place concrete strength. Equation 6.4.3.1 is a simplification of criteria given in ACI 214.4 that gives similar results because it accounts for the impact and uncertainty of strength correction factors for length-to-diameter ratio, core diameter, and drilling damage. This approach is specified in the Canadian Highway Bridge Design Code*

(CAN/CSA S6-06 2006) and is based on the approach proposed by Bartlett and MacGregor (1995). When the testing requirements of ASTM C42/42M are not met, the user should consult ACI 214.4.

6.4.3.2 Nondestructive strength testing to evaluate in-place strength of concrete shall be permitted if a valid correlation is established with core sample compressive strength test results and nondestructive test results. Quantifications of concrete compressive strength by NDT alone shall not be permitted as a substitute for core sampling and testing.

6.4.3.2C *ACI 228.1R provides information on NDT methods for evaluation of concrete compressive strength and development of statistical correlations between NDT and core test results.*

6.4.4 *Steel reinforcement*

6.4.4.1 The size, number, and location, including effective depth of steel reinforcing bars or elements shall be established. If the original construction documents are not available and if the properties of the reinforcing bars are unknown, historical values provided in 6.3.6 shall be permitted in place of testing. If the grade of material is unknown, the lowest grade provided in Table 6.3.1b for a given historic period shall be used.

6.4.4.1C *The age of the structure may be known but the grade of reinforcement is unknown. In this case, the lowest grade of reinforcement corresponding to the structure's age should be used. If no information is available, the lower bound value of f_y equal to 27,000 psi may be used instead of testing, provided it is conservative. In some instances assuming higher yield strengths may be more conservative. Where the demand on one member is governed by the capacity of a connected member, it is appropriate to assign higher yield strengths to the connected member. For example, in seismic analysis at beam column joints, the moment strength of the columns should exceed the moment strength of the beams. When assessing this requirement it is more conservative to assume a higher yield strength for the beam reinforcement than for the column reinforcement.*

6.4.5 *Reinforcement sampling and testing*

6.4.5.1 Coupon samples for the determination of the yield and tensile strength for steel reinforcement shall be obtained in accordance with ASTM A370. A minimum of three sample coupons, taken from different segments of reinforcement shall be obtained from the members being evaluated.

6.4.5.1C *Often the steel reinforcement in a structure is of a common grade and strength. Occasionally, more than one grade of steel is used, for example, smaller diameter (#3 and 4) stirrups and other complex bent bars were often fabricated with lower strength material than the longitudinal bars.*

CRSI (2014): Vintage Reinforcement in Concrete Structures contains supplemental information on *mechanical properties of the reinforcement used in different construction eras.*

Steel reinforcement information includes square, rectangular, and round bars with and without deformations, prestressing wire, bars, multi-wire strands, and structural shapes. Historically, wire rope and chain have also been used as reinforcement.

6.4.6. The equivalent specified yield strength f_{yeq} used for analysis shall be calculated by:

$$f_{yeq} = (\overline{f_y} - 3500)\exp(-1.3k_sV) \quad (6.4.6)$$

where $\overline{f_y}$ is the average yield strength value from the tests, in psi; V is the average coefficient of variation determined from testing; n is the number of strength tests; and k_s is the steel coefficient of variation modification factor, as obtained from Table 6.4.6.

Table 6.4.6—Steel coefficient of variation modification factor, k_s

n	k_s
3	3.46
4	2.34
5	1.92
6	1.69
8	1.45
10	1.32
12	1.24
16	1.14
20	1.08
25	1.03
30 or more	1.00

6.4.6C *The equivalent specified yield strength determined using this procedure can be used in strength equations with the strength reduction factors from Chapter 5. The yield strength value obtained using this procedure is an estimate of the 10 percent fractile of the static steel strength. It is assumed that the yield strength measured during a coupon test exceeds the static yield strength by 3500 psi. This approach is specified in the Canadian Highway Bridge Design Code (CAN/CSA S6-06 2006). N as presented above represents the number of strength tests performed for a given set of tested reinforcement.*

The factors in Table 6.4.6 reflect the uncertainty of the sample standard deviation for a small sample size. They are the 95 percent one-sided tolerance limits on the 10 percent fractile, and they have been reduced by a constant factor to be equal to 1.0 for n *= 30 specimens.*

6.4.7 If the properties of the connector steel are unknown, strength shall be determined by (a), (b), or (c):

a) Testing of coupons taken from the connector steel.
b) Documentation giving connector steel properties in the original construction documents.
c) Use of historic default values in accordance with 6.3.6.

***6.4.7C** The historic default value is obtained from ASCE/SEI 41.*

6.4.8 Coupon specimens for the determination of yield and tensile strengths of structural steel shall be tested in accordance with ASTM A370. A minimum of three specimens shall be taken from representative elements.

The equivalent specified yield strength f_y of each specimen shall be its reported yield strength. The f_{yeq} used for analysis shall be calculated by:

$$f_{yeq} = (\bar{f}_y - 4000)\exp(-1.3 k_s V) \quad (6.4.8)$$

where $\bar{f}_y$ is the average yield strength value from tests, in psi; V is the average coefficient of variation determined from testing; n is the number of strength tests; and k_s is the steel coefficient of variation modification factor, as obtained from Table 6.4.6.

6.4.9 The sampling of prestressing steel reinforcement for strength testing shall be required if strength and historical data are not available. Testing of the prestressing reinforcement shall be in accordance with ASTM A1061/1061M.

6.4.10 If welding of reinforcement is required, carbon equivalent shall be determined in accordance with D1.4/D1.4M:2011.

6.5—Structural analysis of existing structures

6.5.1 The gravity and lateral-force-resisting structural systems shall be analyzed for the maximum effects on the affected members. Loads and load combinations shall be determined in accordance with this code.

***6.5.1C** Structural evaluation and analyses are conducted to verify strength and serviceability. The analytical methods of 6.5 are used with factored loads to determine strength requirements for a combination of flexure, shear, torsion, and axial loads of pertinent structural members. A service-load analysis may be required to evaluate serviceability issues such as deflection and cracking.*

6.5.2 Analysis of the structure shall use accepted engineering principles that satisfy force equilibrium and the principles of compatibility of deformations and strains.

6.5.3 Analysis shall consider material properties, member geometry and deformation, lateral drift, duration of loads, shrinkage and creep, and interaction with the supporting foundation.

***6.5.3C** The licensed design professional is responsible for determining the appropriate method of analysis. Appropriate methods include linear elastic analysis, nonlinear analysis, and other traditionally accepted engineering analysis methods. If a linear elastic analysis method is used, the effects of cracking, second-order and other nonlinear effects should be included in the analysis using engineering approximations.*

The analysis may include the effects of the size and member geometry to determine the forces on individual members of a structure. The analysis should consider external effects, including prestressing, material volume changes, temperature variations, and differential foundation movement.

6.5.4 Members shall be analyzed considering the effect of any material degradation, bond loss, and the redistribution of forces in members and in the structural system as a whole.

6.5.4C *Member deterioration and damage may result in distribution of internal forces different than the distribution of forces of the original structural design. The strength and integrity of prestressed structures with damaged prestressing reinforcement requires careful consideration to assess the impact of the damage. Actual redistribution of moments in existing structures may exceed the moment redistribution permitted in ACI 318-14. The state of the structure should be accurately modeled to determine the distribution of forces. Redistribution of forces may be determined using material nonlinear analysis, by load tests described in ACI 437.2, or by linear analysis, which bounds the limits of redistributed forces.*

6.5.5 Analysis shall consider the load path from the load application through the structure to the foundation. Three-dimensional distribution of loads and forces in the complete structural system shall be considered unless a two-dimensional analysis adequately represents the part of the structure being evaluated.

6.5.5C *The evaluation of load effects requires consideration of both the load paths through the structure and how the forces are distributed in members.*

6.5.6 Analysis shall consider the effects of previous repairs and of any previous structural modifications on the behavior of the structure.

6.5.6C *Modifications to structures in the form of repairs, alterations, or additions may affect the force distribution and load path in a structure.*

6.5.7 The analysis shall be based on available documentation, as-built dimensions, and the in-place properties of the structure including section loss. The determination of in-place material properties shall be in accordance with 6.3.

6.5.7C *Available documentation may include original drawings, specifications, shop drawings, structural assessments, testing, and geotechnical reports. Deviations between the existing construction and construction documents are to be identified and recorded. If section loss has occurred, a more accurate analysis may be developed by direct measurement of the section, and by calculation of section properties based on actual conditions. Additional information may be obtained in ACI 364.10T.*

6.6—Structural serviceability

6.6.1 If serviceability problems have been identified in accordance with 6.2, the licensed design professional shall perform a serviceability evaluation based on the existing geometry and properties of the structure.

6.6.1C *Structural serviceability problems may include deflections, vibrations, leakage, and objectionable cracking. The data gathered to determine serviceability should include the effects of material degradation, such as loss of concrete strength from sulfate attack or loss of steel area due to corrosion.*

The specific performance criteria and the intended function of the structure should be considered. Floor deflection criteria can be found in ACI 318.-14. Vibration criteria are given in Murray et al. (1999).

6.7—Structural analysis for repair design

6.7.1 The structural analysis used for repair design shall consider the structural repair process. The analysis shall consider the effects of the sequence of load application and material removal during the anticipated phases of the evaluation and repair process.

6.7.1C *The construction process may involve the application, removal and replacement of loads. The analysis needs to consider the effects of the application and removal of construction loads to determine the maximum loading during anticipated construction phases. The additional applied loads may be due to prestressing, vibration, material volume changes (such as creep and shrinkage, or temperature changes), effect of shoring, and unequal deformation of supports.*

6.7.2 Structural analysis shall account for repairs where the materials change through the section.

6.7.2C *The intent of this section is to address differences in stiffness between repair material and existing substrate. In these situations, localized deformation may occur in the material with the lower modulus of elasticity, affecting the force distribution in the repaired structure.*

6.7.3 Section analysis shall use principles of mechanics and shall assume (a), (b), or (c) as appropriate:

a) full composite action with no slip at interfaces between repair materials and existing materials
b) separate action with full slip between repair and existing materials
c) partial composite action with friction at interfaces between repair and existing materials

6.7.3C *Depending on the repair construction process and the selection of repair materials, the repair materials and the existing concrete or reinforcement may not act compositely. The analysis should model the anticipated degree of composite action of the repaired structure. An example of partial composite behavior are beams* *that contain shear studs to develop nominal strength, yet lack bond between the overlay and substrate. In this situation, the overlay and substrate do not maintain strain compatibility.*

6.7.4 *Seismic analysis of repaired structure*

6.7.4.1 The interaction of structural members and nonstructural components that affect the response of the structure to seismic motions shall be considered in the analysis.

6.7.4.2 Existing, repaired, and added supplementary members assumed not to be a part of the seismic-force-resisting system shall be permitted, provided their effect on the response of the system is considered and accommodated in the repair design. Consequences of failure of structural members that are not a part of the seismic-force-resisting system and nonstructural components shall be considered.

6.7.4.3 The method of analysis shall consider the structural configuration and material properties after repair.

6.7.4.3C *Procedures for seismic rehabilitation of concrete buildings, including analysis, are provided in ASCE/SEI 41 and supplemented in ACI 369R. These references provide details for forces, rehabilitation methods, analysis and modeling procedures, and seismic rehabilitation design. Additional references for repair of building damage by a seismic event and rehabilitation of concrete buildings include FEMA 308, FEMA 395 through FEMA 400, and FEMA 547.*

6.8—Strength evaluation by load testing

6.8.1 Load testing in accordance with ACI 437.2-13 shall be permitted to supplement an analysis or to demonstrate the strength of the original or repaired structure

6.8.1C *Information obtained during a structural evaluation may be insufficient to determine the strength or serviceability of deteriorated or repaired structural members. Structural condition assessments, including destructive testing, can provide some of the information required, but the costs for these assessments can be significant. Further, the results of a structural evaluation may still be inconclusive due to unknown effects of existing conditions or interaction with the repair. In such cases, load testing may provide the most effective means of verifying the strength of a structure or member. Load testing can also be a valuable tool for evaluating the effectiveness of structural repairs. For example, load testing, as defined in ACI 437, can be performed to determine if the service load deflection and cracking are acceptable.*

6.8.2 Model analysis shall be permitted to supplement calculations.

6.8.2C *This code permits model analysis to be used to supplement structural analysis and design calculations. Model analysis involves the construction and experimental testing of full or* *scale models of structure components, assemblages, or systems. Documentation of the model tests and subsequent interpretation should be provided with the related calculations. Model analysis should be performed by an individual having experience in this technique. References are provided in Harris and Sabnis, (1999), ACI SP-24 (1970).*

6.9—Recommendations

6.9.1 Recommendations shall be developed based upon the results of the evaluation. Repair and rehabilitation design, if performed, shall be in accordance with this code.

CHAPTER 7—DESIGN OF STRUCTURAL REPAIRS

7.1—General

7.1C *Repair and rehabilitation, as defined in Chapter 2, are processes in which deficiencies and damage in a structure or member are corrected. The methods used to correct deficiencies and damage in structures will be the same for both repair and rehabilitation projects. For the purposes of this chapter, design requirements for repair and rehabilitation can be considered to be equivalent.*

Durability requirements for repairs are in Chapter 8.

7.1.1 Repaired structures and connections shall have design strengths at all sections at least equal to the required strengths calculated using the factored loads and forces in such combinations as stipulated in this code.

