BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE (ACI 318-02) AND COMMENTARY (ACI 318R-02)

REPORTED BY ACI COMMITTEE 318

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The code portion of this document covers the proper design and construction of buildings of structural concrete. The code has been written in such form that it may be adopted by reference in a general building code and earlier editions have been widely used in this manner.

Among the subjects covered are: drawings and specifications; inspection; materials; durability requirements; concrete quality, mixing, and placing; formwork; embedded pipes; construction joints; reinforcement details; analysis and design; strength and serviceability; flexural and axial loads; shear and torsion; development and splices of reinforcement; slab systems; walls; footings; precast concrete; composite flexural members; prestressed concrete; shells and folded plate members; strength evaluation of existing structures; special provisions for seismic design; structural plain concrete; strut-and-tie modeling in Appendix A; alternative design provisions in Appendix B; alternative load and strength-reduction factors in Appendix C; and anchoring to concrete in Appendix D.

The quality and testing of materials used in construction are covered by reference to the appropriate ASTM standard specifications. Welding of reinforcement is covered by reference to the appropriate ANSI/AWS standard.

Because the ACI Building Code is written as a legal document so that it may be adopted by reference in a general building code, it cannot present background details or suggestions for carrying out its requirements or intent. It is the function of this commentary to fill this need.

The commentary discusses some of the considerations of the committee in developing the code with emphasis given to the explanation of new or revised provisions that may be unfamiliar to code users.

References to much of the research data referred to in preparing the code are cited for the user desiring to study individual questions in greater detail. Other documents that provide suggestions for carrying out the requirements of the code are also cited.

Keywords: admixtures; aggregates; anchorage (structural); beam-column frame; beams (supports); **building codes;** cements; cold weather construction; columns (supports); combined stress; composite construction (concrete and steel); composite construction (concrete to concrete); compressive strength; **concrete construction; concretes;** concrete slabs; construction joints; continuity (structural); contraction joints; cover; curing; deep beams; deflections; drawings; earthquake resistant structures; embedded service ducts; flexural strength; floors; folded plates; footings; formwork (construction); frames; hot weather construction; inspection; isolation joints; joints (junctions); joists; lightweight concretes; loads (forces); load tests (structural); materials; mixing; mix proportioning; modulus of elasticity; moments; pipe columns; pipes (tubing); placing; plain concrete; precast concrete; prestressed concrete; prestressing steels; quality control; **reinforced concrete**; reinforcing steels; roofs; serviceability; shear strength; shearwalls; shells (structural forms); spans; specifications; splicing; strength; strength analysis; stresses; **structural analysis; structural concrete; structural design;** structural integrity; T-beams; torsion; walls; water; welded wire fabric.

ACI 318-02 was adopted as a standard of the American Concrete Institute November 1, 2001 to supersede ACI 318-99 in accordance with the Institute's standardization procedure.

A complete metric companion to ACI 318/318R has been developed, 318M/318RM; therefore no metric equivalents are included in this document.

ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This Commentary is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom. Reference to this commentary shall not be made in contract documents. If items found in this Commentary are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

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ACI 318 Building Code and Commentary
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The 2002 ACI Building Code and Commentary are presented in a side-by-side column format, with code text placed in the left column and the corresponding commentary text aligned in the right column. To further distinguish the Code from the Commentary, the Code has been printed in Helvetica, the same type face in which this paragraph is set. Vertical lines in the margins indicate changes from ACI 318-99, including nontechnical changes such as a new section or equation number.

This paragraph is set in Times Roman, and all portions of the text exclusive to the Commentary are printed in this type face. Commentary section numbers are preceded by an "R" to further distinguish them from Code section numbers. Vertical lines in the margins indicate changes from ACI 318R-99, including nontechnical changes such as a new section or equation number.

INTRODUCTION

This commentary discusses some of the considerations of Committee 318 in developing the provisions contained in "Building Code Requirements for Structural Concrete (ACI 318-02)," hereinafter called the code or the 2002 code. Emphasis is given to the explanation of new or revised provisions that may be unfamiliar to code users. In addition, comments are included for some items contained in previous editions of the code to make the present commentary independent of the commentary for ACI 318-99. Comments on specific provisions are made under the corresponding chapter and section numbers of the code.

The commentary is not intended to provide a complete historical background concerning the development of the ACI Building Code,* nor is it intended to provide a detailed résumé 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, "Building Code Requirements for Structural Concrete (ACI 318-02)" is meant to be used as part of a legally adopted building 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 all buildings of the usual types, both large and small. Requirements more stringent than the code provisions may be desirable for unusual construction. The code and commentary cannot replace sound engineering knowledge, experience, and judgement.

A building code states only the minimum requirements necessary to provide for public health and safety. The code 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 protect the public as stated in the code. However, lower standards are not permitted.

The commentary directs attention to other documents that provide suggestions for carrying out the requirements and intent of the code. However, those documents and the commentary are not a part of the code.

