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Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20) and Commentary (ACI 350R-20)

Reported by ACI Committee 350

ACI 350-20



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Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20) and Commentary (ACI 350R-20)

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Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20) and Commentary (ACI 350R-20)

An ACI Standard

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PREFACE

The “Code Requirements for Environmental Engineering Concrete Structures” (Code) portion of this document covers the structural design, materials selection, and construction of environmental engineering concrete structures. Such structures are used for conveying, storing, or treating water and wastewater, other liquids, and solid waste. The term “solid waste” as used in the Code encompasses the heterogeneous mass of disposed-of materials, as well as more homogeneous agricultural, industrial, and mineral wastes.

The Code also covers the evaluation of existing environmental engineering concrete structures.

Environmental engineering concrete structures are subject to uniquely different loadings and severe exposure conditions that require more restrictive serviceability requirements and may provide longer service lives than non-environmental structures.

Loadings include normal dead and live loads, earth pressure loads, hydrostatic and hydrodynamic loads, and vibrating equipment loads. Exposures include concentrated chemicals, alternate wetting and drying, high-velocity flowing liquids, and freezing and thawing of saturated concrete. Serviceability requirements include liquid-tightness, gas-tightness, and durability.

Proper design, materials, and construction of environmental engineering concrete structures are required to produce serviceable concrete that is dense, durable, nearly impermeable, and resistant to relevant chemicals, with limited deflections and cracking. This includes minimizing leakage and control over the infiltration of, or contamination to, the environment or groundwater.

The Code presents additional material as well as modified portions of the ACI 318-05, ACI 318-08, and ACI 318-11 building codes that are applicable to environmental engineering concrete structures.

The Commentary discusses some of the considerations of the committee in developing the ACI 350 Code, and its relationship with ACI 318. Emphasis is given to the explanation of provisions that may be unfamiliar to some users of the Code. References to much of the research data referred to in preparing the Code are given for those who wish to study certain requirements in greater detail.

The chapter and section numbering of the Code are followed throughout the Commentary.

Among the subjects covered are: drawings and specifications, inspections, materials, concrete quality, mixing and placing, forming, embedded pipes, joints, reinforcement details, analysis and design, strength and serviceability, flexural and axial loads, shear and torsion, development of reinforcement, slab systems, walls, footings, precast concrete, prestressed concrete, shell structures, folded plate members, provisions for seismic design, and an alternate design method in Appendix A.

The quality and testing of materials used in the construction are covered by reference to the appropriate standard specifications. Welding of reinforcement is covered by reference to the appropriate AWS standard. Criteria for liquid-tightness and gas-tightness testing may be found in ACI 350.1.

Keywords: chemical attack; coatings; concrete durability; concrete finishing (fresh concrete); concrete slabs, crack width and spacing; cracking (fracturing); environmental engineering; hydraulic structures; inspection; joints (junctions); joint sealers; liners; liquid; patching; permeability; pipe columns; pipes (tubes); prestressed concrete; prestressing steels; protective coatings; reservoirs; roofs; serviceability; sewerage; solid waste facilities; tanks (containers); temperature; torque; torsion; vibration; volume change; walls; wastewater treatment; water; water-cementitious materials ratio; water supply; water treatment.

INTRODUCTION

The Code and Commentary includes excerpts from ACI 318 that are pertinent to ACI 350. The Commentary discusses some of the considerations of ACI Committee 350 in developing this Code. Emphasis is given to the explanation of provisions that may be unfamiliar to users of the standard.

This Commentary is not intended to provide a complete historical background concerning the development of the Code, nor is it intended to provide a detailed summary of the studies and research data reviewed by the committee in formulating the provisions of the Code. However, references to some of the research data are provided for those who wish to study the background material in depth.

As the name implies, “Code Requirements for Environmental Engineering Concrete Structures” may be used as part of a legally adopted Code and, as such, must differ in form and substance from documents that provide detailed specifications, recommended practice, complete design procedures, or design aids.

The Code is intended to cover environmental engineering concrete structures but is not intended to supersede ASTM standards for precast structures.

Requirements more stringent than Code provisions may be desirable for unusual structures. The Code and Commentary cannot replace sound engineering knowledge, experience, and judgment.

A code for design and construction states the minimum requirements necessary to provide for public health and safety. ACI 350 is based on this principle. For any structure, the owner or the structural designer may require the quality of materials and construction to be higher than the minimum requirements necessary to provide serviceability and to protect the public as stated in the Code. Lower standards, however, are not permitted.

ACI 350 has no legal status unless adopted by government bodies having the power to regulate building design and construction. Where the Code has been adopted, it cannot present background details or suggestions for carrying out its requirements or intent. It is the function of the Commentary to fill this need. Where the Code has not been adopted, it may serve as a reference to good practice.

The Code provides a means of establishing minimum standards for acceptance of design and construction by a legally appointed building official or designated representatives. The Code and Commentary are not intended for use in settling disputes between the owner, engineer, architect, contractor, or their agents, subcontractors, material suppliers, or testing agencies. Therefore, the Code cannot define the contractual responsibility of the involved parties. General references requiring compliance with ACI 350 in the job specifications should be avoided, as the contractor is rarely in the position of accepting responsibility for architectural and engineering design details. Generally, the drawings, specifications, and contract documents should contain all the necessary requirements to ensure compliance with the Code. In part, this can be accomplished by reference to specific code sections in

the job specifications. Other ACI publications, such as ACI 350.5, “Specifications for Environmental Concrete Structures,” are written specifically for use as part of the contract documents for construction.

ACI Committee 350 recognizes the desirability of standards of performance for individual parties involved in the contract documents. Available for this purpose are the certification programs of the American Concrete Institute, plant certification programs of the Precast/Prestressed Concrete Institute and the National Ready Mixed Concrete Association, and qualification standards of the American Society of Concrete Contractors. Also available are “Standard Specification for Agencies Engaged in Construction Inspection and/or Testing” (ASTM E329) and “Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation” (ASTM C1077).

Design aids (general concrete design aids are listed in ACI 318-11):

“Rectangular Concrete Tanks,” Portland Cement Association, Skokie, IL, 1998, 182 pp. (Presents data for design of rectangular tanks.)

“Circular Concrete Tanks Without Prestressing,” Portland Cement Association, Skokie, IL, 1993, 54 pp. (Presents design data for circular concrete tanks built in or on ground. Walls may be free or restrained at the top. Wall bases may be fixed, hinged, or have intermediate degrees of restraint. Various layouts for circular roofs are presented.)

Concrete Manual, U.S. Department of Interior, Bureau of Reclamation, eighth edition, 1981, 627 pp. (Presents technical information for the control of concrete construction, including linings for tunnels, impoundments, and canals.)

“Design of Liquid-Containing Concrete Structures for Earthquake Forces,” Portland Cement Association, Skokie, IL, 2002, 60 pp. (Presents design examples for designing for hydrodynamic forces.)

“Moments and Reactions for Rectangular Plates” Engineering Monograph No. 27, United States Department of the Interior, Bureau of Reclamation, 1990, 100 pp. (Presents design aids for rectangular plates.)

GENERAL COMMENTARY

Environmental engineering concrete structures are subject to stringent service conditions and should be designed for extended service life expectancy and detailed with care. The quality of concrete is important, and rigorous quality control must be maintained during construction to obtain dense, durable concrete suitable for the expected service conditions.

Environmental engineering concrete structures for the containment, treatment, or transmission of liquid such as water and wastewater as well as solid waste disposal facilities, should be designed and constructed to be liquid-tight, and where required, gas-tight, with minimal leakage under normal service conditions.

The liquid-tightness and gas-tightness of a structure will be reasonably assured if:

- a) The concrete mixture is properly proportioned, mixed, placed, consolidated, finished, and cured.
- b) Crack widths and depths are minimized.
- c) Joints are properly spaced, sized, designed, water-stopped, and constructed.
- d) Adequate reinforcing steel is provided, properly detailed, fabricated, and placed.
- e) Impervious protective coatings or barriers are used where required.

Usually it is more economical and dependable to resist liquid or gas permeation through the use of quality concrete, proper design of joint details, and adequate reinforcement, rather than by means of an impervious protective barrier or coating. Liquid-tightness or gas-tightness can also be obtained by appropriate use of shrinkage-compensating concrete. However, the engineer must recognize and account for the limitations, characteristics, and properties of shrinkage-compensating concrete as described in ACI 223 and ACI 224.2R.

Reduced permeability of the concrete is obtained by lowering the water-cementitious materials ratio as low as possible, without sacrificing acceptable workability and consolidation. Permeability decreases dramatically with extended periods of moist curing. In some cases, surface treatments can be an alternative to moist curing. Reduced permeability of the concrete surface can be achieved through the use of smooth forms or by troweling.

Air entrainment increases consolidation, reduces segregation and bleeding, increases workability, and provides

resistance to the effect of freezing-and-thawing cycles. Other admixtures, such as water reducers, are useful, as they increase workability and improve consolidation while lowering the water-cementitious materials ratio (w/cm), which can increase strength characteristics. Use of some supplementary cementitious materials can also provide similar benefits. In addition, supplementary cementitious materials can also reduce permeability, increase durability, and extend service life.

Joint design should also account for movement resulting from thermal dimensional changes, differential settlements, and shrinkage strains induced by placement sequencing. Joints that form a barrier to the passage of liquids and gases are required to include waterstops in complete, closed circuits. Proper rate of concrete placement operations, adequate consolidation, and proper curing are also essential to control of cracking in environmental engineering concrete structures. Additional information on cracking is contained in ACI 224R and ACI 224.2R.

The design of the entire environmental engineering concrete structure as well as all individual members should be in accordance with the Code, which has been adapted from ACI 318. When all relevant loading conditions are considered, the design should provide adequate safety and serviceability, with a service life significantly greater than the service life expected if these structures were designed following the provisions of ACI 318. Some components of the structure, such as jointing materials, have a shorter life expectancy and will require maintenance or replacement.

The size of elements and amount of reinforcement should be selected on the basis of the serviceability and stress limits to promote long service life.

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CODE

CHAPTER 1—GENERAL
REQUIREMENTS

1.1—Scope

1.1.1 Except for primary containment of hazardous materials, this Code, where adopted under the requirements of the legally adopted building code, provides minimum requirements for the design and construction of reinforced concrete elements of environmental engineering concrete structures. In areas without a legally adopted building code, this Code defines minimum acceptable standards for materials, design, and construction practice. This Code also covers the strength

COMMENTARY

CHAPTER R1—GENERAL
REQUIREMENTS

R1.1—Scope

The American Concrete Institute “**Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20)**,” hereinafter referred to as this Code, provides minimum requirements for environmental engineering concrete design and construction practices.

The 2020 edition of this Code revised the previous code, ACI 350-06. This Code includes in one document the requirements for all reinforced concrete used for environmental engineering structures. This covers the spectrum of concrete containing nonprestressed reinforcement, prestressing steel, or composite steel shapes, pipe, or tubing.

Prestressed concrete is included under the definition of reinforced concrete. Provisions of this Code apply to prestressed concrete except those that are specifically stated to apply to nonprestressed concrete.

Chapter 13 of this Code contains provisions for design and detailing of earthquake-resistant structures. Refer to 1.1.9.

Appendix A of this Code contains provisions for an alternate method of design for nonprestressed reinforced concrete members using service loads (without load factors) and permissible service load stresses. The strength design method of this Code is intended to give design results similar to the Alternate Design Method.

Appendix B of this Code contains provisions for the design of regions near geometrical discontinuities, or abrupt changes in loadings.

Appendix C of this Code contains provisions for reinforcement limits based on $0.75p_b$, determination of the strength reduction factor ϕ , and moment redistribution that have been in the ACI 318 codes for many years, including ACI 318-99. The provisions are applicable to reinforced and prestressed concrete members. When used, the provisions of Appendix C are to be used in their entirety.

Appendix D of this Code permits the use of load, environmental durability, strength reduction factors, and flexural reinforcement distribution provisions similar to those in Chapters 9 and 10 of ACI 350-01. Designs made using the provisions of Appendix D are equally acceptable as those based on the body of this Code, provided the provisions of Appendix D are used in their entirety.

Appendix E of this Code contains provisions for anchoring to concrete.

R1.1.1 A hazardous material may be defined as a liquid, solid, gas, or sludge waste that contains properties that are dangerous or potentially harmful to human health or the environment. The Environmental Protection Agency (EPA) listed wastes are organized into three categories under the Resource Conservation and Recovery Act (RCRA): source-specific wastes, generic wastes, and land treatment unit products. Source-specific wastes include sludges and waste-

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evaluation and condition assessment of environmental engineering concrete structures.

In this Code, the term “concrete” shall also include shotcrete except where specifically indicated otherwise.

The specified concrete compressive strength shall not be less than 4000 psi. No maximum specified compressive strength shall apply unless restricted by a specific Code provision.

1.1.1.1 Environmental engineering concrete structures are defined as concrete structures intended for conveying, storing, or treating water, wastewater, or other liquids and non-hazardous materials such as solid waste, and for secondary containment of hazardous liquids. For ancillary structures for which liquid-tightness, gas-tightness, or enhanced durability are essential, design considerations shall also conform to requirements of environmental engineering concrete structures.

1.1.2 Precast concrete environmental structures designed and constructed in accordance with ASTM standards are not covered in this Code.

1.1.3 This Code supplements the general building code and shall govern in all matters pertaining to design and construction of reinforced concrete elements of environmental engineering concrete structures, except wherever this Code is in conflict with requirements in legally adopted codes addressing environmental engineering concrete structures.