7.1.1C Loads include those from externally applied loads and those from imposed deformations, from such actions as prestressing, and shrinkage of repair materials, temperature changes, creep, unequal settlement of supports, and listing, leaning and tilting displacements.

7.2—Strength and serviceability

7.2.1 Repaired structures shall be designed to have adequate stiffness to limit lateral and vertical deflections, vibrations, cracking, or any deformations that adversely affect strength or serviceability of a structure.

7.2.1C *Adequate stiffness needs to be determined on a project-specific basis and is a function of the structure type, the desired performance of the structure, and loading conditions and use.*

7.2.2 Repair design and construction procedures shall consider loading, internal forces, and deformations in both the existing and repaired structure during the repair process.

7.2.2C *During the repair process, it may not be possible or practical to relieve existing stresses or deformations. Consideration should be given to the in-place internal forces and deformations present in the structure during the repair and the subsequent internal forces from the design loads that the repaired section will resist. Internal forces and deformations caused by existing loads may be locked in by the repair.*

Analysis to evaluate the effects of structural modifications should verify that strength is adequate and that serviceability conditions are met. As an example, creating a large opening in structural slabs may necessitate cutting reinforcement, which can significantly influence the global behavior of the structure. Supplementary strengthening may be required to address force redistribution that can exceed the existing strength. Slab punching shear strength should be evaluated for openings at the intersection of column strips to verify that the *slab is adequate. This is especially critical near corner and edge columns where the slab shear stress is typically highest.*

7.3—Behavior of repaired systems

7.3.1 Repairs to sections, components, reinforcement, connections of members, or systems, or incorporating new members shall be designed to be integrated with the existing structure, creating a structural system capable of sharing and transferring loads.

7.3.1C *Repair of a structure may be achieved by improving the global behavior of the structure by adding new structural members that act integrally with the existing structural system or improving the behavior of the existing members.*

Load sharing and load transfer should exist between the structure and the new members so that the assumed load path and force distribution can occur. The effects of adding new members on the global stiffness and force distribution should be considered.

7.3.1.1 The design of the repair shall consider the structural interaction between the structure and new members. The effect of the new members on the structure shall be evaluated according to the design-basis code.

7.3.1.1C *The design of the repair should consider connections of new members to the structure. Connections of new members should be designed to transfer design forces between new members and the structure.*

New members may need to be separated from adjacent members to prevent or minimize interaction that may result in damage to adjacent portions of the structure. Transfer of forces between new and existing members should not compromise the performance of the structural system.

7.3.2 Repairs to members shall account for force transfer at the interface between the member and the repair material or repair system. It shall be permitted to use ACI 318-14 to design the force transfer mechanism between new and existing concrete.

7.3.2C *In a repaired member, induced forces on the repaired member are shared between the member and the repair material or system. The repair should be designed to allow for transfer of forces between the components.*

The requirements for composite behavior between the repair and the member may vary depending on the type of repair (structural or nonstructural), the performance criteria at service, and the required strength at the ultimate limit states. While certain designs require composite behavior up to an ultimate limit state, others may be limited to service conditions. Composite behavior can be achieved by chemical bonding, mechanical means, or a combination thereof. The design should specify the repair materials and techniques that will develop the *level of composite behavior to achieve the intended performance of the repaired member. Specific reference is made to ACI 318-14, 16.4 and 22.9, for force transfer requirements between new and existing concrete. Techniques other than shear-friction may be acceptable.*

Design provisions for fiber-reinforced polymer (FRP) are provided in ACI 440.1R, 440.2R and 440.7R (Design provisions for composite structural steel sections are provided in the Steel Construction Manual *(AISC 360-10 Chapter I).*

7.3.2.1 Structural repairs required for strength or stiffness shall maintain composite behavior under service load. The repaired system shall have sufficient redundancy to mitigate the potential for falling hazards in the event that bond between the repair and the substrate is lost.

7.3.2.1C *Non-structural repairs intended to improve durability or aesthetics might not require composite behavior under service loads. Redundancy of the repair material can be provided by the encapsulation of the existing steel reinforcement with the repair material, by installing new anchors within the repair or by other means.*

7.4—Interface Bond

7.4.1 Repair design shall include an analysis to determine the interface shear and tension stresses across bonded interfaces between repair materials and the existing substrate. The interface analysis shall use factored loads in addition to internal forces resulting from restrained volume change to calculate the resultant interface stress demand (v_u) from the transfer of tension and shear.

7.4.1C *The forces acting on the interface between repair material and existing substrate can include tension, shear, or a combination of tension and shear depending on repair geometry and the applied loads. The tensile and shear demand at an interface between a repair material and the substrate from applied loads and from volume changes that occur as a result of shrinkage or thermal movement can be calculated using principles of structural mechanics, but these calculations can be complex. Guidance on designing the interface for horizontal shear can be found in Chapter 16 of ACI 318-14, AISC 360-10, Chapter I and Bakhsh (2010). Repair materials include cementitious and polymer concretes, fiber reinforced concrete, and mortar.*

Where the required nominal interface shear stress is lower than 80 psi, and where good surface preparation, placement and curing techniques, and adequate repair materials are provided, satisfactory composite behavior will likely be achieved without interface reinforcement.

7.4.1.1 Interface shear stress shall be designed based on:

$$v_u \leq \varphi v_{ni} \qquad (7.4.1.1)$$

where v_{ni} is nominal interface shear stress and φ is in accordance with 5.3.2.

7.4.1.2 Testing requirements shall be in accordance with Table 7.4.1.2

Table 7.4.1.2—Testing requirements where v_u is partially or totally resisted by the concrete

v_u	Reference	Testing Requirements
Less than 30 psi	7.4.2	Bond-integrity testing
Between 30 and 60 psi	7.4.3	Quantitative bond strength testing
Greater than 60 psi	7.4.4	Quantitative bond strength testing

7.4.2 If v_u does not exceed 30 psi, interface reinforcement shall not be required. Bond-integrity testing as specified in the construction documents shall be performed.

7.4.2C *The 30 psi bond stress specified by this code is based on half of a nominal shear stress of 80 psi multiplied the strength reduction in 5.3.2.*

A properly prepared substrate is achieved by removing existing deteriorated, damaged, or contaminated concrete. The exposed sound concrete is then roughened and cleaned to allow for adequate bond of a repair material. ICRI No. 210.3 presents a discussion of achievable tensile bond strengths, suggests a minimum value of 100 psi for less critical applications, and indicates that tensile bond test values less than 175 psi that fail at the bond interface or superficially within the existing concrete substrate may indicate a partially damaged, contaminated, or otherwise inadequate bond surface. EN 1504-10 suggests minimum direct tension strengths of 100 psi for non-structural repair and 175 to 215 psi for structural repairs. Interface reinforcement may be needed if sufficient interface capacity cannot be achieved through bond.

Bond integrity testing can consist of various qualitative test methods such as sounding in accordance with ASTM D4580, nondestructive methods such as ground penetrating radar or impact-echo described in ACI 228.2R or ICRI 210.4.

7.4.3 If v_u is between 30 psi and 60 psi, interface reinforcement is not required. Quantitative bond strength testing shall be performed to verify performance. Direct tension pull-off tests (ASTM C1583) or other similar quantitative test methods shall be specified. The frequency of tests and acceptance criteria shall be specified, but the number of tests on a project shall be at least three (3).

7.4.3C *The 60 psi bond stress is based on a nominal shear stress of 80 psi multiplied by the strength reduction in 5.3.2*

Testing to verify the bond of repair materials to the substrate is recommended as part of a quality assurance program on most concrete repair projects. ICRI No. 210.3 provides guidance on *the number of tests that should be performed based upon the repair area and acceptance criteria.*

Bond capacity has primarily been evaluated using direct tension pull-off tests, as defined in ASTM C1583 and as described in ICRI No. 210.3. In some instances, laboratory slant shear tests in accordance with ASTM C882 of cores made in the lab or cores taken from mockups in the field have been used to assist the licensed design professional to make informed design decisions. Slant shear test results typically exceed direct tension pull-off test results, but the slant shear strength is greatly influenced by the compressive stress the test setup introduces across the interface and may not be directly comparable to field conditions. Typically direct shear strengths are larger than direct tension strengths. Comparisons of these tests and other tests, for the purpose of achieving adequate bond is discussed in Bakhsh (2010). It generally is adequate to assume that the repair to substrate bond will resist an interfacial shear equal to the direct tensile pull-off test result.

If failure during direct pull-off testing occurs at the bond line, it may indicate inadequate surface preparation of the concrete substrate or the substrate surface was damaged by the surface preparation method (bruising of the substrate) Modifications to the surface preparation procedures may improve the tensile bond strength. Discussion of proper methods for surface preparation can be found in ACI 546R and ICRI 310.2R.

7.4.4. If v_u exceeds 60 psi, interface reinforcement shall be provided.

7.4.5 If v_u is completely resisted by interface reinforcement, quantitative bond strength testing is not required.

7.4.5C *This provision provides an alternative to bond strength testing.*

7.4.6 Interface reinforcement shall be designed in accordance with ACI 318-14, 16.4.4 through 16.4.7.

7.4.7 Construction documents shall specify testing requirements for interface reinforcement in the repair applications.

7.4.7C *Testing to verify the performance of the interface reinforcement to transfer horizontal shear can be performed in accordance with the recommendations contained in ACI 355.2 and 355.4. Specific requirements for testing of ties should be included in a quality assurance plan.*

Direct tension testing of post-installed interface reinforcement is recommended to provide verification of the installation. Guidance to determining the number of tests and acceptance criteria of the direct tension testing is similar to principles used in developing direct tension pull-off testing requirements described in ICRI 210.3.

7.5—Materials

7.5.1 Design of the repair system shall consider the properties and installation of the repair materials and systems. These include, but are not limited to: physical properties of the repair materials, type of application, adhesion, volume stability, thermal movement, durability, corrosion resistance, installation methods, curing requirements, and environmental conditions.

7.5.1C *Physical properties include mechanical, chemical, and electrical properties. Documentation should be obtained for properties of each repair material. The stated properties should be verified that they satisfy the project requirements. ACI and ICRI provide guidelines for the selection of repair materials (ACI 301, ACI 318-14, ACI 503R, ACI 503.5R, ACI 503.6R, ACI 506R-05 ACI 546.3R, ICRI No. 320.2R, ICRI No. 320.3R, ICRI No. 330.1, and ICRI No. 340.1). The design of a repair should consider the compatibility of the repair materials and the materials of the existing structure. Compatibility of repair materials and systems include volume stability, bond compatibility and durability, mechanical compatibility, and electrochemical and permeability compatibility. Generally, the intent is to use a repair material or repair system that has physical, mechanical, and other properties that are as close as possible to those of the parent material to provide long-term performance.*

Individual repair materials may have different properties yet will perform satisfactorily when combined in a repair system. An example of this is where materials with differing thermal coefficients of expansion may be used, provided that the overall performance of the system is not affected by thermal changes.

Volume stability is often estimated as changes in a linear dimension of the repair and should be considered in the design of a repair system. Autogenous shrinkage, chemical shrinkage, degree of restraint, environmental conditions, drying shrinkage, creep, thermal changes, moisture absorption, and other factors all affect volume stability. Experience has shown that volume change of repair materials has often been the cause of poor performance of repairs. Properties of repair materials should be selected for volume stability with the structure to reduce the probability of cracking caused by volume changes.

Volume stability is discussed in ACI 209R, ACI 209.1R, ACI 546.3R, and ICRI No. 320.2R.

Repair materials such as portland-cement concrete, portland-cement mortar, polymer-cement concrete, polymer concrete, fiber-reinforced concrete, resin-based materials, and similar products are commonly used. Repair materials might not necessarily contain portland cement, but should be selected to achieve the necessary service, strength, and durability requirements.

The selection of reinforcement material should consider the durability, performance at elevated *temperatures, and ductility. Electrical and chemical reactivity between the reinforcement, the repair material, and the existing reinforcement should also be considered.*

Refer to ACI 440.1R for internal FRP reinforcement, ACI 440.2R for externally bonded FRP reinforcement, and ICRI No. 330.1 and ACI SP-66 (ACI Committee 315 2004) for steel reinforcement.

Required properties of the repair reinforcement should be specified in the construction documents. Specified reinforcement properties are dependent on the requirements of the repair and may include physio-chemical (for example, glass transition temperature, and coefficient of thermal expansion) as well as mechanical properties (for example, ultimate strength, tensile modulus, and ultimate elongation).

7.5.2 Materials in a structure shall be permitted to remain if such materials are performing satisfactorily.

7.5.3 Materials permitted by ACI 318-14 or permitted by this code shall be used for repairs and alterations.

7.5.4 Alternate materials shall be permitted following approval in accordance with 1.4.

7.6—Design and detailing considerations

7.6.1 Repair design shall be based upon the member conditions in Chapter 6.

7.6.2 *Concrete*—The in-place properties of the concrete, in accordance with Chapter 6, shall be used in the repair design.

7.6.2C *The extent and cause of deterioration and the concrete strength and quality should be assessed, including compressive strength, chlorides, carbonation, sulfate attack, alkali-silica reaction, physical damage, corrosion-induced spalling, and cracking.*

Chloride penetration can cause corrosion that can lead to cracking and spalling. The depth of a spall reduces the effective area of concrete section. Degradation of the concrete affects the concrete compressive strength.

7.6.3 *Reinforcement*

7.6.3.1 Reinforcement that is damaged or corroded shall be permitted to remain. The effective cross-sectional area of remaining reinforcement shall be permitted to be used in the repair design in accordance with the design basis code. The effect of corrosion damage on development of steel reinforcement shall be considered; where original deformations are no longer effective, reinforcing bars shall be considered as smooth bars.