The code has no legal status unless it is adopted by the governments bodies having the police power to regulate building design and construction. Where the code has not been adopted, it may serve as a reference to good practice even though it has no legal status.

The code provides a means of establishing minimum standards for acceptance of designs and construction by a legally appointed building official or his 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 contract responsibility of each of the parties in usual construction. General references requiring compliance with the code in the job specifications should be avoided since the contractor is rarely in a position to accept responsibility for design details or construction requirements that depend on a detailed knowledge of the design. Generally, the drawings, specifications and contract documents should contain all of 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 "Specifications for Structural Concrete (ACI 301)" are written specifically for use as contract documents for construction.

It is desirable to have testing and certification programs for the individual parties involved with the execution of work performed in accordance with this code. Available for this purpose are the plant certification programs of the Precast/Prestressed Concrete Institute, the Post-Tensioning Institute and the National Ready Mixed Concrete Association; the personnel certification programs of the American Concrete Institute and the Post-Tensioning Institute; and the Concrete Reinforcing Steel Institute's Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants. In addition, "Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction" (ASTM E 329-00b) specifies performance requirements for inspection and testing agencies.

* For a history of the ACI Building Code see Kerekes, Frank, and Reid, Harold B., Jr., "Fifty Years of Development in Building Code Requirements for Reinforced Concrete," ACI JOURNAL, *Proceedings* V. 50, No. 6, Feb. 1954, p. 441. For a discussion of code philosophy, see Siess, Chester P., "Research, Building Codes, and Engineering Practice," ACI JOURNAL, *Proceedings* V. 56, No. 5, May 1960, p. 1105.

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Design reference materials illustrating applications of the code requirements may be found in the following documents. The design aids listed may be obtained from the sponsoring organization.

Design aids:

"ACI Design Handbook," ACI Committee 340, Publication SP-17(97), American Concrete Institute, Farmington Hills, Mich., 1997, 482 pp. (Provides tables and charts for design of eccentrically loaded columns by the Strength Design Method. Provides design aids for use in the engineering design and analysis of reinforced concrete slab systems carrying loads by two-way action. Design aids are also provided for the selection of slab thickness and for reinforcement required to control deformation and assure adequate shear and flexural strengths.)

"ACI Detailing Manual—1994," ACI Committee 315, Publication SP-66(94), American Concrete Institute, Farmington Hills, Mich., 1994, 244 pp. (Includes the standard, ACI 315-92, and report, ACI 315R-94. Provides recommended methods and standards for preparing engineering drawings, typical details, and drawings placing reinforcing steel in reinforced concrete structures. Separate sections define responsibilities of both engineer and reinforcing bar detailer.)

"Guide to Durable Concrete (ACI 201.2R-92)," ACI Committee 201, American Concrete Institute, Farmington Hills, Mich., 1992, 41 pp. (Describes specific types of concrete deterioration. It contains a discussion of the mechanisms involved in deterioration and the recommended requirements for individual components of the concrete, quality considerations for concrete mixtures, construction procedures, and influences of the exposure environment. Section R4.4.1 discusses the difference in chloride-ion limits between ACI 201.2R-92 and the code.)

"Guide for the Design of Durable Parking Structures (362.1R-97)," ACI Committee 362, American Concrete Institute, Farmington Hills, Mich., 1997, 40 pp. (Summarizes practical information regarding design of parking structures for durability. It also includes information about design issues related to parking structure construction and maintenance.)

"CRSI Handbook," Concrete Reinforcing Steel Institute, Schaumburg, Ill., 8th Edition, 1996, 960 pp. (Provides tabulated designs for structural elements and slab systems. Design examples are provided to show the basis of and use of the load tables. Tabulated designs are given for beams; square, round and rectangular columns; one-way slabs; and one-way joist construction. The design tables for two-way slab systems include flat plates, flat slabs and waffle slabs. The chapters on foundations provide design tables for square footings, pile caps, drilled piers (caissons) and cantilevered retaining walls. Other design aids are presented for crack control; and development of reinforcement and lap splices.)

"Reinforcement Anchorages and Splices," Concrete Reinforcing Steel Institute, Schaumberg, Ill., 4th Edition, 1997, 100 pp. (Provides accepted practices in splicing reinforcement. The use of lap splices, mechanical splices, and welded splices are described. Design data are presented for development and lap splicing of reinforcement.)

"Structural Welded Wire Reinforcement Manual of Standard Practice," Wire Reinforcement Institute, Findlay, Ohio, 4th Edition, Apr. 1992, 31 pp. (Describes wire fabric material, gives nomenclature and wire size and weight tables. Lists specifications and properties and manufacturing limitations. Book has latest code requirements as code affects welded wire. Also gives development length and splice length tables. Manual contains customary units and soft metric units.)

