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ACI Committee 562

Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings

562 Public Discussion Draft

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1 **Preface**

2 *This code provides the minimum requirements for the evaluation, repair, rehabilitation, and*
3 *strengthening of existing concrete buildings and, where applicable, in nonbuilding structures.*

4 *The code is comprised of both prescriptive and performance requirements. Commentary is*
5 *provided for both the prescriptive and performance requirements and is intended to provide*
6 *guidance to the licensed design professional and referenced sources for additional information*
7 *the material presented in the code provisions.*

8 *The code and commentary is intended for use by individuals who are competent to evaluate the*
9 *significance, limitations of its content and recommendations, and who will accept responsibility*
10 *for the application of the material it contains.*

11 *The materials, processes, quality control measures, and inspections described in this document*
12 *should be tested, monitored, or performed as applicable only by individuals holding the*
13 *appropriate ACI Certifications or equivalent.*

14

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15 **INTRODUCTION**

16 The purpose of this code is to provide minimum material and design requirements for the
17 evaluation, repair, and rehabilitation of structural concrete members to comply with the general
18 existing building code.

19

20 **CHAPTER 1—GENERAL**

21 **1.1—Scope**

22 **1.1.1** The scope, purpose, applicability, exclusions, interpretation principles, language, and
23 units of measure are defined in this chapter.

1 **1.1.2** The “general existing building code” refers to the code adopted by a jurisdiction that
2 regulates existing buildings.

3 *1.1.2C The general existing building code establishes the limit to which a repair and*
4 *rehabilitation can occur in accordance with the original building code. Above these limits, the*
5 *repair and rehabilitation is in accordance with the general building code. The general existing*
6 *building code in the United States is usually based on the International Existing Building Code*
7 *(IEBC) developed by the International Code Council. The IEBC is revised every three years and*
8 *was first published in 2003.*

9 **1.1.3** The “general building code” refers to the building code adopted by a jurisdiction that
10 regulates new building design and construction. The “original building code” refers to the
11 general building code adopted by a jurisdiction at the time the existing building was constructed.

12 *1.1.3C The general building code establishes the design requirements for construction*
13 *materials. The general building code in the United States is usually based on the International*
14 *Building Code (IBC) published by the International Code Council. The IBC is revised every*
15 *three years and was first published in 2000. For the design and construction of concrete*
16 *structures, the IBC and legacy codes reference ACI 318, Building Code Requirements for*
17 *Structural Concrete, with exceptions and additions.*

18 **1.1.4** The “design basis code” is the general building code or the original building code under
19 which the evaluation, repair, and rehabilitation are implemented. If a jurisdiction has adopted a
20 general existing building code, the design basis code shall be determined in accordance with
21 Chapter 4. If a jurisdiction has not adopted a general existing building code, 1.3 applies.

1 **1.1.4C** *The general existing building code establishes limits to which a repair and*
2 *rehabilitation can occur in accordance with the original building code. Above these limits, the*
3 *repair and rehabilitation is in accordance with the general building code.*

4 **1.1.5** This code is intended to supplement the evaluation requirements of the general existing
5 building code.

6 **1.1.5C** *This code provides evaluation procedures for existing concrete structures. It also*
7 *provides material and design requirements that allow the licensed design professional to bring*
8 *existing concrete structures in compliance with building codes written for new construction.*

9 **1.1.6** This code provides minimum material and design requirements for the repair of damaged,
10 deteriorated, or deficient structural concrete members and systems repaired in accordance with
11 the design basis code. Structural repair includes restoring or increasing strength and deformation
12 capacities as well as the durability of existing members.

13 **1.1.7** This code supplements the general existing building code and shall govern in all matters
14 pertaining to the evaluation, repair, rehabilitation, strengthening of concrete members, and
15 concrete sections of composite members in existing concrete buildings, except wherever this
16 code is in conflict with the requirements in the general existing building code. Wherever this
17 code is in conflict with requirements in other referenced standards, this code shall govern.

18 **1.1.8** *Provisions for seismic resistance*

19 **1.1.8.1** Seismic evaluation and rehabilitation design shall be in accordance with the general
20 existing building code.

21 **1.1.8.2** Where seismic rehabilitation is not required by the general existing building code,
22 voluntary seismic rehabilitation shall be permitted.

1 **1.1.8C** *Conditions for such evaluation and repair are provided in ACI 369R, ASCE/SEI 31*
2 *and ASCE/SEI 41. Significant improvements to a building's seismic performance can be made*
3 *using repair techniques that provide less than those detailing and reinforcement methods*
4 *required for new construction. As an example, providing additional reinforcement to confine*
5 *concrete in flexural hinging regions will increase the energy dissipation and seismic*
6 *performance even though the amount of confinement reinforcement may not satisfy the*
7 *confinement requirements for new structures (Kahn 1980, Priestley et al. 1996; Harris and*
8 *Stevens 1991).*

9 *Components of the seismic-force-resisting system that require strength and ductility should be*
10 *identified. Force-controlled (nonductile) action is acceptable for some classifications of*
11 *components of the seismic-force-resisting system (ASCE 41). The strength requirement of 7.1 is*
12 *applicable to these force-controlled components. ASCE 41 and ACI 369R provide information on*
13 *seismic rehabilitation. Seismic-resisting components requiring energy-dissipating capability*
14 *should maintain the ability to dissipate energy when repaired. Design and detailing*
15 *requirements for proper seismic performance of cast-in-place or precast concrete structures are*
16 *addressed in ACI 318 and 369R.*

17 **1.1.9** This code does not provide complete design procedures or construction means and
18 methods.

19 **1.1.10** This code is not intended for repair of nonstructural concrete or for aesthetic
20 improvements except if the failure of such repairs would result in an unsafe condition.

21 **1.1.11** *Licensed design professional*

22 **1.1.11.1** All references in this code to the licensed design professional shall be
23 understood to mean persons who are licensed to practice structural design in the jurisdiction

1 where this code is being used. The licensed design professional for a project is responsible for
2 and in charge of the evaluation or repair design or both.

3 **1.1.11.2** The licensed design professional must exercise sound engineering knowledge,
4 experience, and judgment when interpreting and applying this code.

5 **1.1.11.3** The licensed design professional is permitted to require evaluation, design,
6 construction, and quality assurance that exceed the minimum requirements of this code.

7 8 **1.2—Applicability**

9 **1.2.1** The requirements of this code are applicable when performing evaluation, repair,
10 rehabilitation, and strengthening of existing concrete buildings and concrete portions of other
11 existing buildings.

12 **1.2.2** This code shall govern the evaluation, repair, rehabilitation, and strengthening of
13 nonbuilding concrete structures when required by the Building Official.

14 *1.2.2C Such structures can include arches, tanks, reservoirs, bins and silos, blast- and impact-*
15 *resistant structures, and chimneys.*

16 **1.2.3** This code shall govern the evaluation, repair, rehabilitation, and strengthening of building
17 foundation members.

18 *1.2.3C Foundation elements include spread footings, mat foundations, concrete piles, drilled*
19 *piers, and caissons embedded in the ground. The design and installation of piling fully embedded*
20 *in the ground is regulated by the general building code. For the repair of such members, the*
21 *provisions within this code apply if not in conflict with the general building code. For the*
22 *portions of concrete piling in air or water, or in soil not capable of providing adequate lateral*

1 *restraint throughout the piling to prevent buckling, the provisions of this code govern where*
2 *applicable.*

3 **1.2.4** This code governs the evaluation, repair, rehabilitation, and strengthening of soil-
4 supported structural slabs that transmit vertical loads or lateral forces from the structure to the
5 soil.

6 **1.2.5** This code governs the evaluation, repair, rehabilitation, and strengthening of the concrete
7 portions of composite members.

8 **1.2.6** This code governs the evaluation, repair, rehabilitation, and strengthening of precast
9 concrete cladding that transmits lateral loads to diaphragms or bracing members.

10

11 **1.3—Jurisdictions without a general existing building code**

12 **1.3.1** Section 1.3 only applies if a jurisdiction has not adopted a general existing building code.

13 **1.3.2** Sections 4.1, 4.2, and 4.4 do not apply.

14 **1.3.3** Structures designed by a previous version of ACI 318 shall be evaluated in accordance
15 with 4.3 and chapter 6 of this code to determine if the structure is:

16 (a) in compliance with that previous version of ACI 318

17 (b) not in compliance with that previous version of 318 but safe

18 (c) not in compliance with that previous version of 318 and unsafe.

19 **1.3.4** If the structure is determined to be unsafe, modifications shall be in accordance with ACI
20 318-11 and this code. If the structure is determined to be safe, modifications shall be in
21 accordance with previous version of ACI 318 and with this code.

22 **1.3.4C** *If the original construction properly implemented the design and detailing requirements*
23 *of a previous version of ACI 318, there is no need to modify an existing building to satisfy the*

1 *ACI 318-11, unless the building is deemed unsafe. The principal goal of structural rehabilitation*
2 *is to ensure that the structural system is safe. Whereas one or more members may not conform to*
3 *current structural design requirements, those deficiencies may not result in an unsafe structural*
4 *system. Evaluation of the entire existing structure is used to determine the safety of the whole.*

5 **1.3.5** For complete replacement of building members or attachment of new construction to
6 existing building members, the design shall be in accordance with ACI 318-11 and this code.

7 **1.4—Administration and enforcement**

8 **1.4.1** The licensed design professional shall specify that all materials, including protection
9 materials, used for repair, rehabilitation, or strengthening shall satisfy governing regulatory
10 requirements at the time the Work is implemented.

11 **1.4.2—Approval of special systems of design or construction—**Sponsors of any repair design
12 or construction system, which does not conform to this code but which has been shown to be
13 adequate by successful use, analysis, or testing, shall have the right to present the data on which
14 their repair is based to the building official or to a board of examiners appointed by the building
15 official. This board shall be composed of competent engineers and shall have authority to
16 investigate the data so submitted, to require tests, and to formulate rules governing repair design
17 and construction of such systems to meet the intent of this code. These rules, when approved by
18 the building official and promulgated, shall be of the same force and effect as the provisions of
19 this code.

20 **1.4.2C** *New methods of design, new materials, and new uses of materials for repair and*
21 *rehabilitation should undergo a period of development before being specifically covered in a*
22 *code. Hence, good systems or components might be excluded from use by implication if means*
23 *are not available to obtain acceptance. For systems considered under this section, specific tests,*

1 *load factors, strength reduction factors, deflection limits, and other pertinent requirements*
2 *should be set by the board of examiners, and should be consistent with the intent of this code.*
3 *The provisions of this section do not apply to model tests used to supplement calculations or to*
4 *strength evaluation of existing structures.*

5
6 **1.5—Responsibilities**

7 **1.5.1** Licensed design professionals are responsible for the evaluation, design, detailing, and
8 specifying material requirements, establishing criteria for executing the Work, preparing
9 documents to perform the Work, and specifying a quality assurance program.

10 **1.5.1C** *At times, contractors employ a licensed design professional to design certain temporary*
11 *elements such as shoring or bracing. Although the design of temporary elements is generally not*
12 *performed by the licensed design professional responsible for the repair design for the project,*
13 *the licensed design professional may provide these services if requested by the contractor and*
14 *approved by the owner as long as there is no conflict of interest.*

15 *The licensed design professional may include a note in their documents that the contractor is*
16 *responsible for all means and methods to implement the repairs consistent with the plans and*
17 *specifications prepared by the licensed design professional.*

18 *During the evaluation and repair process, the licensed design professional should request that*
19 *the owner provide all available information regarding the building's condition, plans, previous*
20 *engineering reports, and disclose the presence of any known hazardous materials in the repair*
21 *area and any other pertinent information to the parties involved in the Work. This information*
22 *may require that remedial measures be taken before or during the construction process, which*
23 *should be considered when determining the scope of Work.*

1 **1.5.3** The licensed design professional shall notify the owner of any maintenance requirements
2 after the Work is completed in accordance with 1.7.

3 **1.5.4** The licensed design professional shall report identified unsafe structural conditions to the
4 owner and to jurisdictional authorities, in accordance with local ordinances.

5 **1.5.4C** *Unsafe structural conditions may be observed at the start of an evaluation process or, if*
6 *hidden, become evident during the repairs. The licensed design professional performing the*
7 *evaluation is responsible for informing the owner about the presence of unsafe structural*
8 *conditions found. When required, these conditions, with recommendations for remediation,*
9 *should be reported to the proper jurisdictional authorities by the licensed design professional or*
10 *owner. The owner should take measures to limit the potential risk associated with exposure to*
11 *these conditions. The remediation of risk may require immediate evacuation, limiting access to*
12 *portions of a structure, the installation of shoring, encapsulation or removal of delaminated*
13 *concrete, or other structural remedies.*

15 **1.6—Contract documents**

16 **1.6.1** The contract documents shall convey necessary information to perform the Work.

17 **1.6.1C** *At a minimum, these contract documents should indicate:*

- 18 • *Name and date of issue of the building code and supplements to which the evaluation,*
19 *repairs, rehabilitation, or strengthening conforms.*
- 20 • *Loads and other demand-related criteria.*
- 21 • *Design assumptions including specified properties of materials used for the project and*
22 *the strength requirements at stated ages or stages of the construction.*

- 1 • *Details and notes indicating the size, configuration, reinforcement, anchors, repair*
- 2 *materials, preparation requirements, and other pertinent information to implement the*
- 3 *repairs, strengthening, or rehabilitation of the structure.*
- 4 • *Magnitude and location of prestressing forces.*
- 5 • *Anchorage details for prestressing reinforcement.*
- 6 • *Development length of reinforcement and length of lap splices.*
- 7 • *Type and location of mechanical or welded splices of reinforcement.*
- 8 • *Shoring or bracing necessary before, during, and at completion of the evaluation, repair,*
- 9 *rehabilitation, or strengthening projects.*
- 10 • *Quality assurance program including special inspections.*

11 **1.6.2** Calculations pertinent to design shall be filed with the contract documents when required
12 by the building official. Analyses and designs using computer programs shall be permitted
13 provided design assumptions, user input, and computer-generated output are submitted. Model
14 analysis shall be permitted to supplement calculations.

15 **1.6.3** The licensed design professional shall provide the owner with copies of evaluation
16 reports, project documents, field reports, and other project documents produced by the licensed
17 design professional in addition to documenting the location of the completed repairs.

18 **1.6.3C** *Documentation of the protection and repairs that have been carried out, including any*
19 *test results, and instructions on inspection and maintenance to be undertaken during the*
20 *remaining design service life of the repaired part of the concrete structure should be provided to*
21 *the owner. The extent and type of records should be consistent with the agreement recorded in*
22 *the repair construction documents. It is good practice for the owner to keep documentation of*

1 *repairs, inspection, monitoring, and investigations as a record retention plan developed for*
2 *future reference.*

3

4 **1.7—Maintenance and monitoring**

5 **1.7.1** Maintenance recommendations shall be documented by the licensed design professional
6 as part of the repair design.

7 **1.7.1C** *A maintenance protocol that addresses project-specific conditions should be*
8 *established as part of the repair design that includes inspections and period of time between*
9 *inspections, after completion of the repair installation. Maintenance and frequent preventative*
10 *approaches that occur early in the service life of the structure generally result in improved*
11 *service life with less interruption and a lower life cycle cost (Tuutti 1980). A licensed design*
12 *professional should provide recommendations to the owner on inspection and maintenance to be*
13 *undertaken during the remaining design service life of the repaired part of the structure.*

14 *A maintenance protocol, including periodic inspections after completion of the repair that*
15 *addresses project-specific conditions provides the most effective method to ensure the durability*
16 *of the repair design. A maintenance protocol should be provided in the as-built or close-out*
17 *contract documents. Maintenance occurring early in the service life of the structure with more*
18 *frequent preventative approaches generally results in improved service life with less interruption*
19 *and a lower life cycle cost (ACI 365.1R). Maintenance of the repair can be incorporated in*
20 *instruction manuals from the designer, the contractor, or the manufacturer of the products.*

21 **1.7.2** Repairs, inspections, quality assurance reports, and tests required by the licensed design
22 professional shall be documented.