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waters from treatment and production processes in specific industries such as petroleum refining and wood preserving. The list of generic wastes includes wastes from common manufacturing and industrial processes such as solvents used in degreasing operations. The third list contains specific chemical products such as benzene, creosote, mercury, and various pesticides.

Shotcrete is pneumatically placed whereas other types of concrete are typically placed by gravity or pumped.

Below-grade structures, such as pump stations and pipe galleries, which are part of treatment facilities and which may be exposed to external groundwater pressures, generally are designed as environmental engineering concrete structures. Above-grade building structures that are not directly exposed to liquids, solid wastes, corrosive chemicals, corrosive gases, or high humidity associated with treatment facilities generally may be designed in accordance with the general building code or applicable industry standards. Nevertheless, consideration of corrosive effects on such structures may still be advisable.

R1.1.1.1 Environmental engineering concrete structures include but are not limited to tanks, reservoirs, clarifiers, separators, lagoon liners, and secondary containment structures. Also included are hydraulic structures associated with flood control and water supply projects such as stilling basins, channels, portions of power houses, spillway piers, spray walls, training walls, flood walls, intake and outlet structures, flood control tunnels and shafts, energy-dissipating structures such as impact basins, lock walls, guide and guard walls, canal linings, and reinforced sections of concrete gravity dams.

R1.1.2 Although precast environmental concrete structures designed and constructed in accordance with ASTM standards are not included in the scope of this Code, the licensed design professional should evaluate whether additional requirements may be necessary to minimize deterioration and to achieve the desired durability and service life of the structure. For example, ASTM C478 allows a maximum w/cm of 0.53 and the standard has no criteria that will permit addressing service conditions where the concrete may be exposed to freezing and thawing, harmful chemicals and gases, or harmful sulfates, all of which could accelerate deterioration and reduce durability of the structure and the expected service life.

R1.1.3 The American Concrete Institute recommends that this Code be adopted in its entirety; however, it is recognized that when this Code is made a part of a legally adopted general building code, that general building code may modify some provisions of this Code.

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1.1.4 This Code shall apply in all matters pertaining to design, construction, and material properties wherever this Code is in conflict with requirements contained in other standards referenced in this Code.

1.1.5 The provisions of this Code shall govern for tanks, reservoirs, and other reinforced concrete elements of environmental engineering concrete structures. For special structures such as arches, bins and silos, blast-resistant structures, and chimneys, provisions of this Code shall govern where applicable. When an environmental concrete structure may be considered a building structure then it shall be designed to the requirements of this Code.

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R1.1.5 Environmental engineering projects can contain several types of structures. For example, a treatment plant can contain environmental engineering concrete structures such as tanks and reservoirs, as well as an administration building. The ACI 350 Code would apply to the environmental structures, while ACI 318 could apply to the administration building. Also, the following ACI publications could apply to other structures.

“Code Requirements for Reinforced Concrete Chimneys (ACI 307-08) and Commentary” by ACI Committee 307. This standard prescribes material, construction, and design requirements for circular cast-in-place reinforced chimneys. It sets forth minimum loadings for the design of reinforced concrete chimneys and contains methods for determining the stresses in the concrete and reinforcement required as a result of these loadings.

“Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials (ACI 313-16) and Commentary” reported by ACI Committee 313. This specification provides material, design, and construction requirements for reinforced concrete bins, silos, and bunkers and stave silos for storing granular materials. It includes recommended design and construction criteria based on experimental and analytical studies plus worldwide experience in silo design and construction.

Bins, silos, and bunkers are special structures, posing special problems not encountered in normal building design. While ACI 313 refers to **“Building Code Requirements for Structural Concrete (ACI 318)”** for many applicable requirements, it provides supplemental detail requirements and ways of considering the unique problems of static and dynamic loading of silo structures. Much of the criteria are empirical, but this specification does not preclude the use of more sophisticated methods that give equivalent or better safety and reliability.

ACI 313 sets forth recommended loadings and methods for determining the stresses in the concrete and reinforcement resulting from these loadings. Methods are recommended for determining the thermal effects resulting from stored material and for determining crack width in concrete walls due to pressure exerted by the stored material. Appendixes provide recommended minimum values of overpressure and impact factors.

“Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-06) and Commentary” reported by ACI Committee 349. This standard provides minimum requirements for design and construction of concrete structures that form part of a nuclear power plant and that have nuclear safety-related functions. This stan-



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1.1.6 This Code does not govern design and installation of portions of concrete piles, drilled piers, and caissons embedded in ground except for structures in regions of high seismic risk or assigned to high seismic performance or design categories. Refer to 21.10.4 for requirements for concrete piles, drilled piers, and caissons in regions of high seismic risk or assigned to high seismic performance or design categories.

1.1.7 This Code governs the design and construction of both structural and non-structural slabs-on-ground for environmental engineering concrete structures.

1.1.8 *Concrete on steel deck*

1.1.8.1 Design and construction of structural concrete slabs cast on stay-in-place, non-composite steel form deck are governed by this Code.

dard does not cover concrete reactor vessels and concrete containment structures that are covered by ACI 359.

“Code for Concrete Reactor Vessels and Containments (ACI 359-07)” reported by Joint ACI-ASME Committee 359. This standard provides requirements for the design, construction, and use of concrete reactor vessels and concrete containment structures for nuclear power plants.

R1.1.6 The design and installation of concrete piles fully embedded in the ground is regulated by the general building code. For portions of a pile in air or water, or in soil not capable of providing adequate lateral restraint throughout the length of the pile to prevent buckling, the design provisions of this Code govern where applicable.

Recommendations for concrete piles are presented in detail in **“Guide to Design, Manufacture, and Installation of Concrete Piles (ACI 543R-12)”** reported by ACI Committee 543. This report provides recommendations for the design and use of most types of concrete piles for many kinds of construction.

Recommendations for drilled piers are presented in detail in **“Design and Construction of Drilled Piers (ACI 336.3R-93(06))”** reported by ACI Committee 336. This document provides recommendations for design and construction of foundation piers 2-1/2 ft in diameter or larger made by excavating a hole in the soil and then filling it with concrete.

Detailed recommendations for precast, prestressed concrete piles are presented in **“Recommended Practice for Design, Manufacture and Installation of Prestressed Concrete Piling”** prepared by the PCI Committee on Prestressed Concrete Piling (1993).

R1.1.7 Certain requirements that are only applicable to nonstructural liquid-containing slabs-on-ground are included in Chapter 22. These types of tank floor slabs frequently transfer the loads from liquid contents directly to the soil below. Otherwise, requirements for all slabs-on-ground are included in other chapters of this Code. An example of an environmental nonstructural, non-liquid-containing slab-on-ground is the floor of a transfer station or similar slab where enhanced durability is essential.

R1.1.8 *Concrete on steel deck*

R1.1.8.1 In its most basic application, the steel form deck serves as a form, and the concrete slab is designed to carry all loads, while in other applications the concrete slab may be designed to carry only superimposed loads. The design of the steel deck for this application is described in **“Standard for Non-Composite Steel Floor Deck (ANSI/SDI NC-2010).”** This standard refers to ACI 318 for the design and construction of the structural concrete slab.

The licensed design professional should consider the potential for corrosion of steel deck and make the neces-

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1.1.8.2 This Code does not govern the design of stay-in-place, composite steel form deck. However, the concrete design and construction shall be governed by this Code, where applicable.

1.1.9 Provisions for earthquake resistance

1.1.9.1 The Seismic Design Category of a structure shall be determined in accordance with the legally adopted building code, or determined by other authority having jurisdiction in areas without a legally adopted building code.

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sary provisions for corrosion resistance. Corrosion losses of form deck do not directly affect the strength of the slab; however, such corrosion may be undesirable for reasons such as aesthetics, or the possibility of corrosion products dislodging from the underside of a slab. The presence of steel deck does not allow visual inspection of the underside of the concrete slab.

R1.1.8.2 Another type of steel deck commonly used develops composite action between the concrete and steel deck. In this type of construction, the steel deck serves as the positive moment reinforcement. The design and construction of composite slabs on steel deck is described in “**Standard for Composite Steel Floor Deck (ANSI/ASCE DI C1.0-2006)**.” The standard refers to the appropriate portions of ACI 318 for the design and construction of the concrete portion of the composite assembly. International Building Code (IBC 2006) also provides guidance for design of composite slabs on steel deck. The design of negative moment reinforcement to create continuity at supports is a common example where a portion of the slab is designed in conformance with this Code. Corrosion losses of composite deck may result in reduced strength of the slab.

R1.1.9 Provisions for earthquake resistance

R1.1.9.1 Design requirements for an earthquake-resistant structure in this Code are determined by the Seismic Design Category (SDC) to which the structure is assigned. In general, the SDC relates to seismic hazard level, soil type, occupancy, and use of the structure. Assignment of a structure to an SDC is under the jurisdiction of a general building code rather than ACI 350.

Seismic Design Categories in this Code are adopted directly from ASCE/SEI 7-10. Similar designations are used by the 2009 edition of the “**International Building Code (IBC 2009)**” and the “**Building Construction and Safety Code (NFPA 5000:2009)**.” The “**BOCA National Building Code, 13th edition**” and “**Standard Building Code (SDC 1996)**” use Seismic Performance Categories. The 1997 “**Uniform Building Code (UBC 1997)**” relates design requirements for earthquake resistance to seismic zones, whereas previous editions of ACI 350 related design requirements for earthquake resistance to seismic risk levels. Table R1.1.9.1 correlates Seismic Design Categories to the low, moderate/intermediate, and high seismic risk terminology used in ACI 318 for several editions before the 2008 edition, and to the various methods of assigning design requirements in use in the United States under the various model building codes, the ASCE/SEI 7 standard and the NEHRP Recommended Provisions (FEMA 450-2003).

In the absence of a general building code that prescribes earthquake loads and seismic zoning, it is the intent of ACI Committee 350 that application of provisions for earthquake-resistant design be consistent with national standards

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Table R1.1.9.1—Correlation between seismic-related terminology in model codes

Code, standard, or resource document and edition	Level of seismic risk or assigned seismic performance or design categories as defined in this Code		
ACI 350-20, ACI 318-11; IBC 2000, 2003, 2006, 2009; NFPA 5000, 2003, 2006, 2009; ASCE 7-98, 7-02, 7-05, 7-10; NEHRP 1997, 2000, 2003, 2009	SDC* A, B	SDC C	SDC D, E, F
ACI 350-06 and 350.3-06 and previous editions ACI 318-05 and previous editions	Low seismic risk	Moderate/ intermediate seismic risk	High seismic risk
BOCA National Building Code 1993, 1996, 1999; Standard Building Code 1994, 1997, 1999; ASCE 7-93, 7-95; NEHRP 1991, 1994	SPC† A, B	SPC C	SPC D, E
Uniform Building Code 1991, 1994, 1997	Seismic Zone 0, 1	Seismic Zone 2	Seismic Zone 3, 4

*SDC = Seismic Design Category as defined in code, standard, or resource document.

†SPC = Seismic Performance Category as defined in code, standard, or resource document.

or model building codes such as ASCE/SEI 7-10, IBC 2006, and NFPA 5000:2009. The model building codes also specify overstrength factors, Ω_o , that are related to the seismic-force-resisting system used for the structure and used for the design of certain elements.

1.1.9.2 Applicable provisions based on Seismic Design Category are defined in Chapter 13 for structures not otherwise exempted by the legally adopted general building code.

1.1.10 For prestressed concrete environmental structures, Chapters 1 through 22 cover prestressing in general.

1.2—Contract documents

1.2.1 Design drawings, typical details, and specifications for all concrete construction shall bear the dated signature and seal of a licensed design professional. These drawings, details, and specifications shall indicate:

- (a) Name and date of issue of the applicable building code and supplement to which design conforms
- (b) Live load and other loads used in design
- (c) Specified compressive strength of concrete at stated ages or stages of construction for which each part of structure is designed
- (d) Specified strength or grade of reinforcement
- (e) Size and location of all concrete elements and reinforcement
- (f) Requirements for type, size, location, and installation of anchors, and qualifications for post-installed anchor installers as required by E.9
- (g) Provision for dimensional changes resulting from creep, shrinkage, and change in temperature
- (h) Magnitude and location of prestressing forces
- (i) Anchorage of reinforcement and location and length of lap splices
- (j) Type and location of mechanical and welded splices of reinforcement

R1.2—Contract documents

R1.2.1 The provisions for preparation of contract documents are, in general, consistent with those of most general building codes and are intended as supplements.

This Code lists some of the more important items of information that are to be included in the contract documents. This Code does not imply an all-inclusive list, and additional items may be required by the building official.

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- (k) The design liquid level for each structure designed to contain liquid
- (l) Minimum concrete compressive strength at time of post-tensioning
- (m) Stressing sequence for post-tensioning tendons
- (n) Statement if slab-on-ground is designed as a structural diaphragm; refer to 13.12.3.4
- (o) Design gas pressure for structural elements subjected to pressurized gas or liquid
- (p) Concrete properties and ingredients including type of cement, type of supplementary cementitious materials, maximum permitted water-cementitious materials ratio, and, if permitted, admixtures and additives
- (q) Additional requirements, such as limitations on drying shrinkage
- (r) Requirements for liquid-tightness testing, including liquid-tightness testing before backfilling
- (s) Where Eq. (9.8) is used in the design: all limitations on tightness testing, future adjacent construction, operation, and maintenance required to ensure that H will continue to act simultaneously with F
- (t) Details and locations of all joints

1.2.2 Calculations pertinent to design shall be filed with the contract documents when required by the building official:

- (a) Analyses and designs using computer programs shall be permitted provided design assumptions, user input, and computer-generated output are submitted.
- (b) Model analyses shall be permitted to supplement calculations.
- (c) Building official shall mean the officer or other designated authority charged with the administration and enforcement of this Code, or his duly authorized representative.