7.6.3.1C *Repair design should consider the in-place condition of the reinforcement, including the effective cross-sectional area of the reinforcing bars. The effective area is calculated* *using the remaining effective diameter of the reinforcing bar accounting for the loss of section due to corrosion. Further considerations may also include the location of the corroded areas, loss of confinement, the loss of bond, and the effect of corrosion on member strength. If the structure is fire damaged, steel reinforcement may be annealed, and the yield strength reduced. Refer to ACI 216.1R for additional guidance. Durability requirements related to corroded reinforcement are addressed in 8.4 and ACI 364.1R. CRSI (2014) provides information on older reinforcement systems*

7.6.3.2 Design shall consider the location and detailing of the reinforcement in accordance with the evaluation requirements of Chapter 6.

7.6.3.2C *The location and detailing includes the horizontal and vertical positions, orientation, geometry of the reinforcement, development of reinforcement, and the presence of hooks and crossties. Field examination to locate reinforcement may be required.*

7.6.3.3 Both existing and new reinforcement shall be adequately developed. Development length shall be permitted to be calculated based upon development in both the existing concrete and new materials and in accordance with the design basis code.

7.6.3.3C *Reinforcement development may be inadequate due to corrosion, mechanical damage, insufficient or loss of concrete cover, delaminated concrete, concrete strength, or other conditions. The design of the repair should evaluate the required development length. Detailing of the repair should include the proper development of new reinforcement to achieve the design force. ACI 318-14 provides development equations and requirements for detailing of steel reinforcement. ACI 440.1R and ACI 440.2R provide detailing guidance for internal FRP reinforcement and externally bonded FRP reinforcement, respectively. Additional information can be found in FIB Bulletin No. 10.*

7.6.4 *Prestressed structures*

7.6.4.1 The effects of prestressing shall be included in the repair design.

7.6.4.1C *Requirements for repair of structures with bonded and unbonded prestressing are different. Post-tensioned structures (with bonded and unbonded tendons) are often cast-in-place monolithic structures, whereas pretensioned structures (with bonded strands) are often single-span precast structures. Each system is unique and should be individually considered. The repair of prestressed structures requires a condition assessment of the existing tendons. Repair of unbonded tendons may require tendon detensioning. Guidance for analysis, evaluation methods and repair techniques of unbonded post-tensioned structures is provided in ACI 423.4R, ACI 222.2R, ICRI No. 210.2, ICRI No. 320.4, and PTI DC80.2-10 and DC 80.3-12.*

7.6.4.2 The effects of modifications to existing structure geometry, damage conditions, loss of prestressing force, and repair sequence shall be included in the repair design.

7.6.4.2C *Analysis to evaluate the effects of structural modifications should verify that strength is adequate and that all serviceability conditions (for example, deflection limits) are satisfied.*

Analysis of prestressed structures is required to evaluate the effect of damaged or severed prestressing reinforcement on structural strength and performance. The effect of a severed bonded tendon is typically localized because the severed tendon is effective after a development length is achieved and the full strength of the tendon is reestablished. For structures with bonded tendons, shoring, if necessary, may only be required locally at the repair area.

Review of grouting quality assurance and supervision documents should be performed to evaluate grouted tendons in advance of any repair or rehabilitation of bonded post-tensioning systems. The presences of voids, moisture in ducts, chlorides or extent of carbonation need to be identified in the existing grout. Methods for evaluation of chloride-ion content are listed in ASTM C1152M, ASTM C1218, and AASHTO T260. Field evaluation of grout may be required even if documentation of the original construction is available.

Unbonded tendons are designed to be permanently debonded from the member and often extend over multiple spans. As a result, damage or discontinuity of a tendon at one location will reduce the strength for the entire length of the tendon.

If unbonded tendons are severed, the prestressing force is assumed to be lost for the full length of the tendon. Releasing or cutting tendons may affect multiple spans and may require shoring beyond the area where cutting or releasing of tendons occurs. Adjacent spans may require temporary shoring depending on the number of tendons severed at one time and the applied loads. Analysis based on actual loading at the time of the modification may show shoring to be unnecessary.

Repair and structural modification may require detensioning of prestressing tendons. Unbonded tendons should be detensioned in a controlled manner to ensure performance and safety. Unless not needed based on analysis, unbonded tendons should be reanchored and restressed to restore required structural strength. Cut or damaged unbonded tendons can be restored by splicing or by installing new tendon with anchors at intermediate locations, at the end of the structural member or the edge of any new openings.

The stressing force in a repaired tendon depends on the condition and type of the repaired post-tensioned system and in certain cases this force can be less than the original force if considered acceptable by structural analysis.

Further discussion of this topic can be found in PTI DC80.3-12/ICRI 320.6 (2012)

Corrosion on prestressing strands for bonded and unbonded post-tensioned systems may have an effect on strand integrity and strength. Prestressing strands require examination for conditions such as corrosion pitting and hydrogen embrittlement (refer to ICRI No 210.2 and ACI 222.2R).

If repairs to prestressed slabs or beams result in increased concrete tensile stress (i.e. changing the classification of the prestressed flexural member as defined in ACI 318-14), impacts of the repair scheme on serviceability should be evaluated.

7.6.4.3 Stresses in remaining section after concrete removal during repair shall not exceed the limits established in the design basis code.

7.6.4.3C *Removing surface concrete from a prestressed member may cause excessive compressive and tensile stress in the remaining concrete section and may alter secondary forces and moments due to prestressing in indeterminate structures. This condition is more critical for prestressed joists and girders that have a relatively small section and large prestressing force. Slabs are less critical due to the relatively small initial precompression. This change is acceptable as long as durability and strength are addressed as part of the repair design. The impact of removing concrete from a post-tensioned structure is addressed in Scollard and Bartlett (2004). ICRI No. 320.4 provides guidance for removing concrete around anchors and splices to prevent catastrophic loss of anchor.*

7.6.5 *Anchoring to concrete*—Post-installed anchors and dowels shall be designed to transfer design forces to the substrate considering possible anchor failure modes and the condition of the substrate into which the anchor is installed. The design of post-installed anchors shall be in accordance with ACI 318-14.

7.6.5C *The design of post-installed anchors requires careful consideration of the loads to be resisted. Anchors should have adequate strength to transfer design forces across all interfaces and into the existing member. All possible anchor failure modes should be considered to determine the design strength. Anchors should be selected considering the expected concrete substrate cracking condition. For example, post-installed anchors used in the tension zone of concrete members and in structures located in regions of moderate or high seismic risk should be able to transfer the design seismic forces assuming a cracked concrete condition.*

Design of post-installed anchors is provided in ACI 318-14, Chapter 17, which includes provisions that require performance of post-installed anchors in both cracked and uncracked concrete. ACI 355.2 and 355.4 provide the standard required for qualifying post-installed anchors in cracked and uncracked concrete.

Specifications for post-installed anchors should include installation, testing, and inspection procedures.

For post-installed expansion or undercut anchors, manufacturer's installation instructions specify procedures for drilling, hole cleaning, installation, torque magnitude, and procedures to engage the anchor.

For adhesive anchors and dowels, hole cleaning and moisture conditions are critically important. Manufacturer's printed installation instructions should specify procedures for drilling, hole cleaning, installation, and the care to be taken until the adhesive has cured.

Testing and inspection of post-installed anchors should be specified in the construction documents. Many building codes require that adhesive anchors be installed under special inspection procedures to ensure that the installation is correctly performed in accordance with the design and manufacturer's procedure. Refer to ACI 318-14 Chapters 17 and 26 for specific inspection requirements for post-installed anchors

7.6.6 *Repair geometry*—Configuration of repairs shall consider the potential for stress concentrations and cracking in both the existing structure and the repair area.

7.6.6C *Repair shapes with sharp reentrant corners can cause stress concentrations that may result in cracking. Long, slender (high aspect ratio) repair areas also may result in cracking. The shape of the repair should be considered to reduce stress concentrations and possible cracking. Methods discussed in ICRI No. 310.1R provide guidance to reduce cracking in concrete repairs including providing a uniform depth of edges and substrate, repair geometry, surface preparation, concrete removal below reinforcement (undercutting) and elimination of feather edge repairs.*

7.7—Repair using supplemental post-tensioning

7.7.1 Supplemental post-tensioning shall be permitted for repair of structures.

7.7.1C *Supplemental post-tensioning can be applied to the structure externally, internally, or both.*

7.7.2 Design of the repair shall include the effects of the supplemental post-tensioning on the behavior of the structure.

7.7.2C *Supplemental post-tensioning can introduce moment, shear, and axial forces within the structure that should be considered in the design and detailing of the repair. The internal forces induced by the supplemental post-tensioning can be significant. For statically indeterminate structures, restraint to post-tensioning deformations can result in significant internal forces. Refer to ICRI 330.1 for selecting strengthening systems for concrete structures.*

7.7.2.1 Stresses due to supplemental post-tensioning shall be combined with existing stresses and the total shall not exceed the limits in the design basis code.

7.7.2.1C *Adding supplemental post-tensioning to a prestressed member may cause excessive compressive and tensile stress and may alter secondary forces and moments. External post-tensioning may result in changing the classification of prestressed flexural members as defined in ACI 318-14 Section 24.5.2. This change is acceptable as long as durability and strength are addressed as part of the repair design.*

7.7.2.2 Design of supplemental post-tensioning shall provide for the transfer of post-tensioning forces between the post-tensioning system and the structure. Design of concrete supplemental post-tensioning anchor zones shall be in accordance with ACI 318-14. Design of steel brackets and supplementary structural steel shall be in accordance with ANSI/AISC 360-10.

7.7.2.2C *Anchors for new post-tensioned reinforcement should be designed and detailed for the transfer of post-tensioning forces to the existing structure. Bearing, spalling, and bursting forces created at anchor zones should be considered. Strut-and-tie modeling, as given in ACI 318-14 Section 25.9, may be used to design post-tensioning anchor zones.*

7.7.3 Provisions shall be made for effects of post-tensioning, temperature, and shrinkage on adjoining construction, including immediate and long-term deformations, deflections, changes in length, and rotations due to prestressing.

7.7.3C *The post-tensioning may be restrained by adjacent stiff members such as walls, and reduce the effect of the prestressing on the intended member or have unintended effects on the adjacent construction.*

7.7.4 Post-tensioning losses shall be included in the design of supplemental post-tensioning systems.

7.7.4C *Losses include wedge seating in the anchor; elastic shortening; creep of original concrete; shrinkage of original concrete; creep of repair material; shrinkage of repair material; prestressing relaxation; and friction and wobble between the post-tensioning reinforcement and ducts, bearings, or deviators. Assessment of losses of supplemental post-tensioning force should consider the existing conditions of the repaired elements, as the members may have already experienced time-dependent creep and shrinkage.*

7.7.5 Construction documents shall specify the repair sequence, including tendon placement, anchors, and stressing of the post-tensioned system.

7.7.5C *Repair design using supplemental post-tensioning systems should include construction documents for installation sequence including shoring, removal of concrete, placement of new material and reinforcement, additional anchor requirements, horizontal shear transfer* *requirements, curing, and stressing. Installation of supplementary post-tensioning involves application of significant forces, which may require project safety and protection procedures by the installer. Refer to 8.4.1 for corrosion protection requirements.*

7.7.6 Structural members repaired or modified with externally installed unprotected post-tensioning shall have adequate unrepaired strength, in accordance with 5.5.

7.7.6C *Unless protection of the post-tensioning strengthening system is provided to prevent sudden failure of the member in case the external post tensioning reinforcement is damaged or becomes ineffective (such as in an extraordinary event like fire or impact), the structural member should have adequate strength without the post-tensioning reinforcement to support factored loads, as defined for extraordinary events in Chapter 5.*

7.8—Repair using fiber-reinforced polymer (FRP) composites

7.8.1 Fiber-reinforced polymer composites in conformance with ACI 440.6-08 and ACI 440.8-13 shall be permitted to repair concrete structures.

7.8.1C *Fiber-reinforced polymer fabrics, bars, or shapes can be used as externally bonded reinforcement, internal reinforcement, and as internal or external prestressed reinforcement. FRP shapes may be used as additional stand-alone structural members. Design and detailing of externally bonded FRP systems should be consistent with ACI 440.2R. Particular attention should be given to strength increase limits, service limits, and determination of FRP material design properties.*

Design and detailing of internal FRP reinforcement should be consistent with ACI 440.1R. Particular attention should be given to service limits and determination of FRP material design properties.

If internal prestressed FRP reinforcement is used, the design and detailing should be consistent with ACI 440.4R.

FRP systems should only be installed in or on sound concrete. Concrete distress, deterioration, and corrosion of reinforcing steel should be evaluated and addressed before the application of the FRP system. Surface preparation requirements should be based on the intended application of the FRP system. FRP applications can be categorized as bond-critical or contact-critical. Bond-critical applications, such as flexural or shear strengthening of beams, slabs, columns, or walls, require an adhesive bond between the FRP system and the concrete. Contact-critical applications, such as confinement of columns, only require intimate contact between the FRP system and the concrete. Contact-critical applications do not require an adhesive bond between the FRP system and the concrete substrate, although one is often provided to facilitate installation. ACI

440.2R provides descriptions of FRP applications and surface preparation and repair requirements.