1 **1.7.2C** *The licensed design professional should provide the owner with copies of reports and*
2 *other project documents produced by the licensed design professional in addition to*
3 *documenting the location of the completed repairs.*

4

5

CHAPTER 2—NOTATION AND DEFINITIONS

6 **2.1—Notation**

7 A_k = load or load effect resulting from extraordinary event, lb

8 c = depth of neutral axis, in.

9 D = dead load acting on the structure, lb

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

11 E = load effects due to earthquakes, lb

12 F = load due to fluids acting on the structure, lb

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

15 f'_c = specified concrete compressive strength, psi

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

17 f_y = specified yield strength of reinforcing steel, psi

18 \bar{f}_y = average yield strength value for reinforcing steel, psi

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

20 H = load due to weight and pressure of soil, water in soil, or other materials acting on the
21 structure, lb

22 L = live load acting on the structure, lb

23 L_r = roof live load acting on the structure, lb

- 1 n = number of sample tests
- 2 R = rain load acting on the structure, lb
- 3 $(R_n)_{ex}$ = resistance of the structural component without strengthening
- 4 S = snow load acting on the structure, lb
- 5 T = load due to thermal effects acting on the structure, lb
- 6 U = required strength to resist factored loads or related internal moments and forces, lb
- 7 V = coefficient of variation determined from testing
- 8 W = wind load acting on the structure, lb
- 9 ϵ_t = net tensile strain in the extreme tension reinforcement at nominal strength
- 10 ϵ_y = yield strain of reinforcing steel
- 11 ϕ = strength reduction factor
- 12 λ = modification factor related to unit weight of concrete

13 **2.2—Definitions**

14 ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete
15 Terminology,” <http://terminology.concrete.org>. Definitions provided here complement that
16 resource.

17 *2.2C Additional repair-related definitions are provided by “ICRI Concrete Repair*
18 *Terminology,” <http://www.icri.org/GENERAL/repairterminology.aspx>.*

19

20 **bond**— 1. adhesion of the applied materials to reinforcement or other surfaces against which it is
21 placed, including friction due to shrinkage and longitudinal shear in the concrete and repair
22 materials engaged by the bar deformations.

1 2. adhesion or cohesion between layers of a repair area or between a repair material and a
2 substrate produced by adhesive or cohesive properties of the repair material or other
3 supplemental materials throughout the service life of the repair.

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

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

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

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

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

18 2. There exists a significant risk of collapse, detachment or dislodgement of any portion,
19 member, appurtenance or ornamentation of the concrete building or structure under
20 service loads.

21 **Commentary: dangerous**—*this definition is from the International Existing Building Code.*

22 **demand-capacity ratio**—ratio of required strength to design strength.

1 **design basis code**—legally adopted code requirements under which the evaluations, repairs and
2 rehabilitations are designed and constructed.

3 **design criteria**—codes, standards, loads, displacement limits, materials, connections, details,
4 and protections used in the design of mandated and voluntary work.

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

7 **effective area of reinforcement**—cross section area of a reinforcement assumed to resist axial
8 or flexural stresses.

9 **effective area of concrete**—cross section area of a concrete member that resists axial, shear, or
10 flexural stresses.

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

13 **evaluation process**—process of determining the in-place condition of a structure. The process
14 may include field and laboratory testing to determine material properties and the extent of any
15 deleterious processes. Engineering calculations are also typically required to determine the
16 existing structure capacity and demand. The goal of the evaluation process is an assessment of
17 the current or in-place condition of the structure.

18 **existing building**—building for which a legal certificate of occupancy has been issued. For
19 buildings that are not covered by a certificate of occupancy, existing buildings are those that are
20 complete and permitted for use.

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

1 **in-place condition**—existing condition of a structure, member, connection, and component sizes
2 and geometry, material properties, and damage from aging or other event.

3 **jurisdictional authority**—person or entity that has legal control over the applicable building
4 code and permitting procedures for a structure. An example of a jurisdictional authority is the
5 local building official.

6 **licensed design professional**—engineer for the evaluation and design of repairs to a structure
7 and in responsible charge of the engineering project.

8 **nonstructural concrete**—any element made of plain or reinforced concrete that is not part of a
9 structural system required to transfer gravity, lateral load, or both, along a load path to the
10 ground.

11 **objectives of the remedial Work**—restore, maintain, or enhance the performance level of the
12 existing structure for its intended use and life expectancy, which for the design requires specific
13 design criteria and implementing remedial Work.

14 **owner**—corporation, association, partnerships, individual, or public body or authority with
15 whom the Contractor enters into an agreement and for whom the work is provided. The owner is
16 the party in legal possession of the structure.

17 **performance method**—evaluation, repair, rehabilitation, and strengthening of a structure
18 performed under acceptance criteria approved by the building code official. The design basis
19 code for the performance method is established by the building code official.

20 **prescriptive method**—evaluation, repair, rehabilitation, and strengthening of a structure such
21 that the repaired structure satisfies all requirements of the general existing building code. The
22 design basis code for the prescriptive method is the general building code.

1 **renovation**—repair and remodeling of an old building to restore it to its original serviceable
2 condition.

3 **repair process**—1. complete process of evaluating an existing structure, the designing, replacing
4 or correcting deteriorated, damaged, or faulty materials, components, or elements of a structure.
5 The repair process is complete when the use of the repaired structure is transferred to the Owner
6 and/or the repair contract terms are completed.

7 2. procedure of evaluating an existing structure—the designing; replacing; or correcting
8 deteriorated, damaged, or faulty materials, components, or elements of a structure.

9 **repair reinforcement**—reinforcement used to provide additional capacity or confinement to the
10 repaired member.

11 **retrofit**—modification of an existing member or structure to increase its resistance.

12 **service life**—estimate of the remaining useful life of a structure based on the current rate of
13 deterioration or distress, assuming continued exposure to given service conditions without
14 repairs.

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

18 **economic service life**—time in service until replacement of the structure (or part of it) is
19 economically more advantageous than keeping it in service.

20 **expected service life (of a building component or material)**—the period of time after
21 installation or repair during which the performance satisfies the specified requirements when
22 routinely maintained but without being subjected to an overload or extreme event.

1 **functional service life**—time in service until the structure no longer fulfills the functional
2 requirements or becomes obsolete due to change in functional requirements.

3 **technical service life**—time in service until a defined unacceptable state is reached, such as
4 spalling of concrete, safety level below acceptable limits, or failure of elements.

5 **serviceability**—adequate structural performance under service loads.

6 **stability, local**—the stability of an individual member or part of an individual member in an
7 existing structure.

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

10 **strengthening**—process of increasing the load-resistance capacity of a structure or a portion
11 thereof.

12 **structural concrete**—plain or reinforced concrete in a member that is part of a structural system
13 required to transfer gravity and/or lateral loads along a load path to the ground.

14 **structural repair**—To replace, correct, or strengthen deteriorated, damaged, or understrength
15 load-resisting members and nonstructural members which, if failed, would result in an unsafe
16 condition.

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

19 **unsafe**—a structure or individual structural member that is dangerous or that constitutes a fire
20 hazard.

21 **Commentary: unsafe**—*this definition is adapted from the International Existing Building Code.*

1 **upgrade**—to improve the quality, effectiveness, or performance of a structure or its structural or
2 nonstructural components (for example, seismic upgrade of a building by increasing the strength
3 or deformation capacity of columns).

4 **work area method**—method under which the evaluation, repair, rehabilitation, and
5 strengthening of a structure is performed under the requirements of this code. This method
6 requires the establishment of the design basis code for the repair.

8 **CHAPTER 3—REFERENCED STANDARDS**

9
10 *C Both current, past and withdrawn standards are referenced. Standards that are referenced in*
11 *the design basis code are applicable for the evaluation of existing structures. These standards*
12 *may have been withdrawn by the developing organization; however they provide information on*
13 *the materials used at the time of original construction. See 4.3.3 and Chapter 6.*

15 *American Concrete Institute*

16 ACI 216.1-07 Code Requirements for Determining Fire Resistance of Concrete and
17 Masonry Construction Assemblies

18 ACI 318-11 Building Code Requirements for Structural Concrete and Commentary

19 ACI 437.2-12 Code Requirements for Load Testing of Concrete Members of Existing
20 Buildings (Provisional Standard)

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

23

1 *American Welding Society*

2 D1.4:2005 Structural Welding Code – Reinforcing Steel

3

4 *ASTM International*

5 ASTM A15 Specification for Billet-Steel Bars for Concrete Reinforcement (withdrawn

6 1969)

7 ASTM A16 Specification for Rail-Steel Bars of Concrete Reinforcement (withdrawn

8 1969)

9 ASTM A61 Specification for Deformed Rail Steel Bars for Concrete Reinforcement

10 with 60,000 psi Minimum Yield Strength (withdrawn 1969)

11 ASTM A160 Specification for Axle-Steel Bars for Concrete Reinforcement (withdrawn

12 1969)

13 ASTM A185-07/A185M-07 Standard Specification for Steel Welded Wire Reinforcement,

14 Plain, for Concrete

15 ASTM A370-11 Standard Test Methods and Definitions for Mechanical Testing of Steel

16 Products

17 ASTM A408 Specification for Special Large Size Deformed Billet-Steel Bars for

18 Concrete Reinforcement (withdrawn 1968)

19 ASTM A416/A416M-10 Standard Specification for Steel Strand, Uncoated Seven Wire for

20 Prestressed Concrete

21 ASTM A431 Specification for High-Strength Deformed Billet-Steel Bars for Concrete

22 Reinforcement with 75,000 psi Minimum Yield Strength (withdrawn 1968)

- 1 ASTM A432 Specification for Deformed Billet Steel Bars for Concrete Reinforcement
2 with 60,000 psi Minimum Yield Point (withdrawn 1968)
- 3 ASTM A497/A497M-07 Standard Specification for Steel Welded Wire Reinforcement,
4 Deformed, for Concrete
- 5 ASTM A615-09b/A615M-09b Standard Specification for Deformed and Plain Carbon-
6 Steel Bars for Concrete Reinforcement
- 7 ASTM A616/A616M-96a Standard Specification for Rail-Steel Deformed and Plain Bars for
8 Concrete Reinforcement (withdrawn 1999)
- 9 ASTM A617/A617M-96a Standard Specification for Axle-Steel Deformed and Plain Bars for
10 Concrete Reinforcement (withdrawn 1999)
- 11 ASTM A706/A706M-09b Standard Specification for Low-Alloy Steel Deformed and Plain
12 Bars for Concrete Reinforcement
- 13 ASTM A955/A955M-11 Standard Specification for Deformed and Plain Stainless Steel Bars
14 for Concrete Reinforcement
- 15 ASTM C42/C42M-11 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed
16 Beams of Concrete
- 17 ASTM C823/C823M-07 Standard Practice for Examination and Sampling of Hardened
18 Concrete in Constructions
- 19 ASTM C1583/C1583M-04 Standard Test Method for Tensile Strength of Concrete Surfaces
20 and the Bond Strength or Tensile Strength of Concrete Repair and Overlay
21 Materials by Direct Tension (Pull-off Method)

- 1 ASTM D4065-06 Standard Practice for Plastics: Dynamic Mechanical Properties:
2 Determination and Report of Procedures
3 ASTM E 329-11c Standard Specification for Agencies Engaged in Construction Inspection,
4 Testing, or Special Inspection
5

6 *American Society of Civil Engineers*

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

8 ASCE/SEI 31-03 Seismic Evaluation of Existing Buildings

9 ASCE/SEI 41-06 Seismic Rehabilitation of Existing Buildings
10

10

11 **CHAPTER 4—BASIS FOR COMPLIANCE**

12 **4.1—General**

13 The licensed design professional shall determine, at the start of a project, the design basis code
14 for the project's compliance based on criteria set forth in the general existing building code.

15 *4.1C Structures constructed under previously adopted codes or prior to the adoption of a*
16 *building code may not satisfy all current building code requirements. The International Building*
17 *Code and International Existing Building Code contain specific requirements that determine*
18 *when existing structures should be upgraded to satisfy the requirements of the general building*
19 *code. Local ordinance may also require that a structure be upgraded to satisfy the current ACI*
20 *318. These requirements should be reviewed at the start of a project.*

21

22 **4.2—Compliance method**

1 **4.2.1** The licensed design professional shall design a repair or rehabilitation in accordance with
2 the prescriptive method, the work area method, or the performance method. The compliance
3 method selected and the design basis code shall be used exclusive of the other methods.

4 **4.2.2** The design of a repair or rehabilitation in accordance with the prescriptive method shall
5 be performed in accordance with the requirements of the general building code.

6 **4.2.3** The design of a repair or rehabilitation in accordance with the work area method shall be
7 performed in accordance with 4.4.

8 **4.2.4** The design of a repair or rehabilitation in accordance with the performance method shall
9 be performed in accordance with the acceptance criteria approved by the building code official.
10

11 **4.3—Initial analysis**

12 **4.3.1** The licensed design professional shall review the necessary plans, construction data,
13 reports, and other available documents to perform the initial analysis.

14 **4.3.2** For the purpose of performing an initial analysis, the licensed design professional is
15 permitted to either assume a design basis code or analyze the building in accordance with 4.3.3
16 and 4.3.4.

17 **4.3.3** Existing site conditions shall be visually assessed by the Licensed Design Professional to
18 verify existing structural geometry and conditions. The Licensed Design Professional shall make
19 a determination if substantial structural damage has occurred.

20 **4.3.3C** *Substantial structural damage refers to damage in a structure which results in a*
21 *significant decrease in either the gravity or lateral load carrying capacity of a structure. The*
22 *International Existing Building Code provides a definition for substantial structural damage. In*

1 *most building codes, when substantial structural damage has occurred, the structure must be*
2 *repaired sufficiently to satisfy structural design requirements for new construction.*

3 **4.3.4** *The design strength of the existing structure, with the impact of deficiencies considered,*
4 *shall be determined considering in-place geometric dimensions and material properties. When*
5 *material properties are not immediately available, a preliminary analysis shall be completed*
6 *using reasonable assumptions for material properties as described in Chapter 6.*

7 **4.3.4C** *Strength calculations should be based on in-place conditions and should include an*
8 *assessment of the loss of strength due to deterioration mechanisms. Guidelines for assessing in-*
9 *place conditions include ACI 201.2R, ACI 214.4R, ACI 228.1R, ACI 228.2R, ACI 364.1R, ACI*
10 *437.1R, ASCE/SEI 11, ASCE/SEI 31, ASCE/SEI 41, ATC 20, ATC 45; and The Concrete Society*
11 *Technical Report 68 (2008). Material properties can be assessed by testing as described in these*
12 *references. When material test results are initially unavailable, historical properties based on*
13 *typical values used at the time of construction can be used in preliminary analyses.*

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

17 *Assessing fire damage and other deterioration mechanisms that result in a change in material*
18 *properties (such as compressive strength or modulus of elasticity) should include an evaluation*
19 *of the effect of the damage on the material properties and the impact of the damage on the*
20 *performance of the existing structure. Examples of deterioration mechanisms that result in*
21 *possible changes in material properties include corrosion of reinforcing steel, thermal damage,*
22 *concrete reactions such as alkali-aggregate, and freezing and thawing.*

23

1 *structural analysis protocol for the repair and establishes some tolerances. Applicable loads are*
2 *determined in accordance with the building code and standards such as ASCE/SEI 7, ASCE/SEI*
3 *37, and ASCE/SEI 41.*

4 **5.1.3** It is not permitted to use load factors and load combinations from the original design
5 building code with strength reduction factors from this Chapter. It is not permitted to use load
6 factors and load combinations from this Chapter with strength reduction factors from the original
7 design building code.

8 **5.1.3C** *Mixing of load factors and load combinations from one code with strength reduction*
9 *factors from a different code may result in an inconsistent level of reliability and safety.*

10 **5.1.4** Loads during all phases of the construction and repair process shall be used to design
11 shoring during repairs or other temporary construction. If the building is occupied during the
12 construction period, loading shall be in accordance with ASCE/SEI 7. If the building is
13 unoccupied during the construction period, loads shall be in accordance with ASCE/SEI 37.