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R1.2.2 Documented computer output is acceptable in lieu of manual calculations. The extent of input and output information required will vary, according to the specific requirements of individual building officials. When a computer program has been used by the designer, however, only skeleton data should normally be required. This should consist of sufficient input and output data and other information to allow the building official to perform a detailed review and make comparisons using another program or manual calculations. Input data should be identified as to member designation, applied loads, and span lengths. The related output data should include member designation and the shears, moments, and reactions at key points in the span. For column design, it is desirable to include moment magnification factors in the output where applicable.

This Code permits model analysis to be used to supplement structural analysis and design calculations. Documentation of the model analysis should be provided with the related calculations. Model analysis should be performed by a licensed design professional having experience in this technique.

“Building official” is the term used by many general building codes to identify the person charged with administration and enforcement of the provisions of the general building code. Such terms as “building commissioner” or “building inspector,” however, are variations of the title, and the term “building official” as used in this Code is intended to include those variations as well as others that are used in the same sense.

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1.3—Inspection

1.3.1 Concrete construction shall be inspected as required by the legally adopted general building code. In the absence of such requirements, concrete construction shall be inspected throughout the various work stages by or under the supervision of a licensed design professional or by a qualified inspector.

1.3.2 The inspector shall observe the work for compliance with the contract documents. Unless specified otherwise in the legally adopted general building code, inspection records shall include:

R1.3—Inspection

The quality of concrete structures depends largely on workmanship in construction. The best of materials and design practice will not be effective unless the construction is performed well. Inspection is necessary to observe that construction is in accordance with the contract documents. Proper performance of the structure depends on construction that accurately represents the design and meets Code requirements within the tolerances permitted. Qualification of the inspectors can be obtained from a certification program, such as the ACI Certification Program for Concrete Construction Special Inspector.

R1.3.1 Inspection of construction by or under the supervision of the licensed design professional responsible for the design is recommended because the person in charge of the design is the best qualified to inspect for conformance with the design. When such an arrangement is not feasible, inspection of construction through other licensed design professionals or through separate accredited inspection organizations, with demonstrated capability for performing the inspection, may be used.

Qualified inspectors should establish their qualification by becoming certified to inspect and record the results of concrete construction, including preplacement, placement, and post-placement operations through the ACI Inspector Certification Program: Concrete Construction Special Inspector.

When inspection is done independently of the licensed design professional responsible for the design, it is recommended that a licensed design professional be employed to oversee inspection and observe the work to see that the design requirements are properly executed.

In some jurisdictions, legislation has established special registration or licensing procedures for persons performing certain inspection functions. A check should be made in the general building code or with the building official to ascertain if any such requirements exist within a specific jurisdiction.

Inspection reports should be promptly distributed to all parties, including the owner, licensed design professional, inspector, contractor, appropriate subcontractors, appropriate suppliers, and the building official to allow timely identification of compliance or the need for corrective action.

Inspection responsibility and the degree of inspection required should be set forth in the contracts between the owner, architect, engineer, and contractor. Adequate fees should be provided consistent with the scope of inspection and equipment necessary to properly perform the inspection.

R1.3.2 By “inspection,” this Code does not mean that the inspector should supervise the construction. Rather, it means that the one employed for inspection should visit the project with the frequency necessary to observe the various stages of work and ascertain that it is being done in compliance with contract documents. The frequency should be at least

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- (a) Delivery, placement, and testing reports documenting the quantity, location of placement, fresh concrete tests, strength, and other tests of all concrete mixtures
- (b) Construction and removal of forms and reshoring
- (c) Placing of reinforcement and anchors
- (d) Mixing, placing, and curing of concrete
- (e) Sequence of erection and connection of precast members
- (f) Tensioning of tendons
- (g) Any significant construction loadings on completed floors, members, or walls
- (h) Description and results of tightness testing of liquid- and gas-containing structures
- (i) General progress of work

1.3.3 When the ambient temperature falls below 40°F or rises above 95°F, a record shall be kept of concrete temperatures and of protection provided for concrete during placement and curing.

1.3.4 Records of inspection required in 1.3.2 and 1.3.3 shall be preserved by the inspector for at least 2 years after completion of the project.

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enough to provide general knowledge of each operation, whether this is several times a day or once in several days.

Inspection in no way relieves the contractor's obligation to follow the contract documents and to provide the designated quality and quantity of materials and workmanship for all work stages. Some of the information regarding designated concrete mixtures on a project is often provided in a preconstruction submittal to the licensed design professional. For instance, concrete mixture ingredients and composition are often described in detail in the submittal and are subsequently identified by a mixture designation (reflected on a delivery ticket). The inspector should be present as frequently as necessary to judge whether the quality and quantity of the work complies with the contract documents; to counsel on possible ways of obtaining the desired results; to see that the general system proposed for formwork appears proper (though it remains the contractor's responsibility to design and build adequate forms and to leave them in place until it is safe to remove them); to see that reinforcement is properly installed; to see that concrete is of the correct quality, properly placed, and cured; and to see that tests for quality control are being made as specified.

This Code prescribes minimum requirements for inspection of all structures within its scope. It is not a construction specification and any user of this Code may require higher standards of inspection than cited in the general building code if additional requirements are necessary.

Recommended procedures for organization and conduct of concrete inspection are given in detail in ACI 311.4. This guide sets forth procedures relating to concrete construction to serve as a guide to owners, architects, and engineers in planning an inspection program.

Detailed methods of inspecting concrete construction are given in "ACI Manual of Concrete Inspection (ACI SP-2(07))," reported by ACI Committee 311. This manual describes methods of inspecting concrete construction that are generally accepted as good practice. It is intended as a supplement to project specifications and as a guide in matters not covered by project specifications.

R1.3.3 The term "ambient temperature" means the temperature of the environment to which the concrete is directly exposed. Concrete temperature as used in this section may be taken as the surface temperature of the concrete. Surface temperatures may be determined by placing temperature sensors in contact with concrete surfaces or between concrete surfaces and covers used for curing, such as insulation blankets or plastic sheeting.

R1.3.4 A record of inspection in the form of a project diary is required in case questions subsequently arise concerning the performance or safety of the structure or members. Photographs documenting progress of the work may also be desirable.

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1.3.5 For special moment frames designed in accordance with Chapter 13, continuous inspection of the placement of the reinforcement and concrete shall be made by a qualified inspector. The inspector shall be under the supervision of the licensed design professional of the structural design or under the supervision of a licensed design professional with demonstrated capability for supervising inspection of special moment frames.

1.3.6 For thin shell spherical domes with prestressed dome rings designed in accordance with Chapters 19 and 20, continuous inspection of the placement of the prestressed and nonprestressed reinforcement and concrete shall be made by a qualified inspector. The inspector shall be under the supervision of the licensed design professional of the structural design or under the supervision of a licensed design professional with demonstrated capability for supervising inspection of thin shell spherical domes with prestressed dome rings.

1.4—Approval of special systems of design or construction

Sponsors of any system of design or construction within the scope of this Code, for which the structural adequacy, durability, serviceability, and service life have been shown by successful use or by analysis or test, but which does not conform to or is not covered by this Code, shall have the right to present the data on which their design is based to the building official or to a board of examiners appointed by the building official. This board shall be composed of competent engineers and shall have authority to investigate the data so submitted, to require tests, and to formulate rules governing design and construction of such systems to meet the intent of this Code. These rules, when approved by the building official and promulgated, shall be of the same force and effect as the provisions of this Code.

Records of inspection are required to be preserved for at least 2 years after the completion of the project. The completion of the project is the date at which the owner accepts the project, or when a certificate of occupancy is issued, whichever date is later. The general building code or other legal requirements may require a longer preservation of such records.

R1.3.5 The purpose of this section is to ensure that the special detailing required in concrete ductile frames is properly executed through inspection by personnel who are qualified to perform the inspection. Qualifications of inspectors should be determined by the jurisdiction enforcing the general building code.

R1.3.6 The thin shell spherical domes with prestressed dome rings that meet the tolerances stated in Chapter 12 have typically been designed and constructed by firms that specialize in this type of construction. Special inspection by qualified personnel becomes more critical for contractors without specific experience in the construction of these structural elements. The purpose of this section is to ensure that the construction is properly executed through inspection by personnel who are qualified to perform the inspection. Qualifications of inspectors should be determined by the licensed design professional in responsible charge of the design of the structure.

R1.4—Approval of special systems of design or construction

New methods of design, new materials, and new uses of materials must undergo a period of development before being specifically covered in a code. Hence, good systems or components might be excluded from use by implication if means were not available to obtain acceptance.

For special systems considered under this section, specific tests, load factors, deflection limits, and other pertinent requirements should be set by the board of examiners, and should be consistent with the intent of this Code.

The provisions of this section do not apply to model tests used to supplement calculations under 1.2.2 or to strength evaluations of existing structures under Chapter 22.

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CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Code notation

The terms in this list are used in this Code and as needed in the Commentary.

- a = depth of equivalent rectangular stress block as defined in 10.2.7.1, in., Chapters 10, 12
- a_v = shear span, equal to distance from center of concentrated load to either: (a) face of support for continuous or cantilevered members, or (b) center of support for simply supported members, in., Chapter 11, Appendix B
- A_b = area of an individual bar or wire, in.², Chapters 10, 12
- A_{brg} = net bearing area of the head of stud, anchor bolt, or headed deformed bar, in.², Chapter 12, Appendix E
- A_c = area of concrete section resisting shear transfer, in.², Chapters 11, 13
- A_c = area of core of spirally reinforced compression member measured to outside diameter of spiral, in.², Chapters 10, 13
- A_{cf} = larger gross cross-sectional area of the slab-beam strips of the two orthogonal equivalent frames intersecting at a column of a two-way slab, in.², Chapter 19
- A_{ch} = cross-sectional area of a structural member measured to the outside edges of transverse reinforcement, in.², Chapters 10, 13
- A_{cp} = area enclosed by outside perimeter of concrete cross section, in.², see 11.5.1, Chapter 11
- A_{cs} = cross-sectional area at one end of a strut in a strut-and-tie model, taken perpendicular to the axis of the strut, in.², Appendix B
- A_{ct} = area of that part of cross section between the flexural tension face and center of gravity of gross section, in.², Chapter 19
- A_{cv} = gross area of concrete section bounded by web thickness and length of section in the direction of shear force considered, in.², Chapter 13

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CHAPTER R2—NOTATION AND DEFINITIONS

R2.1—Commentary notation

The terms used in this list are used in the Commentary, but not in the Code.

Units of measurement are given in the Notation to assist the user and are not intended to preclude the use of other correctly applied units for the same symbol, such as ft or kip. Nevertheless, care should be taken to properly account for the effect of differing units on constants given in equations that may include factors to account for the units of defined variables.

The factored prestressing force P_{su} is the product of the load factor (1.2 from Section 9.2.5) and the maximum prestressing force permitted. Under 19.5.1, this is usually overstressing to $0.94f_{py}$ but not greater than $0.80f_{pu}$, which is permitted for short periods of time

$$P_{su} = (1.2)(0.80)f_{pu}A_{ps} = 0.96f_{pu}A_{ps}$$

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A_{cw}	= area of concrete section of an individual pier, horizontal wall segment, or coupling beam resisting shear, in. ² , Chapter 13
A_f	= area of reinforcement in bracket or corbel resisting factored moment, in. ² , see 11.8 , Chapter 11
A_g	= gross area of concrete section, in. ² For a hollow section, A_g is the area of the concrete only and does not include the area of the void(s), see 11.5.1 , Chapters 9-11 , 13 , 15-17 , Appendixes C , D
A_h	= total area of shear reinforcement parallel to primary tension reinforcement in a corbel or bracket, in. ² , see 11.8 , Chapter 11
A_j	= effective cross-sectional area within a joint in a plane parallel to plane of reinforcement generating shear in the joint, in. ² , see 13.7.4.1 , Chapter 13
A_ℓ	= total area of longitudinal reinforcement to resist torsion, in. ² , Chapter 11
$A_{\ell,min}$	= minimum area of longitudinal reinforcement to resist torsion, in. ² , see 11.5.5.3 , Chapter 11
A_n	= area of reinforcement in bracket or corbel resisting tensile force N_{uc} , in. ² , see 11.8 , Chapter 11
A_{nz}	= area of a face of a nodal zone or a section through a nodal zone, in. ² , Appendix A
A_{Na}	= projected influence area of a single adhesive anchor or group of adhesive anchors, for calculation of bond strength in tension, in. ² , see E.5.5.1 , Appendix E
A_{Nao}	= projected influence area of a single adhesive anchor, for calculation of bond strength in tension if not limited by edge distance or spacing, in. ² , see E.5.5.1 , Appendix E
A_{Nc}	= projected concrete failure area of a single anchor or group of anchors, for calculation of strength in tension, in. ² , see E.5.2.1 , Appendix E
A_{Nco}	= projected concrete failure area of a single anchor, for calculation of strength in tension if not limited by edge distance or spacing, in. ² , see E.5.2.1 , Appendix E
A_o	= gross area enclosed by shear flow path, in. ² , Chapter 11
A_{oh}	= area enclosed by centerline of the outermost closed transverse torsional reinforcement, in. ² , Chapter 11
A_{ps}	= area of prestressing reinforcement in flexural tension zone, in. ² , Chapter 19 , Appendix C
A_s	= area of nonprestressed longitudinal tension reinforcement, in. ² , Chapters 8 to 12 , 15 , 16 , 19 , Appendix C
A'_s	= area of compression reinforcement, in. ² , Chapter 8 , 9 , 19 , Appendix B
A_{sc}	= area of primary tension reinforcement in a corbel or bracket, in. ² , see 11.8.3.5 , Chapter 11