For bond critical applications, the concrete substrate should possess the necessary strength to develop the design forces of the FRP system through bond. The substrate, including all bond surfaces between repaired areas and the original concrete, should have sufficient direct tensile and shear strength to transfer force between the existing substrate and FRP system. The tensile strength of the substrate should be at least 200 psi as determined by a pull-off type adhesion test per ASTM D7522. Contact-critical applications are not required to meet this minimum bond value as the design forces of the FRP are developed by deformation or dilation of the concrete section.

For bond-critical applications, the concrete surface should be prepared to a minimum concrete surface profile (CSP) 3 as defined by the ICRI 310.2. In contact-critical applications, surface preparation should promote continuous intimate contact between the concrete surface and the FRP system. Surfaces to be wrapped should, at a minimum, be flat or convex to promote proper loading of the FRP system.

FRP systems should not be applied to damp or wet surfaces unless the epoxies are formulated by the manufacturer for such applications. Moisture content of the concrete substrate should be evaluated before application of the FRP system as it may inhibit bonding between the concrete substrate and epoxy polymer. Surface moisture should not exceed the limits established by the manufacturer. Testing for presence of moisture should be done in accordance with manufacturer's written recommendations or one of the following: ASTM D4263 – Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method; AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 1st Edition; ACI 548.1R; ASTM F1869 – Standard Test Method for Measuring Moisture Vapor Emission Rat (MVER) of Concrete Subfloor Using Anhydrous Calcium Chloride; ASTM F2170 – Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes; or ASTM F2420 Standard Test Method for Determining Relative Humidity on the Surface of Concrete Floor Slabs Using Relative Humidity Probe Measurements and Insulated Hood.

The surfaces to receive moisture testing and the testing equipment should be acclimated near the relative humidity levels and temperatures that the design is anticipated to have in service. Variation between testing and in-service conditions may provide inaccurate or misleading testing results

7.8.2 Structural members repaired or modified with externally-applied FRP composites shall have adequate unrepaired strength, in accordance with 5.5.

7.8.2C *Unless protection of the strengthening system is provided, to prevent sudden failure of the member in case the FRP system is damaged or becomes ineffective (such as in an extraordinary event like fire or impact), the structural member should have adequate strength without the FRP reinforcement to support factored loads, as defined for extraordinary events in Chapter 5. The design and use of externally bonded FRP may be limited by the service requirements of the repaired member.*

7.9—Performance under fire and elevated temperatures

7.9.1 Design of the repair system shall consider elevated temperature performance and shall comply with the fire resistance ratings of the structural members and other fire safety requirements in accordance with the design basis code.

7.9.1C *Regardless of the repair system, performance of the repaired element under fire and elevated temperatures should be evaluated and the system should be detailed and material selected to provide adequate protection. The repaired elements should comply with applicable building code requirements and relevant fire regulations valid at the project location. Structures renovated for different use or strengthened to support higher loads may require a more stringent fire rating than the original structure. Other requirements such as flame spread and smoke density should also be considered in accordance with the general existing building code and ASTM E84.*

7.9.2 It shall be permitted to design a repair without supplemental fire protection if the unrepaired member has adequate strength considering the reduced material properties due to fire exposure in accordance with 5.5.

7.9.2C *A repair system can be selected without additional fire protection provided that the existing unrepaired member has adequate strength to support the loads, as defined in 5.5, during a fire event. Fire performance requirements and evaluation procedures are outlined in ACI 216.1, ACI 318-14, ACI 440.2R, ASCE/SEI/SFPE 29-05, and* AISC Design Guide 19 *(Ruddy et al. 2003).*

7.9.3 The properties of the specified repair materials at elevated temperatures shall be considered.

7.9.3C *Repair material specifications should comply with the requirements of relevant fire regulations valid at the project location. If there is a conflict between the properties of specific products or systems and fire regulations, alternative repair principles or methods should be used to avoid such a conflict. In general, polymer mortar and polymer concrete have higher coefficients of thermal expansion and higher resistance to water vapor transmission and lower resistance to fire and elevated* *temperatures compared to cementitious alternatives.*

7.9.4 Repairs using adhesives shall consider their performance at elevated temperatures.

7.9.4C *ACI 440.2R reports that the physical and mechanical properties of the resin components of FRP systems are influenced by temperature and can degrade at temperatures close to and above their glass-transition temperature T_g. An acceptable service temperature for FRP is established by ACI 440.2R as $T_g - 27°F$. This value accounts for typical variation in test data for dry environment exposures. Adhesive-bonded FRP reinforcement should not be used if the maximum service temperature exceeds $T_g - 27°F$. A service temperature exceeding this limit temperature should be addressed using an adhesive system with a higher T_g value, using heat protection or insulation systems or using alternate repair systems.*

Adhesive-based repair systems can be considered effective during a fire event if a fire protection system with an established fire rating is used that maintains the temperature of the adhesive-based system below its glass transition temperature. In the absence of an established fire rating, detailed fire analysis may be used to establish a fire rating of the repaired system.

7.9.5 Supplemental fire protection to improve the fire rating of repaired systems shall be permitted.

7.9.5C *Standard fire protection systems can be used to increase the fire rating of repaired systems. National codes and professional organizations list generic ratings for concrete structural members, giving the minimum thickness of concrete cover needed to protect the main steel reinforcement from fire effects (IBC 2015; NFPA 5000 2015; PCA 1985, 1994). In addition to increasing the cover thickness, fire performance of reinforced and prestressed concrete members may be enhanced by fire protection systems as proven by fire testing or analytical methods (ACI 216.1). Concrete cover for nonmetallic reinforcement may need to exceed cover for steel reinforcement to achieve the same fire resistance rating.*

7.9.6 Fire rating of repaired systems, based on ACI 216.1, shall be permitted.

7.9.6C *The fire rating of a repaired system or assembly can be determined in accordance with ACI 216.1, which requires the application of the expected service load to the test specimen. The applied load should reflect the use of the tested member in terms of magnitude and layout.*

The criteria for evaluating a structure for fire safety are different than those for strength design and typically incorporate lower material strengths and load factors, and may not require the use of strength reduction factors. The licensed *design professional should verify that the fire-reduced strength of the member exceeds the force demand due to expected service loads during the fire event. The fire-reduced strength should be based on reduced material strengths for the maximum expected temperature in a fire event, which can be determined in accordance with ASTM E119 and ACI 216.1.*

Section 1.2 of ACI 216.1 allows alternative methods to assess the fire resistance of assemblies. The fire reduced strength as well as the effect of fire protection system on the overall performance and fire rating of an existing and repaired element can also be determined utilizing available design models and finite element numerical procedures. Descriptions of the detailed analytical methods can be found in Buchanan, (2001) and Technical Report No. 68 (2008) by the Concrete Society.

CHAPTER 8—DURABILITY

8.1—General

8.1.1 Durability of materials incorporated into a repair shall be considered for individual repairs, the overall durability of the repaired structure, and the interaction of the repair system with the structure.

8.1.1C *The durability of materials incorporated into a repair depends on their ability to withstand the environment where they are installed. The durability of repairs is dependent on the compatibility between repair materials, the structure, and the surrounding environment. To achieve compatibility, the repair and the structure need to interact on several levels without detriment, including chemical, electrochemical, and physical behavior.*

8.1.2 Repair materials and methods shall be selected that are intended to be compatible with the structure, and are durable within the service environment. Anticipated maintenance shall be considered in the selection.

8.1.2C *The design service life of a structure and repaired members is established by the licensed design professional in consultation with the Owner to achieve an economical repair that satisfies strength, safety, and serviceability requirements. Only through satisfactory repair construction practices, including application of the specified repair materials, is it possible to achieve the design service life. The design service life of the structure and repaired members, including maintenance requirements, should be estimated by considering the durability of the materials. Such design service life should be reflected in the repair design and maintenance requirements, as well as be incorporated into the construction documents. A repaired section is considered to be the combination of the installed repair material(s) and the substrate material(s). Service life is discussed in ACI 365.1R.*

Some examples of end-of-service life include:

a) Structural safety is unacceptable due to material degradation or the nominal strength is less than the required strength.

b) Maintenance requirements exceed resource limits.

c) Aesthetics become unacceptable.

d) Structural functionality is no longer sufficient.

e) Deformation capacity of the structure has been degraded due to a seismic event.

The cause of degradation should be determined as a first step in predicting each type of service life. Causes of degradation include:

a) Mechanical (abrasion, fatigue, impact, overload, settlement, explosion, vibration, excessive displacement, loads, or ground motion from a seismic event) *b) Chemical (alkali-aggregate reaction, sulfate attack, acid dissolution, soft water leaching, or biological action)*

c) Physical (freezing and thawing cycles, scaling, differing coefficients of thermal expansion, salt crystallization, radiation exposure [ultraviolet light], fire, or differential permeability between materials)

d) Reinforcement corrosion (carbonation, corrosive contaminants, dissimilar metals, stray currents, or stress corrosion cracking)

Preparation methods, materials, placement, and installed systems should be defined in the construction documents to reflect the design intent and requirements to achieve compatibility.

Repaired sections should be resistant to expected service conditions that can result in degradation, including the causes of degradation listed previously within the design service life, and combinations of these causes.

Repaired sections should be resistant to:

a) Chlorides and other corrosive contaminants that are present in the concrete or the penetration of corrosive contaminants into the concrete (such as chlorides) that lead to corrosion of reinforcement or other embedments (8.4).

b) Thermal exposure and cycles.

c) Freezing-and-thawing damage if subject to saturation and a freezing-and-thawing environment. ASTM C666 may be used to define a durability factor. A durability factor exceeding 80 percent has generally been found to be acceptable in many locations for resistance to freezing and thawing for cementitious materials (refer to ACI 546.3R).

d) Scaling if exposed to salts.

e) Exposure to ultraviolet or other radiation degradation within the repair environment unless other means are provided to address such degradation.

f) Fatigue resulting from loading cycles and load reversal. For example, fatigue resistance may be needed in repair areas subject to many cycles of repeated loading.

g) Impact, erosion, and vibration effects if exposed to conditions causing deterioration by these mechanisms.

h) Abrasion resistance of repaired sections subject to heavy traffic, impingement of abrasive particles, or similar conditions.

i) Chemical exposure may include sulfate attack, acids, alkalis, solvents, leaching of cementitious materials due to soft water, salt crystallization, and other factors that are known to attack or deteriorate the repair material or concrete substrate. Water penetration into concrete is associated with many types of chemical attack and other deterioration mechanisms.

j) The carbonation susceptibility, depth, and rate of both the existing concrete and the repair material in repairs containing reinforcement or other embedments requiring alkaline passivation of the metal for protection from corrosion (refer to 8.4).

k) Alkali-aggregate reactions.

l) Differential permeability between the repair and existing concrete if the repair material or the substrate concrete is vulnerable to deterioration due to trapped moisture, such as freezing-and-thawing damage of saturated concrete, corrosion of embedded steel reinforcement, alkali-aggregate reactions, or sulfate attack (refer to ACI 546.3R).

8.2—Cover

8.2.1 Concrete cover shall be in accordance with the design basis criteria. For alternative materials and methods, an equivalent cover that provides sufficient corrosion protection shall be approved in accordance with 1.4.2. Sufficient anchorage and development for the reinforcement shall be provided regardless of methods used to provide corrosion protection.

8.2.1C *The code language is intended to allow materials that provide equivalent cover to be used if they can be demonstrated to be effective according to the approval procedure detailed in 1.4.2. If alternative methods of corrosion protection are used, anchorage and development lengths should be reviewed.*

8.2.2 *Corrosion*—Where concrete cover for existing reinforcement is insufficient to provide corrosion protection for the design service life of the structure, additional concrete cover or an alternate means of corrosion protection shall be provided to mitigate corrosion of reinforcement within the repair area.

8.2.2C *Alternative means of protecting reinforcement include the application of waterproof membranes (ACI 515.2R Guide to Protective Systems), corrosion inhibitors, and various forms of cathodic protection. Reinforcement corrosion, chloride contamination, and carbonation should be considered when evaluating the maintenance requirements and design service life of alternative methods for corrosion protection. Ongoing metal corrosion may create distress and deterioration beyond the limit of the repair area. The design service life requirements should be reviewed when widespread durability issues are considered. Issues related to concrete cover need to be addressed in a timely manner.*

8.3—Cracks

8.3.1 The cause(s) of cracks shall be assessed, and mitigating cracking shall be considered in the rehabilitation design.

8.3.1C *Cracks can reduce the protection provided by the effective cover over steel reinforcement and lead to water and deleterious material ingress, which accelerates the deterioration of embedded reinforcement and can cause other concrete deterioration issues such as freezing-and-thawing deterioration, alkali-aggregate deterioration, and chemical attack. Identification of their cause(s) and evaluation of their impact on a structure or a concrete component is described in ACI 224.1R.*

As part of a repair design, cracking mitigation methods should consider the causes, movement, size, orientation, width, and complexity of the network of cracks. The characteristics of the substrate, location, and evidence of water transmission should be determined to assess the appropriate method of repair. Active water infiltration should be corrected as required for the durability of the structure.

8.3.2 The design of repairs shall consider the effects of cracks on the expected durability, performance, and design service life of the repair and structure as a whole.