"Structural Welded Wire Reinforcement Detailing Manual," Wire Reinforcement Institute, Findlay, Ohio, 1994, 252 pp. (Updated with current technical fact sheets inserted.) The manual, in addition to including ACI 318 provisions and design aids, also includes: detailing guidance on welded wire reinforcement in one-way and two-way slabs; precast/prestressed concrete components; columns and beams; cast-in-place walls; and slabs-on-ground. In addition, there are tables to compare areas and spacings of high-strength welded wire with conventional reinforcing.

"Strength Design of Reinforced Concrete Columns," Portland Cement Association, Skokie, Ill., 1978, 48 pp. (Provides design tables of column strength in terms of load in kips versus moment in ft-kips for concrete strength of 5000 psi and Grade 60 reinforcement. Design examples are included. Note that the PCA design tables do not include the strength reduction factor f in the tabulated values; M_u/f and P_u/f must be used when designing with this aid.

"PCI Design Handbook—Precast and Prestressed Concrete," Precast/Prestressed Concrete Institute, Chicago, 5th Edition, 1999, 630 pp. (Provides load tables for common industry products, and procedures for design and analysis of precast and prestressed elements and structures composed of these elements. Provides design aids and examples.)

"Design and Typical Details of Connections for Precast and Prestressed Concrete," Precast/Prestressed Concrete Institute, Chicago, 2nd Edition, 1988, 270 pp. (Updates available information on design of connections for both structural and architectural products, and presents a full spectrum of typical details. Provides design aids and examples.)

"PTI Post-Tensioning Manual," Post-Tensioning Institute, Phoenix, 5th Edition, 1990, 406 pp. (Provides comprehensive coverage of post-tensioning systems, specifications, and design aid construction concepts.)

"PTI Design of Post-Tensioned Slabs," Post-Tensioning Institute, Phoenix, 2nd Edition, Apr. 1984, 56 pp. (Illustrates application of the code requirements for design of one-way and two-way post-tensioned slabs. Detailed design examples are presented.)

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PART 1 — GENERAL

CHAPTER 1 — GENERAL REQUIREMENTS

CODE

1.1 — Scope

1.1.1 — This code provides minimum requirements for design and construction of structural concrete elements of any structure erected under requirements of the legally adopted general building code of which this code forms a part. In areas without a legally adopted building code, this code defines minimum acceptable standards of design and construction practice.

For structural concrete, the specified compressive strength shall not be less than 2500 psi. No maximum specified compressive strength shall apply unless restricted by a specific code provision.

COMMENTARY

R1.1 — Scope

The American Concrete Institute **"Building Code Requirements for Structural Concrete (ACI 318-02),"** referred to as the code, provides minimum requirements for structural concrete design or construction.

The 2002 edition of the code revised the previous standard **"Building Code Requirements for Structural Concrete (ACI 318-99)."** This standard includes in one document the rules for all concrete used for structural purposes including both plain and reinforced concrete. The term "structural concrete" is used to refer to all plain or reinforced concrete used for structural purposes. This covers the spectrum of structural applications of concrete from nonreinforced concrete to concrete containing nonprestressed reinforcement, prestressing steel, or composite steel shapes, pipe, or tubing. Requirements for structural plain concrete are in Chapter 22.

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

Chapter 21 of the code contains special provisions for design and detailing of earthquake resistant structures. See 1.1.8.

In the 1999 code and earlier editions, Appendix A contained provisions for an alternate method of design for nonprestressed reinforced concrete members using service loads (without load factors) and permissible service load stresses. The Alternate Design Method was intended to give results that were slightly more conservative than designs by the Strength Design Method of the code. The Alternate Design Method of the 1999 code may be used in place of applicable sections of the 2002 code.

Appendix A of the code contains provisions for the design of regions near geometrical discontinuities, or abrupt changes in loadings.

Appendix B of the 2002 code contains provisions for reinforcement limits based on $\mathbf{0.75}r_b$, determination of the strength reduction factor f, and moment redistribution that have been in the code for many years, including the 1999 code. The provisions are applicable to reinforced and prestressed concrete members. Designs made using the provisions of Appendix B are equally acceptable as those based on the body of the code, provided the provisions of Appendix B are used in their entirety.

Appendix C of the code allows the use of the factored load combinations given in Chapter 9 of the 1999 code.

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1.1.2 — This code supplements the general building code and shall govern in all matters pertaining to design and construction of structural concrete, except wherever this code is in conflict with requirements in the legally adopted general building code.

1.1.3 — This code shall govern 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.

1.1.4 — For special structures, such as arches, tanks, reservoirs, bins and silos, blast-resistant structures, and chimneys, provisions of this code shall govern where applicable. See also 22.1.2.

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Appendix D contains provisions for anchoring to concrete.

R1.1.2 — The American Concrete Institute recommends that the code be adopted in its entirety; however, it is recognized that when the code is made a part of a legally adopted general building code, the general building code may modify provisions of this code.