CODE

COMMENTARY

$A_{se,N}$	= effective cross-sectional area of anchor in tension, in. ² , Appendix E
$A_{se,V}$	= effective cross-sectional area of anchor in shear, in. ² , Appendix E
A_{sh}	= total cross-sectional area of transverse reinforcement (including crossties) within spacing s and perpendicular to dimension b_c , in. ² , Chapter 13
A_{si}	= total area of surface reinforcement at spacing s_i in the i -th layer crossing a strut, with reinforcement at an angle α_i to the axis of the strut, in. ² , Appendix B
$A_{s,min}$	= minimum area of flexural reinforcement, in. ² , see 10.5 , Chapter 10
A_{st}	= total area of nonprestressed longitudinal reinforcement (bars or steel shapes), in. ² , Chapters 10, 13
A_{sx}	= area of structural steel shape, pipe, or tubing in a composite section, in. ² , Chapter 10
A_t	= area of one leg of a closed stirrup resisting torsion within spacing s , in. ² , Chapter 11
A_{tp}	= area of prestressing steel in a tie, in. ² , Appendix B
A_{tr}	= total cross-sectional area of all transverse reinforcement within spacing s that crosses the potential plane of splitting through the reinforcement being developed, in. ² , Chapter 12
A_{ts}	= area of nonprestressed reinforcement in a tie, in. ² , Appendix A
A_v	= area of shear reinforcement within spacing s , in. ² , Chapters 11, 12, 18
A_{vd}	= total area of reinforcement in each group of diagonal bars in a diagonally reinforced coupling beam, in. ² , Chapter 13
A_{vf}	= area of shear-friction reinforcement, in. ² , Chapters 11, 13
A_{vh}	= area of shear reinforcement parallel to flexural tension reinforcement within spacing s_2 , in. ² , Chapter 11
$A_{v,min}$	= minimum area of shear reinforcement within spacing s , in. ² , see 11.4.6.3 and 11.4.6.4 , Chapter 11
A_{Vc}	= projected concrete failure area of a single anchor or group of anchors, for calculation of strength in shear, in. ² , see E.6.2.1 , Appendix E
A_{Vco}	= projected concrete failure area of a single anchor, for calculation of strength in shear, if not limited by corner influences, spacing, or member thickness, in. ² , see E.6.2.1 , Appendix E
A_1	= loaded area, in. ² , Chapter 10
A_2	= area of the lower base of the largest frustum of a pyramid, cone, or tapered wedge contained wholly within the support and having for its upper base the loaded area, and having side slopes of 1 vertical to 2 horizontal, in. ² , Chapter 10
b	= width of compression face of member, in., Chapter 8, 9, 10, 19, Appendix C

CODE

COMMENTARY

b_c	= cross-sectional dimension of member core measured to the outside edges of the transverse reinforcement composing area A_{sh} , in., Chapter 13
b_o	= perimeter of critical section for shear in slabs and footings, in., see 11.11.1.2 , Chapters 11
b_s	= width of strut, in., Appendix B
b_t	= width of that part of cross section containing the closed stirrups resisting torsion, in., Chapter 11
b_v	= width of cross section at contact surface being investigated for horizontal shear, in., Chapter 17
b_w	= web width, wall thickness, or diameter of circular section, in., Chapters 10 to 12 , Appendix C
b_1	= dimension of the critical section b_o measured in the direction of the span for which moments are determined, in., Chapter 14
b_2	= dimension of the critical section b_o measured in the direction perpendicular to b_1 , in., Chapter 14
c	= distance from extreme compression fiber to neutral axis, in., Chapters 9, 10, 13, 15
c_{ac}	= critical edge distance required to develop the basic strength as controlled by concrete breakout or bond of a post-installed anchor in tension in uncracked concrete without supplementary reinforcement to control splitting, in., see E.8.6 , Appendix E
$c_{a,max}$	= maximum distance from center of an anchor shaft to the edge of concrete, in., Appendix E
$c_{a,min}$	= minimum distance from center of an anchor shaft to the edge of concrete, in., Appendix E
c_{a1}	= distance from the center of an anchor shaft to the edge of concrete in one direction, in. If shear is applied to anchor, c_{a1} is taken in the direction of the applied shear. If tension is applied to the anchor, c_{a1} is the minimum edge distance, Appendix E . Where anchors subject to shear are located in narrow sections of limited thickness, see E.6.2.4
c_{a2}	= distance from center of an anchor shaft to the edge of concrete in the direction perpendicular to c_{a1} , in., Appendix E
c_b	= smaller of: (a) the distance from center of a bar or wire to nearest concrete surface, and (b) one-half the center-to-center spacing of bars or wires being developed, in., Chapter 12
c_c	= clear cover of reinforcement, in., see 10.6.4 , Chapters 10, 19
c_{Na}	= projected distance from center of an anchor shaft on one side of the anchor required to develop the full bond strength of a single adhesive anchor, in., see E.5.5.1 , Appendix E

c_{a1}' = limiting value of c_{a1} when anchors are located less than $1.5c_{a1}$ from three or more edges (refer to [Fig. RE.6.2.4](#)), [Appendix E](#)

CODE

COMMENTARY

c_t	= distance from the interior face of the column to the slab edge measured parallel to c_1 , but not exceeding c_1 , in., Chapter 13	
c_1	= dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direction of the span for which moments are being determined, in., Chapters 11, 13, 14 ,	
c_2	= dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direction perpendicular to c_1 , in., Chapters 11, 14	
C	= cross-sectional constant to define torsional properties of slab and beam, see 14.6.4.2 , Chapter 14	C = compression force acting on a nodal zone, lb, Appendix B
C_m	= factor relating actual moment diagram to an equivalent uniform moment diagram, Chapter 10	
C_s	= average coefficient of shrinkage for the reinforced concrete, in./in. See 9.2.8 , Chapter 9	
d	= distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in., Chapters 8 to 13, 15, 18, 19, Appendix C	
d'	= distance from extreme compression fiber to centroid of longitudinal compression reinforcement, in., Chapters 9, 11, 19, Appendix D	
d_a	= outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt, in., see E.8.4, Appendix E	
d_a'	= value substituted for d_a when an oversized anchor is used, in., see E.8.4, Appendix E	
d_b	= nominal diameter of bar, wire, or prestressing strand, in., Chapters 10, 12, 13	
d_c	= thickness of concrete cover measured from extreme tension fiber to center of bar or wire located closest thereto, in., Chapter 10	
d_p	= distance from extreme compression fiber to centroid of prestressing steel, in., Chapters 11, 19, Appendix C	
d_{pile}	= diameter of pile at footing base, in., Chapter 16	
d_s	= distance from extreme tension fiber to centroid of tension reinforcement, in., Chapter 9	
d_t	= distance from extreme compression fiber to centroid of extreme layer of longitudinal tension steel, in., Chapters 9, 10, Appendix D	
D	= dead loads, or related internal moments and forces, Chapters 8, 9, 19, 22, Appendix D	
D_T	= inside diameter of a circular tank, ft, Chapter 13	
e	= base of Napierian logarithms, Chapter 19	
e_h	= distance from the inner surface of the shaft of a J- or L-bolt to the outer tip of the J- or L-bolt, in., Appendix E	
e_N'	= distance between resultant tension load on a group of anchors loaded in tension and the centroid of the group of anchors loaded in tension, in.; e_N' is always positive, Appendix E	
e_V'	= distance between resultant shear load on a group of anchors loaded in shear in the same direction, and the centroid of the group of anchors loaded	

CODE

COMMENTARY

	in shear in the same direction, in.; e_V' is always positive, Appendix E		
E	= load effects of earthquake, or related internal moments and forces, Chapters 9, 13, Appendix D		
E_c	= modulus of elasticity of concrete, psi, see 8.5.1, Chapters 8 to 10, 15, 20		
E_{cb}	= modulus of elasticity of beam concrete, psi, Chapter 14		
E_{cs}	= modulus of elasticity of slab concrete, psi, Chapter 14		
E_p	= modulus of elasticity of prestressing steel, psi, see 8.5.3, Chapter 8		
E_s	= modulus of elasticity of reinforcement and structural steel, psi, see Eq. (10-13) and Eq. (10-14), Chapters 8, 10, 14		
EI	= flexural stiffness of compression member, in. ² -lb, see 10.10.6, Chapter 10		
f_c'	= specified compressive strength of concrete, psi, Chapters 4, 5, 8-13, 15, 19, 20, Appendixes B to E	f_c'	= specified compressive strength of concrete, psi
$\sqrt{f_c'}$	= square root of specified compressive strength of concrete, psi, Chapters 8, 9, 11, 12, 13, 19, 20, Appendix E		
f_{ce}	= effective compressive strength of the concrete in a strut or a nodal zone, psi, Chapter 16, Appendix A		
f_{ci}'	= specified compressive strength of concrete at time of initial prestress, psi, Chapters 12, 19		
$\sqrt{f_{ci}'}$	= square root of specified compressive strength of concrete at time of initial prestress, psi, Chapters 13, 19		
f_{cr}'	= required average compressive strength of concrete used as the basis for selection of concrete proportions, psi, Chapter 5	f_{cr}'	= required average compressive strength of concrete used as the basis for selection of concrete proportions, psi
f_{ct}	= average splitting tensile strength of lightweight aggregate concrete, psi, Chapters 5, 11, 12		
$f_{c,tension}$	= service level tensile hoop stress in the transformed section of concrete in walls of nonprestressed circular tanks due to combined shrinkage and applied hoop tension, psi, Chapter 9		
f_d	= stress due to unfactored dead load, at extreme fiber of section where tensile stress is caused by externally applied loads, psi, Chapter 11		
f_{dc}	= decompression stress; stress in the prestressing steel when stress is zero in the concrete at the same level as the centroid of the prestressing steel, psi, Chapter 19		
f_g'	= specified compressive strength of shotcrete, psi, Chapter 4, 5	f_g'	= specified compressive strength of shotcrete, psi
f_{gr}'	= required average compressive strength of shotcrete used as the basis for selection of shotcrete proportions, psi, Chapter 5	f_{gr}'	= required average compressive strength of shotcrete used as the basis for selection of shotcrete proportions, psi
f_{pc}	= compressive stress in concrete (after allowance for all prestress losses) at centroid of cross section resisting externally applied loads or at junction of web and flange when the centroid lies		

CODE

COMMENTARY

	within the flange, psi (In a composite member, f_{pc} is the resultant compressive stress at centroid of composite section, or at junction of web and flange when the centroid lies within the flange, due to both prestress and moments resisted by precast member acting alone.), Chapter 11	
f_{pc}	= average compressive stress in concrete due to effective prestress force only (after allowance for all prestress losses), psi, Chapter 19	
f_{pe}	= compressive stress in concrete due to effective prestress forces only (after allowance for all prestress losses) at extreme fiber of section where tensile stress is caused by externally applied loads, psi, Chapter 11	
f_{ps}	= stress in prestressing steel at nominal flexural strength, psi, Chapters 12, 19	
f_{pu}	= specified tensile strength of prestressing steel, psi, Chapters 11, 19	
f_{py}	= specified yield strength of prestressing steel, psi, Chapter 19	
f_r	= modulus of rupture of concrete, psi, see 9.5.2.3, Chapters 9, 15, 19, Appendix C	
f_s	= calculated tensile stress in reinforcement at service loads, psi, Chapters 10, 19	
f_s'	= stress in compression reinforcement under factored loads, psi, Appendix B	
f_{se}	= effective stress in prestressing steel (after allowance for all prestress losses), psi, Chapters 12, 19, Appendix B	
		f_{si} = stress in the i -th layer of surface reinforcement, psi, Appendix B
$f_{s,max}$	= maximum allowable tensile stress in reinforcement at service loads, psi, Chapters 9-10	
f_t	= extreme fiber stress in tension in the precompressed tensile zone calculated at service loads using gross section properties, psi, see 19.3.3, Chapter 19	
f_{uta}	= specified tensile strength of anchor steel, psi, Appendix E	
f_y	= specified yield strength of nonprestressed reinforcement, psi, Chapters 3, 9-13, 15, 18-20, Appendixes B to D	f_y = specified yield strength of nonprestressed reinforcement, psi
f_{ya}	= specified yield strength of anchor steel, psi, Appendix E	
f_{yt}	= specified yield strength f_y of transverse reinforcement, psi, Chapters 9 to 13	
F	= loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights, or related internal moments and forces, Chapter 9, Appendix D	
F_n	= nominal strength of a strut, tie, or nodal zone, lb, Appendix B	
F_{nn}	= nominal strength at face of a nodal zone, lb, Appendix B	
F_{ns}	= nominal strength of a strut, lb, Appendix B	
F_{nt}	= nominal strength of a tie, lb, Appendix B	

CODE

COMMENTARY

F_u = factored force acting in a strut, tie, bearing area, or nodal zone in a strut-and-tie model, lb, [Appendix B](#)

h = overall thickness or height of member, in., Chapters [9](#) to [13](#), [15](#), [18](#), [19](#), [22](#), Appendixes B, [D](#)

h_a = thickness of member in which an anchor is located, measured parallel to anchor axis, in., [Appendix E](#)

h_{ef} = effective embedment depth of anchor, in., see [E.1](#), [E.8.5](#), Appendix E. Where anchors subject to tension are close to three or more edges, see [E.5.2.3](#)

h_{anc} = dimension of anchorage device or single group of closely spaced devices in the direction of bursting being considered, in., Chapter 19

h_{ef}' = limiting value of h_{ef} when anchors are located less than $1.5h_{ef}$ from three or more edges (see [Fig. RE.5.2.3](#)), Appendix E

h_v = total depth of shearhead cross section, in., [Chapter 11](#)

h_w = height of entire wall from base to top, or clear height of wall segment or wall pier considered, in., Chapters [11](#), [13](#)

h_x = maximum center-to-center horizontal spacing of crossties or hoop legs on all faces of the column, in., Chapter 13