8.3.2C *Not all cracks need to be repaired, however, all cracks have the potential to become active cracks. Cracks in concrete structures can be detrimental to the long-term performance of a structure if the cracks are of sufficient size to allow for the ingress of deleterious materials into the structure, and guidance for critical crack sizes is provided in ACI 224R, Table 4.1. Consideration should be given to post-repair cracking and the need for protection of the existing concrete and repair material from the ingress of deleterious materials. ACI 224.1R provides guidance for the prevention and control of cracks.*

There are a variety of different materials that have been used for crack repair, and their correct specification for a given application will govern the design service life of the repair. For cracks that are essentially acting as a joint or are active, one type of effective repair is to seal the crack with an elastomeric sealant. Materials used for crack injection include, epoxy, polyurethane, latex in a cement matrix, microfine cement, and polymethacrylate. For repair by crack injection, the process and material should be appropriate to the site conditions. Crack injection should not be used to repair cracks caused by corrosion of steel reinforcement and alkali aggregate reaction unless supplemental means are employed to mitigate the cause of the cracks.

8.4—Corrosion and deterioration of reinforcement and metallic embedments

8.4.1 The corrosion and deterioration of reinforcement and embedded components shall be considered in the durability design. Repair materials shall not contain intentionally added constituents that are corrosive to reinforcement within the repair area.

8.4.1C *Untreated reinforcement corrosion limits the life expectancy of repair areas, repair materials, and repaired structures. ICRI No. 310.1R provides guidelines on removal of damaged concrete and cleaning of reinforcing steel. Repairs that do not address reinforcement corrosion may negatively impact the design service life and require more intensive monitoring. The structural design considerations for corroding reinforcing steel on repairs are described in 7.6.3.1.*

8.4.2 The impact on the design service life of the repaired structure shall be considered if it is anticipated that corrosion products cannot be removed during repair.

8.4.2C *Ideally corrosion products should be removed from reinforcing steel in repairs. In some situations, due to congestion of steel reinforcement, access limitations, load considerations, or other factors, it is not possible to remove corrosion products from the steel reinforcement. Situations exist where corroding reinforcement that cannot be adequately cleaned or repaired will remain in the repaired structure.*

The effects of uncleaned reinforcing steel on the long-term durability of the repaired structure should be considered in these situations. Supplemental corrosion mitigation strategies may be needed in these situations.

8.4.3 The quality of existing concrete and its ability to protect reinforcement from corrosion, fire and other forms of damage and deterioration shall be considered.

8.4.3C *Water and chemical penetration into the concrete can cause corrosion of metallic embedments and damage to nonmetallic reinforcement. Where concrete cover over reinforcement is insufficient to provide corrosion protection for the design service life of the structure, additional concrete cover or an alternate means of corrosion protection should be provided to mitigate reinforcement corrosion.*

The corrosion of embedded metals adjacent to the repair may be accelerated due to differing electrical potential between electrically continuous reinforcement in the repair area and external to the repair area. This form of corrosion is commonly referred to as the "anodic ring" or "halo effect", and is discussed in ACI 546R, ACI 364.3T, and ACI RAP BULLETIN 8 (Whitmore 2006). The rate of anodic ring corrosion depends upon the chloride content, internal relative humidity, and temperature.

The anodic ring effect that can be induced by certain repairs should be addressed by incorporating appropriate corrosion mitigation strategies such as cathodic protection or corrosion inhibitors. ACI 222R, ACI 222.3R, ACI 364.3T, ACI 546R and the Concrete Society Technical Report 50 and FAQ sections from Concrete International (2002a, b, c) provide guidance for corrosion prevention, mitigation and inhibition. Both carbonation and chloride *contamination may require consideration and are discussed in ACI 546R.*

Aesthetics may be affected by different means of protection and may also require consideration. Damage due to fire and fire protection requirements are discussed in 7.9.

8.4.4 Existing steel reinforcement and added reinforcement shall be protected from corrosion, fire and other forms of damage and deterioration to satisfy durability requirements.

8.4.4C *Reinforcing steel in concrete construction is usually protected by concrete cover from deleterious materials and also provides fire protection. The minimum cover is typically required by the design basis criteria. Adequate protection may be provided by increased section thickness and appropriate coatings, such as sealers, intumescent coatings, or electrochemical methods.*

8.4.5 Galvanic corrosion between electrochemically dissimilar materials shall be considered.

8.4.5C *Reinforcement or metallic embedments in the repair area with differing electrochemical potentials, environments, or both, should be isolated from the existing reinforcement, or the existing reinforcement and metal embedments should be protected to minimize galvanic corrosion. For example, rail or post-pocket repairs that use dissimilar metals from conventional steel reinforcement could accelerate the deterioration of the installation (refer to ACI 222R).*

8.4.6 Corrosion protection of bonded and unbonded prestressing materials and prestressing system components shall be addressed during the repair design.

8.4.6C *The presence of prestressing force in the steel and the need to transfer the prestressing force into the concrete makes corrosion damage in prestressed concrete members more critical than traditionally reinforced structures (refer to ACI 423.4R). Section 7.6.4 addresses the structural requirements for the repair.*

The bonded or unbonded nature of the prestressing steel, the condition of the steel at the repair area, the attachment of the steel to the structure, the as-designed corrosion protection measures, the existing corrosion condition, and the continuity of the prestressing steel need to be considered to address corrosion protection of the structure. Refer to ICRI 320.4, and 222.2R.

Hydrodemolition and other types of material removal methods should be used cautiously if the structure contains unbonded prestressing steel reinforcement. In these situations, water can be introduced into the corrosion protection (sheathing) surrounding the steel (refer to ICRI No. 310.3), affecting the long-term durability of the prestressing steel reinforcement.

8.4.7 If electrochemical protection systems are used to protect steel reinforcement in repair areas and structures, the interaction of the protection system with the repaired elements, the entire structure, and environment shall be considered.

8.4.7C *Structures using impressed current electrochemical protection or mitigation systems should have continuous reinforcement, separate zones, or provisions should be made to make the steel electrically continuous. Impressed current electrochemical protection systems should be designed and maintained to not promote an alkali-aggregate reaction (AAR) and to avoid embrittlement of prestressing steel.*

Impressed current electrochemical protection systems should include a monitoring and maintenance plan developed by a licensed design professional specializing in the design of corrosion protection systems (refer to NACE SP0290, NACE SP0390, NACE 01105, NACE 01102, NACE 01101, NACE 01104, and NACE SP0107).

8.4.8 Repair materials and reinforcement shall be selected and detailed to be compatible such that the characteristics of each material do not adversely affect the durability of the other materials or of the existing concrete and reinforcement.

8.4.8C *Incompatibilities can arise from the use of inappropriate materials or components, or dissimilar electrochemical characteristics or physical properties, which can negatively impact the concrete and reinforcement. Some examples include:*

a) In certain situations such as exposure to high temperatures, polyvinyl chloride (PVC) and other polymer-based materials can deteriorate, releasing decomposition products found to cause corrosion.

b) Even if the conventional steel reinforcement becomes more noble in electrical contact with a dissimilar metal (for example, embedded aluminum conduit in the presence of chlorides), considerable concrete damage can arise (Monfore and Ost 1965).

c) Fiber-reinforced polymer (FRP) wrapping should not be used as a corrosion repair strategy on members experiencing corrosion of embedded reinforcement unless the concrete is repaired and corrosion mitigated. Appropriate sections within this code and referenced documents concerning FRP repairs should be consulted (refer to ACI 440.2R).

8.5—Surface treatments and coatings

8.5.1 Moisture transmission through the structure and the influence of the surface treatment on the durability of the structure shall be considered.

8.5.1C *Surface treatments, coatings, sealers, or membranes are commonly used to limit the ingress of deleterious materials and moisture into the structure to reduce future deterioration of the* *structure. Surface treatments, coatings, sealers, and membranes may have a shorter service life than the concrete and can be considered as consumable or requiring periodic replacement or repair to maintain effective protection of the concrete (ACI 515.1R).*

In some situations, encapsulation of moisture and deleterious materials by a surface treatment has been found to cause or accelerate deterioration. The condition of the concrete should be appropriate to receive a specific surface treatment, coating, or membrane (ICRI No. 310.2).

8.5.2 The selection of surface treatments applied to concrete surfaces shall consider concrete cracks and their anticipated expansion and contraction, or surface deflections on the repair system durability, the surface treatment, and the anticipated design service life of the structure.

8.5.2C *Crack development and propagation provide an accelerated mechanism for ingress of moisture and deleterious materials and may also cause a surface treatment to become ineffective.*

CHAPTER 9—CONSTRUCTION

9.1—General

Construction documents shall specify:

a) Contractor has the responsibility to construct the project in accordance with the construction documents and with appropriate standards.
b) Contractor shall provide the necessary resources and access for inspection, testing, field observations, and quality control of the work.
c) Specific temporary shoring and bracing requirements.
d) Specific jacking requirements
e) Project-specific inspection, testing, and field observation requirements of Chapter 10.

9.1C *The information to be presented in construction documents is described in 1.6.1. Specific to the construction process, the construction documents should indicate that the contractor is responsible for construction consistent with the project plans and specifications, and convey project specific shoring, bracing and jacking requirements. During the work, the contractor should make the work available for inspection and observations by the licensed design professional, repair inspectors, and other quality assurance personnel.*

9.2—Stability and temporary shoring requirements

9.2.1 Construction documents shall specify:

a) Portions of the work that require temporary shoring and bracing during the period before the repair implementation for safety purposes and during construction.
b) Design loads and spacing requirements for the temporary shoring and bracing.
c) Contractor responsibilities to install, provide quality control, and properly maintain the temporary shoring and bracing.

9.2.1C *Project-specific design criteria for the temporary shoring and bracing in the construction documents should include, as necessary: loads, displacements, spacing, placement, and quality control requirements during construction.*

9.2.2 Temporary shoring and bracing design shall consider:

a) accommodation for in-place conditions and changes in conditions over the period of the repair phases, per 9.2.7
b) effects from measured lateral and vertical displacements, tilting or listing, secondary effects, and superimposed loads
c) impact of the temporary shoring and bracing on the structure
d) effects of deformation compatibility of the shoring system with the supported and

supporting structural members and systems, in accordance with 9.2.6

e) structural stability of members, systems, and the structure in accordance with 9.2.5 and 9.2.6

f) effects of damage or deterioration of existing members and systems in accordance with 9.2.8

9.2.2C *Temporary shoring and bracing members should be designed to consider changes in bracing and shoring conditions during repair construction and as required to support construction operations. Design of temporary shoring and bracing members should be based on the in-place loads and forces on the structure, deformations of the structure, and anticipated superimposed loads during construction. Secondary effects that may need to be examined in shoring and bracing design include geometric and material nonlinear response, member and foundation displacement, and internal member forces developed due to placement and alignment of shoring and bracing elements.*

Anticipated loads, such as snow, seismic, wind, and construction and occupancy live loads, should be considered in the design criteria of the temporary shoring and bracing. Design requirements for shoring are contained in ASCE/SEI 37. Shoring design guidelines are contained in AISC Steel Design Guide Series 10 (Fisher and West 2003) and ACI SP-4 (ACI SP-4).

9.2.3 Shoring and bracing design shall be performed by a licensed design professional.

9.2.3C *Shoring and bracing design is not usually performed by the licensed design professional of record for the repair design. The contractor will usually retain a specialty engineer to prepare the temporary shoring design details and shoring-plans, showing loads, member type, spacing, and placement sequence for temporary shores and braces at the phases of planned repairs.*

9.2.4 The licensed design professional of record for the repair design shall review temporary shoring and bracing design and details to determine if they comply with the requirements of the project repair design and the temporary shoring and bracing criteria.

9.2.4C *Temporary shoring and bracing design and installation details should be reviewed by the licensed design professional for the repair project to assess the impact of the shoring on the structure, and to verify conformance of the proposed shoring with project-specific requirements. Refer to 5.1.4 for load requirements associated with shoring and temporary construction. Review of the shoring design by the licensed design professional for the repair design does not normally include a comprehensive review of the shoring design prepared by the specialty engineer and should not be considered a validation of the specialty engineer's design.*

9.2.5 The shoring and bracing shall maintain the global structural stability of the structure before remedial construction and during the repair phases.

9.2.5C *The assessment of global structural stability includes the overall structure, members and systems affected by repair, and temporary lateral bracing elements that contribute to overall stability. Stability of these elements should be considered during the phases of the repair process. Temporary measures may be needed to provide lateral bracing and shoring of affected members and systems. If necessary, the criteria to temporarily preload members should be included in the construction documents. Review and redesign for variations in the construction proposed by the contractor with changes in temporary shoring and bracing design and detailing should be addressed in the construction documents.*

9.2.6 The shoring and temporary bracing shall maintain the structural stability of members and systems before construction and during the repair phases.

The lateral forces for temporary bracing design shall be determined using generally accepted engineering principles or as required by the design basis code. Temporary shoring and bracing shall be designed to provide sufficient stiffness to prevent excessive vertical and lateral displacement of the shored or braced members as specified by the licensed design professional for the repair in the construction drawings.

9.2.6 *Supplemental bracing for compression members may be required if the cross section or unbraced length of a compression member is modified during the repair process. Compression members include columns, walls, beam flanges, and other members, such as chords of diaphragms, that resist compressive loads. The design of bracing members is described in various publications (AISC 2006; ANSI/AF&PA NDS 2005). The design load for a bracing member should be based on the existing dead and live loads, construction loads, and other loads that may be resisted by the compression member. A lateral force of 2 percent of the axial load in the member being braced is commonly used as a minimum load in the design of bracing members (ANSI/AISC 360-10).*

9.2.7 The design of shoring and bracing members to accommodate in-place conditions and changes in conditions during construction shall include consideration of the changes in load paths, construction loads, unbraced lengths, and the redistribution of loads and internal forces that result from removal of existing adjacent framing or changes in applied loads on structural members.