14 **5.1.5** When assessing an existing structure or designing repairs or rehabilitation, consideration
15 shall be given to forces including but not limited to prestressing, crane loads, vibration, impact,
16 shrinkage, temperature changes, creep, and unequal settlement of supports.

17 **5.1.5C** *These factors may not have been specified in the original building code and therefore*
18 *should be considered in the evaluation and design of repairs.*

19
20 **5.2—Load factors and load combinations**

21 **5.2.1** Design of the repair shall account for existing loads on the structure; the effects of load
22 removal; and the sequencing of load application, including construction and shoring loads,
23 during the repair process.

1 calculated in accordance with requirements and assumptions of this code, multiplied by the
 2 strength reduction factors ϕ in 5.3.2 and 5.3.4.

3 **5.3.2** The strength reduction factor ϕ shall be as given in the following:

4	Tension-controlled sections (steel tensile strain at failure greater than $2.5\varepsilon_y$ where	
5	ε_y is the yield strain).....	0.90
6	Compression-controlled sections (tensile strain at failure less than or equal to ε_y)	
7	(a) Members with spiral reinforcement.....	0.75
8	(b) Other reinforced members.....	0.65

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

12	Shear and torsion.....	0.75
13	Bearing on concrete (except for post-tensioned anchorage zones and strut-and-	
14	tie models).....	0.65
15	Post-tensioned anchorage zones	0.85
16	Strut-and-tie models and struts, ties, nodal zones, and bearing areas in such	
17	models.....	0.75

18 **5.3.2.1C** For a steel yield strength of 60 ksi, the steel tensile strains corresponding to the
 19 tension- and compression-controlled limits are 0.005 and 0.002, respectively. Because the
 20 compressive strain in the concrete at nominal strength is typically assumed to be 0.003, the net
 21 tensile strain limits for compression-controlled members may also be stated in terms of the ratio
 22 c/d_t , where c is the depth of the neutral axis at nominal strength, and d_t is the distance from the
 23 extreme compression fiber to the centroid of extreme tension reinforcement. The c/d_t limits for

1 *compression- and tension-controlled sections are 0.6 and 0.375, respectively. The 0.6 limit for*
2 *compression-controlled sections applies to sections reinforced with Grade 60 steel and to*
3 *prestressed sections.*

4 **5.3.3** Development lengths do not require a ϕ -factor.

5 **5.3.4** For flexure, compression, shear, and bearing of structural plain concrete, ϕ shall be 0.60.

6

7 **5.4—Strength reduction factors for evaluation**

8 **5.4.1** If the required structural element dimensions, location of reinforcement, and material
9 properties are determined according to Chapter 6, it shall be permitted to increase ϕ from those
10 specified in 5.3, but ϕ shall not be more than:

11	Tension-controlled section.....	1.0
12	Compression-controlled sections:	
13	Members with spiral reinforcement.....	0.9
14	Other reinforced members	0.8
15	Shear and/or torsion	0.8
16	Bearing on concrete	0.8

17 **5.4.1C** *Strength reduction factors given in 5.4.1 are larger than those specified in 5.3.1. These*
18 *increased values are justified by the improved reliability due to the use of accurate field-*
19 *obtained material properties, actual in-place dimensions, and well-understood methods of*
20 *analysis. They have been deemed appropriate for use in ACI 318-11, Chapter 20, and have had a*
21 *lengthy history of satisfactory performance.*

1 **5.4.2** If an evaluation of members with no observed deterioration is based on historical material
2 properties as given in Tables 6.3.1a through 6.3.1c, the ϕ factors not greater than those given in
3 5.3 shall apply.

4 **5.4.3** Material properties of deteriorated members shall be determined by physical testing in
5 accordance with 6.3.5. It shall be permitted to increase ϕ for evaluation of these members from
6 the values specified in 5.3, but ϕ shall not be more than specified in 5.4.1.

7

8 **5.5—Load combinations for structures repaired with external reinforcing systems**

9 **5.5.1** For repairs achieved with unprotected external reinforcing systems, the required strength
10 U of a structure without repair shall be at least equal to the effects of factored loads in Eq.
11 (5.5.1).

$$12 \qquad U_{ex} \geq 1.2D + 0.5L + A_k + 0.2S \qquad (5.5.1)$$

13 where U_{ex} is the factored resistance of the structure without repair; D , L , and S are the specified
14 dead, live, and snow loads, respectively, calculated for the rehabilitated structure; and A_k is the
15 load or load effect resulting from the extraordinary event. For cases where the design live load
16 acting on the member to be strengthened has a high likelihood of being present for a sustained
17 period of time, a live load factor of 1.0 shall be used in place of 0.5 in Eq. (5.5.1).

18 **5.5.1C** *For repairs achieved with external reinforcing systems, such as externally bonded*
19 *fiber-reinforced polymer, externally bonded steel plates, or external post-tensioning systems, the*
20 *unrepaired structure should maintain a minimum strength should failure of the repair system*
21 *occur due to extraordinary events. Fire, impact, and blast are considered examples of*
22 *extraordinary events. Wind and earthquake forces are not considered extraordinary events, as*
23 *they are unlikely to cause damage to the unprotected external reinforcing systems. The minimum*

1 *limit of Eq. (5.5.1) will allow the structure to maintain sufficient structural strength until the*
2 *damaged repair system has been repaired. Examples of cases where the live load is present for a*
3 *sustained period of time include library stack areas, heavy storage areas, warehouses, and other*
4 *occupancies with a live load exceeding 150 lb/ft².*

5

6

CHAPTER 6 —EVALUATION AND ANALYSIS

7

6.1—Requirements for structural evaluation

8

6.1.1 A structural evaluation shall be comprised of a structural assessment and analysis.

9

6.1.1.C *Guidance on assessments may be obtained in ASCE/SEI 31 and ACI 364.1R.*

10

6.1.2 A structural evaluation shall be performed if an existing member, portion, or the entire structure exhibits signs of deterioration or behavior that is inconsistent with available design and contract documents or code requirements in effect at the time of construction.

11

12

6.1.3 A structural evaluation shall be performed when insufficient information is available to determine if a member, portion, or all of the existing structure is capable of supporting existing or new design loads.

13

14

6.1.3C *The data gathered for determining strength 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. The effect of deterioration on the ductility of the section should be considered in the evaluation. The strength or serviceability of a structure may be compromised by spalling, excessive cracking, large deflections, or other forms of degradation.*

15

16

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21

1 *If the strength of a structure is known, improvements to the strength, serviceability, durability,*
2 *and fire performance of a structure may be completed without performing a structural*
3 *evaluation.*

4 **6.1.4** A structural evaluation shall document existing conditions, including (a) through (g):

5 (a) The physical condition of the structural members shall be examined and the extent and
6 location of the degradation.

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

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

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

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

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

17 (g) Necessary information to assess earthquake resistance, seismicity, lateral-force-resisting
18 systems, span lengths, support conditions, building use and type, and architectural features.

19 **6.1.4C** *The construction documents may not represent as-built conditions. Therefore, the*
20 *licensed design professional is encouraged to research and verify the material properties*
21 *obtained from record documents are accurate. Material testing may be required to verify these*
22 *values. Additional information regarding the extent of the evaluation is provided in 6.3.5C.*

1 **6.1.5** Where repairs are required on an element in a structure, it shall be determined if similar
2 elements throughout the structure also require repair.

3 **6.1.5C** *If there is no evidence of distress or deterioration of similar elements to those that*
4 *required repair elsewhere in a structure, there is no need to implement repairs at those locations*
5 *unless conditions are such that life safety is an issue. Life safety may be a concern if there are*
6 *significant variances from the original design intent such as lower-strength concrete or*
7 *misplaced reinforcement. In addition, if the similar elements are in an environment that could*
8 *foster deterioration, then repairs or strengthening may be required, as opposed to a similar*
9 *element in a less severe environment.*

10

11 **6.2—Structural assessment**

12 **6.2.1** At a minimum, the structural assessment shall include affected structural members.

13 **6.2.1C** *Assessment may include visual, destructive, and nondestructive testing where evidence*
14 *of deterioration is apparent. At a minimum, areas of known deterioration and distress in the*
15 *structural elements should be identified, inspected, and recorded as to the type, location, and*
16 *degree of severity. Procedures are referenced in ACI 201.1R, ACI 228.1R, ACI 364.1R, and ACI*
17 *437R. Engineering judgment may be required when performing a structural assessment. The*
18 *affected structural elements are not only members with obvious signs of distress but also*
19 *contiguous elements in the structural system.*

20 **6.2.2** If an analysis is required, the structural assessment shall document the requirements of
21 6.1.4 and (a) through (c).

22 (a) As-measured structural member section properties and dimensions

23 (b) The presence and effect of any alterations to the structural system

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

2
3 **6.3—Material properties**

4 **6.3.1** Material properties shall be obtained from available drawings, specifications, and other
5 documents for existing construction. If such documents do not provide sufficient information to
6 characterize the material properties, this information shall be obtained from the historical data
7 provided in Tables 6.3.1a through 6.3.1c, or determination of material properties in accordance
8 with the requirements of 6.3.5, or both.

9 **6.3.1C** *Material properties required for seismic evaluation and rehabilitation are discussed in*
10 *ASCE/SEI 31 and ASCE/SEI 41. Where the as-built conditions and properties of historical*
11 *buildings require evaluation and rehabilitation, care should be taken to minimize the impact of*
12 *design and investigation procedures (U.S. Department of the Interior 1995). Material properties*
13 *include all physical and chemical properties of the concrete and reinforcement specified and*
14 *includes all references to ASTM standards and other methods of determining physical and*
15 *chemical properties.*

16 **6.3.2** As a minimum, concrete compressive strength and steel reinforcement yield strength
17 shall be determined for the existing structure where a structural evaluation is required. When
18 tests are used to determine material properties, test methods shall comply with the requirements
19 set forth in 6.3.5.

20 **6.3.2C** *Additional factors and characteristics affecting materials that may be required to be*
21 *evaluated include:*

22 (a) *Ductility of the element based on the stress-strain curves of the material.*

1 (b) Presence of corrosion of embedded reinforcing steel, including carbonation, chloride
2 intrusion, and corrosion-induced spalling.

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

5 (d) Degradation due to cyclic freezing and thawing.

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

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

10 Chloride penetration can cause reinforcing steel corrosion that can lead to cracking and
11 spalling. The depth of a spall will affect the effective area of concrete section. Concrete
12 degradation will affect its compressive strength.

13 **6.3.3** Nominal material properties shall be determined by (a), (b) or (c):

14 (a) Historical material properties provided in Tables 6.3.1a through 6.3.1c.

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

16 (c) Physical testing in accordance with 6.4.

17 **6.3.3C** The construction documents may not represent as-built conditions. Therefore, the
18 licensed design professional is encouraged to research and verify that the material properties
19 obtained from record documents are accurate. Material testing may be required to verify these
20 values.

21 **6.3.4** The material properties provided in the original construction test reports or material test
22 reports shall be permitted to be used unless deterioration has occurred.

1 **6.3.4.C** *When the results of material testing from original construction are available, these*
2 *results may be used in analysis models. Additional testing is required to confirm these material*
3 *test results when deterioration is observed.*

4 **6.3.5** *When properties are to be determined by in-place testing, the locations and numbers of*
5 *material samples shall be defined by the licensed design professional. The number of samples*
6 *shall not be less than required by the test standard.*

7 **6.3.5C** *The licensed design professional should research and acquire available records from*
8 *original construction. Assessment, historical research, and documentation of the geometry,*
9 *material properties, steel grades, and detailing used in the construction are invaluable and may*
10 *be used to reduce the amount of required in-place testing. The data gathered to determine*
11 *strength should include the effects of material degradation, such as loss of concrete strength*
12 *from sulfate attack and loss of steel area due to corrosion. The impact of deterioration on the*
13 *expected strength and ductility of the section also needs to be considered in the evaluation.*

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

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

1 **6.3.6** If historic data are not given in either Table 6.3.1b or 6.3.1c, the historic default value
 2 for yield strength shall be taken as 27,000 psi.

3 **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

4 * Taken from ASCE/SEI 41-06.

5 **Table 6.3.1b—Default tensile and yield strength properties for reinforcing for various**
 6 **periods ***

		Structural [†]	Intermediate [†]	Hard [†]				
	Grade	33	40	50	60	65	70	75
	Min. Yield (psi)	33,000	40,000	50,000	60,000	65,000	70,000	75,000
Year	Min. 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	-

7 * An entry of "X" indicates the grade was available in those years.

8 † The terms structural, intermediate, and hard became obsolete in 1968.

1 **Table 6.3.1c Default Tensile and Yield Strength Properties of Reinforcing for Various**
 2 **ASTM Specifications and Periods***

				Structural [†]	Intermediate [†]	Hard [†]				
			Grade	33	40	50	60	65	70	75
			Min. Yield (psi)	33,000	40,000	50,000	60,000	65,000	70,000	75,000
ASTM Designation [‡]	Steel Type	Year Range	Min. 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		-	-	-	-	-		-
A615	Billet	1968-1972		-	X	-		-	-	-X
A615	Billet	1974-1986		-	X	-	X	-		-
A615	Billet	1987-Present		-	X	-	X	-		X
A616	Rail	1968-Present		-	-	-	X	-		-
A617	Axle	1968-Present		-	X	-	-	-		-
A706 [#]	Low-Alloy	1974-Present		-	-	-	X	-	X	-
A955	Stainless	1996-Present		-	X	-	X	-		X

- 1 *An entry of "X" indicates the grade was available in those years.
 2 †The terms structural, intermediate, and hard became obsolete in 1968.
 3 ‡ASTM steel is marked with the letter W.
 4 §Rail bars are marked with the letter R.
 5 ||Bars marked with "s!" (ASTM A616) have supplementary requirements for bend tests.
 6 #ASTM A706 has a minimum tensile strength of 80 ksi, but not less than 1.25 times the actual yield strength.

7

8 **6.4—Test methods to determine or confirm material properties**

9 **6.4.1 General**—Destructive and nondestructive test methods used to obtain in-place
 10 mechanical properties of materials and member properties shall comply with the requirements of
 11 this section. It shall be permitted to determine the compressive strength of sound concrete by
 12 taking and testing cores. It shall be permitted to determine steel reinforcement properties by
 13 removal of reinforcement samples and destructive testing.

14 **6.4.2 Core sampling of concrete for testing**— It shall be permitted to determine the
 15 compressive strength of sound concrete by taking cores from the members being evaluated. Steel
 16 reinforcement shall be located by nondestructive testing before locating the cores to be extracted.

17 **6.4.2C Sample testing and the equivalent to specified concrete strength (f'_{ceq}) values may be**
 18 *determined in accordance with ACI 214.4R.*

19 **6.4.3 Concrete**—The cores shall be selected and removed in accordance with ASTM C42
 20 and ASTM C823. The equivalent specified concrete strength, f_{ceq} , shall be calculated using Eq.
 21 (6.4.3).

22
$$f_{ceq} = 0.9\bar{f}_c \left[1 - 1.28\sqrt{\frac{(k_e V)^2}{n} + 0.0015} \right] \quad (6.4.3)$$

23 where \bar{f}_c is the average core strength, as modified to account for the diameter and moisture
 24 condition of the core; V is the coefficient of variation of the core strengths; n is the number of

1 cores taken; and k_c is the coefficient of variation modification factor, as obtained from Table
2 6.4.3.

3 **Table 6.4.3—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

14 **6.4.3C** *The equivalent specified strength determined using this procedure can be used in*
15 *strength equations with the strength reduction factors from Chapter 5. The strength value*
16 *obtained using this procedure is an estimate of the 13 percent fractile of the in-place concrete*
17 *strength. This approach is specified in the Canadian Highway Bridge Design Code (CAN/CSA*
18 *S6-06 2006) and is based on the approach proposed by Bartlett and MacGregor (1995). Guides*
19 *for obtaining and evaluating cores are provided in ACI 214.4R.*

20 **6.4.3.1** Quantifications of concrete compressive strength by nondestructive testing (NDT)
21 alone shall not be permitted as a substitute for core sampling and testing. NDT shall be permitted
22 when a valid correlation is established with core sample strength test results and nondestructive
23 test results.