H = loads due to lateral pressure of soil, water in soil, or other materials, or related internal moments and forces, lb, [Chapter 9](#), Appendix D

H_L = depth of stored liquid, ft, Chapter 13

I = moment of inertia of section about centroidal axis, in.⁴, Chapters [10](#), [11](#)

I_b = moment of inertia of gross section of beam about centroidal axis, in.⁴, see [14.6.1.6](#), [Chapter 14](#)

I_{cr} = moment of inertia of cracked section transformed to concrete, in.⁴, Chapter 9

I_e = effective moment of inertia for computation of deflection, in.⁴, see [9.5.2.3](#), Chapter 9

I_g = moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement, in.⁴, Chapters [9](#), [10](#), [15](#)

I_s = moment of inertia of gross section of slab about centroidal axis defined for calculating α_f and β , in.⁴, [Chapter 14](#)

I_{se} = moment of inertia of reinforcement about centroidal axis of member cross section, in.⁴, Chapter 10

I_{sx} = moment of inertia of structural steel shape, pipe, or tubing about centroidal axis of composite member cross section, in.⁴, Chapter 10

k = effective length factor for compression members, Chapters [10](#), [15](#)

k_c = coefficient for basic concrete breakout strength in tension, [Appendix E](#)

k_{cp} = coefficient for pryout strength, Appendix E

CODE

COMMENTARY

K	= wobble friction coefficient per foot of tendon, Chapter 19
K_{tr}	= transverse reinforcement index, see 12.8.2.3 , Chapter 12
ℓ	= span length of beam or one-way slab; as defined in 8.7 ; clear projection of cantilever, in., see 8.9 and 9.5 , Chapters 8 and 9
ℓ_a	= additional embedment length beyond centerline of support or point of inflection, in., Chapter 12
ℓ_c	= length of compression member in a frame, measured center-to-center of the joints in the frame, in., Chapters 10, 15
ℓ_d	= development length in tension of deformed bar, deformed wire, plain and deformed welded-wire reinforcement, or pretensioned strand, in., Chapters 12, 13, 20
ℓ_{dc}	= development length in compression of deformed bars and deformed wire, in., Chapter 12
ℓ_{dh}	= development length in tension of deformed bar or deformed wire with a standard hook, measured from critical section to outside end of hook (straight embedment length between critical section and start of hook [point of tangency] plus inside radius of bend and one bar diameter), in., Chapters 12, 13
ℓ_{dt}	= development length in tension of headed deformed bar, measured from the critical section to the bearing face of the head, in. Chapter 12
ℓ_e	= load-bearing length of anchor for shear, in., see E.6.2.2 , Appendix E
ℓ_n	= length of clear span measured face-to-face of supports, in., Chapters 8, 10, 11, 13, 14, 17, 19
ℓ_n	= length of clear span in long direction of two-way construction, measured face-to-face of supports in slabs without beams and face-to-face of beams or other supports in other cases, Chapter 9
ℓ_o	= length, measured from joint face along axis of structural member, over which special transverse reinforcement must be provided, in., Chapter 13
ℓ_t	= span of member under load test, taken as the shorter span for two-way slab systems, in. Span is the smaller of: (a) distance between centers of supports, and (b) clear distance between supports plus thickness h of member. Span for a cantilever shall be taken as twice the distance from face of support to cantilever end, Chapter 22
ℓ_u	= unsupported length of compression member, in., see 10.10.1.1 , Chapter 10

K_t	= torsional stiffness of torsional member; moment per unit rotation, see R14.7.5 , Chapter 14
K_{05}	= coefficient associated with the 5 percent fractile, Appendix E
ℓ_{anc}	= length along which anchorage of a tie occurs, in., Appendix B
ℓ_b	= width of bearing, in., Appendix B

CODE

COMMENTARY

ℓ_v	= length of shearhead arm from centroid of concentrated load or reaction, in., Chapter 11	
ℓ_w	= length of entire wall, or length of wall segment or wall pier considered in direction of shear force, in., Chapters 11, 13, 15	
ℓ_x	= length of prestressing steel element from jacking end to any point x , ft, see Eq. (19-1) and (19-2) Chapter 19	
ℓ_1	= length of span in direction that moments are being determined, measured center-to-center of supports, in., Chapter 14	
ℓ_2	= length of span in direction perpendicular to ℓ_1 , measured center-to-center of supports, in., see 14.6.2.3 and 14.6.2.4 , Chapter 14	
L	= live loads, or related internal moments and forces, Chapters 8, 9, 13, 19, 22, Appendix D	
L_r	= roof live load, or related internal moments and forces, Chapter 9	
L_T	= length of rectangular tank (inside dimension) parallel to the design earthquake direction being evaluated, ft, Chapter 13	
LBA	= pounds of portland cement alkali	
		M = moment acting on anchor or anchor group, Appendix E
M_a	= maximum moment in member due to service loads at stage deflection is computed, in.-lb, Chapters 9, 15	
M_c	= factored moment amplified for the effects of member curvature used for design of compression member, in.-lb, see 10.10.6, Chapter 10	
M_{cr}	= cracking moment, in.-lb, see 9.5.2.3, Chapters 9, 15	
M_{cre}	= moment causing flexural cracking at section due to externally applied loads, in.-lb, Chapter 11	
M_m	= factored moment modified to account for effect of axial compression, in.-lb, see 11.2.2.2, Chapter 11	
M_{max}	= maximum factored moment at section due to externally applied loads, in.-lb, Chapter 11	
M_n	= nominal flexural strength at section, in.-lb, Chapters 11, 12, 13, 15, 19,	
M_{nb}	= nominal flexural strength of beam including slab where in tension, framing into joint, in.-lb, see 13.6.2.2, Chapter 13	
M_{nc}	= nominal flexural strength of column framing into joint, calculated for factored axial force, consistent with the direction of lateral forces considered, resulting in lowest flexural strength, in.-lb, see 13.6.2.2, Chapter 13	
M_o	= total factored static moment, in.-lb, Chapter 14	
M_p	= required plastic moment strength of shearhead cross section, in.-lb, Chapter 11	
M_{pr}	= probable flexural strength of members, with or without axial load, determined using the properties of the member at the joint faces assuming a tensile stress in the longitudinal bars of at least	

CODE

COMMENTARY

	1.25 f_y and a strength reduction factor ϕ of 1.0, in.-lb, Chapter 13	
M_s	= factored moment due to loads causing appreciable sway, in.-lb, Chapter 10	
M_{slab}	= portion of slab factored moment balanced by support moment, in.-lb, Chapter 13	
M_u	= factored moment at section, in.-lb, Chapters 10, 11 , 13 , 14 , 15 ,	
M_{ua}	= moment at midheight of wall due to factored lateral and eccentric vertical loads, not including $P\Delta$ effects, in.-lb, Chapter 15	
M_v	= moment resistance contributed by shearhead reinforcement, in.-lb, Chapter 11	
M_1	= smaller factored end moment on a compression member, to be taken as positive if member is bent in single curvature, and negative if bent in double curvature, in.-lb, Chapter 10	
M_{1ns}	= factored end moment on a compression member at the end at which M_1 acts, due to loads that cause no appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb, Chapter 10	
M_{1s}	= factored end moment on compression member at the end at which M_1 acts, due to loads that cause appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb, Chapter 10	
M_2	= larger factored end moment on compression member. If transverse loading occurs between supports, M_2 is taken as the largest moment occurring in member. Value of M_2 is always positive, in.-lb, Chapter 10	
$M_{2,min}$	= minimum value of M_2 , in.-lb, Chapter 10	
M_{2ns}	= factored end moment on compression member at the end at which M_2 acts, due to loads that cause no appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb, Chapter 10	
M_{2s}	= factored end moment on compression member at the end at which M_2 acts, due to loads that cause appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb, Chapter 10	
n	= number of items, such as strength tests, bars, wires, monostrand anchorage devices, anchors, or shearhead arms, Chapters 5 , 11 , 12 , 19 , Appendix E	
		N = tension force acting on anchor or anchor group, Appendix E
N_a	= nominal bond strength in tension of a single adhesive anchor, lb, see E.5.5.1 , Appendix E	
N_{ag}	= nominal bond strength in tension of a group of adhesive anchors, lb, see E.5.5.1 , Appendix E	
N_b	= basic concrete breakout strength in tension of a single anchor in cracked concrete, lb, see E.5.2.2 , Appendix E	
N_{ba}	= basic bond strength in tension of a single adhesive anchor, lb, see E.5.5.2 , Appendix E	

CODE

COMMENTARY

N_c	= resultant tensile force acting on the portion of the concrete cross section that is subjected to tensile stresses due to the combined effects of service loads and effective prestress, lb, Chapter 19
N_{cb}	= nominal concrete breakout strength in tension of a single anchor, lb, see E.5.2.1 , Appendix E
N_{cbg}	= nominal concrete breakout strength in tension of a group of anchors, lb, see E.5.2.1 , Appendix E
N_n	= nominal strength in tension, lb, Appendix E
N_p	= pullout strength in tension of a single anchor in cracked concrete, lb, see E.5.3.4 and E.5.3.5 , Appendix E
N_{pn}	= nominal pullout strength in tension of a single anchor, lb, see E.5.3.1 , Appendix E
N_{sa}	= nominal strength of a single anchor or individual anchor in a group of anchors in tension as governed by the steel strength, lb, see E.5.1.1 and E.5.1.2 , Appendix E
N_{sb}	= side-face blowout strength of a single anchor, lb, Appendix E
N_{sbg}	= side-face blowout strength of a group of anchors, lb, Appendix E
N_u	= factored axial force normal to cross section occurring simultaneously with V_u or T_u ; to be taken as positive for compression and negative for tension, lb, Chapter 11
N_{ua}	= factored tensile force applied to anchor or individual anchor in a group of anchors, lb, Appendix E
$N_{ua,g}$	= total factored tensile force applied to anchor group, lb, Appendix E
$N_{ua,i}$	= factored tensile force applied to most highly stressed anchor in a group of anchors, lb, Appendix E
$N_{ua,s}$	= factored sustained tension load, lb, see E.3.5 , Appendix E
N_{uc}	= factored horizontal tensile force applied at top of bracket or corbel acting simultaneously with V_u , to be taken as positive for tension, lb, Chapter 11
P_b	= nominal axial strength at balanced strain conditions, lb, see Appendixes B, C
P_c	= critical buckling load, lb, see 10.10.6 , Chapter 10
P_n	= nominal axial load strength of cross section, lb, Chapters 9, 10, 15
$P_{n,max}$	= maximum allowable value of P_n , lb, see 10.3.6 , Chapter 10
P_o	= nominal axial strength at zero eccentricity, lb, Chapter 10
P_{pu}	= factored prestressing force at anchorage device, lb, Chapter 19
P_{px}	= prestressing force evaluated at distance ℓ_{px} from the jacking end, lb, Chapter 19

CODE

COMMENTARY

P_s	=	unfactored axial load at the design (midheight) section including effects of self-weight, lb, Chapter 15	
P_s	=	prestressing force at jacking end, lb, Chapter 19	
P_u	=	factored axial force at given eccentricity; to be taken as positive for compression and negative for tension, lb, $\leq \phi P_n$, Chapters 10 , 13 , 15 ,	
P_x	=	prestressing force at any point x , lb, Chapter 19	
p_{cp}	=	outside perimeter of concrete cross section, in., see 11.5.1 , Chapter 11	
p_h	=	perimeter of centerline of outermost closed transverse torsional reinforcement, in., Chapter 11	
q_{Du}	=	factored dead load per unit area, Chapter 14	
q_{Lu}	=	factored live load per unit area, Chapter 14	
q_u	=	factored load per unit area, Chapter 14	
Q	=	stability index for a story, see 10.10.5 , Chapter 10	
r	=	radius of gyration of cross section of a compression member, in., Chapter 10	
R	=	rain load, or related internal moments and forces, Chapter 9	R = reaction, lb, Appendix B
R	=	numerical coefficient representing the combined effect of the structure's ductility, energy-dissipating capacity, and structural redundancy, Chapter 13	
s	=	center-to-center spacing of items, such as longitudinal reinforcement, transverse reinforcement, prestressing tendons, wires, or anchors, in., Chapters 10 to 13 , 18 to 20 , 22 , Appendix E	
s_i	=	center-to-center spacing of reinforcement in the i -th layer adjacent to the surface of the member, in., Appendix B	
s_o	=	center-to-center spacing of transverse reinforcement within the length ℓ_o , in., Chapter 13	
s_s	=	sample standard deviation, psi, Chapter 5 , Appendix E	
s_{sk}	=	spacing of skin reinforcement, in., Chapter 10	
s_{sg}	=	sample standard deviation for shotcrete, psi, Chapter 5	s_{sg} = sample standard deviation for shotcrete, psi
s_2	=	center-to-center spacing of longitudinal shear or torsion reinforcement, in., Chapter 11	
S	=	snow load, or related internal moments and forces, Chapters 9 , 13	
S_d	=	environmental durability factor, see 9.2.6 , Chapter 9 , 11 , 13	
S_e	=	moment, shear, or axial force at connection corresponding to development of probable strength at intended yield locations, based on the governing mechanism of inelastic lateral deformation, considering both gravity and earthquake effects, Chapter 13	
S_n	=	nominal flexural, shear, or axial strength of connection, Chapter 13	
S_y	=	yield strength of connection, based on f_y , for moment, shear, or axial force, Chapter 13	
t	=	wall thickness of hollow section, in., Chapter 11	