9.2.7C *Removal of column, beam, wall, and floor slab elements or parts thereof during repair construction and the placement of shoring and bracing can result in the redistribution of loads* *and internal forces within the building structure. The removal of framing members, diaphragms, or slabs can also affect the unbraced length of the framing members in the removal area. Effects of the removal of elements should be considered in assessing the structure and shoring and bracing design.*

9.2.8 Where structural members support the structure and superimposed loads before repair and during construction, the structural capacity of damaged or deteriorated members shall be evaluated. The evaluation shall consider the actual cross section of the member and reinforcing at the time of the repair including losses of capacity due to damage and deterioration. Unless the in-place strength of the member exceeds the required strength for all superimposed loads, including construction loads, temporary shoring and bracing shall be specified in the construction drawings to be installed and maintained in place until the member is repaired.

9.2.8C *Design of shoring and bracing members and the -evaluation of members should be based on the member cross sections before and during the time of repair implementation. To account for unknown conditions, the evaluation by the licensed design professional should consider the importance of the member to the overall stability of the structure.*

9.3—Temporary conditions

9.3.1 Load and load factors during the assessment and construction processes shall be in accordance with 5.1.4.

9.3.1C *During the assessment and repair process, a temporary reduction in design load may be allowed, except if prohibited by jurisdictional authorities or local building codes. Reduction in the design load intensity should be determined using the in-place condition of the structure and the time required for the completion of stabilization measures or repairs. ASCE SEI 37 provides information on reductions in loads based upon the duration of a project. If a change in the length of the project or a delay occurs, the reduced design loads may no longer be appropriate.*

9.4—Environmental issues

9.4.1 Construction documents shall specify the contractor or other designated party is responsible for implementing specified environmental remediation measures, reporting new conditions encountered, and controlling construction debris, including environmentally hazardous materials and conditions.

9.4.1C *Assessment and repair of a structure can result in the exposure of workers and the public to potentially hazardous materials and conditions. Hazardous materials may be exposed, dislodged, carried into the air, or discharged as effluent into surface drainage during the assessment and repair process. Hazardous* *conditions include noise, nuisance dust, misdirected drainage, and falling debris. The owner should have an environmental assessment performed during the structural assessment and repair process in the areas to be repaired before any work to identify hazardous materials with the potential to present health issues to the workers and public, unless the owner can attest that the structure is free of hazardous materials.*

During the repair project, the contractor normally is responsible for the implementation of repairs and, accordingly, the control of construction debris, dust, and other materials. Any new conditions uncovered during the repair process should be reported to the owner and licensed design professional.

CHAPTER 10—QUALITY ASSURANCE

10.1—General

10.1.1 Quality assurance requirements of this chapter supplement the current and existing-building code provisions and shall be used for repair and rehabilitation construction.

10.1.1C *The construction documents for repair and rehabilitation projects should include a project-specific quality assurance and inspection program. The quality assurance program should include:*

a) Review of the contractor's quality assurance program

b) Quality control procedures during the repair process

c) Review of conditions during the project

d) Testing of materials used and material installation procedures

Usually, the quality control requirements are specified in the construction documents and the owner retains the quality control personnel. The contractor is responsible for the work quality, including the quality of materials and workmanship.

10.2—Inspection

10.2.1 Concrete repair and rehabilitation construction shall be inspected as required by the construction documents.

10.2.1C *The quality of concrete repairs is largely dependent upon the workmanship during construction. Inspection is necessary to verify repairs and rehabilitation work are completed in accordance with construction documents. Construction documents should specify inspection requirements for concrete repair and rehabilitation construction during the various work stages. The licensed design professional should recommend that the owner retain a licensed design professional, a qualified inspector, a qualified individual, or some combination thereof for the necessary inspections.*

10.2.2 The construction documents shall include testing and inspection requirements applicable to the project.

10.2.2C *Required testing and inspections may include (a) through (j):*

a) Delivery, placement, and testing reports documenting the identity, quantity, location of placement, repair materials tests, and other tests as required

b) Construction and removal of forms and reshoring

c) Concrete removal and surface preparation of the concrete and reinforcement

d) Placing of reinforcement and anchors

e) Mixing, placing, and curing of repair materials

f) Sequence of erection and connection of new members

g) Tensioning of tendons

h) Review and reporting of construction loads on floors, beams, columns, and walls

i) General progress of work

j) Installation and testing of post-installed anchors

Inspection and test results should be submitted to the licensed design professional and the owner.

Repair construction should be inspected to verify the quality of materials, quality of workmanship, and for compliance with the intent of the construction documents. Inspection should be provided by either repair inspectors, the licensed design professional, or a combination of repair inspectors and the licensed design professional. Responsibilities for performing the inspections should be clearly delineated at the start of a project.

Repair inspector qualifications for inspection of concrete repairs should be demonstrated by certification or previous work history and as required by the jurisdictional authority before being retained. An individual who has been certified as an ICRI Concrete Surface Repair Testing Technician (ICRI Concrete Surface Repair Technician - Grade 1) or as an ACI Construction Inspector (ACI C630) are examples of qualified inspectors. The licensed design professional may provide inspection services.

Inspection of concrete repair construction as specified in the construction documents should include review of the work in the field, review of construction documents, comparison of the work with construction documents, documentation and report of the work inspected as conforming or nonconforming, and whether corrections were made and verified or are still needed. Inspection and testing of post-installed anchor installation should be performed as required by the construction documents and in accordance with Chapters 17 and 26 of ACI 318-14.

Repair inspections should determine compliance with the intent of the contract documents, document the inspection, and report the inspection results. If the inspection shows conformance with the contract documents and no corrections are necessary, then the inspected work should be documented as conforming and reported to the licensed design professional and contractor, noting no corrections. If the inspection shows readily correctable issues and the issues are corrected by the contractor, then the inspected work should be documented as conforming and reported to the licensed design professional and contractor with corrections noted and verified as completed. Nonconforming or deficient components, processes, and procedures including the parts of the repairs not passing inspection should be reported to the licensed design professional for review. Actions should be made to correct the process before resuming the repair construction and inspection process. Nonconforming repair construction may include:

a) *Existing construction that differs from the repair documents*
b) *Deterioration, distress, or levels of distress beyond those anticipated in the design of repairs*
c) *Deficiencies in repair components*
d) *Deficiencies in construction processes and procedures*

Material data sheets indicate the manufacturer's stated material properties that should satisfy the required properties of each specific repair. The manufacturing date and shelf life of the repair material provide information that the material is within the manufacturer's recommended time limits for installation.

Existing conditions describe the nature and extent of damage or deterioration, and size and condition of the members. Those conditions need to be verified for conformance to the design assumptions. The following are some items where inspections are beneficial:

a) *Location of repairs*
b) *Surface preparation of existing concrete and reinforcement*
c) *Placement of reinforcement and anchors*
d) *Specific materials used in the repairs*
e) *Delivery, placement, and testing reports documenting the quantity and location of placement, repair material tests, strength, and other tests of all repair materials*
f) *Construction and removal of forms and shoring*
g) *Mixing, placing, and curing of repair materials*
h) *Sequence of repair construction*
i) *Tensioning of tendons*
j) *Construction loads*
k) *General progresses of the repair work*

10.2.3 The construction documents shall establish inspection requirements of existing conditions and reinforcement before concealing with materials that obscure visual inspection.

10.2.3C *Removal of deteriorated concrete and reinforcement often uncovers unanticipated conditions that should be examined. Visual inspection and verification of existing conditions may require review of project specific conditions before continuing the construction process and thus require pauses in the construction processes so as not to conceal components of the work before completing necessary inspections and verifications. If unanticipated conditions are identified by the repair inspector, the licensed design professional should be informed. The licensed design professional should examine these conditions and determine what measures are to be implemented before placement of new repair materials. The construction should specify the locations where inspection is necessary before concealment and provide for possible changes in these locations due to unforeseen conditions. In some projects, all locations will not* *need to be inspected and representative locations will provide suitable inspection.*

10.3—Testing of repair materials

10.3.1 Repair material tests and test frequencies shall be specified in the construction documents. Results of tests shall be reported as required by the construction documents and the design-basis code. Test records shall be retained by the testing agency as required by the design-basis code. In the absence of record retention requirements in the design-basis code, the construction documents shall require that the test records be retained by the testing agency for a minimum of 3 years beyond completion of construction.

10.3.1C *Tests of repair materials should comply with testing and test frequency of new concrete construction, unless otherwise specified in the contract documents and approved by the jurisdictional authority. It is generally not practical to verify all manufacturers' listed properties of proprietary materials, such as shrinkage, compressive and tensile creep, thermal expansion coefficient, and modulus of elasticity. In such cases, the licensed design professional should seek independent testing data from the manufacturer or others to verify specific manufacturer's listed properties that are critical to the application for the specific lots (or batches) of material to be used. The licensed design professional should evaluate the data and, if necessary, have manufacturers perform testing to confirm that their material achieves the published values that they provided for the project. Refer to ACI 546.3R and ICRI 320.2R for guidance. Tests of repair materials' bond to existing materials should comply with requirements of the contract documents.*

Concrete repair materials testing personnel should be qualified by demonstrating competence to the satisfaction of the licensed design professional and building code official for testing types required of concrete repair and rehabilitation work.

As a minimum level of record keeping, the testing agency should maintain a record of the tests performed and the results consistent with the requirements for records of ASTM E329.

10.4—Construction observations

10.4.1 Construction observation shall be performed as required by the construction documents.

10.4.1C *A primary purpose of construction observation of rehabilitation work is to verify that the exposed existing construction is as assumed in the design and that the work detailed in the contract documents will fulfill the design intent. Construction observations are in addition to the inspection requirements described in 10.2. Construction observations should be performed by the licensed design professional that designed the work or other designated representative to provide these services.*

If the existing construction differs from the design assumptions, requiring modification of the design, changes should be documented and the work modified as necessary. The licensed design professional or designated person responsible for construction observations should report design changes in writing to the owner, rehabilitation inspector, contractor, and jurisdictional authority resulting from existing construction, nonconforming rehabilitation work, and observed construction deficiencies. When construction observations are made by a party designated by the licensed design professional, design changes (construction deviations from the repair design) should also be reported to the licensed design professional. Revised design or construction work necessary to correct these deficiencies, and the construction corrections, should be observed.

CHAPTER 11—COMMENTARY REFERENCES

American Association of State Highway Transportation Officials

AASHTO T 260-97 (2011) Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

American Concrete Institute

ACI 201.1R-08 Guide for Conducting a Visual Inspection of Concrete in Service

ACI 201.2R-08 Guide to Durable Concrete

ACI 209R-92 Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures

ACI 209.1R-05 Report on Factors Affecting Shrinkage and Creep of Hardened Concrete

ACI 214.4R-10 Guide for Obtaining Cores and Interpreting Compressive Strength Results

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

ACI 222R-01 Protection of Metals in Concrete against Corrosion

ACI 222.2R-14 Corrosion of Prestressing Steels

ACI 222.3R-11 Design and Construction Practices to Mitigate Corrosion of Reinforcement in Concrete Structures

ACI 224R-01 Control of Cracking in Concrete Structures

ACI 224.1R-07 Causes, Evaluation, and Repair of Cracks in Concrete Structures

ACI 228.1R-03 In-Place Methods to Estimate Concrete Strength

ACI 228.2R-98 Nondestructive Test Methods for Evaluation of Concrete in Structures

ACI 301-10 Specifications for Structural Concrete

ACI 318-63 Building Code Requirements for Reinforced Concrete

ACI 318-14 Building Code Requirements for Structural Concrete and Commentary

ACI 355.2-07 Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary

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

ACI 364.1R-07 Guide for Evaluation of Concrete Structures before Rehabilitation

ACI 364.3T-14	Treatment of Exposed Epoxy-Coated Reinforcement in Repair
ACI 364.10T-14	Rehabilitation of Structure with Reinforcement Section Loss (TechNote)
ACI 365.1R-00	Service-Life Prediction
ACI 369R-11	Guide for Seismic Rehabilitation of Existing Concrete Frame Buildings and Commentary
ACI 423.4R- 14	Corrosion and Repair of Unbonded Single-Strand Tendons
ACI 437.2-13	Code Requirements for Load Testing of Existing Concrete Structures and Commentary
ACI 437R-03	Strength Evaluation of Existing Concrete Buildings
ACI 437.1R-07	Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria
ACI 440R-07	Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures
ACI 440.1R-15	Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars.
ACI 440.2R-08	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures
ACI 440.4R-04	Prestressing Concrete Structures with FRP Tendons
ACI 440.7R-10	Guide for the Design and Construction of Externally Bonded Fiber-Reinforced Polymer Systems for Strengthening Unreinforced Masonry Structures
ACI 503R-93	Use of Epoxy Compounds with Concrete
ACI 503.5R-92	Guide for the Selection of Polymer Adhesives in Concrete
ACI 503.6R-97	Guide for Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concrete
ACI 503.7-07	Specification for Crack Repair by Epoxy Injection
ACI 506R-05	Guide to Shotcrete
ACI 515.2R-13	Guide to Selecting Protective Treatments for Concrete
ACI 546R-14	Concrete Repair Guide
ACI 546.3R-14	Guide for the Selection of Materials for the Repair of Concrete
ACI 548.1R	
ACI C630	Construction Inspector Certification