1 **6.4.3.1C** *ACI 228.1R provides information on NDT methods for assessment of concrete*
2 *compressive strength and development of statistical correlations between NDT and core test*
3 *results.*

4 **6.4.4 Reinforcing steel**—The size, number, and location of steel reinforcing bars or elements
5 shall be established. If the original construction documents are not available and if the properties
6 of the reinforcing steel are unknown, historical values provided in 6.3.5.2 shall be permitted in
7 place of testing. If the grade of material is unknown, the lowest grade provided in Table 6.3.1b
8 for a given historic period shall be used. When historical default strength properties are not used,
9 testing is required.

10 **6.4.4C** *The ASTM designation or age of the structure may be known but the grade of*
11 *reinforcement is not known. In this case the lowest grade of reinforcement corresponding to the*
12 *age or ASTM designation should be used. When no information is available, the Licensed Design*
13 *Professional may use the lower bound value of 27,000 psi in lieu of testing.*

14 **6.4.5 Reinforcement sampling and testing**—Removal of reinforcement samples and the
15 laboratory destructive testing shall be permitted as a method of determining existing steel
16 reinforcement properties. The yield and tensile strength for reinforcing steels shall be obtained in
17 accordance with ASTM A370.

18 **6.4.5C** *Generally, the reinforcing steel used in a structure is of a common grade and*
19 *strength. Occasionally, more than one grade of steel is used in a structure. Historical research*
20 *from The Concrete Reinforcing Steel Institute (2001) may contain supplemental information on*
21 *mechanical properties of the reinforcement used in different construction eras.*

1 *Reinforcing steel includes square, rectangular, and round bars with and without*
 2 *deformations, prestressing wire, bars, multi-wire strands, and structural shapes. Historically,*
 3 *wire rope and chain have also been used as reinforcement.*

4 **6.4.6.** A minimum of three sample coupons, taken from different segments of
 5 reinforcement, shall be obtained from the members being evaluated. The equivalent specified
 6 yield strength, f_{yeq} , used for analysis shall be calculated by

$$7 \qquad f_{yeq} = (\bar{f}_y - 3,500)^{(-1.3k_s V)} \qquad (6.4.6)$$

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

11 **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

19 **6.4.6C** *The equivalent specified yield strength determined using this procedure can be used*
 20 *in strength equations with the strength reduction factors from Chapter 5. The yield strength*
 21 *value obtained using this procedure is an estimate of the 10 percent fractile of the static steel*
 22 *strength. It is assumed that the difference between the yield strength measured during a coupon*

1 test and the static yield strength is 3500 psi. This approach is specified in the Canadian Highway
2 Bridge Design Code (CAN/CSA S6-06 2006).

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

7 **6.4.7** If the properties of the steel used for connections are unknown, both yield and tensile
8 strengths shall be determined by one of the following:

- 9 (a) Testing of coupons taken from the connector steel.
- 10 (b) Documentation giving connector steel properties in the original construction documents.
- 11 (c) Use of historic default values given in 6.3.5.2.

12 **6.4.8** Coupon specimens for the determination of yield and tensile strengths of structural steel
13 shall be tested in accordance with ASTM A370. A minimum of three specimens shall be taken
14 from representative elements.

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

$$17 \quad f_{yeq} = (\bar{f}_y - 4,000)^{(-1.3k_s V)} \quad (6.4.8)$$

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

21 **6.4.9** The sampling of prestressing steel reinforcement for strength testing shall be required if
22 strength and historical data are not available. Testing of the prestressing reinforcement shall be in
23 accordance with ASTM A416.

1 **6.4.10** If welding of reinforcement is required, carbon equivalency shall be determined in
2 conformance with AWS D1.4.

4 **6.5—Structural analysis of existing structures**

5 **6.5.1** The structural system shall be analyzed for the maximum effects on the affected
6 members. Loads and load combinations shall be determined in accordance with the provisions of
7 Chapter 5.

8 **6.5.1C** *Structural evaluation analyses are conducted to verify strength and serviceability. The*
9 *analytical methods of 6.7 are used with factored loads to determine strength requirements for a*
10 *combination of moments, shears, and axial loads of pertinent structural members. A service load*
11 *level analysis may be completed to evaluate serviceability, including deflections and expected*
12 *crack size and distribution.*

13 **6.5.2** Analysis of the structure shall use accepted engineering principles that satisfy force
14 equilibrium and the principles of compatibility of deformations and strains.

15 **6.5.3** Analysis shall consider material properties, member geometry and deformation, lateral
16 drift, duration of loads, shrinkage and creep, and interaction with the supporting foundation.

17 **6.5.3C** *The licensed design professional is responsible for determining the appropriate method*
18 *of analysis. Appropriate methods include linear elastic analysis, nonlinear analysis, and other*
19 *traditionally accepted engineering analysis methods. If a linear elastic analysis method is used,*
20 *the effects of cracking and other nonlinear effects should be included in the analysis using*
21 *engineering approximations.*

22 *The analysis may include the effects of the size and member geometry to determine the forces*
23 *on individual members of a structure. The analysis should consider external effects including*

1 *prestressing, material volume changes, temperature variations, and differential foundation*
2 *movement.*

3 **6.5.4** Members shall be analyzed considering the effect of any material degradation, bond loss,
4 and the redistribution of forces in members and in the structural system as a whole.

5 **6.5.4C** *Member deterioration and damage may result in distribution of internal forces different*
6 *than the distribution of forces for which the structure was originally designed. The strength and*
7 *integrity of prestressed structures with damaged prestressing reinforcement requires careful*
8 *consideration to assess the impact of the damage. Redistribution of moments may exceed the*
9 *moment distribution permitted in ACI 318-11. The actual state of the structure should be*
10 *accurately modeled to determine the distribution of forces. Redistribution of forces may be*
11 *determined using material nonlinear analysis, by load tests described in ACI 437, or by linear*
12 *analysis which bounds the limits of redistributed forces.*

13 **6.5.5** Analysis shall consider the load path from the load application through the structure to
14 the foundation. Three-dimensional distribution of loads and forces in the complete structural
15 system shall be considered unless a two-dimensional analysis adequately represents the part of
16 the structure being evaluated.

17 **6.5.5C** *The evaluation of load effects requires consideration of both the load paths through the*
18 *structure and how the forces are distributed in members.*

19 **6.5.6** Analysis shall consider the effects of previous repairs and of any previous structural
20 modifications on the behavior of the structure.

21 **6.5.6C** *Modifications to structures in the form of repairs, alterations, or additions may affect*
22 *the force distribution and load path in a structure. The effect of these modifications should be*
23 *accounted for in analytical models.*

1 **6.5.7** The analysis shall be based on available documentation, as-built dimensions, and the in-
2 place properties of the structure. The assessment of in-place material properties shall be as
3 described in 6.3. If section loss has occurred, the loss shall be quantified by direct measurement,
4 and section properties shall be adjusted according to the principles of structural mechanics.

5 **6.5.7C** *Available documentation may include original drawings, specifications, shop drawings,*
6 *structural assessments, testing, and geotechnical reports. Deviations between the existing*
7 *construction and construction documents are to be identified and recorded.*

9 **6.6—Structural serviceability**

10 **6.6.1** The licensed design professional shall perform a serviceability evaluation for parts or all
11 of a structure to ensure the structure meets the serviceability requirements. The serviceability
12 evaluation shall be based on the in-place geometry and properties of the structure.

13 **6.6.1C** *Structural serviceability problems may include, but are not limited to, deflections,*
14 *vibrations, leakage, and objectionable cracking. The data gathered for the purpose of*
15 *determining serviceability should include the effects of material degradation, such as loss of*
16 *concrete strength from sulfate attack or loss of steel area due to corrosion.*

17 *The specific performance criteria and the intended function of an individual structure should*
18 *be defined. Floor deflection criteria can be found in ASCE/SEI 7. Vibration criteria are given in*
19 *Murray et al. (1999).*

21 **6.7—Structural analysis for repair design**

1 **6.7.1** The structural analysis used for repair design shall use a method that models the
2 structural repair process. The analysis shall consider the effects of the sequence of load
3 application and material removal during all phases of the evaluation and repair process.

4 **6.7.1C** *The construction process may involve the application and removal and replacement of*
5 *loads. The analysis needs to consider the effects of the application and removal of construction*
6 *loads to determine the maximum loading during all construction phases. The additional applied*
7 *loads may be due to prestressing, vibration, material volume changes such as creep and*
8 *shrinkage, temperature changes, effect of shoring, and unequal deformation of supports.*

9 **6.7.2** Structural modeling shall account for repairs where the materials change through the
10 section.

11 **6.7.3** Section analysis shall use principles of mechanics and shall assume (a), (b), or (c): (a) full
12 composite action with no slip at interfaces between repair materials and existing materials; (b)
13 separate action with full slip between repair and existing materials; or (c) partial composite
14 action with friction at interfaces between repair and existing materials.

15 **6.7.3C** *Depending on the repair construction process and the selection of repair materials, the*
16 *repair materials and the existing concrete or reinforcement may not act compositely. The*
17 *analysis should appropriately model the behavior of the correct degree of the expected*
18 *composite action of the repaired structure. An example of partial composite behavior are beams*
19 *that contain shear studs to develop ultimate strength, yet lack bond between the overlay and*
20 *substrate. In this situation, the overlay and substrate do not maintain strain compatibility.*

21 **6.7.4** Seismic analysis of repaired structure

22 **6.7.4.1** The interaction of structural members and nonstructural components that affect the
23 response of the structure to earthquake motions shall be considered in the analysis.

1 **6.7.4.2** Existing, repaired, and added supplementary members assumed not to be a part of the
2 seismic force-resisting system shall be permitted provided their effect on the response of the
3 system is considered and accommodated in the repair design. Consequences of failure of
4 structural members that are not a part of the seismic force-resisting system and nonstructural
5 components shall be considered.

6 **6.7.4.3** The method of analysis shall consider the structural configuration and material
7 properties after repair.

8 **6.7.4C** *Procedures for seismic rehabilitation of concrete buildings, including analysis, are*
9 *provided in ASCE/SEI 41 and supplemented in ACI 369R. These references provide details for*
10 *forces, rehabilitation methods, analysis and modeling procedures, and seismic rehabilitation*
11 *design.*

13 **6.8—Strength evaluation by load testing**

14 **6.8.1** Load testing in accordance with ACI 437.2 shall be permitted to supplement the analysis
15 and to demonstrate the strength of the original or repaired structure

16 **6.8.1C** *The licensed design professional may lack information required to determine the load*
17 *carrying capacity of deteriorated or repaired structural members. Field assessments, including*
18 *destructive and in-place testing, can provide some of the information required, but the costs for*
19 *these assessments can be significant; however, the results of strength evaluation may still be*
20 *inconclusive due to unknown effects of existing conditions or interaction with the repair. In these*
21 *cases, load testing can verify the strength of a member and of a structural system and to achieve*
22 *a reliable estimate of the short-term strength. In such cases, load testing may provide the most*
23 *effective means of verifying the load-carrying capacity of an existing structure or element. Load*

1 *testing can also be a valuable tool for evaluating the effectiveness of structural repairs. For*
2 *example, load testing, as defined in ACI 437.2, can be performed to determine that the service*
3 *load deflection and cracking are acceptable.*

4 **6.8.2** Model testing shall be permitted to supplement analysis.

5 **6.8.2C** *This code permits model testing to be used to supplement structural analysis and design*
6 *calculations. Documentation of the model tests and subsequent interpretation should be provided*
7 *with the related calculations. Model testing should be performed by an individual having*
8 *experience in this technique. Guidelines for model testing and analysis are given by Sabnis et al.*
9 *(1983).*

11 **CHAPTER 7 —DESIGN OF STRUCTURAL REPAIRS**

12 **7.1—General**

13 Repaired structures, structural members, and connections shall be designed to have
14 design strengths at all sections at least equal to the required strengths calculated for factored
15 loads and forces in such combinations as stipulated in this code.

17 **7.2—Strength and serviceability**

18 **7.2.1** Repaired members shall be designed to have adequate stiffness to limit deflections,
19 vibrations, cracking, or any deformations that adversely affect strength or serviceability of a
20 structure.

21 **7.2.1C** *Adequate stiffness needs to be determined on a project-specific basis and is a function*
22 *of the structure type, the desired performance of the structure, and loading conditions and use.*

1 **7.2.2** Repair design and construction procedures shall consider the loading, internal forces, and
2 deformations in both the existing and repaired structure during the repair process.

3 **7.2.2C** *During the repair process, it may not be possible or practical to relieve existing*
4 *stresses or deformations. Consideration should be given to the in-place internal forces and*
5 *deformation present in the existing structure during the repair and the subsequent internal forces*
6 *from the design loads that the repaired section will carry. Internal forces and deformations*
7 *caused by existing loads may be locked-in by the repair.*

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

17 **7.3—Behavior of repaired systems**

18 **7.3.1** Repairs incorporating new members shall be designed to integrate the new members with
19 the existing structure, creating a structural system capable of sharing and transferring loads.

20 **7.3.1C** *Repair of an existing structure may be achieved by improving the global behavior of the*
21 *structure by adding new structural members that act integrally with the existing structural*
22 *system. Repair can also be achieved by improving the behavior of the existing members that*
23 *incorporate repair materials or systems.*

1 *Load sharing and load transfer should exist between the existing structure and the new*
2 *members so that the load path and force distribution assumed by the designer can occur. The*
3 *effects of adding new members on the global stiffness and force distribution should be*
4 *considered.*

5 **7.3.1.1** The design of the repair system shall consider the structural interaction between the
6 existing structure and new members. The effect of the new members on the existing structure
7 shall be evaluated according to the design basis code.

8 **7.3.1.1C** *The design of the repair system should consider connections of new members to the*
9 *existing structure. Connections of new members should be designed to transfer design forces*
10 *between new members and the existing structure.*

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

15 **7.3.2** Repairs to existing members shall account for force transfer at the interface between the
16 existing member and the repair material or repair system. It is permissible to use ACI 318-11
17 provisions in the design of force transfer between new and existing concrete.

18 **7.3.2C** *In repairing existing members, induced forces on the repaired member are shared*
19 *between the existing member and the repair material or system. The repair should be designed to*
20 *allow for transfer of forces between the components.*

21 *The requirements for composite behavior between the repair and the existing member may*
22 *vary depending on the type of repair (structural or nonstructural) and the performance criteria*
23 *at service and ultimate states. While certain designs require composite behavior up to ultimate*

1 state, others may be limited to service conditions. Composite behavior can be achieved by
2 chemical bonding, mechanical means, or a combination thereof. The design should specify the
3 repair materials and techniques that will develop the level of composite behavior to achieve the
4 intended performance of the repaired member. Specific reference is made to ACI 318-11 –
5 Sections 11.6 and 17.5 for design requirements for force transfer between new and existing
6 concrete.

7 Design provisions for fiber reinforced polymer (FRP) are provided in ACI 440R. Design
8 provisions for composite structural steel sections are provided in the Steel Construction Manual
9 (2011). Techniques other than shear-friction are acceptable.

10 Repair design may not require all components of the repair to remain composite with the
11 existing member at factored load. For example, externally bonded steel plates and FRP
12 composites that are used in bond critical applications to increase or restore the strength of the
13 member should be designed and detailed to remain bonded at the factored load. Strength
14 calculations should be based on the achievable level of composite behavior.

15 Spalling of cover concrete or other repair materials may be tolerated at conditions such as a
16 seismic event. In these situations, the member may achieve ultimate strength without the repair
17 material in place. Section 7.3.2.1 applies in these events.

18 **7.3.2.1** Structural repairs shall maintain composite behavior under service loads. Repairs
19 shall be designed for the material and existing substrate to perform as a composite section at
20 service loads.