R1.1.4 — Some special structures involve unique design and construction problems that are not covered by the code. However, many code provisions, such as the concrete quality and design principles, are applicable for these structures. Detailed recommendations for design and construction of some special structures are given in the following ACI publications:

"Standard Practice for the Design and Construction of Reinforced Concrete Chimneys" reported by ACI Committee 307.[1.1] (Gives 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.)

"Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials" reported by ACI Committee 313.[1.2] (Gives 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.)

"Environmental Engineering Concrete Structures" reported by ACI Committee 350.[1.3] (Gives material, design and construction recommendations for concrete tanks, reservoirs, and other structures commonly used in water and waste treatment works where dense, impermeable concrete with high resistance to chemical attack is required. Special emphasis is placed on a structural design that minimizes the possibility of cracking and accommodates vibrating equipment and other special loads. Proportioning of concrete, placement, curing and protection against chemicals are also described. Design and spacing of joints receive special attention.)

"Code Requirements for Nuclear Safety Related Concrete Structures" reported by ACI Committee 349.[1.4] (Provides minimum requirements for design and construction of concrete structures that form part of a nuclear power plant and have nuclear safety related functions. The code does not cover concrete reactor vessels and concrete containment structures which are covered by ACI 359.)

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"Code for Concrete Reactor Vessels and Containments" reported by ACI-ASME Committee 359.[1.5] (Provides requirements for the design, construction, and use of concrete reactor vessels and concrete containment structures for nuclear power plants.)

1.1.5 — 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. See 21.10.4 for requirements for concrete piles, drilled piers, and caissons in structures in regions of high seismic risk or assigned to high seismic performance or design categories.

R1.1.5 — The design and installation of piling fully embedded in the ground is regulated by the general building code. For portions of piling in air or water, or in soil not capable of providing adequate lateral restraint throughout the piling length to prevent buckling, the design provisions of this code govern where applicable.

Recommendations for concrete piles are given in detail in **"Recommendations for Design, Manufacture, and Installation of Concrete Piles"** reported by ACI Committee 543.[1.6] (Provides recommendations for the design and use of most types of concrete piles for many kinds of construction.)

Recommendations for drilled piers are given in detail in **"Design and Construction of Drilled Piers"** reported by ACI Committee 336.[1.7] (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 given in **"Recommended Practice for Design, Manufacture, and Installation of Prestressed Concrete Piling"** prepared by the PCI Committee on Prestressed Concrete Piling.[1.8]

1.1.6 — This code does not govern design and construction of soil-supported slabs, unless the slab transmits vertical loads or lateral forces from other portions of the structure to the soil.

1.1.7 — Concrete on steel form deck

R1.1.7 — Concrete on steel form deck

In steel framed structures, it is common practice to cast concrete floor slabs on stay-in-place steel form deck. In all cases, the deck serves as the form and may, in some cases, serve an additional structural function.

1.1.7.1 — Design and construction of structural concrete slabs cast on stay-in-place, noncomposite steel form deck are governed by this code.

R1.1.7.1 — In its most basic application, the steel form deck serves as a form, and the concrete serves a structural function and, therefore, are to be designed to carry all superimposed loads.

1.1.7.2 — This code does not govern the design of structural concrete slabs cast on stay-in-place, composite steel form deck. Concrete used in the construction of such slabs shall be governed by Parts 1, 2, and 3 of this code, where applicable.

R1.1.7.2 — Another type of steel form 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 of composite slabs on steel deck is regulated by **"Standard for the Structural Design of Composite Slabs"** (ANSI/ASCE 3).[1.9] However, ANSI/ASCE 3 references the appropriate portions of ACI 318 for the design and construction of the concrete portion of the composite assembly. Guidelines for the construction of composite steel deck slabs are given in

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"Standard Practice for the Construction and Inspection of Composite Slabs" (ANSI/ASCE 9).[1.10]

1.1.8 — Special provisions for earthquake resistance

R1.1.8 — Special provisions for earthquake resistance

Special provisions for seismic design were first introduced in Appendix A of the 1971 code and were continued without revision in the 1977 code. These provisions were originally intended to apply only to reinforced concrete structures located in regions of highest seismicity.

The special provisions were extensively revised in the 1983 code to include new requirements for certain earthquake-resisting systems located in regions of moderate seismicity. In the 1989 code, the special provisions were moved to Chapter 21.

1.1.8.1 — In regions of low seismic risk, or for structures assigned to low seismic performance or design categories, provisions of Chapter 21 shall not apply.

R1.1.8.1 — For structures located in regions of low seismic risk, or for structures assigned to low seismic performance or design categories, no special design or detailing is required; the general requirements of the main body of the code apply for proportioning and detailing of reinforced concrete structures. It is the intent of Committee 318 that concrete structures proportioned by the main body of the code will provide a level of toughness adequate for low earthquake intensity.

1.1.8.2 — In regions of moderate or high seismic risk, or for structures assigned to intermediate or high seismic performance or design categories, provisions of Chapter 21 shall be satisfied. See 21.2.1.