ACI SP-4 Formwork for Concrete, 8th Edition

ACI SP-6604 ACI Detailing Manual

American Institute of Steel Construction

AISC 2006 Standard for Steel Building Structures

ANSI/AISC 360-10 Specification for Structural Steel Buildings

American Society of Civil Engineers

ASCE/SEI 7-05 Minimum Design Loads for Buildings and Other Structures

ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures

ASCE/SEI 7-16 Minimum Design Loads for Buildings and Other Structures

ASCE/SEI 11-99 Guideline for Structural Condition Assessment of Existing Buildings

ASCE/SEI 37-14 Design Loads on Structures during Construction

ASCE/SEI 41-13 Seismic Rehabilitation of Existing Buildings

ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection

American Forest and Paper Association

ANSI/AF&PA NDS-2014 National Design Specification (NDS) for Wood Construction

Applied Technology Council

ATC 20-89 Procedures for Post-Earthquake Safety Evaluation of Buildings

ATC 45-04 Field Manual: Safety Evaluation of Buildings after Windstorms and Floods

ATC-58 Seismic Performance Assessment of Buildings

ATC 78 Project Mitigation of Nonductile Concrete Buildings

ATC 78-1 Evaluation of the Methodology to Select and Prioritize Collapse Indicators in Older Concrete Buildings

ASTM International

ASTM C666/C666M-03(2008) Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C1152/C1152M-04(2012) Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

ASTM C1218/C1218M-99(2008) Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C1581/C1581M-09 Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage

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 D4263-83(2012) Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method

ASTM D7522/D7522M-09 Standard Test Method for Pull-Off Strength for FRP Bonded to Concrete Substrate

ASTM E84-15 Standard Test Method for Surface Burning Characteristics of Building Materials

ASTM E119-14a Standard Test Methods for Fire Tests of Building Construction and Materials

ASTM E329-13a Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection

ASTM F1869-11 Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride

ASTM F2170-11 Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes

ASTM F2420-05 Standard Test Method for Determining Relative Humidity on the Surface of Concrete Floor Slabs Using Relative Probe Measurement and Insulated Hood

Canadian Standards Association

CAN/CSA S6-14 Canadian Highway Bridge Design Code and Commentary

Concrete Reinforcing Steel Institute

Vintage Steel Reinforcement in Concrete Structures

Federal Emergency Management Agency

FEMA P-58 Seismic Performance Assessment of Buildings: Volume 1 & 2

FEMA P-695 Quantification of Building Seismic Performance Factors

FEMA 306 Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings

FEMA 307 Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings

FEMA 308 The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings

FEMA 395 FEMA Risk Assessment Database

FEMA 396 Risk Management Series: Incremental Seismic Rehabilitation of Hospital Buildings

FEMA 397 Risk Management Series: Incremental Seismic Rehabilitation of Office Buildings

FEMA 398 Risk Management Series: Incremental Seismic Rehabilitation of Multifamily Apartment Buildings: Providing Protection to People and Buildings

FEMA 399 Risk Management Series: Incremental Seismic Rehabilitation of Retail Buildings: Providing Protection to People and Buildings

FEMA 400 Risk Management Series: Incremental Seismic Rehabilitation of Hotel and Motel Buildings

FEMA 547 Techniques for the Seismic Rehabilitation of Existing Buildings

FEMA P-154 Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook. Third Edition

FIB

FIB Bulletin 10 Bond of Reinforcement in Concrete

International Code Council

IBC-2015 International Building Code

IEBC-2015 International Existing Building Code

International Concrete Repair Institute

ICRI No. 210.2-02 Guideline for the Evaluation of Unbonded Post-Tensioned Concrete Structures

ICRI No. 210.3-13 Guide for Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials

ICRI No. 310.1R-08 Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion

ICRI No. 310.2-13 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays

ICRI No. 310.3-14 Guide for the Preparation of Concrete Surfaces for Repair Using Hydrodemolition Methods

ICRI No. 320.2R-09 Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces

ICRI No. 320.3R-12 Guideline for Inorganic Repair Material Data Sheet Protocol

ICRI No. 320.4-06 Guideline for the Repair of Unbonded Post-Tensioned Concrete Structures

ICRI No. 330.1-06 Guideline for the Selection of Strengthening Systems for Concrete Structures

ICRI No. 340.1-06 Guideline for the Selection of Grouts to Control Leakage in Concrete Structures

ICRI Concrete Surface Repair Technician - Grade 1

NACE International

NACE 01101 Electrochemical Chloride Extraction from Steel-Reinforced Concrete—A State-of-the-Art Report

NACE 01102-02 State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed Concrete Structures

NACE 01104 Electrochemical Realkalization of Steel-Reinforced Concrete—A State-of-the-Art Report

NACE 01105-05 Sacrificial Cathodic Protection of Reinforced Concrete Elements—A State-of-the-Art Report

NACE SP0107-07 Electrochemical Realkalization and Chloride Extraction for Reinforced Concrete

NACE SP0290-2007 Standard Recommended Practice—Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures.

NACE SP0390-09 (formerly RP0390) Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures

Post-Tensioning Institute

PTI DC80.2-10 Guide for Creating Openings and Penetrations in Existing Slabs with Unbonded Post-Tensioning

PTI DC80.3-12/ICRI 320.6 Guide for evaluation and repair of unbonded post-tensioned concrete structures

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APPENDIX A – CRITERIA WHEN USING THIS CODE AS A STAND-ALONE CODE

A.1—General

This appendix shall apply if a jurisdiction has adopted this code by reference. When this appendix is used, Chapter 4 shall not apply.

A.1C *This appendix is used when this code is used for existing concrete structures as a stand-alone code without the use of the IEBC.*

A.2—Design-Basis Code Criteria

A.2.1 Unless prohibited by the jurisdictional authority, the design-basis code criteria of the project shall be based on requirements set forth in this Appendix.

A.2.1C *This code contains specific requirements that determine if existing structures should be rehabilitated or retrofitted to satisfy the requirements of the current building code. Local ordinances may also require that a structure be rehabilitated to satisfy the current codes. These requirements should be reviewed at the start of a project.*

The licensed design professional should determine if seismic evaluation and retrofit of an existing concrete structure (buildings, members, system, and, where applicable, nonbuilding structures where the construction is concrete or mixed construction with concrete and other materials) are necessary using ASCE/SEI 41. Provisions of ASCE/SEI 41 may or may not be applicable to nonbuildings. Section A.3.3 provides minimum assessment criteria for seismic safety provisions.

A.2.2 It shall be permitted to use the current building code as the design-basis code for all damage states, deterioration, and faulty design and construction.

A.2.2C *The current building code per 1.2.2 provides acceptable safety based on consistent statistical probabilities. When using the current building code the resulting demand-capacity ratios provide the limits that need not be exceeded if assessing and designing remedial construction.*

A.2.3 As an alternative to using the current building code, this Appendix shall be used to determine the rehabilitation category of work as shown in Table A.2.3 and defined in A.3 through A.9.

A.2.3C *Unless the local jurisdiction provides more restrictive requirements, this appendix should be used to determine the assessment and design-basis criteria for the rehabilitation categories of A.3 through A.9 and as summarized in Table A.2.3.*

Table A.2.3 –Assessment and Design-basis Criteria for Rehabilitation Categories

Rehabilitation Category	Sections of this code to use for the	Primary code of the design-basis criteria used with this code

	assessment criteria	
Unsafe structural conditions for gravity and wind loads	A.3.2	For unsafe structures, current building code* supplemented by ASCE/SEI 41 for seismic if the structure is seismic design category D or higher
Unsafe structural conditions for seismic forces in regions of high seismicity (Seismic design category D or higher)	A.3.3	
Substantial structural damage to vertical members of the lateral-force-resisting system	A.4	current building code* for substantial structural damage
Substantial structural damage to vertical members of the gravity-load-resisting system	A.4	current building code* for substantial structural damage
Damage less than substantial structural damage, deterioration and faulty construction with capacity increase	A.5	current building code* unless compliant with Sections A.5.1, A.5.2 or A5.3 for the original building code†
Damage less than substantial structural damage, deterioration and faulty construction without capacity increase	A.6	this code, Chapters 8 through 10
Additions	A.7	current building code* unless compliant with Section A.7 for the original building code†
Alterations	A.8	current building code* unless compliant with Section A.8 for the original building code†
Changes in Occupancy	A.9	If rehabilitation is required then use the current building code*

*Current building code is as per 1.2.2.
†Original building code is as per 1.2.3.

A.2.4 The detailing of the existing reinforcement need not be in accordance with ACI 318-14 if (a) through (d) are satisfied:

a) The structure is in seismic design categories A, B, or C and only deterioration is addressed;

b) The repaired structure shall have capacity equal to or greater than demand per 5.2.2 using the original building code;

c) No unsafe structural conditions were determined to be present;

d) The structure has demonstrated historical structural reliability.

A.2.4C *The licensed design professional should determine if structural distress as identified by observations, testing or measurements is proportional to that predicted based on historical data of the loads the structure has experienced and if this demonstrates statically acceptable past performance. Where the structural performance indicates adequate behavior based on historical data, such as acceptable resistance of previous loads which equal or exceed the loads that would be predicted for the remaining life of the structure, the licensed design professional may judge the structure to have demonstrated historical structural reliability. ACI 224.1R-07, ACI 437R-03 and ACI*

437.1R-07 provide guidance in judging acceptable performance.

A.2.5 This code shall be used for design of repairs to existing structures. ACI 318-14 shall be used for design of new members and connection of new members to existing construction.

A.3—Unsafe structural conditions

A.3.1 A structural assessment shall be performed to determine if unsafe structural conditions are present.

A.3.2 For gravity and wind loads, unsafe structural conditions include: instability, potential collapse of overhead components or pieces (falling hazards), or structures where the demand-capacity ratio is more than 1.5, as shown in Eq. (A.3.2).

$$U_c / \varnothing R_{cn} > 1.5 \qquad \text{(A.3.2)}$$

In Equation A.3-2, the strength design demand (U_c) shall be determined for current building code nominal dead, live, snow and wind loads, excluding earthquake using factored load combinations of ASCE/SEI 7, and the strength reduction factors (ϕ) of 5.3 or 5.4 shall apply.

If the demand-capacity ratio exceeds 1.5 for structures, the design-basis criteria shall be the current building code. Unsafe structural conditions shall be reported as described in 1.5.2.

If the demand-capacity ratio does not exceed 1.5 for structures, A.4 through A.9 shall be used to determine the design-basis criteria.

A.3.2C *In assessing unsafe structural conditions the strength design demand of Eq.A.3.2 combines current building code nominal gravity loads (dead, live, and snow) and lateral wind forces excluding earthquake loads using factored load combinations (strength design) of ASCE/SEI 7. A demand to capacity ratio greater than 1.5, calculated using Equation A.3.2, represents a condition with limited to no margin of safety against failure.*

In the assessment of unsafe structural conditions, the licensed design professional should determine if it may be appropriate to include: structural redundancies, alternate load paths, primary and secondary supporting elements, redistribution of loads, collapse mechanisms, reduced live loads, measured displacements (listing, leaning, and tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth pressures, self-straining loads, ice, and floods. References for unsafe structural conditions include: commentary to Chapter 1 of ASCE/SEI 7-10, Galambos, Ellingwood, MacGregor and Cornell 1982, "Probability Based Load Criteria: Assessment of Current Design Practice," Galambos, T.V., Ellingwood, B.R., MacGregor, J.G., and Cornell, C.A., 1982, "Probability Based Load Criteria: Load Factors and Load

Combinations," and Ellingwood and Ang 1972, "A Probability Study of Safety Criteria for Design." These references provide target reliability indexes, basic probability theory and concepts for an evaluation using the specific details of the demand as it relates to the capacity with the strength reduction factors of Chapter 5 for concrete structures.

A.3.3 Assessment criteria for unsafe structural conditions of seismic resistance is limited to structures in seismic design category D, E, and F of ASCE/SEI 7 and shall be determined using ASCE/SEI 41 and this code. The design-basis criteria for rehabilitation design and construction of unsafe structures shall be this code and ASCE/SEI 41.

A.3.3C *Compliance with ASCE/SEI 41 for Structural Performance Level, Collapse Prevention using an applicable Earthquake Hazard Level as determined by the local jurisdictional authority for the assessment of unsafe structural conditions. Additional research on the appropriate seismic hazard level for safety is needed to set local requirements. If no requirements for unsafe structural conditions are provided by the local jurisdictional authority, the licensed design professional should reference the IEBC and ASCE 41 appendices for guidance. ATC-78 provides the most up to date documentation of the earthquake resistance necessary for the safety of existing concrete structures.*

Structures in regions of low and moderate seismicity are not required to assess unsafe structural conditions for seismic resistance.