21 **7.3.2.1C** Repairs may be needed to improve durability or aesthetics. Therefore, they may not
22 require composite behavior under service or ultimate load. In some cases, such as overhead
23 repair or facade repair, nonstructural repairs may be required to maintain composite behavior

1 under both service and ultimate design loads. If composite behavior cannot be achieved, the
2 repaired system should have sufficient redundancy or connections to prevent falling hazards.

3 The licensed design professional will typically design and detail repairs to be fully composite
4 under ultimate strength conditions, and that design will typically satisfy service load strength
5 requirements. The provisions of ACI 318-11 (Sections 11.6 and 17.5) can be used to design fully
6 composite repairs. Alternately, principles of engineering mechanics can be used to assess force
7 demand at service load conditions.

8

9 **7.4—Bond**

10 **7.4.1** The required bond strength shall be at least 1.5 times greater than the calculated design
11 bond force at the repair material to existing concrete interface.

12 **7.4.1.1** The measured bond strength shall not be less than the lower of the required bond
13 strength or the tensile strength of the existing concrete. If the tensile strength of undamaged
14 existing concrete is unknown, it shall be permitted to take the tensile strength as $4\lambda\sqrt{f'_c}$.

15 **7.4.1.2** Testing to measure bond strength of repair materials to existing concrete and the
16 tensile strength of the existing concrete shall be in accordance with ASTM C1583.

17 **7.4.1.2C** Bond strength testing may not be required in all repairs. ACI 503R and ICRI 210.3
18 provide guidance for performing the test and the test frequency.

19 **7.4.1.3** It shall be permitted to provide supplementary reinforcement to achieve required
20 bond strength.

21 **7.4.1.3C** For bonded repairs, the tensile and shear strength of the repair system interface
22 should be greater than that of the substrate. Lower bond strength may be acceptable for
23 situations with high substrate strength and the bond strength meets design requirements. When

1 *failure occurs within the substrate, failure should occur within the substrate at a depth sufficient*
2 *to preclude bruising or microfractures causing low bond strength.*

3 *A properly prepared substrate is achieved by removing the layer of existing deteriorated or*
4 *contaminated concrete. The exposed sound concrete is then roughened and cleaned to allow for*
5 *adequate bond of a repair material or protective coating to the substrate.*

6 *Adequate bond means continued adhesion of the applied materials to reinforcement or other*
7 *surfaces against which it is placed. Bond should be sufficient to resist stress due to tension,*
8 *shear, and compressive forces due to differential shrinkage and creep between repair materials*
9 *and the existing concrete. Bond between the repair material and reinforcement should develop*
10 *the design tensile and compressive strength of the reinforcement. The adhesion or cohesion*
11 *provided by the bond should not deteriorate unacceptably over the anticipated service life of the*
12 *repair.*

13 *Heavy corrosion products on the reinforcement, on the concrete surface, or both, inhibit*
14 *development of bond between existing concrete and new repair materials. Heavy corrosion*
15 *products can be considered Rust Grade 5 or less in accordance with ASTM D610. Corrosion or*
16 *other bond-inhibiting products should be removed to achieve proper bond.*

17 **7.4.2** The licensed design professional shall verify the concrete substrate has adequate
18 strength to sustain and transfer design forces of externally attached reinforcement.

19 **7.4.2C** *If external reinforcement is added to a structure, the minimum strength of the existing*
20 *concrete necessary for the transfer of load from the external reinforcement to the structure needs*
21 *to be established. For example, ACI 440.2R requires a minimum concrete compressive strength*
22 *of 2500 psi to bond FRP.*

1 **7.4.3** Adhesives used to bond existing concrete, repair materials, and repair reinforcement shall
2 transfer required forces between elements.

3 **7.4.3C** *Guide for the verification of bond can be found in ACI 440R, ACI 503R, ICRI 210.3,*
4 *and ASTM C1583.*

5 **7.4.4** The selection of adhesives used in repair shall consider load type and duration and the
6 effect of exposure conditions on adhesive properties.

7 **7.4.4C** *ACI 503.5R, ACI 503R, and ACI SP-165 provide guidance for the selection of*
8 *adhesives.*

10 **7.5—Materials**

11 **7.5.1** The LDP shall consider the properties of repair materials and systems in designing repairs
12 and in specifying repair materials and repair procedures. These include but are not limited to:
13 physical properties of the repair materials, type of application, adhesion, shrinkage, thermal
14 movement, durability, corrosion resistance, installation methods, curing requirements, and
15 environmental condition.

16 **7.5.1C** *Physical properties include mechanical, chemical and electrical properties.*
17 *Documentation should be provided for properties of each repair material. The stated properties*
18 *should be verified that they satisfy the project requirements. ACI and ICRI provide guidelines for*
19 *the selection of repair materials (ACI 301, ACI 318-11, ACI 503R, ACI 503.5R, ACI 503.6R, ACI*
20 *546.3R, ICRI No. 320.2R, ICRI No. 320.3, ICRI No. 330.1, and ICRI No. 340.1).*

21 *The design of a repair should consider the compatibility of the repair materials and the*
22 *materials of the existing structure. Compatibility of repair materials and systems include*
23 *dimensional compatibility, bond compatibility and durability, mechanical compatibility, and*

1 *electrochemical and permeability compatibility. Generally, the intent is to use a repair material*
2 *that has physical and mechanical properties that are as close as possible to those of the parent*
3 *material to which the repair material is to be adhered.*

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

8 *Volume stability of repair materials should be accounted for in the design of the repair.*
9 *Volume stability, also known as dimensional compatibility, refers to initial and time-dependent*
10 *changes in the volume of the repair material after placement. Volume stability is often measured*
11 *as changes in a linear dimension of the repair and should be accounted for in the design of a*
12 *repair system. Autogenous shrinkage, chemical shrinkage, degree of restraint, environmental*
13 *conditions, drying shrinkage, creep, thermal changes, moisture absorption, and other factors all*
14 *affect volume stability. Experience has shown that volume change of the repair materials has*
15 *often been the cause of poor performance of repairs. Properties of repair materials should be*
16 *selected for volume stability and dimensional compatibility with the existing structure to reduce*
17 *the probability of cracking caused by volume changes. Directional compatibility refers to*
18 *movement or shrinkage differences in a single direction or multiple directions.*

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

20 *Repair materials such as portland cement concrete, portland cement mortar, polymer-cement*
21 *concrete, polymer concrete, fiber-reinforced concrete, resin-based materials, and similar*
22 *products are commonly used. The repair materials do not necessarily contain portland cement.*

1 *Repair materials should be selected to achieve the necessary service, strength, and durability*
2 *requirements.*

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

6 *Refer to ACI 440.1R for internal FRP reinforcement, ACI 440.2R for externally bonded FRP*
7 *reinforcement, and ICRI No. 330.1 and the ACI Detailing Manual (ACI SP-66) for steel*
8 *reinforcement.*

9 *Required properties of the repair reinforcement should be specified in the contract documents.*
10 *Specified properties are dependent on the requirements of the repair and may include yield*
11 *strength, tensile strength, chemical properties, elongation, material type, and moduli.*

12 **7.5.2** Materials conforming to the design basis code already in use in a building shall be
13 permitted to remain in use.

14 **7.5.3** Materials conforming to ACI 318-11 or permitted by this code shall be used for repairs
15 and alterations.

16 **7.5.4** Alternate materials shall be permitted according to the licensed design professional's
17 approval and in accordance with 1.4.

18

19 **7.6—Design and detailing considerations**

20 **7.6.1** Repair design shall be based upon the member conditions identified in Chapter 6.

21 **7.6.2 Concrete**—The in-place properties of the existing concrete, as identified in Chapter 6,
22 shall be used in the repair design.

1 **7.6.2C** *The extent and cause of deterioration and the concrete strength and quality should be*
2 *determined, including compressive strength, chlorides, carbonation, sulfate attack, alkali silica*
3 *reaction, physical damage, corrosion-induced spalling, and cracking.*

4 *Chloride penetration can cause corrosion that can lead to cracking and spalling. The depth*
5 *of a spall reduces the effective area of concrete section. Degradation of the concrete will affect*
6 *the compressive strength of the concrete.*

7 **7.6.3 Reinforcement**

8 **7.6.3.1** Reinforcement that is damaged or corroded shall be permitted to remain. The
9 effective cross-sectional area shall be used in the repair design in accordance with the design
10 basis code. The effect of corrosion damage on development of reinforcing steel shall be assessed
11 by the licensed design professional. At locations where deformations are no longer present,
12 reinforcing steel shall be considered as smooth bars.

13 **7.6.3.1C** *Strength evaluation and repair design should consider the in-place condition of the*
14 *existing reinforcement, including the effective cross-sectional area of the reinforcing bars after*
15 *removal of corroded material. The effective area is calculated using the remaining effective*
16 *diameter of the reinforcement accounting for the loss of metal due to corrosion considering the*
17 *location of the loss of area within the member. Further considerations may also include the*
18 *location of the corroded areas, loss of confinement, the loss of bond, and the effect of corrosion*
19 *on member strength. If fire damaged the structure, steel reinforcement may be annealed, and the*
20 *yield stress reduced. Specific durability requirements related to corroded reinforcement are*
21 *addressed in Section 8.4.*

22 **7.6.3.2** Design shall consider the location and detailing of the existing reinforcement in
23 accordance with the evaluation of Chapter 6.

1 **7.6.3.2C** *The location and detailing includes the horizontal and vertical positions,*
2 *development length, orientation, geometry of the reinforcement, and the presence of hooks and*
3 *cross-ties. Field examination to locate existing reinforcement may be required.*

4 **7.6.3.3** Both existing and new reinforcement shall be adequately developed. Development
5 length shall be permitted to be calculated based upon development in both the existing concrete
6 and new materials.

7 **7.6.3.3C** *Reinforcement development may be inadequate due to corrosion, mechanical*
8 *damage, insufficient or loss of concrete cover, delaminated concrete, concrete strength, or other*
9 *conditions. The design of the repair should evaluate the required development length to develop*
10 *the design force of existing reinforcement. Detailing of the repair should include the proper*
11 *development of new reinforcement to achieve the design force. ACI 318-11 provides guidance for*
12 *detailing of steel reinforcement. ACI 440.1R and ACI 440.2R provide detailing guidance for*
13 *internal FRP reinforcement and externally-bonded FRP reinforcement, respectively.*

14 **7.6.4** *Prestressed structures*

15 **7.6.4.1** The effects of existing prestressing shall be included in the repair design.

16 **7.6.4.1C** *Requirements for repair of structures with bonded and unbonded prestressing are*
17 *different. Post-tensioned structures (with bonded and unbonded tendons) are often cast-in-place*
18 *monolithic structures, whereas pretensioned structures (with bonded strands) are often single-*
19 *span precast structures. Each system is unique and should be individually considered. The repair*
20 *of prestressed structures requires an assessment of the existing tendons. Repair of unbonded*
21 *tendons may require tendon detensioning. Guidance for evaluation methods and repair*
22 *techniques of unbonded post-tensioned structures is provided in ACI 423.4R, ACI 222.2R, ICRI*
23 *No. 210.2, ICRI No. 320.4., and PTI DC80.2 (2010).*

1 **7.6.4.2** The effects of modifications to existing structure geometry, existing damage
2 conditions, prestressing force release, and construction sequence shall be included in the repair
3 design.

4 *7.6.4.2C Analysis of prestressed structures is required to evaluate the effect of damaged or
5 severed prestressing reinforcement on the structural strength and performance. The effect of
6 severed bonded tendon is typically localized because the free end of the tendon will be effective
7 after a transmission length is developed and will reestablish the full tendon force.*

8 *Review of grouting quality assurance and supervision documents may be required to ensure
9 adequately grouted tendons after the application of prestress. Field evaluation of existing grout
10 may be required in the absence of sufficient documentation of the original construction.*

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

14 *Analysis to evaluate the effects of structural modifications such as installation of slab openings
15 should verify that strength is adequate and that all serviceability conditions (for example,
16 deflections) are met. Large openings can significantly influence the global behavior of the
17 structure and may result in strengthening needs.*

18 *Corrosion on prestressing strands may have an effect on strand integrity and strength.
19 Prestressing strand requires examination for conditions such as corrosion pitting and hydrogen
20 embrittlement (refer to ICRI No 210.2 and ACI 222.2R). Analysis methods of unbonded post-
21 tensioned structures are provided in ACI 222.2R, ACI 423.4R, ICRI No. 210.2, ICRI No. 320.4,
22 PTI (2006), and PTI DC80.2 (2010).*

1 *Repair and structural modification may require detensioning of prestressing tendons.*
2 *Unbonded tendons should be detensioned in a controlled manner to ensure performance and*
3 *safety. Unless not needed based on analysis, all interrupted unbonded tendons should be*
4 *reanchored and restressed to restore full structural strength. This can be achieved by splicing or*
5 *by installing new tendon anchorages at the edge of new opening, and after concrete reaches the*
6 *necessary strength, the tendons are restressed.*

7 *For structures with bonded tendons, shoring may only be required locally at the repair area.*
8 *When unbonded tendons are severed, the prestressing force will be lost for the full length of the*
9 *tendon. Releasing or cutting tendons may affect multiple spans and may require shoring beyond*
10 *the area where cutting or releasing of tendons occurs. Adjacent spans require temporary shoring*
11 *depending on the number of tendons severed at one time and the applied loads . Analysis based*
12 *on actual loading at the time of the modification may show shoring to be unnecessary.*

13 *Guidance for analysis of unbonded post-tensioned structures is provided in ICRI No. 320.4,*
14 *PTI (2006), and PTI DC80.2 (2010).*

15 **7.6.4.3** *Stresses in remaining section after concrete removal shall not exceed the limits*
16 *established in the design basis code.*

17 **7.6.4.3C** *Removing surface concrete from a prestressed member may cause excessive*
18 *compressive and tensile stress in the remaining concrete section and may alter secondary forces*
19 *and moments due to prestressing in indeterminate structures. This condition is more critical for*
20 *prestressed joists and girders that have a relatively small section and large prestressing force.*
21 *Slabs are less critical due to the relatively small initial precompression. Repairs of prestressed*
22 *members may result in changing the class of the members from Class U to Class T or from Class*
23 *T to Class C as defined in ACI 318-11. This change is acceptable as long as durability and*

1 *strength are addressed as part of the repair design. The impact of removing concrete from a*
2 *post-tensioned structure is addressed in Scollard and Bartlett (2004). ICRI No. 320.4 provides*
3 *guidance for removing concrete around anchorages and splices to prevent catastrophic loss of*
4 *anchorage.*

5 **7.6.5 Anchoring to concrete**—Post-installed anchors and dowels shall be designed to transfer
6 design forces to the substrate considering anchor failure modes and the condition of the substrate
7 into which the anchor is installed. The design of post-installed anchors shall be in accordance
8 with ACI 318-11.

9 **7.6.5C** *The design of post-installed anchors requires a careful consideration of the loads to*
10 *be resisted. As an example, a long-term tensile load may require a different anchoring*
11 *mechanism than a short-term wind or seismic load. Anchors should have adequate strength to*
12 *transfer design forces across all interfaces and into the existing member. All possible anchor*
13 *failure modes should be considered to determine its design strength. Anchors should be selected*
14 *considering the expected concrete substrate cracking condition. For example, post-installed*
15 *anchors used in the tension zone of concrete members and in structures located in regions of*
16 *moderate or high seismic risk should be able to transfer the design seismic forces assuming a*
17 *cracked concrete condition.*

18 *Design of post-installed anchors is provided in ACI 318-11, Appendix D. Building code*
19 *requirements have prompted the need to verify performance of post-installed anchors in both*
20 *cracked and uncracked concrete. ACI 355.2 and 355.4 provide the standard required for*
21 *qualifying post-installed anchors in cracked and uncracked concrete. Specifications for post-*
22 *installed anchors should include installation, testing, and inspection procedures.*

1 *For mechanical anchors, manufacturer’s installation instructions should specify procedures*
2 *for drilling, hole cleaning, installation, torque magnitude, and procedures to engage the anchor.*

3 *For adhesive anchors and dowels, hole cleaning and moisture conditions are critically*
4 *important to almost all adhesive anchor installations. Manufacturer’s installation instructions*
5 *should specify procedures for drilling, hole cleaning, installation, and the care to be taken until*
6 *the adhesive has cured.*

7 *Testing and inspection of post-installed anchors should conform to Chapter 10. Many building*
8 *codes require that adhesive anchors be installed under special inspection procedures to ensure*
9 *that the installation is correctly performed in accordance with the design and manufacturer’s*
10 *procedure.*

11 **7.6.6 Repair geometry**—Configuration of repairs shall consider the potential for stress
12 concentrations and cracking in both the existing structure and the repair area.