R1.1.8.2 — For structures in regions of moderate seismic risk, or for structures assigned to intermediate seismic performance or design categories, reinforced concrete moment frames proportioned to resist seismic effects require special reinforcement details, as specified in 21.12. The special details apply only to beams, columns, and slabs to which the earthquake-induced forces have been assigned in design. The special reinforcement details will serve to provide a suitable level of inelastic behavior if the frame is subjected to an earthquake of such intensity as to require it to perform inelastically. There are no Chapter 21 requirements for cast-in-place structural walls provided to resist seismic effects, or for other structural components that are not part of the lateral-force-resisting system of structures in regions of moderate seismic risk, or assigned to intermediate seismic performance or design categories. For precast wall panels designed to resist forces induced by earthquake motions, special requirements are specified in 21.13 for connections between panels or between panels and the foundation. Cast-in-place structural walls proportioned to meet provisions of Chapters 1 through 18 and Chapter 22 are considered to have sufficient toughness at anticipated drift levels for these structures.

For structures located in regions of high seismic risk, or for structures assigned to high seismic performance or design categories, all building components that are part of the lateral-force-resisting system, including foundations (except plain concrete foundations as allowed by 22.10.1), should satisfy requirements of 21.2 through 21.10. In addition, frame members that are not assumed in the design to be part of the lateral-force-resisting system should comply with 21.11. The special proportioning and detailing require-

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1.1.8.3 — The seismic risk level of a region, or seismic performance or design category of a structure, shall be regulated by the legally adopted general building code of which this code forms a part, or determined by local authority.

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ments of Chapter 21 are intended to provide a monolithic reinforced concrete or precast concrete structure with adequate "toughness" to respond inelastically under severe earthquake motions. See also R21.2.1.

R1.1.8.3 — Seismic risk levels (Seismic Zone Maps) and seismic performance or design categories are under the jurisdiction of a general building code rather than ACI 318. Changes in terminology were made to the 1999 edition of the code to make it compatible with the latest editions of model building codes in use in the United States. For example, the phrase "seismic performance or design categories" was introduced. Over the past decade, the manner in which seismic risk levels have been expressed in United States building codes has changed. Previously they have been represented in terms of seismic zones. Recent editions of the "BOCA National Building Code" (NBC)[1.11] and "Standard Building Code" (SBC),[1.12] which are based on the 1991 NEHRP,[1.13] have expressed risk not only as a function of expected intensity of ground shaking on solid rock, but also on the nature of the occupancy and use of the structure. These two items are considered in assigning the structure to a Seismic Performance Category (SPC), which in turn is used to trigger different levels of detailing requirements for the structure. The 2000 "International Building Code" (IBC)[1.14] also uses the two criteria of the NBC and SBC and also considers the effects of soil amplification on the ground motion when assigning seismic risk. Under the IBC, each structure is assigned a Seismic Design Category (SDC). Among its several uses, it triggers different levels of detailing requirements. Table R1.1.8.3 correlates low, moderate/intermediate, and high seismic risk, which has been the terminology used in this code for several editions, to the various methods of assigning risk in use in the U.S. under the various model building codes, the ASCE 7 standard, and the NEHRP Recommended Provisions.

In the absence of a general building code that addresses earthquake loads and seismic zoning, it is the intent of Committee 318 that the local authorities (engineers, geologists, and building code officials) should decide on proper need and proper application of the special provisions for seismic design. Seismic ground-motion maps or zoning maps, such as recommended in References 1.10, 1.15, and 1.16, are suitable for correlating seismic risk.

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TABLE R1.1.8.3—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 the code section		
	Low (21.2.1.2)	Moderate/ intermediate (21.2.1.3)	High (21.2.1.4)
International Building Code 2000; NEHRP 1997	SDC[1] A, B	SDC C	SDC D, E, F
BOCA National Building Code 1993, 1996, 1999; Standard Building Code 1994, 1997, 1999; ASCE 7-93, 7-95, 7-98; NEHRP 1991, 1994	SPC[2] A, B	SPC C	SPC D, E
Uniform Building Code 1991, 1994, 1997	Seismic Zone 0, 1	Seismic Zone 2	Seismic Zone 3, 4

[1]SDC = *Seismic Design Category* as defined in code, standard, or resource document.
[2]SPC = *Seismic Performance Category* as defined in code, standard, or resource document.

1.2 — Drawings and specifications

1.2.1 — Copies of design drawings, typical details, and specifications for all structural concrete construction shall bear the seal of a registered engineer or architect. These drawings, details, and specifications shall show:

(a) Name and date of issue of 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 structural elements, reinforcement, and anchors;

(f) Provision for dimensional changes resulting from creep, shrinkage, and temperature;

(g) Magnitude and location of prestressing forces;

(h) Anchorage length of reinforcement and location and length of lap splices;

(i) Type and location of mechanical and welded splices of reinforcement;

(j) Details and location of all contraction or isolation joints specified for plain concrete in Chapter 22;

(k) Minimum concrete compressive strength at time of post-tensioning;

R1.2 — Drawings and specifications

R1.2.1 — The provisions for preparation of design drawings and specifications are, in general, consistent with those of most general building codes and are intended as supplements.