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T = cumulative effect of temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete, [Chapter 9](#), [Appendix D](#)

T_{hoop} = service level hoop tension force in the concrete section under consideration, lb, [Chapter 9](#)

T_n = nominal torsional moment strength, in.-lb, [Chapter 11](#)

T_u = factored torsional moment at section, in.-lb, [Chapter 11](#)

U = required strength to resist factored loads or related internal moments and forces, [Chapter 9](#), [13](#), [Appendix D](#)

v_n = nominal shear stress, psi, see [11.11.7.2](#), [Chapters 11](#), [13](#)

T = tension force acting on a nodal zone, lb, [Appendix A](#)

V = shear force acting on anchor or anchor group, [Appendix E](#)

$V_{\parallel}$ = applied shear parallel to the edge, lb, [Appendix E](#)

$V_{\perp}$ = applied shear perpendicular to the edge, lb, [Appendix E](#)

V_b = basic concrete breakout strength in shear of a single anchor in cracked concrete, lb, see [E.6.2.2](#) and [E.6.2.3](#), [Appendix E](#)

V_c = nominal shear strength provided by concrete, lb, [Chapters 8](#), [9](#), [11](#), [13](#), [14](#),

V_{cb} = nominal concrete breakout strength in shear of a single anchor, lb, see [E.6.2.1](#), [Appendix E](#)

V_{cbg} = nominal concrete breakout strength in shear of a group of anchors, lb, see [E.6.2.1](#), [Appendix E](#)

V_{ci} = nominal shear strength provided by concrete when diagonal cracking results from combined shear and moment, lb, [Chapter 11](#)

V_{cp} = nominal concrete pryout strength of a single anchor, lb, see [E.6.3.1](#), [Appendix E](#)

V_{cpg} = nominal concrete pryout strength of a group of anchors, lb, see [E.6.3.1](#), [Appendix E](#)

V_{cw} = nominal shear strength provided by concrete when diagonal cracking results from high principal tensile stress in web, lb, [Chapter 11](#)

V_d = shear force at section due to unfactored dead load, lb, [Chapter 11](#)

V_e = design shear force for load combinations including earthquake effects, lb, see [13.5.4.1](#) and [13.6.5.1](#), [Chapter 13](#)

V_i = factored shear force at section due to externally applied loads occurring simultaneously with M_{max} , lb, [Chapter 11](#)

V_n = nominal shear strength, lb, [Chapters 8](#), [10](#) to [13](#), [Appendix E](#)

V_{nh} = nominal horizontal shear strength, lb, [Chapter 18](#)

V_p = vertical component of effective prestress force at section, lb, [Chapter 11](#)

V_s = nominal shear strength provided by shear reinforcement, lb, [Chapters 9](#), [11](#)

V_{sa} = nominal shear strength of a single anchor or individual anchor in a group of anchors as governed

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	by the steel strength, lb, see E.6.1.1 and E.6.1.2, Appendix E		
V_u	= factored shear force at section, lb, Chapters 9, 11-14, 17,		
V_u	= factored horizontal shear in a story, lb, Chapter 10		
V_{ua}	= factored shear force applied to a single anchor or group of anchors, lb, Appendix E		
$V_{ua,g}$	= total factored shear force applied to anchor group, lb, Appendix E		
$V_{ua,i}$	= factored shear force applied to most highly stressed anchor in a group of anchors, lb, Appendix E		
V_{ug}	= factored shear force on the slab critical section for two-way action due to gravity loads, lb, see 13.13.6 Chapter 13		
V_{us}	= factored horizontal shear in a story, lb, Chapter 10		
w_c	= density (unit weight) of normalweight concrete or equilibrium density of lightweight concrete, lb/ft ³ , Chapters 8, 9		
		w_s	= width of a strut perpendicular to the axis of the strut, in., Appendix B
		w_t	= effective height of concrete concentric with a tie, used to dimension nodal zone, in., Appendix B
		$w_{t,max}$	= maximum effective height of concrete concentric with a tie, in., Appendix A
w_u	= factored load per unit length of beam or one-way slab, Chapter 8		
W	= wind load, or related internal moments and forces, Chapter 9, Appendix D		
		W_a	= service-level wind load, refer to R15.8.4
x	= shorter overall dimension of rectangular part of cross section, in., Chapter 14		
y	= longer overall dimension of rectangular part of cross section, in., Chapter 14		
y_t	= distance from centroidal axis of gross section, neglecting reinforcement, to extreme fiber in tension face, in., Chapters 9, 11		
α	= angle defining the orientation of reinforcement, Chapters 11, 13, Appendix B		
α_c	= coefficient defining the relative contribution of concrete strength to nominal wall shear strength, see 13.9.4.1, Chapter 13		
α_f	= ratio of flexural stiffness of beam section to flexural stiffness of a width of slab bounded laterally by centerlines of adjacent panels (if any) on each side of the beam, see 14.6.1.6, Chapters 9, 14		
α_{fm}	= average value of α_f for all beams on edges of a panel, Chapter 9		
α_{f1}	= α_f in direction of ℓ_1 , Chapter 14		
α_{f2}	= α_f in direction of ℓ_2 , Chapter 14		
α_i	= angle between the axis of a strut and the bars in the i -th layer of reinforcement crossing that strut, Appendix B		

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α_{px}	= total angular change of prestressing tendon profile in radians from tendon jacking end to any point x , Chapter 19
α_s	= constant used to compute V_c in slabs and footings, Chapter 11
α_v	= ratio of flexural stiffness of shearhead arm to that of the surrounding composite slab section, see 11.11.4.5 , Chapter 11
β	= ratio of long to short dimensions: clear spans for two-way slabs, see 9.5.3.3 ; sides of column, concentrated load or reaction area, see 11.11.2.1 ; or sides of a footing, see 16.4.4.2 , Chapters 9 , 11 , 16
β	= ratio of distances to the neutral axis from the extreme tension fiber and from the centroid of the main reinforcement, Chapter 10
β_b	= ratio of area of reinforcement cut off to total area of tension reinforcement at section, Chapter 12
β_d	= (a) for nonsway frames, β_d is the ratio of the maximum factored axial dead load to the total factored axial load; (b) for sway frames, except as required in (c), β_d is the ratio of the maximum factored sustained shear within a story to the total factored shear in that story; and (c) for stability checks of sway frames carried out in accordance with 10.13.6 , β_d is the ratio of the maximum factored sustained axial load to the total factored axial load, Chapter 10
β_{dns}	= ratio used to account for reduction of stiffness of columns due to sustained axial loads, see 10.10.6.2 , Chapter 10
β_{ds}	= ratio used to account for reduction of stiffness of columns due to sustained lateral loads, see 10.10.4.2 , Chapter 10
β_n	= factor to account for the effect of the anchorage of ties on the effective compressive strength of a nodal zone, Appendix B
β_p	= factor used to compute V_c in prestressed slabs, Chapter 11
β_s	= factor to account for the effect of cracking and confining reinforcement on the effective compressive strength of the concrete in a strut, Appendix B
β_t	= ratio of torsional stiffness of edge beam section to flexural stiffness of a width of slab equal to span length of beam, center-to-center of supports, see 14.6.4.2 , Chapter 14
β_1	= factor relating depth of equivalent rectangular compressive stress block to neutral axis depth, see 10.2.7.3 , Chapters 10 , 19 , Appendix C
γ_f	= factor used to determine the unbalanced moment transferred by flexure at slab-column connections, see 14.5.3.2 , Chapters 11 , 13 , 14
γ_p	= factor for type of prestressing steel, see 19.7.2 , Chapter 19

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γ_s	= factor used to determine the portion of reinforcement located in center band of footing, see 16.4.4.2, Chapter 16	
γ_v	= factor used to determine the unbalanced moment transferred by eccentricity of shear at slab-column connections, see 11.11.7.1, Chapter 11	
δ	= moment magnification factor to reflect effects of member curvature between ends of compression member, Chapter 10	
δ_{ns}	= moment magnification factor for frames braced against sidesway, to reflect effects of member curvature between ends of compression member, Chapter 10	
δ_s	= moment magnification factor for frames not braced against sidesway, to reflect lateral drift resulting from lateral and gravity loads, Chapter 10	
δ_u	= design displacement, in., Chapter 13	
Δ_{cr}	= computed, out-of-plane deflection at midheight of wall corresponding to cracking moment M_{cr} , in., Chapter 15	
Δ_n	= computed, out-of-plane deflection at midheight of wall corresponding to nominal flexural strength M_n , in., Chapter 15	
Δ_o	= relative lateral deflection between the top and bottom of a story due to lateral forces computed using a first-order elastic frame analysis and stiffness values satisfying 10.11.1, in., Chapter 10	
Δ_r	= difference between initial and final (after load removal) deflections for load test or repeat load test, in., Chapter 22	
Δ_s	= computed, out-of-plane deflection at midheight of wall due to service loads, in., Chapter 15	
Δ_u	= computed deflection at midheight of wall due to factored loads, in., Chapter 15	
Δ_1	= measured maximum deflection during first load test, in., see 22.5.2, Chapter 22	
Δ_2	= maximum deflection measured during second load test relative to the position of the structure at the beginning of second load test, in., see 22.5.2, Chapter 22	
Δf_p	= increase in stress in prestressing steel due to factored loads, psi, Appendix B	
Δf_{ps}	= stress in prestressing steel at service loads less decompression stress, psi, Chapter 19	
Δf_{pt}	= f_{ps} at the section of maximum moment minus the stress in the prestressing steel due to prestressing and factored bending moments at the section under consideration, psi, see R11.5.3.10, Chapter 11	Δf_{pt} = f_{ps} at the section of maximum moment minus the stress in the prestressing steel due to prestressing and factored bending moments at the section under consideration, psi, refer to R11.5.3.10, Chapter 11
ϵ_t	= net tensile strain in extreme layer of longitudinal tension reinforcement at nominal strength, excluding strains due to effective prestress,	ϵ_{cu} = maximum usable strain at extreme concrete compression fiber, Fig. R10.3.3

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	creep, shrinkage, and temperature, Chapters 8 to 11, Appendix D	
θ	= angle between axis of strut, compression diagonal, or compression field and the tension chord of the member, Chapter 11, Appendix B	
λ	= modification factor reflecting the reduced mechanical properties of lightweight concrete, all relative to normalweight concrete of the same compressive strength, see 8.6.1, 11.6.4.3, 11.2.1, 12.5.2, 12.8.2.4(d), E.3.6, Chapters 9, 11 to 13, 19, 20, and Appendixes B, E	
λ_a	= modification factor reflecting the reduced mechanical properties of lightweight concrete in certain concrete anchorage applications, see E.3.6, Appendix E	
λ_Δ	= multiplier for additional long-term deflection due to long-term effects, see 9.5.2.5, Chapter 9	
μ	= coefficient of friction, see 11.6.4.3, Chapters 11, 13	
μ	= curvature friction coefficient, Chapter 19	
ξ	= time-dependent factor for sustained load, see 9.5.2.5, Chapter 9	
ρ	= ratio of nonprestressed tension reinforcement, A_s/bd , Chapters 9 to 11, 13, 14, 19, Appendix C	
ρ'	= reinforcement ratio for nonprestressed compression reinforcement, A_s'/bd of A_s' to bd , Chapter 9, 19, Appendix C	
ρ_b	= reinforcement ratio of A_s to bd producing balanced strain conditions, see 10.3.2, Chapters 9 and 10, Appendix C	
ρ_ℓ	= ratio of area of distributed longitudinal reinforcement to gross concrete area perpendicular to that reinforcement, Chapters 11, 13, 15	
ρ_p	= ratio of A_{ps} to bd_p , Chapter 19	
ρ_s	= ratio of volume of spiral reinforcement to total volume of core confined by the spiral (measured out-to-out of spirals), Chapters 10, 13	
ρ_t	= ratio of area of distributed transverse reinforcement to gross concrete area perpendicular to that reinforcement, Chapters 11, 13, 15	
ρ_v	= ratio of tie reinforcement area to area of contact surface, see 18.5.3.3, Chapter 18	
ρ_w	= ratio of A_s to $b_w d$, Chapter 11	
ϕ	= strength reduction factor, see 9.3, Chapters 8 to 11, 13 to 14, 16 to 20, Appendixes B to E	
ϕ_K	= stiffness reduction factor, see R10.12.3, Chapter 10	ϕ_K = stiffness reduction factor, refer to R10.10, Chapter 10
τ_{cr}	= characteristic bond stress of adhesive anchor in cracked concrete, psi, see E.5.5.2, Appendix E	
τ_{uncr}	= characteristic bond stress of adhesive anchor in uncracked concrete, psi, see E.5.5.2, Appendix E	
$\Psi_{c,N}$	= factor used to modify tensile strength of anchors based on presence or absence of cracks in concrete, see E.5.2.6, Appendix E	