13 **7.6.6C** *Some repair shapes with sharp reentrant corners and long slender (high aspect ratio)*
14 *repair areas can cause stress concentrations that may result in cracks. The shape of the repair*
15 *should be considered to reduce stress concentrations and possible cracking. ICRI No. 310.1R*
16 *provides guidance for repair shapes. Methods to reduce cracking in concrete repairs include*
17 *configuring to maximize right-angle geometry, avoiding reentrant corners, uniform depth of*
18 *edge and uniform depth of substrate reconditioning, and undercutting of reinforcement with no*
19 *feather edge conditions.*

20

21 **7.7—Repair using supplemental post-tensioning**

22 **7.7.1** Supplemental post-tensioning shall be permitted for repair and rehabilitation of
23 structures.

1 **7.7.1C** *The supplemental post-tensioning can be applied to the structure externally, internally,*
2 *or both.*

3 **7.7.2** Design of repair shall include the effects of the supplemental post-tensioning on the
4 behavior of the structure.

5 **7.7.2C** *Supplemental post-tensioning can introduce additional moment, shear, and axial forces*
6 *within the existing structure that should be considered in the design and detailing of the repair.*
7 *The internal forces induced by the supplemental post-tensioning can be significant. For statically*
8 *indeterminate structures, restraint to post-tensioning deformations can result in significant*
9 *internal forces. Refer to ICRI 330.1 for selecting strengthening systems for concrete structures.*

10 **7.7.2.1** Stresses due to supplemental post-tensioning shall be combined with existing stresses
11 and the total shall not exceed the limits in the design basis code.

12 **7.7.2.1C** *Adding supplemental post tensioning to a prestressed member may cause excessive*
13 *compressive and tensile stress and may alter secondary forces and moments. External post*
14 *tensioning may result in changing the class of the members from Class U to Class T or from*
15 *Class T to Class C as defined in ACI 318-11. This change is acceptable as long as durability*
16 *and strength are addressed as part of the repair design.*

17 **7.7.2.2** Design of supplemental post-tensioning shall provide for the transfer of post-
18 tensioning forces between the post-tensioning system and the structure. Design of concrete
19 supplemental post-tensioning anchorage zones shall be in accordance with ACI 318-11. Design
20 of steel brackets and supplementary steel shall be in accordance with ANSI/AISC 360-10.

21 **7.7.2.2C** *Anchorage of the new post-tensioned reinforcement should be designed and detailed*
22 *for the transfer of post-tension forces to the existing structure. The designer should consider all*

1 *bearing, spalling, and bursting forces created at anchor zones. Strut and tie modeling, as given*
2 *in ACI 318-11, may be used to design post-tension anchorage zones.*

3 **7.7.3** Provisions shall be made for effects of post-tensioning, temperature, and shrinkage on
4 adjoining construction, including immediate and long-term deformations, deflections, changes in
5 length, and rotations due to prestressing

6 **7.7.3C** *The additional post-tensioning may be restrained by adjacent stiff members such as*
7 *walls, and reduce the effect of the prestressing on the intended member or have unintended*
8 *effects on the adjacent construction.*

9 **7.7.4** Post-tensioning losses shall be included in the design of supplemental post-tensioning
10 systems.

11 **7.7.4C** *Losses include the following: seating (anchorage); elastic shortening; creep of original*
12 *concrete; shrinkage of original concrete; creep of repair material; shrinkage of repair material;*
13 *tendon relaxation; and friction between the post-tensioning reinforcement and ducts, bearings,*
14 *or deviators. Assessment of losses of supplemental post-tensioning force should consider the*
15 *existing conditions of the repaired elements as the members may have already experienced time-*
16 *dependent creep and shrinkage.*

17 **7.7.5** Repair construction documents shall define the repair sequence, including tendon
18 placement, anchorage, and stressing of the post-tensioned system.

19 **7.7.5C** *Repair design using supplemental post-tensioning systems should include contract*
20 *documents for installation sequence including shoring, removal of concrete, placement of new*
21 *material and reinforcement, additional anchorage requirements, horizontal shear transfer*
22 *requirements, curing, and stressing. Installation of supplementary post-tensioning involves*
23 *application of significant forces, which may require project safety and protection procedures.*

1 **7.8—Repair using FRP composites**

2 **7.8.1** FRP in conformance with ACI 440.6 shall be permitted to repair existing concrete
3 structures.

4 *7.8.1C FRP fabrics, bars, or shapes can be used as externally bonded reinforcement, internal*
5 *reinforcement, and as internal or external prestressed reinforcement. FRP shapes may be used*
6 *as additional stand-alone structural members. Design and detailing of externally bonded FRP*
7 *systems should be consistent with ACI 440.2R. Particular attention should be given to strength*
8 *increase limits, service limits, and determination of FRP material design properties.*

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

12 *When internal prestressed FRP reinforcement is used, the design and detailing should be*
13 *consistent with ACI 440.4R.*

14 **7.8.2** Structural members repaired or modified with externally-applied FRP composites shall
15 have adequate unrepaired strength, as defined in 5.5.

16 *7.8.2C Unless protection is provided, to prevent sudden failure of the member in case the*
17 *FRP system is damaged or becomes ineffective (such as in an extraordinary event like fire), the*
18 *structural member should have adequate strength without the FRP reinforcement to support*
19 *factored loads, as defined for extraordinary events in Chapter 5. The design and use of*
20 *externally bonded FRP may be limited by the service requirements of the repaired member.*

21

22 **7.9—Performance under fire and elevated temperatures**

1 **7.9.1** Design of the repair system shall consider elevated temperature performance and shall
2 comply with the fire resistance ratings of the structural members and other fire safety
3 requirements in accordance with the general existing building code.

4 **7.9.1C** *Regardless of the repair system used, performance of the repaired element under fire
5 and elevated temperatures should be evaluated and the system should be detailed and material
6 selected to provide adequate protection. The repaired elements should comply with applicable
7 building code requirements and relevant fire regulations valid at the project location. Structures
8 renovated for different use or strengthened to carry higher loads may require more stringent fire
9 rating than the original structure. Other requirements such as flame spread and smoke density
10 should also be considered in accordance with the general existing building code and ASTM E-
11 84.*

12 **7.9.2** It shall be permitted to design a repair without supplemental fire protection if the
13 unrepaired member has adequate strength in accordance with 5.5.

14 **7.9.2C** *A repair system can be selected without additional fire protection provided that the
15 existing unrepaired member has adequate strength to support the loads, as defined in 5.5, during
16 a fire event. Fire performance requirements and evaluation procedures are outlined in ACI
17 216.1, ACI 318-11, ACI 440.2R, ASCE/SEI/SFPE 29, and AISC Design Guide 19 (Ruddy et al.
18 2003).*

19 **7.9.3** The properties of the specified repair materials at elevated temperatures shall be
20 considered.

21 **7.9.3C** *Repair material specifications should comply with the requirements of relevant fire
22 regulations valid at the project location. Where there is a conflict between the properties of
23 specific products or systems and fire regulations, alternative repair principles or methods should*

1 *be used to avoid such a conflict. In general, polymer mortar and polymer concrete have higher*
2 *coefficients of thermal expansion and higher resistance to water vapor transmission and lower*
3 *resistance to fire and elevated temperatures compared to cementitious alternatives.*

4 **7.9.4** Repairs using adhesives shall consider their performance at elevated temperatures.

5 **7.9.4C** *ACI 440.2R reports that the physical and mechanical properties of the resin*
6 *components of FRP systems are influenced by temperature and can degrade at temperatures*
7 *close to and above their glass-transition temperature. An acceptable service temperature for*
8 *FRP is established by ACI 440.2R as $T_g - 27F$. This value accounts for typical variation in test*
9 *data for dry environment exposures. Adhesive-bonded FRP reinforcement should not be used if*
10 *the maximum service temperature is greater than $T_g - 27F$. A service temperature exceeding this*
11 *limit is considered an elevated temperature and should be addressed using adhesive system with*
12 *a higher T_g value or using alternate repair systems.*

13 *When performance at elevated temperatures is critical, the use of mechanical or cementitious*
14 *grouted anchors may provide a higher level of reliability than adhesive anchors and adhesively*
15 *bonded systems.*

16 *An appropriate fire rating can be achieved using materials with an established fire rating. In*
17 *the absence of an established fire rating, detailed fire analysis may be used to establish a fire*
18 *rating.*

19 *Most repair adhesives cannot resist elevated temperatures (temperatures greater than their*
20 *glass transition temperature) such as the temperatures generated during a fire event. Because of*
21 *the degradation of most adhesive-based repair systems (such as adhesive-bonded anchors and*
22 *adhesive-bonded reinforcement) at elevated temperature, the bond strength of these systems*
23 *should be assumed to be completely lost when temperatures exceed the glass transition*

1 *temperature. The repair material should be selected such that the critical temperature is greater*
2 *than the expected service temperature. The critical temperature should be taken as the lowest*
3 *Tg-27F of the components of the repair system.*

4 *Adhesive-based repair systems can be considered effective during a fire event if a fire*
5 *protection system is used that maintains the temperature of the adhesive-based system below its*
6 *critical temperature.*

7 **7.9.5** Supplemental fire protection to improve the fire rating of repaired systems shall be
8 permitted.

9 **7.9.5C** *Standard fire protection systems can be used to increase the fire rating of repaired*
10 *systems. National codes and professional organizations list generic ratings for concrete*
11 *structural members, giving the minimum thickness of concrete cover needed to protect the main*
12 *steel reinforcement from fire effects (IBC 2006; NFPA 5000 2009; PCA 1985,1994). In addition*
13 *to increasing the cover thickness, fire performance of reinforced and prestressed concrete*
14 *members may be enhanced by fire protection systems as proven by fire testing or analytical*
15 *methods (ACI 216.1). Concrete cover for nonmetallic reinforcement may need to be substantially*
16 *greater than cover for steel reinforcement to achieve the same fire resistance rating.*

17 **7.9.6** Fire rating of repaired systems, based on ACI 216.1 shall be permitted.

18 **7.9.6C** *The fire rating of a repaired system or assembly can be determined in accordance*
19 *with ACI 216.1 that requires the application of the expected service load to the test specimen.*
20 *The applied load should reflect the use of the tested member in terms of magnitude and layout.*

21 *The criteria for evaluating a structure for fire safety is different than that for strength design*
22 *and typically incorporates lower material strengths and load factors, and may not require the*
23 *use of strength-reduction factors. The designer should verify that the fire-reduced strength of the*

1 member is greater than the force demand due to expected service loads during the fire event. The
2 fire-reduced strength should be based on reduced material strengths for the maximum expected
3 temperature in a fire event, determined in accordance with ASTM E119 and ACI 216.1.

4

5

CHAPTER 8 — DURABILITY

6

8.1—General

7

8 **8.1.1** Durability of repair materials shall be considered for individual repairs, the overall
9 durability of the repaired structure, and the interaction of the repair system with the existing
10 structure.

11

12 **8.1.1C** *The durability of repair materials depends on their ability to withstand the environment
13 where they are installed. The durability of repairs is dependent on the compatibility between the
14 repair material and its surroundings. To achieve compatibility, the repair and the structure need
15 to interact on several levels, including chemical, electrochemical, and physical behavior, without
16 detriment.*

17

18 **8.1.2** Repair materials and methods shall be selected that are appropriate for the intended use,
19 be compatible with the structure, and durable within the anticipated in-service environment.

20

21 **8.1.2C** *The design service life of a structure and repaired members is a goal established by the
22 licensed design professional to achieve an economical repair which satisfies both safety and
23 serviceability requirements. Only satisfactory repair construction including application of the
specified repair materials can satisfy but not necessarily achieve that goal. The design service
life of the structure and repaired members, including maintenance requirements, should be
estimated in consultation with the owner and consideration of the properties of the materials.
Such design service life should be reflected in the repair design and maintenance requirements,*

1 as well as incorporated into the construction documents. A repaired section is considered to be
2 the combination of the installed repair material(s) and the substrate material(s). Service life is
3 discussed in ACI 365.1R.

4 Some examples of end-of-service life include:

- 5 • Structural safety is unacceptable due to material degradation or design strength is less than
6 the required strength.
- 7 • Maintenance requirements exceed resource limits.
- 8 • Aesthetics become unacceptable.
- 9 • Structural functionality is no longer sufficient.
- 10 • Deformation capacity of the structure has been degraded due to an event such as an
11 earthquake.

12 The cause of degradation should be addressed as a first step in predicting each type of service
13 life. Types of degradation include:

- 14 • Mechanical (abrasion, fatigue, impact, overload, settlement, explosion, vibration, and
15 excessive displacement, loads, or hammering from a seismic event).
- 16 • Chemical (alkali-aggregate reaction, sulfate attack, acid dissolution, soft water
17 leaching, and biological action).
- 18 • Physical (freezing and thawing, scaling, differing coefficients of thermal expansion, salt
19 crystallization, radiation exposure (ultraviolet light), fire, and differential permeability
20 between materials).
- 21 • Reinforcement corrosion (carbonation, corrosive contaminants, dissimilar metals, stray
22 currents, and stress corrosion cracking).

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

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

5 *Repaired sections should be resistant against:*

- 6 • *Freezing and thawing damage if subject to saturation and a freeze/thaw environment.*
7 *ASTM C666, Method B, may be used to define a durability factor. A durability factor of*
8 *greater than 80 percent has generally been found to be acceptable in many locations for*
9 *resistance to freezing and thawing for cementitious materials.*
- 10 • *Scaling if exposed to deicing salts within the design service life.*
- 11 • *Exposure to ultraviolet or other radiation degradation within the repair environment*
12 *unless other means are provided to address such degradation within the design service*
13 *life.*
- 14 • *Fatigue resulting from loading cycles and load reversal. For example, fatigue resistance*
15 *may be needed in repair areas subject to many cycles of repeated loading.*
- 16 • *Impact, erosion, and vibration effects if exposed to conditions causing deterioration by*
17 *these mechanisms within the design service life.*
- 18 • *Abrasion resistance of repaired sections subject to heavy traffic, impingement of*
19 *abrasive particles, or similar conditions.*
- 20 • *Chemical exposure may include sulfate attack, acids, alkalis, solvents, leaching of*
21 *cementitious materials due to soft water, salt crystallization, and other factors that are*
22 *known to attack or deteriorate the repair material or concrete substrate. Water*

1 *penetration into concrete is associated with many types of chemical attack and other*
2 *deterioration mechanisms.*

- 3 • *Thermal exposure and cycles.*
- 4 • *Alkali-aggregate reactions.*
- 5 • *Differential permeability between the repair and existing concrete if the repair material*
6 *or the substrate concrete is vulnerable to deterioration due to trapped moisture, such as*
7 *freezing-and-thawing damage of saturated concrete, corrosion of embedded reinforcing*
8 *steel, alkali-aggregate reactions, or sulfate attack (refer to ACI 546.3R).*
- 9 • *The carbonation susceptibility, depth, and rate of both the existing concrete and the*
10 *repair material in repairs containing reinforcement or other embedments requiring*
11 *alkaline passivation of the metal for protection from corrosion (refer to 8.4).*
- 12 • *The penetration of corrosive contaminants into the concrete (such as chlorides) that lead*
13 *to corrosion of reinforcement or other embedments (refer to 8.4).*

15 **8.2—Cover**

16 **8.2.1** The concrete cover requirements shall be in accordance with the design basis code. For
17 alternative materials and methods, an equivalent cover that provides sufficient corrosion
18 protection and fire protection shall be in accordance with 1.4.2. Sufficient anchorage and
19 development for the reinforcement shall be provided regardless of methods used to provide
20 corrosion protection.