The code lists some of the more important items of information that should be included in the design drawings, details, or specifications. The code does not imply an all inclusive list, and additional items may be required by the building official.

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(l) Stressing sequence for post-tensioning tendons;

(m) Statement if slab on grade is designed as a structural diaphragm, see 21.10.3.4.

1.2.2 — Calculations pertinent to design shall be filed with the drawings when required by the building official. Analyses and designs using computer programs shall be permitted provided design assumptions, user input, and computer-generated output are submitted. Model analysis shall be permitted to supplement calculations.

1.2.3 — Building official means the officer or other designated authority charged with the administration and enforcement of this code, or his duly authorized representative.

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 inspection requirements, concrete construction shall be inspected throughout the various

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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. However, when a computer program has been used by the designer, 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.

The 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 an engineer or architect having experience in this technique.

R1.2.3 — 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 building code. However, 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.

R1.3 — Inspection

The quality of concrete structures depends largely on workmanship in construction. The best of materials and design practices will not be effective unless the construction is performed well. Inspection is necessary to confirm that the construction is in accordance with the design drawings and project specifications. Proper performance of the structure depends on construction that accurately represents the design and meets code requirements, within the tolerances allowed. Qualification of inspectors can be obtained from a certification program such as the certification program for Reinforced Concrete Inspector sponsored by ACI, International Conference of Building Officials (ICBO), Building Officials and Code Administrators International (BOCA), and Southern Building Code Congress International (SBCCI).

R1.3.1 — Inspection of construction by or under the supervision of the registered design professional responsible for the design should be considered because the person in charge of the design is usually the best qualified to determine if compli-

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work stages by or under the supervision of a registered design professional or by a qualified inspector.

1.3.2 — The inspector shall require compliance with design drawings and specifications. Unless specified otherwise in the legally adopted general building code, inspection records shall include:

(a) Quality and proportions of concrete materials and strength of concrete;

(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 com-

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struction is in conformance with construction documents. When such an arrangement is not feasible, inspection of construction through other registered design professionals or through separate 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 postplacement operations through the Reinforced Concrete Special Inspector program sponsored by ACI, ICBO, BOCA, and SBCCI or equivalent.

When inspection is done independently of the registered design professional responsible for the design, it is recommended that the registered design professional responsible for the design be employed at least 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 the owner, registered design professional responsible for the design, 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, contractor, and inspector. Adequate fees should be provided consistent with the work and equipment necessary to properly perform the inspection.

R1.3.2 — By inspection, the 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 and code requirements. The frequency should be at least enough to provide general knowledge of each operation, whether this be several times a day or once in several days.

Inspection in no way relieves the contractor from his obligation to follow the plans and specifications and to provide the designated quality and quantity of materials and workmanship for all job stages. The inspector should be present as frequently as he or she deems 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

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pleted floors, members, or walls;

(h) 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 given to 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 inspecting engineer or architect for 2 years after completion of the project.

1.3.5 — For special moment frames resisting seismic loads in regions of high seismic risk, or in structures assigned to high seismic performance or design categories, 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 engineer responsible for the structural design or under the supervision of an engineer with demonstrated capability for supervising inspection of special moment frames resisting seismic loads in regions of high seismic risk, or in structures assigned to high seismic performance or design categories.

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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.

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

Recommended procedures for organization and conduct of concrete inspection are given in detail in **"Guide for Concrete Inspection,"** reported by ACI Committee 311.[1.17] (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"** (SP-2) reported by ACI Committee 311.[1.18] (Describes methods of inspecting concrete construction that are generally accepted as good practice. Intended as a supplement to specifications and as a guide in matters not covered by 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 air temperature near the surface of the concrete; however, during mixing and placing it is practical to measure the temperature of the mixture.

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

Records of inspection should 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 special moment frames is properly executed through inspection by personnel who are qualified to do this work. Qualifications of inspectors should be acceptable to the jurisdiction enforcing the general building code.

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1.4 — Approval of special systems of design or construction

Sponsors of any system of design or construction within the scope of this code, the adequacy of which has 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.

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

New methods of design, new materials, and new uses of materials should 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 the code.

The provisions of this section do not apply to model tests used to supplement calculations under 1.2.2 or to strength evaluation of existing structures under Chapter 20.

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CHAPTER 2 — DEFINITIONS

CODE

2.1 — 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 with a dry, loose weight of 70 lb/ft^3 or less.

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.

Basic monostrand anchorage device — Anchorage device used with any single strand or a single 5/8 in. or smaller diameter bar that satisfies 18.21.1 and the anchorage device requirements of ACI 423.6, "Specification for Unbonded Single-Strand Tendons."