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- $\Psi_{cp,N}$ = factor used to modify tensile strength of post-installed anchors intended for use in uncracked concrete without supplementary reinforcement to account for the splitting tensile stresses due to installation, see E.5.2.7, Appendix E
- $\Psi_{cp,Na}$ = factor used to modify tensile strength of adhesive anchors intended for use in uncracked concrete without supplementary reinforcement to account for the splitting tensile stresses due to installation, see E.5.5.5, Appendix E
- $\Psi_{c,P}$ = factor used to modify pullout strength of anchors based on presence or absence of cracks in concrete, see E.5.3.6, Appendix E
- $\Psi_{c,V}$ = factor used to modify shear strength of anchors based on presence or absence of cracks in concrete and presence or absence of supplementary reinforcement, see E.6.2.7 for anchors in shear, Appendix E
- Ψ_e = factor used to modify development length based on reinforcement coating, see 12.8.2.4, Chapter 12
- $\Psi_{ec,N}$ = factor used to modify tensile strength of anchors based on eccentricity of applied loads, see E.5.2.4, Appendix E
- $\Psi_{ec,Na}$ = factor used to modify tensile strength of adhesive anchors based on eccentricity of applied loads, see E.5.5.3, Appendix E
- $\Psi_{ec,V}$ = factor used to modify shear strength of anchors based on eccentricity of applied loads, see E.6.2.5, Appendix E
- $\Psi_{ed,N}$ = factor used to modify tensile strength of anchors based on proximity to edges of concrete member, see E.5.2.5, Appendix E
- $\Psi_{ed,Na}$ = factor used to modify tensile strength of adhesive anchors based on proximity to edges of concrete member, see E.5.5.4, Appendix E
- $\Psi_{ed,V}$ = factor used to modify shear strength of anchors based on proximity to edges of concrete member, see E.6.2.6, Appendix E
- $\Psi_{h,V}$ = factor used to modify shear strength of anchors located in concrete members with $h_a < 1.5c_{a1}$, see E.6.2.8, Appendix E
- Ψ_s = factor used to modify development length based on reinforcement size, see 12.8.2.4, Chapter 12
- Ψ_t = factor used to modify development length based on reinforcement location, see 12.8.2.4, Chapter 12
- Ψ_w = factor used to modify development length for welded deformed wire reinforcement in tension, see 12.8.7, Chapter 12
- ω = tension reinforcement index, see 19.7.2, Chapter 19, Appendix C
- ω' = compression reinforcement index, see 19.7.2, Chapter 19, Appendix C
- ω_p = prestressing steel index, see 19.8.1, Appendix C
- ω_w, ω_{pw}

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- ω_w' = reinforcement indexes for flanged sections computed as for ω , ω_p , and ω' except that b shall be the web width, and reinforcement area shall be that required to develop compressive strength of web only, see 19.8.1, Chapter 19, Appendix C
- Ω_o = amplification factor to account for overstrength of the seismic-force-resisting system determined in accordance with the legally adopted general building code, Chapter 13, Appendix E

2.2—Definitions

The following terms are defined for general use in this Code. Specialized definitions appear in individual chapters.

admixture—material other than water, aggregate, or hydraulic cement, used as an ingredient of concrete and added to concrete before or during its mixing to modify its properties.

aggregate—granular material, such as sand, gravel, crushed stone, and iron blast-furnace slag, used with a cementing medium to form a hydraulic cement concrete or mortar.

aggregate, lightweight—aggregate meeting the requirements of ASTM C330 and having a loose bulk density of 70 lb/ft³ or less, determined in accordance with ASTM C29.

anchorage device—in post-tensioning, the hardware used for transferring a post-tensioning force from the prestressing steel to the concrete.

anchorage zone—in post-tensioned members, the portion of the member through which the concentrated prestressing force is transferred to the concrete and distributed more uniformly across the section. Its extent is equal to the largest dimension of the cross section. For anchorage devices located away from the end of a member, the anchorage zone includes the disturbed regions ahead of and behind the anchorage devices.

backer rod—a compressible rod placed between joint filler and sealant and used to provide support for and to control the depth of sealant.

base of structure—level at which the horizontal earthquake ground motions are assumed to be imparted to an environmental engineering concrete structure. This level does not necessarily coincide with the ground level. Refer to Chapter 13.

basic monostrand anchorage device—anchorage device used with any single strand or a single 5/8 in. or smaller diameter bar that satisfies 19.21.1 and the anchorage device requirements of ACI 423.7.

basic multistrand anchorage device—anchorage device used with multiple strands, bars, or wires, or with single bars

R2.2—Definitions

For consistent application of the Code, it is necessary that terms be defined where they have specific meanings in the Code. The definitions given are for use in application of this Code only and do not always correspond to ordinary usage. A glossary of most-used terms relating to cement manufacturing, concrete design and construction, and research in concrete is contained in “Concrete Terminology” available on the ACI website.

anchorage device—Most anchorage devices for post-tensioning are standard manufactured devices available from commercial sources. In some cases, “special” details or assemblages are developed that combine various wedges and wedge plates for anchoring prestressing steel. These informal designations as standard anchorage devices or special anchorage devices have no direct relation to the Code and AASHTO “Standard Specifications for Highway Bridges” classification of anchorage devices as Basic Anchorage Devices or Special Anchorage Devices.

anchorage zone—The terminology “ahead of” and “behind” the anchorage device is illustrated in Fig. R18.13.1(b).

basic anchorage devices—Devices that are so proportioned that they can be checked analytically for compliance with bearing stress and stiffness requirements without having to undergo the acceptance-testing program required of special anchorage devices.

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larger than 5/8 in. diameter, that satisfies 19.21.1 and the bearing stress and minimum plate stiffness requirements of AASHTO Bridge Specifications, Division I, Articles 9.21.7.2 and 9.21.7.3 of Division I and Article 10.3.2.3 of Division II of AASHTO “Standard Specification for Highway Bridges” (AASHTO 2002).

bonded tendon—tendon in which prestressing steel is bonded to concrete either directly or through grouting.

boundary element—portion along structural wall and structural diaphragm edge strengthened by longitudinal and transverse reinforcement. Boundary elements do not necessarily require an increase in the thickness of the wall or diaphragm. Edges of openings within walls and diaphragms shall be provided with boundary elements as required by 13.9.6. Refer to Chapter 13.

building official—the officer or other designated authority charged with the administration and enforcement of this Code, or a duly authorized representative.

cementitious materials—materials as specified in Chapter 3, which have cementing value when used in concrete either by themselves, such as portland cement, blended hydraulic cements, and expansive cement, or such materials in combination with fly ash, other raw or calcined natural pozzolans, silica fume, and/or slag cement.

chemical attack of concrete—deterioration of the concrete matrix due to exposure to aggressive chemicals.

collector element—element that acts in axial tension or compression to transmit earthquake-induced forces between a structural diaphragm and a vertical element of the seismic-force-resisting system. Refer to Chapter 13.

column—member with a ratio of height-to-least lateral dimension exceeding 3 used primarily to support axial compressive load. For a tapered member, the least lateral dimension is the average of the top and bottom dimensions of the smaller side.

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building official—The term used by many general building codes to identify the person charged with administration and enforcement of provisions of the building code. Such terms as building commissioner or building inspector are variations of the title and the term “building official” as used in this Code, is intended to include those variations, as well as others that are used in the same sense.

column—The term “compression member” is used in the Code to define any member in which the primary stress is longitudinal compression. Such a member need not be vertical but may have any orientation in space. Bearing walls, columns, pedestals, and wall piers qualify as compression members under this definition.

The differentiation between columns and walls in the Code is based on the principal use rather than on arbitrary relationships of height and cross-sectional dimensions. The Code, however, permits walls to be designed using the principles stated for column design (refer to 14.4), as well as by the empirical method (refer to 14.5).

While a wall always encloses or separates spaces, it may also be used to resist horizontal or vertical forces or bending. For example, a retaining wall or a basement wall also supports various combinations of loads.

A column is normally used as a main vertical member carrying axial loads combined with bending and shear. It may, however, form a small part of an enclosure or separation.

In the ACI 318-08, the definitions for column and pedestal were revised to provide consistency between the two terms.

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composite concrete flexural members—concrete flexural members of precast or cast-in-place concrete elements, or both, constructed in separate placements but so interconnected that all elements respond to loads as a unit.

compression-controlled section—a cross section in which the net tensile strain in the extreme tension steel at nominal strength is less than or equal to the compression-controlled strain limit.

compression-controlled strain limit—the net tensile strain at balanced strain conditions. Refer to 10.3.3.

concrete—mixture of portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without admixtures.

concrete, all-lightweight—lightweight concrete containing only lightweight coarse and fine aggregates that conform to ASTM C330.

concrete, lightweight—concrete containing lightweight aggregate and an equilibrium density, as determined by ASTM C567, between 90 and 115 lb/ft³.

concrete, normalweight—concrete containing only aggregate that conforms to ASTM C33.

concrete, sand-lightweight—lightweight concrete containing only normalweight fine aggregate that conforms to ASTM C33 and only lightweight aggregate that conforms to ASTM C330.

concrete, specified compressive strength of, (f'_c)—compressive strength of concrete used in design and evaluated in accordance with provisions of Chapter 5, expressed in pounds per square inch (psi). Whenever the quantity f'_c is under a radical sign, square root of numerical value only is intended, and result has units of pounds per square inch (psi).

connection—a region that joins two or more members. In Chapter 13, a connection also refers to a region that joins members of which one or more is precast, for which the following more specific definitions apply:

ductile connection—connection that experiences yielding as a result of the earthquake design displacements.

strong connection—connection that remains elastic while adjoining members experience yielding as a result of the earthquake design displacements.

concrete, lightweight—In 2000, ASTM C567 adopted “equilibrium density” as the measure for determining compliance with specified in-service density requirements. According to ASTM C567, equilibrium density may be determined by measurement or approximated by calculation using either the measured oven-dry density or the oven-dry density calculated from the mixture proportions. Unless specified otherwise, ASTM C567 requires that equilibrium density be approximated by calculation.

By Code definition, sand-lightweight concrete is structural lightweight concrete with all the fine aggregate replaced by sand. This definition may not be in agreement with usage by some material suppliers or contractors where the majority, but not all, of the lightweight fines are replaced by sand. For proper application of the Code provisions, the replacement limits should be stated, with interpolation when partial sand replacement is used.

concrete, normalweight—Normalweight concrete typically has a density (unit weight) between 135 and 160 lb/ft³, and is normally taken as 145 to 150 lb/ft³.

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construction joint—an intentionally created interface between concrete placements. Refer to [Chapter 7](#).

contract documents—documents, including the project drawings and project specifications, covering the required work.

contraction joint—formed, sawed, or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure. Refer to [Chapter 7](#).

convective pressure—the hydrodynamic pressure on a liquid-containing structure during an earthquake, due to the upper (sloshing) portion of its contents. Refer to [Chapter 13](#).

cover, specified concrete—the distance between the outermost surface of embedded reinforcement and the closest outer surface of the concrete indicated in contract documents.

crosstie—a continuous reinforcing bar having a seismic hook at one end and a hook not less than 90 degrees with at least a six-diameter extension at the other end. The hooks shall engage peripheral longitudinal bars. The 90-degree hooks of two successive crossties engaging the same longitudinal bars shall be alternated end for end. Refer to [Chapter 13](#).

curvature friction—friction resulting from bends or curves in the specified prestressing tendon profile.

deformed reinforcement—deformed reinforcing bars, bar mats, deformed wire, and welded wire reinforcement conforming to [3.5.3](#).

design displacement—total lateral displacement expected for the design-basis earthquake, as required by the governing code for earthquake-resistant design. Refer to [Chapter 13](#).

design load combination—combination of factored loads and forces in [9.2](#).

design story drift ratio—relative difference of design displacement between the top and bottom of a story, divided by the story height. Refer to [Chapter 13](#).

development length—length of embedded reinforcement, including pretensioned strand, required to develop the design strength of reinforcement at a critical section. Refer to [9.3.3](#) and [12.8.2](#).

drop panel—a projection below the slab used to reduce the amount of negative reinforcement over a column or the

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cover, specified concrete—Tolerances on specified concrete cover are provided in [7.5.2.1](#).

deformed reinforcement—Deformed reinforcement is defined as that meeting the deformed reinforcement specifications of [3.5.3.1](#), or the specifications of [3.5.3.3](#), [3.5.3.4](#), [3.5.3.5](#), [3.5.3.6](#), or [3.5.3.7](#). No other reinforcement qualifies. This definition permits accurate statement of anchorage lengths. Bars or wire not meeting the deformation requirements or welded wire reinforcement not meeting the spacing requirements are “plain reinforcement,” for Code purposes, and may be used only for spirals.

design displacement—The design displacement is an index of the maximum lateral displacement expected in design for the design-basis earthquake. In documents such as ASCE/SEI 7 and the International Building Code, the design displacement is calculated using static or dynamic linear elastic analysis under code-specified actions considering effects of cracked sections, effects of torsion, effects of vertical forces acting through lateral displacements, and modification factors to account for expected inelastic response. The design displacement generally is larger than the displacement calculated from design-level forces applied to a linear-elastic model of the building.