21 **8.2.1C** *The preceding language is intended to allow equivalent cover such as anticarbonation*
22 *coatings, or intumescent coatings to be used if they can be demonstrated to be effective*

1 *according to the approval detailed in 1.4.2. The LDP should review anchorage and development*
2 *requirements when alternative methods of corrosion protection are used.*

3 **8.2.2 Corrosion**—Where concrete cover for existing reinforcement is insufficient to provide
4 corrosion protection for the design service life of the structure, additional concrete cover or an
5 alternate means of corrosion protection shall be provided to mitigate corrosion of reinforcement.

6 **8.2.2C** *Alternate means of protecting reinforcement include the application of waterproof*
7 *membranes, corrosion inhibitors, and various forms of cathodic protection. Existing*
8 *reinforcement corrosion shall be considered when evaluating the maintenance requirements and*
9 *design service life of alternative methods for corrosion protection.*

10

11 **8.3—Cracks**

12 **8.3.1** The design of repairs shall consider the effects of cracks on the expected durability,
13 performance, and design service life of the repair.

14 **8.3.1C** *Protection of repaired concrete may be as vital as the repair itself. Consideration*
15 *should be given to post-repair cracking and the need for protection of the existing concrete and*
16 *repair material from the ingress of deleterious materials. ACI 224.1R provides guidance for the*
17 *prevention and control of cracks. Cracks in concrete structures may impact the long-term*
18 *performance of the structure. The effect of the cracks on the long-term performance is generally*
19 *related to the exposure conditions and the size, number, and location of cracks. When the*
20 *cracked section is subject to aggressive conditions, the design service life is reduced.*

21 *Cracks reduce the protection provided by the effective cover over steel reinforcement and lead to*
22 *water and deleterious material ingress, which accelerates the deterioration of embedded*

1 reinforcement and can cause other concrete deterioration issues such as freezing and thawing
2 deterioration, alkali-aggregate deterioration, and chemical attack.

3 Crack mitigation methods should consider the causes, movement, size, orientation, width, and
4 complexity of the network of cracks. The characteristics of the substrate, location, and evidence
5 of water transmission should be determined to assess the appropriate method of repair. Active
6 water infiltration should be corrected as required for the durability of the structure.

7 ACI 224.1R provides additional guidance on the repair of cracks. ACI 503.7 provides a
8 specification for repair of cracks through polymer injection. The comparative cracking potential
9 of different cementitious materials can be evaluated using ASTM C1581.

10 **8.3.2** The cause and repair of cracking shall be assessed and considered in repair design.

11 **8.3.2C** Cracks in concrete structures can be detrimental to the long-term performance of a
12 structure if the cracks are of sufficient size to allow for the ingress of deleterious materials into
13 the structure. Not all cracks need to be repaired. Cracks above reasonable widths for given
14 exposure conditions (refer to ACI 224R, Table 4-1, for reasonable cracks widths) may require
15 repair or remediation.

16 There are a variety of different materials that have been used for crack repair. For cracks that
17 are essentially acting as a joint or are active, one type of effective repair is to seal the crack with
18 an elastomeric sealant. Materials used for crack injection include, for example, epoxy,
19 polyurethane, latex in a cement matrix, microfine cement, and polymethacrylate. For repair by
20 crack injection, the process and material should be appropriate to the site conditions. Crack
21 injection should not be used to repair cracks caused by corrosion of reinforcing steel and alkali
22 aggregate reaction. ACI 224.1R provides guidance on the causes and investigation of cracking

1 *in reinforced concrete under service loads as well as the evaluation and repair of cracks. All*
2 *cracks have the potential to become active cracks.*

3

4 **8.4—Corrosion of metals and deterioration**

5 **8.4.1** The corrosion and deterioration of reinforcement and embedded components shall be
6 considered in the durability design. Repair materials shall not contain intentionally added
7 constituents which are corrosive to reinforcement. Aggregates shall conform to the requirements
8 of ACI 318-11.

9 *8.4.1C Untreated reinforcement corrosion limits the life expectancy of repair areas, repair*
10 *materials, and repaired structures. Repairs that do not address reinforcement corrosion should*
11 *consider the design service life and monitoring. The corrosion of embedded metals adjacent to*
12 *the repair may be accelerated by the ring anode effect due to differing electrical potential*
13 *between continuous reinforcement in the repair area and that external to the repair area,*
14 *depending on the relative humidity and chloride content (refer to 8.4.3C). Aggregate should*
15 *conform to the limits of ACI 318.*

16 **8.4.2** When evaluating long-term durability and strength of a member, existing reinforcement
17 corrosion that is encapsulated within new repair materials shall be considered.

18 *8.4.2C ICRI No. 310.1R states that all damaged concrete and corrosion products are to be*
19 *removed from reinforcement during repairs. Sufficient concrete should be removed to allow for*
20 *the new repair materials to completely encapsulate the reinforcement. In some situations, due to*
21 *congestion of reinforcing steel, access limitations, load considerations, or other factors, it is not*
22 *possible to remove all corrosion products from the reinforcing steel. Situations exist where*
23 *corroding reinforcement that cannot be adequately cleaned or repaired is encapsulated with new*

1 repair materials. The durability effects of encapsulating the existing reinforcing steel on the
2 member strength should be considered in these situations.

3 **8.4.3** The quality of existing concrete and its ability to protect reinforcement from corrosion
4 and deterioration shall be considered.

5 **8.4.3C** *Water and chemical penetration into the concrete can cause corrosion of metallic and*
6 *damage to nonmetallic reinforcement. Where concrete cover over reinforcement is insufficient to*
7 *provide corrosion protection for the design service life of the structure, additional concrete*
8 *cover or an alternate means of corrosion protection should be provided to mitigate*
9 *reinforcement corrosion. For guidance on alternate methods of corrosion prevention, mitigation,*
10 *and inhibition, refer to ACI 546R and The Concrete Society Technical Report 50 (1997). Both*
11 *carbonation and chloride contamination may require consideration and are discussed in ACI*
12 *546R.*

13 *The anodic ring effect that can be induced by certain repairs should be addressed by*
14 *incorporating appropriate corrosion mitigation strategies such as cathodic protection, corrosion*
15 *inhibitors, or other effective techniques. Considerations should include reduction of the*
16 *phenomenon. ACI 546R, ACI 364.3T, and ACI RAP-8 provide discussion on anodic ring effect.*
17 *ACI 222R, ACI 222.3R, ACI 364.3T, and FAQ sections from Concrete International (2002a, b, c)*
18 *also provide guidance for corrosion mitigation.*

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

21 **8.4.4** Existing steel reinforcement and added reinforcement shall be protected from corrosion
22 and deterioration to satisfy durability requirements.

1 **8.4.4C** Reinforcing steel in concrete construction is traditionally protected by concrete cover,
2 which protects the reinforcing steel from deleterious materials and provides fire protection. The
3 minimum cover thickness is typically required by ACI 318-11. Adequate protection may be
4 provided by increased section thickness and appropriate coatings such as sealers, intumescent
5 coatings, electrochemical methods, or other techniques.

6 **8.4.5** Galvanic corrosion between electrochemically dissimilar materials shall be considered.

7 **8.4.5C** Reinforcement or metal accessories in the repair area with differing electrochemical
8 potentials, environments, or both, should be isolated from the existing reinforcement, or the
9 existing reinforcement should be protected to minimize galvanic corrosion. For example, rail or
10 post-pocket repairs can use dissimilar metals from conventional reinforcing steel, which could
11 accelerate the deterioration of the installation (refer to ACI 222R).

12 **8.4.6** Corrosion protection of bonded and unbonded prestressing materials and prestressing
13 system components shall be addressed during the repair design.

14 **8.4.6C** Prestressed concrete structures are reinforced with stressed, high-strength steel. The
15 prestressing steel can be either bonded or unbonded to the concrete. The presence of a
16 prestressing force in the steel and the need to transfer the prestressing force into the concrete
17 makes corrosion damage in prestressed concrete members more critical than traditionally
18 reinforced structures (refer to ACI 423.4R).

19 Depending on the bonded or unbonded nature of the prestressing steel, the condition of the
20 steel at the repair area, the attachment of the steel to the structure, the as-designed corrosion
21 protection measures, and the continuity of the prestressing steel needs to be considered to
22 address corrosion protection of the structure. See ICRI 320.4, and 222.2R.

1 *Hydrodemolition and other types of high-volume material removal methods should be used*
2 *cautiously when the structure contains unbonded prestressing steel. In these situations, excessive*
3 *concrete removal may damage the tendon or remove the confining concrete, resulting in a*
4 *sudden loss of tension force in the prestressing steel, the introduction of water into the corrosion*
5 *protection (sheathing) surrounding the steel, or both (refer to ICRI No. 310.3).*

6 **8.4.7** If electrochemical protection systems protect reinforcing steel in repair areas and
7 structures, the interaction of the protection system with the repaired elements, the entire
8 structure, and environment shall be considered.

9 **8.4.7C** *Structures using impressed current electrochemical protection or mitigation systems*
10 *should have continuous reinforcement, separate zones, or provisions should be made to make the*
11 *steel electrically continuous. Impressed current electrochemical protection systems should be*
12 *designed and maintained so as to not promote an alkali aggregate reaction (AAR) and to avoid*
13 *embrittlement of prestressing steel.*

14 *Impressed current electrochemical protection systems should include a monitoring and*
15 *maintenance plan developed by a licensed design professional specializing in the design of*
16 *corrosion protection systems (refer to NACE RP0390, NACE 01105, NACE 01102, NACE*
17 *01101, NACE 01104 and NACE SP0107).*

18 **8.4.8** Repair materials and reinforcement shall be designed to be compatible such that the
19 characteristics of each material do not adversely affect the durability of the other materials or of
20 the existing concrete and reinforcement.

21 **8.4.8C** *Materials can degrade under certain exposure conditions with a negative impact on*
22 *reinforcing steel or concrete materials. For example, in certain situations such as exposure to*

1 *high temperatures, PVC and other polymer-based materials can deteriorate, releasing*
2 *decomposition products found to cause corrosion.*

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

6 *FRP wrapping should not be used as a corrosion repair strategy on members experiencing*
7 *corrosion of embedded reinforcement unless the concrete is repaired and corrosion mitigated.*
8 *Appropriate sections within this document and referenced documents concerning FRP repairs*
9 *should be consulted (refer to ACI 440.2R).*

10 *Materials such as salts (chlorides, bromides, etc) and other detrimental constituents should not*
11 *be incorporated into repairs as these materials can increase the corrosion activity.*

12

13 **8.5—Surface treatments and coatings**

14 **8.5.1** *Moisture transmission through the structure and the influence of the surface treatment on*
15 *the durability of the structure shall be considered.*

16 **8.5.1C** *Surface treatments, coatings, sealers, or membranes are commonly used to limit the*
17 *ingress of deleterious materials and moisture into the structure to reduce future deterioration of*
18 *the structure. Surface treatments, coatings, sealers, and membranes may have a shorter service*
19 *life than the concrete and can be considered as consumable or requiring periodic replacement or*
20 *repair to maintain effective protection of the concrete.*

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

1 **8.5.2** The selection of surface treatments applied to concrete surfaces shall consider existing
2 cracks within the concrete and the potential for movement on the repair system durability, the
3 surface treatment, and the anticipated service life of the structure.

4 **8.5.2C** *Crack development and propagation provide an accelerated mechanism for ingress of*
5 *moisture and deleterious materials and may also cause a surface treatment to become*
6 *ineffective.*

7

8

CHAPTER 9—CONSTRUCTION

9

9.1—Stability and temporary shoring requirements

10 **9.1.1** Plans and specifications for repair shall define the temporary shoring and bracing
11 requirements for all phases of the repair project. Temporary shoring and bracing shall be
12 designed by a licensed design professional. Adequate temporary shoring and bracing of affected
13 members shall be provided during evaluation and repair construction. Temporary shoring shall
14 be designed to accommodate in-place conditions in the structure and expected superimposed
15 loads and shall consider the effects of deformation compatibility on the shoring system with the
16 supported and supporting structural elements.

17 Temporary shoring and bracing installation details shall be reviewed by the licensed design
18 professional for the repair to assess the impact of the shoring on the existing structure.

19 **9.1.1C** *Temporary shoring and bracing members should be designed to consider changes in*
20 *bracing and shoring conditions during repair construction and as required to support*
21 *construction operations. Design of temporary shoring members should be based on the in-place*
22 *loads on the structure. Loads, such as snow, seismic, wind, and construction live loads, should*
23 *also be considered in shoring design (ASCE/SEI 37). Design requirements for shoring are also*

1 contained in ASCE/SEI 37. Shoring design guidelines are contained in AISC Steel Design Guide
2 Series 10 (Fisher and West 2003). Temporary shoring and bracing installation is performed by
3 the contractor. Load, spacing, and placement requirements for temporary shoring and bracing
4 at all phases of a repair should be conveyed to the contractor.

5 All temporary shoring and bracing design and installation details should be reviewed by the
6 licensed design professional for the repair to assess the impact of the shoring on the existing
7 structure, and to verify conformance of the proposed shoring with any project-specific
8 requirements. See 5.1.2 for load requirements associated with shoring and temporary
9 construction.

10 **9.1.2** Global structural stability and the stability of individual members shall be maintained
11 prior to and during all stages of the repair process.

12 **9.1.2C** The assessment of structural stability includes the overall existing structure, existing
13 members affected by repair, and temporary bracing elements that contribute to overall stability.
14 Stability of these elements should be considered during all phases of the repair process.
15 Temporary measures may be needed to provide bracing and shoring of affected members. If
16 necessary, requirements to preload temporary members should be included in the repair
17 drawings.

18 **9.1.3** Existing member stability, including the effect of modifications or repairs to existing
19 lateral bracing members, shall be evaluated and maintained at all times.

20 Temporary bracing shall be provided as necessary to maintain the stability of compression
21 members. The lateral force for temporary bracing design shall be determined by generally
22 accepted engineering principles or as required by the general building code. Temporary shoring

1 and bracing shall be designed to provide sufficient stiffness to prevent excessive displacement of
2 the existing braced members as determined by the licensed design professional.

3 **9.1.3C** *Supplemental bracing for compression members may be required if the unbraced length*
4 *of a compression member is modified during the repair process. Compression members include*
5 *columns, walls, and other members, such as diaphragms, that carry compressive loads. The*
6 *design of bracing members is described in various publications (AISC 2006; American Forest*
7 *and Paper Association 2005). The design load for a bracing member should be based on the*
8 *existing dead and live loads, construction loads, and other loads that may be resisted by the*
9 *compression member. A lateral force of 2% of the axial load in the member being braced is*
10 *commonly used as a minimum load in the design of bracing members (e.g. ANSI/AISC 360-10).*

11 **9.1.4** The design of shoring and bracing members during the repair or removal of existing
12 adjacent framing shall consider the changes in load paths and unbraced lengths, and the
13 redistribution of loads and internal forces that result in changes in existing applied loads on
14 structural elements. Redistribution of loading due to deformation of members shall be considered
15 in the design of temporary shoring and bracing.

16 **9.1.4C** *Removal of existing column, beam, wall, and floor slab elements or parts thereof during*
17 *repair construction and the placement of shoring and bracing may result in the redistribution of*
18 *loads and internal forces within the building structure. The removal of existing framing*
19 *members, diaphragms, or slabs can also affect the unbraced length of the existing framing*
20 *members in the removal area. Effects of the removal of elements should be considered in*
21 *assessing the existing structure and shoring and bracing design.*

22 **9.1.5** Where existing structural members support the structure and all loads during the
23 evaluation and repair construction, the design strength of those members shall be evaluated and

1 shall exceed the temporary required strength due to construction loads. This evaluation shall
2 include the effects of deterioration due to section loss and material degradation. If the strength
3 and stiffness of any member is less than required, shoring shall be provided and remain in place
4 until the existing member is repaired.