Basic multistrand anchorage device — Anchorage device used with multiple strands, bars, or wires, or with single bars larger than 5/8 in. diameter, that satisfies 18.21.1 and the bearing stress and minimum plate stiffness requirements of AASHTO Bridge Specifications, Division I, Articles 9.21.7.2.2 through 9.21.7.2.4.

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R2.1 — For consistent application of the code, it is necessary that terms be defined where they have particular meanings in the code. The definitions given are for use in application of this code only and do not always correspond to ordinary usage. A glossary of most used terms relating to cement manufacturing, concrete design and construction, and research in concrete is contained in **"Cement and Concrete Terminology"** reported by ACI Committee 116.[2.1]

Anchorage device — Most anchorage devices for post-tensioning are standard manufactured devices available from commercial sources. In some cases, designers or constructors develop "special" details or assemblages that combine various wedges and wedge plates for anchoring prestressing steel with specialty end plates or diaphragms. These informal designations as standard anchorage devices or special anchorage devices have no direct relation to the ACI Building 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 are those 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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Bonded tendon — Tendon in which prestressing steel is bonded to concrete either directly or through grouting.

Building official — See 1.2.3.

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 ground granulated blast-furnace slag.

Column — Member with a ratio of height-to-least lateral dimension exceeding 3 used primarily to support axial compressive load.

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, and pedestals 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 (see 14.4), as well as by the empirical method (see 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.

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. See 10.3.3.

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

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).

Concrete, structural lightweight — Concrete containing lightweight aggregate that conforms to 3.3 and has an air-dry unit weight as determined by "Test Method for Unit Weight of Structural Lightweight Concrete" (ASTM C 567), not exceeding 115 lb/ft^3. In this code, a lightweight concrete without natural sand is termed "all-lightweight concrete" and lightweight concrete in which all of the fine aggregate consists of normal weight sand is termed "sand-lightweight concrete."

Concrete, structural lightweight — By code definition, sand-lightweight concrete is structural lightweight concrete with all of 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.

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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.

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

Deformed reinforcement — Deformed reinforcing bars, bar mats, deformed wire, welded plain wire fabric, and welded deformed wire fabric conforming to 3.5.3.

Development length — Length of embedded reinforcement required to develop the design strength of reinforcement at a critical section. See 9.3.3.

Duct — A conduit (plain or corrugated) to accommodate prestressing steel for post-tensioned installation. Requirements for post-tensioning ducts are given in Section 18.17.

Effective depth of section (d) — Distance measured from extreme compression fiber to centroid of 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.

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

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 as 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.

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

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. See 8.1.1 and 9.2.

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Deformed reinforcement — Deformed reinforcement is defined as that meeting the deformed bar specifications of 3.5.3.1, or the specifications of 3.5.3.3, 3.5.3.4, 3.5.3.5, or 3.5.3.6. No other bar or fabric qualifies. This definition permits accurate statement of anchorage lengths. Bars or wire not meeting the deformation requirements or fabric not meeting the spacing requirements are "plain reinforcement," for code purposes, and may be used only for spirals.

Loads — A number of 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

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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. See 8.5.

Moment frame — Frame in which members and joints resist forces through flexure, shear, and axial force. Moment frames shall be catergorized as follows:

> ***Intermediate moment frame*** — A cast-in-place frame complying with the requirements of 21.2.2.3 and 21.12 in addition to the requirements for ordinary moment frames.
>
> ***Ordinary moment frame*** — A cast-in-place or precast concrete frame complying with the requirements of Chapters 1 through 18.
>
> ***Special moment frame*** — A cast-in-place frame complying with the requirements of 21.2 through 21.5, or a precast frame complying with the requirements of 21.2 through 21.6. In addition, the requirements for ordinary moment frames shall be satisfied.

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

Pedestal — Upright compression member with a ratio of unsupported height to average least lateral dimension not exceeding 3.

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. See 3.5.4.

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.

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

COMMENTARY

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 code edition to refer to loads multiplied by the appropriate load factors, was discontinued in the 1977 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.

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, adequate

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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 Appendices A through C.

Reinforcement — Material that conforms to 3.5, excluding prestressing steel unless specifically included.

Registered design professional — An individual who is registered or licensed to practice the respective design profession as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.

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.

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 — See 8.7.

Special anchorage device — Anchorage device that satisfies 18.15.1 and the standardized acceptance tests of AASHTO "Standard Specifications for Highway Bridges," Division II, Article 10.3.2.3.

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 C 496 as described in "Specification for Lightweight Aggregates for Structural Concrete" (ASTM C 330). See 5.1.4.

COMMENTARY

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.

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

Special anchorage devices are any devices (monostrand or multistrand) that do not meet the relevant PTI or AASHTO bearing stress and, where applicable, stiffness requirements. Most commercially marketed multibearing surface anchorage devices are Special Anchorage Devices. As provided in 18.15.1, such devices can be used only when they have been shown experimentally to be in compliance with the AASHTO requirements. This demonstration of compliance will ordinarily be furnished by the device manufacturer.