A.4—Substantial Structural Damage

A.4.1 Substantial structural damage shall be assessed using current building code demands. Substantial structural damage to vertical members of the lateral-force-resisting system shall be where in any story, the shear walls or columns of the lateral-force-resisting system are damaged such that the lateral-load-resisting nominal capacity of the structure in any horizontal direction is reduced more than 33 percent from its predamage condition, as shown in Eq. (A.4.1a).

$$\left\{ \left(\sum R_n - \sum R_{cn}\right) \Big/ \sum R_n \right\} > 0.33 \qquad \text{(A.4.1a)}$$

Substantial structural damage to vertical elements of the gravity-load-resisting system shall be where for any wall or column or group of vertical members of the gravity-load-resisting system whose tributary area is more than 30 percent of the total area of the structure's floor(s) and roof(s) are damaged such that the total vertical nominal capacity is reduced more than 20 percent from its predamage condition, as shown in Eq. (A.4.1b)

$$\left\{ \left(\sum R_n - \sum R_{cn} \right) \Big/ \sum R_n \right\} > 0.2 \qquad \text{(A.4.1b)}$$

and concurrently where the current building code factored gravity (dead, live, and snow) load demand to in-place vertical design capacity ratio of these damaged members is more than 1.33, as shown in Eq. A.4.1c.

$$\sum U_c \Big/ \sum \varnothing R_{cn} \geq 1.33 \qquad \text{(A.4.1c)}$$

Capacities according to Chapter 6 and strength-reduction factors per 5.3 or 5.4 shall be used in equations A.4.1a through A.4.1c. The design-basis criteria shall be the current building code demands, supplemented by requirements of this code for the existing structure and ASCE/SEI 41 for seismic design provisions for the following:

a) lateral-force-resisting system in both directions for the case of substantial structural damage in either direction from lateral forces
b) vertical members of the gravity-load-resisting system for the case of substantial structural damage from gravity loads.

Structures assigned to Seismic Design Category D, E, and F per ASCE/SEI 7 with substantial structural damage caused by earthquake shall be assessed or rehabilitated for load combinations that include earthquake effects. The seismic design provisions of ASCE/SEI 41 shall be Earthquake Hazard Level, BSE-1E with the Basic Performance Objective of "Life Safety" for Risk Category I, II, or III (ASCE/SEI 7) and of "Immediate Occupancy" for Risk Category IV.

The design of new structural members and connections to members supporting load from vertical members of the gravity-load-resisting system that have substantial structural damage from gravity loads shall be in accordance with provisions of the current building code.

A.4.1C *The assessment criteria for substantial structural damage are specific to existing concrete structures, which were adapted from the IEBC.*

In Eq. A.4.1c the demand load has been modified from the IEBC's limit of only dead and live loads to include snow load. Further, the current building code factored gravity load demand used in Eq. A.4.1c should include other gravity loads judged to be applicable to the structure, such as drifting snow.

Supplemental requirements of this code for the design-basis criteria include strength reduction factors per Section 5.3 or 5.4, capacities according to Chapter 6, repairs per Chapter 7, durability per Chapter 8, repair construction per Chapter 9, quality assurance per Chapter 10 for existing structures. The referenced seismic design *provisions of ASCE/SEI 41are adapted from those defined in the IEBC.*

A.4.2 The design-basis criteria for structures without substantial structural damage shall be determined in accordance with A.5 through A.9.

A.5—Conditions of Deterioration, Faulty Construction or Damage less than Substantial Structural Damage

A.5.1 If a structure has damage less than substantial structural damage, deterioration, or contains faulty construction and there is a reason to question the capacity of the structure, it shall be assessed by calculating the demand-capacity ratio using the original building code demand (U_o) with nominal loads, load combinations, and capacities of the original building code, as shown in Eq. (A.5.1).

$$U_o / \varnothing R_{cn} > 1.0 \qquad \text{(A.5.1)}$$

In Eq. (A.5.1a), strength reduction factors (ϕ) of original building code shall be used. If the demand-capacity ratio exceeds 1.0, then that member or system strength shall be restored using the original building code. If the demand-capacity ratio does not exceed 1.0, then strengthening shall not be required.

Repairs shall be allowed that restore a member or system to the capacity of the original building code based on material properties of the original construction.

A.5.1C *Most concrete structures with damage less than substantial structural damage, deterioration, or containing faulty construction will provide acceptable safety if restored to the strength of the original building code.*

The demand-capacity ratio of limit of 1.0 as provided in this section allows strengthening that restores the structural reliability of the existing structure to the level prior to damage and deterioration, or as intended in the original building code.

Historical performance is often an acceptable indicator of adequate safety if the structure has been subjected to known loads.

If *the capacity of the structure is not in question, such as indicated by the commentary provisions of 1.7.1C, assessment checks are not required.*

A.5.2 Alternative assessment criteria for, deterioration, faulty construction, or damage less than substantial structural damage shall be permitted. The selected alternative assessment criterion shall substantiate acceptable structural safety using engineering principles for existing structures.

A.5.2C *An alternative assessment criterion to consider is use of the current building code and ASCE/SEI 41. The references of A.3.2C should be considered in the selection of an applicable assessment criterion.*

Beyond using the current building code, the assessment criteria should address if the demand or capacity of the original structure or member is significantly inconsistent with current standards and results in unacceptable structural safety. An increase in load intensity, added loads, change in load factors, strength-reduction factors or load combinations, modification of analytical procedures, determined capacity change between the original and current building codes [such as a change from ASD to strength design], or the benefits received versus the costs incurred should lead the licensed design professional to question the applicability of using the original building code for assessment of an existing structure. Engineering principles used to determine acceptable structural safety are to use either a probabilistic evaluation of loads and capacities to show adequate structural reliability indices or an evaluation procedure using demand-capacity ratios that is derived from the basic engineering principles as presented in current standards.

An assessment criterion for a structure that has damage less than substantial structural damage, deterioration, or faulty construction excluding seismic forces that is based on the demand-capacity ratios of the IEBC is the following:

a) *If the current building code demand (U_c) exceeds the original building code demand (U_o^*) increased by 5 percent* $(U_c > 1.05U_o^*)$, *check the demand-capacity ratio using the current building code demand (U_c) to determine if it exceeds 1.1, as shown in Eq. (A.5.2a).*

$$U_c / \varnothing R_{cn} > 1.1 \qquad \text{(A.5.2a)}$$

If the demand-capacity ratio exceeds 1.1, then that system or member should be strengthened using the current building code demand. If the demand-capacity ratio does not exceed 1.1, then no strengthening is required.

b) *If the current building code demand (U_c) does not exceed the original building code demand (U_o^*) increased by 5 percent* $(U_c \leq 1.05U_o^*)$, *check the demand-capacity ratio using the original building code demand (U_o^*) to determine if it exceeds 1.05, as shown in Eq. (A.5.2b).*

$$U_o^* / \varnothing R_{cn} > 1.05 \qquad \text{(A.5.2b)}$$

If the demand-capacity ratio exceeds 1.05, then that system or member strength should be restored using the original building code demand (U_o^*). If the demand-capacity ratio does not *exceed 1.05, then strengthening is not required.*

Strength reduction factors (ϕ) of sections 5.3 or 5.4 in Eq. (A.5.2a) and (A.5.2b) apply. If the original building code demand is used, the repair design should be supplemented for existing members or systems by this code.

In this assessment criterion, the current building code strength design demand (U_c) combines current building code nominal gravity loads (dead, live, and snow) and lateral wind loads excluding earthquake loads using the factored load combinations of ASCE/SEI 7. The original building code strength design demand (U_o^*) combines the original building code nominal gravity loads (dead, live, and snow) and lateral wind loads excluding earthquake loads using the factored load combinations of ASCE/SEI 7. Consideration should be given to inclusion of ASCE/SEI 41 seismic provisions, redistribution of loads, reduced live loads, measured displacements (listing, leaning, and tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth pressures, self-straining loads, ice, and floods.

Using structure-specific data is acceptable, if substantiated by the licensed design professional. For these assessment criteria, the demand-capacity ratio provisions of part (1) may be used in the assessment regardless of the whether the current building code demand does or does not exceed the original building code demand increased by 5 percent.

A.5.3 If the concrete design regulations of the original building code used only allowable stress design and design service loads, the demand capacity ratio shall be based on service load demand (U_S) and resistance calculated using allowable stresses (R_a) as shown in Eq. (A.5.3)

$$U_s/R_a > 1.0 \qquad \text{(A.5.3)}$$

If the demand-capacity ratio exceeds 1.0, then that member or system strength shall be restored using the original building code. If the demand-capacity ratio does not exceed 1.0, then strengthening shall not be required. Repairs shall be allowed that restore the member or system to its pre-damage or pre-deteriorated state. Repair of structural concrete is permitted based on material properties of the original construction.

***A.5.3C** Before 1963 and the "Building Code Requirements for Reinforced Concrete (ACI 318-63)," the design of reinforced concrete structures was based upon allowable stress or working stress design principles. Original building code demands should include nominal gravity loads (dead, live, and snow) and lateral wind forces including seismic forces using the load combinations of original building code. Consideration should be given to inclusion of measured displacements (listing, leaning, and* *tilting), second-order effects, and other loads specific to the structure, such as drifting snow, lateral earth pressures, self-straining loads, ice, and floods. Using allowable stress design is inconsistent with the reliability principles of strength design. To adequately address safety, consideration should be given to verification using A.5.2 and a check of seismic resistance using ASCE/SEI 41.*

A.5.4 Existing structures other than those to be strengthened per A.3 through A.5 shall use A.6 through A.9 to determine the design-basis criteria.

A.6—Conditions of Deterioration, Faulty Construction, or Damage less than Substantial Structural Damage without Strengthening

A.6.1 If no damage or less than substantial structural damage is present, structures damaged, deteriorated, or containing faulty construction that do not require strengthening in accordance with A.5 shall use the provisions of Chapters 7 through 10 of this code as the design-basis criteria.

A.6.2 *Deflections*—The effects of floor levelness, vibrations and deflections on the performance of the structure shall be assessed. Deflections exceeding those allowed by the original building code shall be permitted provided those deflections do not adversely affect structural performance.

***A.6.2C** The effect of floor deflections, levelness and vibrations on the structural performance should be investigated by the licensed design professional to determine if the performance of the structure is acceptable to the owner and users of the structure. Acceptable performance criteria will need to be established for an individual structure based upon the intended use of the structure.*

A.7—Additions

A.7.1 For existing gravity-load-resisting systems and members where the gravity load demands of the current building code with the addition are more than the original building code increased by 5 percent, the design-basis criteria shall be the current building code, with this code for existing systems and members and ACI 318-14 for new members.

Existing gravity-load-resisting systems and members whose calculated capacity using this code is decreased as part of an addition shall be shown to have an in-place capacity exceeding the current building code demand.

If the addition is not independent of the existing building for lateral-force resistance, the design-basis criteria for the existing lateral-force-resisting system with the addition shall be the current building code supplemented by ASCE/SEI 41 for seismic assessment and design.

Exception: The licensed design professional shall be permitted to use the original building code load demands and capacities for any lateral-force-resisting member where the demand-capacity ratio, with the addition using the current building code, does not exceed the demand-capacity ratio without the addition using the original building code increased by 10 percent.

A.7.1C *The exception permits the licensed design professional to use the original building code for the assessment and design-basis criteria of existing lateral-force-resisting members when the members of the existing lateral-force-resisting system comply with equation A.7.1.*

$$U_c / R_n \,(\text{with the addition}) \leq 1.1U_o / R_n \,(\text{without the addition}) \qquad (A.7.1)$$

A.8—Alterations

A.8.1 For existing gravity-load-resisting systems and members where the gravity load demands of the current building code with the alterations are more than the original building code increased by 5 percent, the design-basis criteria shall be the current building code, with this code applicable for existing systems and members and ACI 318-14 applicable for new members.

If the existing gravity-load-resisting system or member capacity is to be reduced as part of an alteration, the reduced capacity shall not be less than the current building code demand. If the alteration increases design lateral loads resulting in a structural irregularity per ASCE/SEI 7, or decreases the lateral capacity, the design-basis criteria shall be the current building code supplemented by ASCE/SEI 41 for seismic assessment and design. The seismic design provisions of ASCE/SEI 41 shall be Earthquake Hazard Level, BSE-1E with the Basic Performance Objective of “Life Safety” for Risk Category I, II, or III (ASCE/SEI 7) and of “Immediate Occupancy” for Risk Category IV.

Exception: The licensed design professional shall be permitted to use as an alternative to the original building code load demands and capacities for any lateral-force-resisting member where the demand-capacity ratio with the alteration using the current building code is not more than the demand-capacity ratio without the alteration using the original building code increased by 10 percent.

A.8.1C *The exception permits the licensed design professional to use the original building code for the assessment and design-basis criteria of existing lateral-force-resisting members when the members of the existing lateral-force-resisting system comply with equation A.8.1.*

$$U_c / R_n \left(with\, the\, alteration \right) \leq 1.1 U_o / R_n \left(without\, the\, alteration \right) \qquad (A.8.1)$$

Alterations in this section exclude the remedial work of A.3 through A.6.

A.9—Change of Occupancy

A.9.1 The use or occupancy of a structure shall not be changed if it increases the demand on the structure using the current building code as compared with the original building code, unless the structure is evaluated and shown to comply with the current building code or rehabilitated using the current building code supplemented by this code for existing members, ACI 318-14 for new members and ASCE/SEI 41 for seismic design as the design-basis criteria.

Key changes from ACI 562-13 to ACI 562-16 include:

a) Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures (ACI 562-16) and Commentary". These changes were made for consistency in the hierarchy of terminology used in ISO, ASCE and other documents related to existing structures, and for consistency with ACI 318.
b) Definitions were added to Chapter 2 that reflect the hierarchy of terminology.
c) Revisions to Chapters 1-4 to include specific criteria requirements for assessment and design of repair and rehabilitation for varying levels of damage, deterioration, or faulty construction.
d) Revisions to the document to allow for use of document with the International Existing Building Code (see Chapter 4) and as a stand-alone code (Appendix A).
e) Revisions to the load combinations in Chapter 5 used to define the minimum strength of a structure with unprotected external reinforcement.
f) Revisions to the interface bond provisions in Chapter 7.
g) Revisions to the commentary in Chapter 8 to simplify the text.

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