5 *9.1.5C The design of shoring and bracing members and the assessment of existing members*
6 *should be based on the existing cross sections present at the time of repair implementation.*
7

8 **9.2—Temporary conditions**

9 **9.2.1** Load and load factors during the evaluation and repair construction processes shall be in
10 accordance with 5.1.4. The design strength of the structure or member shall exceed the
11 calculated required strength. The construction loads in 5.1.4 shall only be used during ongoing
12 evaluation and repair process.

13 *9.2.1C During the evaluation and repair process, a temporary reduction in design load is*
14 *allowed, except when specifically prohibited by jurisdictional authorities or local building codes.*
15 *The reduction in the design load intensity should be determined based on the in-place condition*
16 *of the structure and the time required for the completion of stabilization measures, or repairs*
17 *using sound engineering principles. The licensed design professional is required to verify that*
18 *the design strength of the existing structure is satisfactory at all times. The licensed design*
19 *professional should also consider the expected project duration when using temporary*
20 *construction loads. If a change in the length of the project or a delay occurs, the reduced design*
21 *loads may no longer be appropriate.*
22

23 **9.3—Environmental issues**

1 **9.3.1** Plans and specifications prepared by the licensed design professional shall instruct the
2 contractor or other designated party to be responsible for the implementation of all specified
3 environmental remediation measures, to report any new conditions encountered, and for the
4 control of all construction debris including environmentally hazardous materials.

5 **9.3.1C** *Evaluation and repair of an existing structure can result in the exposure of workers and*
6 *the public to potentially hazardous materials. These materials may be exposed, dislodged,*
7 *carried into the air, or discharged as effluent into surface drainage during the evaluation and*
8 *repair process. The owner should have an environmental assessment performed during the*
9 *evaluation and repair process in the areas to be repaired before any work to identify hazardous*
10 *materials with the potential to present health issues to the workers and public, unless the owner*
11 *can attest that the existing structure is free of hazardous materials.*

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

17 **CHAPTER 10—QUALITY ASSURANCE**

18 **10.1—Inspection**

19 **10.1.1** Concrete repair and rehabilitation construction shall be inspected as required by the
20 general existing building code or as required by the local jurisdiction. In the absence of such
21 inspection requirements, the licensed design professional shall inform the owner that concrete
22 repair and rehabilitation construction must be inspected during the various Work stages by a
23 licensed design professional, a qualified inspector, or a qualified individual.

1 **10.1.2** The licensed design professional shall require (a) through (j) to be inspected, material
2 tests to be performed, and a report of inspection and testing results submitted.

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

5 (b) Construction and removal of forms and reshoring

6 (c) Concrete removal and surface preparation

7 (d) Placing of reinforcement and anchors

8 (e) Mixing, placing, and curing of repair materials

9 (f) Sequence of erection and connection of new members

10 (g) Tensioning of tendons

11 (h) Construction loadings on floors, members, or walls

12 (i) General progress of Work

13 (j) Installation and testing of post-installed anchors

14 **10.1C** *Repair construction should be checked for quality of materials and workmanship, and*
15 *for compliance with the intent of the repair construction documents. Inspection should be*
16 *provided by either repair inspectors or the licensed design professional. Repair inspectors*
17 *should be qualified by demonstrating competence to the satisfaction of the licensed design*
18 *professional and as required by the building official, to inspect concrete repair construction. If*
19 *qualified, the licensed design professional may provide inspection services.*

20 *Inspection of concrete repair construction requires review of the Work in the field, review of*
21 *construction documents, comparison of the Work with contract documents, documentation and*
22 *report of the Work inspected as conforming or nonconforming, and of corrections to the Work.*
23 *Visual inspection and verification of existing conditions may require review of specific*

1 conditions before continuing the construction process and thus require pauses in the
2 construction processes so as not to conceal components of the Work before completing necessary
3 inspections and verifications. Inspection of post-installed anchor installation and testing should
4 be performed as required by the construction documents and in accordance with 7.6.5.

5 Part of all repair inspections is determining compliance with the intent of the construction
6 documents, documenting the inspection, and reporting the inspection. If the inspection shows
7 conformance with the contract documents and no corrections are necessary, then the inspected
8 Work should be documented as conforming and reported to the licensed design professional and
9 contractor, noting no corrections. If the inspection shows readily correctable issues and the
10 issues are corrected by the contractor, then the inspected Work should be documented as
11 conforming and reported to the licensed design professional and contractor with corrections
12 noted and verified as completed. Nonconforming or deficient components, processes, and
13 procedures (repair not passing inspection) should be reported to the licensed design professional
14 for review and actions should be made to correct the process prior to resuming the repair
15 construction and inspection process. Nonconforming repair construction may include:

- 16 (a) Existing construction that differs from the repair documents
- 17 (b) Existing construction deterioration, distress, or levels of distress beyond those anticipated in
18 the design of repairs
- 19 (c) Deficiencies in repair components
- 20 (d) Deficiencies in construction processes and procedures

21 Material data sheets are to satisfy the requirement of specific repair material used in
22 construction. The manufacturing date and shelf life of the repair material provide information
23 that the material is within the manufacturer's recommended time limits for installation.

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

4 *(a) Location of repairs*

5 *(b) Surface preparation of existing concrete and existing reinforcement*

6 *(c) Placement of reinforcement and anchors*

7 *(d) Specific repair material used in construction*

8 *(e) Delivery, placement, and testing reports documenting the quantity and location of*
9 *placement, repair material tests, strength, and other tests of all repair materials*

10 *(f) Construction and removal of forms and shoring*

11 *(g) Mixing, placing, and curing of repair materials*

12 *(h) Sequence of repair construction*

13 *(i) Tensioning of tendons*

14 *(j) Construction loadings*

15 *(k) General progresses of the repair Work*

16 **10.1.3** *The licensed design professional shall require that existing conditions and reinforcement*
17 *shall not be concealed with materials that obscure visual inspection before completion of*
18 *inspection.*

19 **10.1.3C** *Reinforcement includes existing reinforcement, embedded items such as anodes, new*
20 *reinforcement, and anchors. Removal of deteriorated concrete and reinforcement often uncovers*
21 *defects not anticipated. The licensed design professional should inspect these uncovered*
22 *conditions before placement of new repair materials.*

23

1 **10.2—Testing of repair materials**

2 **10.2.1** Repair material tests and test frequencies shall be specified by the licensed design
3 professional in the contract documents. Results of tests shall be reported as required by the
4 contract documents and the general existing building code. Test records shall be retained by the
5 testing agency as required by the general building code. In the absence of a general building
6 code, the licensed design professional shall require that the test records be retained by the testing
7 agency for a minimum of 3 years beyond completion of construction.

8 *10.2.1C Tests of repair materials should comply with testing and test frequency of new*
9 *concrete construction, unless otherwise directed by the licensed design professional in the*
10 *contract documents and approved by the building code official. It is generally not practical to*
11 *verify all manufacturer’s listed properties of proprietary materials, such as shrinkage, thermal*
12 *expansion coefficient, and modulus of elasticity. In such cases, the licensed design professional*
13 *should rely on manufacturer product data. The licensed design professional should evaluate the*
14 *data and, if necessary, have manufacturers perform testing to confirm that their material*
15 *achieves the published values that they provided for the project. Refer to ACI 546.3R and ICRI*
16 *320.2R for guidance. Tests of repair materials bond to existing materials should comply with*
17 *requirements of the contract documents.*

18 *Testing personnel should be qualified by demonstrating competence to the satisfaction of the*
19 *licensed design professional and building code official for testing types required of concrete*
20 *repair and rehabilitation Work. The testing agency should maintain a record of the tests*
21 *performed and the results consistent with the requirements for records of ASTM E 329.*

22

23 **10.3—Construction observations**

1 **10.3.1** Construction observation shall be performed as required by the licensed design
2 professional.

3 **10.3.1C** *A primary purpose of construction observation of rehabilitation Work is to verify that*
4 *the exposed existing construction is as assumed in the design and that the rehabilitation*
5 *documents will fulfill the design intent. If the existing construction differs from the design*
6 *assumptions, requiring modification of the design, changes should be documented and the Work*
7 *modified as necessary. The licensed design professional should report design changes in writing*
8 *to the owner, rehabilitation inspector, contractor, and building code official resulting from*
9 *existing construction, nonconforming rehabilitation Work and observed construction*
10 *deficiencies. Revised design or construction Work necessary to correct these deficiencies, and*
11 *the construction corrections should be observed.*

12
13 **CHAPTER 11—COMMENTARY REFERENCES**

14
15 International Code Council

16 IBC-2012 International Building Code

17 IEBC-2012 International Existing Building Code

18
19 *ICC Evaluation Service (ICC-ES)*

20 AC58-11 Acceptance Criteria for Adhesive Anchors in Masonry Elements

21 AC308-11 Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete
22 Elements

- 1 *American Concrete Institute*
- 2 ACI E706-05(Reapproved 2010) Field Guide to Concrete Repair Application Procedures—
3 Installation of Embedded Galvanic Anodes
- 4 ACI 201.1R-08 Guide for Conducting a Visual Inspection of Concrete in Service
- 5 ACI 201.2R-08 Guide to Durable Concrete
- 6 ACI 209R-92 (Reapproved 2008) Prediction of Creep, Shrinkage, and Temperature Effects in
7 Concrete Structures
- 8 ACI 209.1R-05 Report on Factors Affecting Shrinkage and Creep of Hardened Concrete
- 9 ACI 214.4R-03 Guide for Obtaining Cores and Interpreting Compressive Strength Results
- 10 ACI 216.1-07 Code Requirements for Determining Fire Resistance of Concrete and
11 Masonry Construction Assemblies
- 12 ACI 222R-01(Reapproved 2010) Protection of Metals in Concrete Against Corrosion
- 13 ACI 222.2R-01(Reapproved 2010) Corrosion of Prestressing Steels
- 14 ACI Committee 222.3R-03 Design and Construction Practices to Mitigate Corrosion of
15 Reinforcement in Concrete Structures
- 16 ACI 224R-01 (Reapproved 2008) Control of Cracking in Concrete Structures
- 17 ACI 224.1R-07 Causes, Evaluation, and Repair of Cracks in Concrete Structures
- 18 ACI 228.1R-03 In-Place Methods to Estimate Concrete Strength
- 19 ACI 228.2R-98 (Reapproved 2004) Nondestructive Test Methods for Evaluation of Concrete in
20 Structures
- 21 ACI 301-10 Specifications for Structural Concrete
- 22 ACI 318-11 Building Code Requirements for Structural Concrete and Commentary

1	ACI 355.2-07	Qualification of Post-Installed Mechanical Anchors in Concrete and
2		Commentary
3	ACI 355.4-10	Acceptance Criteria for Qualification of Post-Installed Adhesive Anchors
4		in Concrete and Commentary (Provisional Standard)
5	ACI 364.1R-07	Guide for Evaluation of Concrete Structures before Rehabilitation
6	ACI 364.3T-10	TechNote: Treatment of Exposed Epoxy-Coated Reinforcement in Repair
7	ACI 365.1R-00	Service-Life Prediction
8	ACI 369R-11	Guide for Seismic Rehabilitation of Existing Concrete Frame Buildings and
9		Commentary
10	ACI 423.4R-98	Corrosion and Repair of Unbonded Single Strand Tendons
11	ACI 437R-03	Strength Evaluation of Existing Concrete Buildings
12	ACI 437.1R-07	Load Tests of Concrete Structures: Methods, Magnitude, Protocols and
13		Acceptance Criteria ACI 437.X-XX Code Requirements for Load Testing
14		of Concrete Members of Existing Buildings
15	ACI 440R-07	Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete
16		Structures
17	ACI 440.1R-06	Guide for the Design and Construction of Structural Concrete Reinforced
18		with FRP Bars.
19	ACI 440.2R-08	Guide for the Design and Construction of Externally Bonded FRP Systems
20		for Strengthening Concrete Structures ACI 440.4R-04 (Reapproved 2011)
21		Prestressing Concrete Structures with FRP Tendons
22	ACI 503R-93 (Reapproved 2008)	Use of Epoxy Compounds with Concrete
23	ACI 503.5R-92 (Reapproved 2003)	Guide for the Selection of Polymer Adhesives in Concrete

- 1 ACI 503.6R-97 (Reapproved 2003) Guide for Application of Epoxy and Latex Adhesives for
2 Bonding Freshly Mixed and Hardened Concrete
- 3 ACI 503.7-07 Specification for Crack Repair by Epoxy Injection
- 4 ACI 546R-04 Concrete Repair Guide
- 5 ACI 546.3R-06 Guide for the Selection of Materials for the Repair of Concrete
- 6
- 7 *American Institute of Steel Construction*
- 8 AISC 325-11 Steel Construction Manual
- 9 ANSI/AISC 360-10 Specification for Structural Steel Buildings
- 10
- 11 *American Society of Civil Engineers*
- 12 ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures
- 13 ASCE/SEI 11-00 Guideline for Structural Condition Assessment of Existing Buildings
- 14 ASCE/SEI 31-03 Seismic Evaluation of Existing Buildings
- 15 ASCE/SEI 37-02 Design Loads on Structures during Construction
- 16 ASCE/SEI 41-07 Seismic Rehabilitation of Existing Buildings
- 17 ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection
- 18
- 19 *American Forest and Paper Association*
- 20 ANSI/AF&PA NDS-2005 National Design Specification for Wood Construction
- 21
- 22 *Applied Technology Council*
- 23 ATC 20-89 Procedures for Post-Earthquake Safety Evaluation of Buildings

- 1 ATC 45-04 Field Manual: Procedures for Safety Evaluation of Buildings after Wind
2 Storms and Floods
3 *ASTM International*
- 4 ASTM C666/C666M-03(2008) Standard Test Method for Resistance of Concrete to Rapid
5 Freezing and Thawing
- 6 ASTM C1581/C1581M-09 Standard Test Method for Determining Age at Cracking and
7 Induced Tensile Stress Characteristics of Mortar and Concrete under
8 Restrained Shrinkage
- 9 ASTM C1583/C1583M-04e1 Standard Test Method for Tensile Strength of Concrete Surfaces
10 and the Bond Strength or Tensile Strength of Concrete Repair and Overlay
11 Materials by Direct Tension (Pull off Method)
- 12 ASTM D610-08 Standard Practice for Evaluating Degree of Rusting on Painted Steel
13 Surfaces
- 14 ASTM D4065-06 Standard Practice for Plastics: Dynamic Mechanical Properties:
15 Determination and Report of Procedures
- 16 ASTM E119-10 Standard Test Methods for Fire Tests of Building Construction and
17 Materials
- 18
- 19 *Canadian Standards Association*
- 20 CAN/CSA S6-06 Canadian Highway Bridge Design Code and Commentary
21
- 22 *International Concrete Repair Institute*

- 1 ICRI No. 210.2-02 Guideline for the Evaluation of Unbonded Post-Tensioned Concrete
2 Structures
- 3 ICRI No. 2010.3-04, “Guide for Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of
4 Concrete Surface Materials”
- 5 ICRI No. 310.1R-08 Guide for Surface Preparation for the Repair of Deteriorated Concrete
6 Resulting from Reinforcing Steel Corrosion
- 7 ICRI No. 310.2-97 Guideline for Selecting and Specifying Concrete Surface Preparation for
8 Sealers, Coatings, and Polymer Overlays
- 9 ICRI No. 310.3-04 Guide for the Preparation of Concrete Surfaces for Repair Using
10 Hydrodemolition Methods
- 11 ICRI No. 320.2R-09 Guide for Selecting and Specifying Materials for Repair of Concrete
12 Surfaces
- 13 ICRI No. 320.3-04 Guideline for Inorganic Repair Material Data Sheet Protocol
- 14 ICRI No. 320.4-06 Guideline for the Repair of Unbonded Post-Tensioned Concrete Structures
- 15 ICRI No. 330.1-06 Guideline for the Selection of Strengthening Systems for Concrete
16 Structures
- 17 ICRI No. 340.1-06 Guideline for Selecting Grouts to Control Leakage in Concrete Structures
18
- 19 *NACE International*
- 20 NACE 01101 Electrochemical Chloride Extraction from Steel-Reinforced Concrete - A
21 State-of-the-Art Report
- 22 NACE 01102-02 State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed
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