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minimum required slab thickness, and to increase the slab shear strength. Refer to 14.2.5 and 14.3.7.

duct—a conduit (plain or corrugated) to accommodate prestressing steel for post-tensioned installation. Requirements for post-tensioning ducts are given in 19.17.

effective depth of section (d)—distance measured from extreme compression fiber to centroid of longitudinal tension reinforcement.

effective prestress—stress remaining in prestressing steel after all losses have occurred.

embedment length—length of embedded reinforcement provided beyond a critical section.

environmental durability factor—factor used to control reinforcement stresses and crack widths in members designed using the strength design approach.

equilibrium density—density of lightweight concrete after exposure to a relative humidity of 50 ± 5 percent and a temperature of $73.5 \pm 3.5^\circ\text{F}$ for a period of time sufficient to reach constant density (refer to ASTM C567).

extreme tension steel—the reinforcement (prestressed or nonprestressed) that is the farthest from the extreme compression fiber.

hacking force—in prestressed concrete, temporary force exerted by device that introduces tension into prestressing steel.

headed deformed bars—deformed reinforcing bars with heads that satisfy 3.5.8 attached at one or both ends.

headed shear stud reinforcement—reinforcement consisting of individual headed studs, or groups of studs, with anchorage provided by a head at each end or by a common base rail consisting of a steel plate or shape.

hoop—a closed tie or continuously wound tie. A closed tie can be made up of several reinforcement elements each having seismic hooks at both ends. A continuously wound tie shall have a seismic hook at both ends. Refer to Chapter 13.

impulsive pressures—the hydrodynamic pressure on a liquid-containing structure during an earthquake, due to the lower portion of its contents. Refer to Chapter 13.

isolation joint—a separation between adjoining parts of a concrete structure, usually a vertical plane, at a designed location such as to interfere least with performance of the structure, yet such to allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete and through which all or part of the bonded reinforcement is interrupted.

headed deformed bars—The bearing area of a headed deformed bar is, for the most part, perpendicular to the bar axis. In contrast, the bearing area of the head of headed stud reinforcement is a nonplanar spatial surface of revolution, as shown in Fig. R3.5.5. The two types of reinforcement differ in other ways. The shanks of headed studs are smooth, not deformed as with headed deformed bars. The minimum net bearing area of the head of a headed deformed bar is permitted to be as small as four times the bar area. In contrast, the minimum stud head area is not specified in terms of the bearing area, but by the total head area which must be at least ten times the area of the shank.

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joint—portion of structure common to intersecting members. The effective cross-sectional area of a joint of a special moment frame, A_j , for shear strength computations is defined in 13.7.4.1. Refer to Chapters 7 and 13.

joint filler—a compressible, preformed material used to fill an expansion joint to prevent the infiltration of debris and to provide support for backer rod and sealants.

joint sealant—a synthetic elastomeric material used to finish a joint and to exclude solid foreign materials.

lateral-force-resisting system—that portion of the structure composed of members proportioned to resist forces related to wind and earthquake effects. Refer to Chapter 13.

licensed design professional—an individual who is licensed to practice structural design as defined by the statutory requirements of the professional licensing laws of the state or jurisdiction in which the project is to be constructed and who is in responsible charge of the structural design; in other documents, also referred to as registered design professional.

lightweight-aggregate concrete—all-lightweight or sand-lightweight aggregate concrete made with lightweight aggregates conforming to 3.3. Refer to Chapter 13.

liquid-containing structure—a primary or secondary containment structure that is designed to contain liquids of fluidized materials and gases. The structure may have any shape in plan and may incorporate various floor or roof designs. Refer to Chapter 13.

load, dead—dead weight supported by a member, as defined by general building code of which this Code forms a part (without load factors).

load, factored—load, multiplied by appropriate load factors, used to proportion members by the strength design method of this Code. Refer to 8.1.1 and 9.2.

load, live—live load specified by general building code of which this Code forms a part (without load factors).

load, service—load specified by general building code of which this Code forms a part (without load factors).

modulus of elasticity—ratio of normal stress to corresponding strain for tensile or compressive stresses below proportional limit of material. Refer to 8.5.

moment frame—frame in which members and joints resist forces through flexure, shear, and axial force. Moment frames designated as part of the seismic-force-resisting system shall be categorized as follows:

ordinary moment frame—a cast-in-place or precast concrete frame complying with the requirements of

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loads—Numerous definitions for loads are given, as the Code contains requirements that are to be met at various load levels. The terms “dead load” and “live load” refer to the unfactored loads (service loads) specified or defined by the general building code. Service loads (loads without load factors) are to be used where specified in the Code to proportion or investigate members for adequate serviceability, as in 9.5, “Control of deflections.” Loads used to proportion a member for adequate strength are defined as factored loads. Factored loads are service loads multiplied by the appropriate load factors specified in 9.2 for required strength. The term “design loads,” as used in the 1971 ACI 318 Code edition to refer to loads multiplied by the appropriate load factors, was discontinued in the 1977 ACI 318 Code to avoid confusion with the design load terminology used in general building codes to denote service loads, or posted loads in buildings. The factored load terminology, first adopted in the 1977 Code, clarifies when the load factors are applied to a particular load, moment, or shear value as used in the Code provisions.

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Chapters 1 through 12 and 17 through 19 and, in the case of ordinary moment frames assigned to Seismic Design Category B, also complying with 13.2.

intermediate moment frame—a cast-in-place frame complying with the requirements of 13.3 in addition to the requirements for ordinary moment frames.

special moment frame—a cast-in-place frame complying with the requirements of 13.1.3 through 13.1.7, 13.5 through 13.7, or a precast frame complying with the requirements of 13.1.3 through 13.1.7 and 13.5 through 13.8. In addition, the requirements for ordinary moment frames shall be satisfied.

net tensile strain—tensile strain at nominal strength exclusive of strains due to effective prestress, creep, shrinkage, and temperature.

normal environmental exposure—exposure to liquids with a pH greater than 5, or exposure to sulfate solutions 1000 ppm or less.

pedestal—member with a ratio of height-to-least lateral dimension less than or equal to 3 used primarily to support axial compressive load. For a tapered member, the least lateral dimension is the average of the top and bottom dimensions of the smaller side.

permeability—the ease with which fluids, both liquids and gases, can enter into, and move through, the concrete.

plain concrete—structural concrete with no reinforcement or with less reinforcement than the minimum amount specified for reinforced concrete.

plain reinforcement—reinforcement that does not conform to definition of deformed reinforcement. Refer to 3.5.4.

plastic hinge region—length of frame element over which flexural yielding is intended to occur due to earthquake design displacements, extending not less than a distance h from the critical section where flexural yielding initiates. Refer to Chapter 13.

post-tensioning—method of prestressing in which prestressing steel is tensioned after concrete has hardened.

precast concrete—structural concrete element cast elsewhere than its final position in the structure.

precompressed tensile zone—portion of a prestressed member where flexural tension, calculated using gross section properties, would occur under unfactored dead and live loads if the prestress force was not present.

prestressed concrete—structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in concrete resulting from loads.

pedestal—In ACI 318-08, the definitions for column and pedestal were revised to provide consistency between the definitions.

plain concrete—The presence of reinforcement (nonprestressed or prestressed) does not prohibit the member from being classified as plain concrete, provided all requirements of Chapter 22 are satisfied.

prestressed concrete—Reinforced concrete is defined to include prestressed concrete. Although the behavior of a prestressed member with unbonded tendons may vary from that of members with continuously bonded tendons, bonded and unbonded prestressed concrete are combined with conventionally reinforced concrete under the generic term “reinforced concrete.” Provisions common to both prestressed and conventionally reinforced concrete are integrated to avoid overlapping and conflicting provisions.

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prestressing steel—high-strength steel element such as wire, bar, or strand, or a bundle of such elements, used to impart prestress forces to concrete.

pretensioning—method of prestressing in which prestressing steel is tensioned before concrete is placed.

reinforced concrete—structural concrete reinforced with no less than the minimum amounts of prestressing steel or nonprestressed reinforcement specified in Chapters 1 through 21 and Appendixes A through D.

reinforcement—material that conforms to 3.5.

reinforcement, structural—reinforcement provided to resist externally applied forces.

reinforcement, shrinkage and temperature—reinforcement provided to control cracking due to strains resulting from drying and thermal shrinkage and temperature gradients.

reshores—shores placed snugly under a concrete slab or other structural member after the original forms and shores have been removed from a larger area, thus requiring the new slab or structural member to deflect and support its own weight and existing construction loads applied prior to the installation of the reshores.

Seismic Design Category—a classification assigned to a structure based on its risk category and the severity of the design earthquake ground motion at the site, as defined by the legally adopted general building code.

seismic-force-resisting system—portion of the structure designed to resist earthquake design forces required by the legally adopted general building code using the applicable provisions and load combinations.

seismic hook—a hook on a stirrup, or crosstie having a bend not less than 135 degrees, except that circular hoops shall have a bend not less than 90 degrees. Hooks shall have a $6d_b$ (but not less than 3 in.) extension that engages the longitudinal reinforcement and projects into the interior of the stirrup or hoop. Refer to Chapter 13.

severe environmental exposure—exposure conditions in which the limits defining normal environmental exposure are exceeded.

shear cap—a projection below the slab used to increase the slab shear strength. Refer to 14.2.6.

sheathing—a material encasing prestressing steel to prevent bonding of the prestressing steel with the surrounding concrete, to provide corrosion protection, and to contain the corrosion inhibiting coating.

shores—vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.

span length—refer to 8.9.

special anchorage device—anchorage device that satisfies 19.15.1 and the standardized acceptance tests of AASHTO “Standard Specifications for Highway Bridges,” Division II, Article 10.3.2.3.

special boundary element—boundary element required by 13.9.6.

specified lateral forces—lateral forces corresponding to the appropriate distribution of the design base shear force

sheathing—Typically, sheathing is a continuous, seamless, high-density polyethylene material extruded directly on the coated prestressing steel.

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prescribed by the legally adopted general building code for earthquake-resistant design. Refer to Chapter 13.

spiral reinforcement—continuously wound reinforcement in the form of a cylindrical helix.

splitting tensile strength (f_{ct})—tensile strength of concrete determined in accordance with ASTM C496 as described in ASTM C330. Refer to 5.1.1.4.

steel fiber-reinforced concrete—concrete containing dispersed randomly oriented steel fibers.

stirrup—reinforcement used to resist shear and torsion stresses in a structural member; typically bars, wires, or welded wire reinforcement either single leg or bent into L, U, or rectangular shapes and located perpendicular to or at an angle to longitudinal reinforcement. (The term “stirrups” is usually applied to transverse reinforcement in flexural members and the term “ties” to transverse reinforcement in compression members.) See also **tie**.

strength, design—nominal strength multiplied by a strength reduction factor ϕ . Refer to 9.3.

strength, nominal—strength of a member or cross section calculated in accordance with provisions and assumptions of the strength design method of this Code before application of any strength reduction factors. Refer to 9.3.1.

strength, required—strength of a member or cross section required to resist factored loads or related internal moments and forces in such combinations as are stipulated in this Code. Refer to 9.1.1.

stress—intensity of force per unit area.

structural concrete—all concrete used for structural purposes, including plain and reinforced concrete.

structural diaphragm—structural member, such as a floor or roof slab, that transmits inertial forces acting in the plane of the member to the vertical elements of the seismic-force-resisting system. Refer to Chapter 13 for requirements in the earthquake-resisting structures.

structural truss—assemblage of reinforced concrete members subjected primarily to axial forces.

structural wall—wall proportioned to resist combinations of shears, moments, and axial forces. A shear wall is a structural wall. A structural wall designated as part of the seismic-force-resisting system shall be categorized as follows:

intermediate precast structural wall—a wall complying with all applicable requirements of Chapters 1 through 12, 15, and 17 through 19 in addition to 13.4.

ordinary reinforced concrete structural wall—a wall complying with the requirements of Chapters 1 through 12, 15, and 17 through 19.

special structural wall—a cast-in-place or precast wall complying with the requirements of 13.1.3 through 13.1.7, 13.9, and 13.10, as applicable, in addition to the requirements for ordinary reinforced concrete structural walls.

strut—an element of a structural diaphragm used to provide continuity around an opening in the diaphragm. Refer to Chapter 13.

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tendon—in pretensioned applications, the tendon is the prestressing steel. In post-tensioned applications, the tendon is a complete assembly consisting of anchorages, prestressing steel, and sheathing with coating for unbonded applications or ducts with grout for bonded applications.

tension-controlled section—a cross section in which the net tensile strain in the extreme tension steel at nominal strength is greater than or equal to 0.005.

tie—loop of reinforcing bar or wire enclosing longitudinal reinforcement. A continuously wound bar or wire in the form of a circle, rectangle, or other polygon shape without re-entrant corners is acceptable. Refer also to **stirrup**.

tie elements—elements that serve to transmit inertia forces and prevent separation of building components such as footings and walls. Refer to **Chapter 13**.

tightness—resistance to leakage of liquids or gases from one face through the opposite face of an element.

transfer—act of transferring stress in prestressing steel from jacks or pretensioning bed to concrete member.

transfer length—length of embedded pretensioned strand required to transfer the effective prestress to the concrete.

unbonded tendon—tendon in which the prestressing steel is prevented from bonding to the concrete and is free to move relative to the concrete. The prestressing force is permanently transferred to the concrete at the tendon ends by the anchorages only.

vertical wall segment—a segment of a structural wall, bounded horizontally by two openings or by an opening and an edge. Wall piers are vertical wall segments.

wall—member, usually vertical, used to enclose or separate spaces.

wall pier—a vertical wall segment within a structural wall, bounded horizontally by two openings or by an opening and an edge, with ratio of horizontal length to wall thickness (ℓ_w/b_w) less than or equal to 6.0, and ratio of clear height to horizontal length (h_w/ℓ_w) greater than or equal to 2.0.

waterstop—a continuous preformed strip of metal, rubber, plastic, or other material inserted across a joint to prevent the passage of liquid through the joint.

welded wire reinforcement—reinforcing elements consisting of carbon-steel plain or deformed wires, fabricated into sheets or rolls in accordance with ASTM A1064; or reinforcing elements consisting of stainless-steel plain or deformed wires fabricated into sheets or rolls conforming to ASTM A1022.

wobble friction—in prestressed concrete, friction caused by unintended deviation of prestressing sheath or duct from its specified profile.

work—the entire construction or separately identifiable parts thereof that are required to be furnished under the contract documents.

yield strength—specified minimum yield strength or yield point of reinforcement in pounds per square inch. Yield strength or yield point shall be determined in tension according to applicable ASTM standards as modified by 3.5 of this Code.



Notes