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Stirrup — Reinforcement used to resist shear and torsion stresses in a structural member; typically bars, wires, or welded wire fabric (plain or deformed) 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 lateral reinforcement in flexural members and the term ties to those in compression members.) See also *Tie*.

Strength, design — Nominal strength multiplied by a strength reduction factor f. See 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. See 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. See 9.1.1.

Stress — Intensity of force per unit area.

Structural concrete — All concrete used for structural purposes including plain and reinforced concrete.

Structural walls — Walls proportioned to resist combinations of shears, moments, and axial forces induced by earthquake motions. A shearwall is a structural wall. Structural walls shall be categorized as follows:

Intermediate precast structural wall — A wall complying with all applicable requirements of Chapters 1 through 18 in addition to 21.13.

Ordinary reinforced concrete structural wall — A wall complying with the requirements of Chapters 1 through 18.

Ordinary structural plain concrete wall — A wall complying with the requirements of Chapter 22.

Special precast structural wall — A precast wall complying with the requirements of 21.8. In addition, the requirements of ordinary reinforced concrete structural walls and the requirements of 21.2 shall be satisfied.

Special reinforced concrete structural wall — A cast-in-place wall complying with the requirements of 21.2 and 21.7 in addition to the requirements for ordinary reinforced concrete structural walls.

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Strength, nominal — Strength of a member or cross section calculated using standard assumptions and strength equations, and nominal (specified) values of material strengths and dimensions is referred to as "nominal strength." The subscript n is used to denote the nominal strengths; nominal axial load strength P_n, nominal moment strength M_n, and nominal shear strength V_n. "Design strength" or usable strength of a member or cross section is the nominal strength reduced by the strength reduction factor f.

The required axial load, moment, and shear strengths used to proportion members are referred to either as factored axial loads, factored moments, and factored shears, or required axial loads, moments, and shears. The factored load effects are calculated from the applied factored loads and forces in such load combinations as are stipulated in the code (see 9.2).

The subscript u is used only to denote the required strengths; required axial load strength P_u, required moment strength M_u, and required shear strength V_u, calculated from the applied factored loads and forces.

The basic requirement for strength design may be expressed as follows:

Design strength ≥ Required strength

$$f P_n \geq P_u$$

$$f M_n \geq M_u$$

$$f V_n \geq V_u$$

For additional discussion on the concepts and nomenclature for strength design see commentary Chapter 9.

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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. See also *Stirrup*.

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

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.

Wall — Member, usually vertical, used to enclose or separate spaces.

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

Yield strength — Specified minimum yield strength or yield point of reinforcement. Yield strength or yield point shall be determined in tension according to applicable ASTM standards as modified by 3.5 of this code.

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PART 2 — STANDARDS FOR TESTS AND MATERIALS

CHAPTER 3 — MATERIALS

CODE

3.0 — Notation

f_y = specified yield strength of nonprestressed reinforcement, psi

3.1 — Tests of materials

3.1.1 — The building official shall have the right to order testing of any materials used in concrete construction to determine if materials are of quality specified.

3.1.2 — Tests of materials and of concrete shall be made in accordance with standards listed in 3.8.

3.1.3 — A complete record of tests of materials and of concrete shall be retained by the inspector for 2 years after completion of the project, and made available for inspection during the progress of the work.

3.2 — Cements

3.2.1 — Cement shall conform to one of the following specifications:

(a) "Specification for Portland Cement" (ASTM C 150);

(b) "Specification for Blended Hydraulic Cements" (ASTM C 595), excluding Types S and SA which are not intended as principal cementing constituents of structural concrete;

(c) "Specification for Expansive Hydraulic Cement" (ASTM C 845).

(d) "Performance Specification for Hydraulic Cement" (ASTM C 1157)

3.2.2 — Cement used in the work shall correspond to that on which selection of concrete proportions was based. See 5.2.

COMMENTARY

R3.0 — Notation

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.

R3.1 — Tests of materials

R3.1.3 — The record of tests of materials and of concrete should be retained for at least 2 years after completion of the project. Completion of the project is the date at which the owner accepts the project or when the certificate of occupancy is issued, whichever date is later. Local legal requirements may require longer retention of such records.

R3.2 — Cements

R3.2.2 — Depending on the circumstances, the provision of 3.2.2 may require only the same type of cement or may require cement from the identical source. The latter would be the case if the standard deviation[3.1] of strength tests used in establishing the required strength margin was based on a cement from a particular source. If the standard deviation

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was based on tests involving a given type of cement obtained from several sources, the former interpretation would apply.

3.3 — Aggregates

3.3.1 — Concrete aggregates shall conform to one of the following specifications:

(a) "Specification for Concrete Aggregates" (ASTM C 33);

(b) "Specification for Lightweight Aggregates for Structural Concrete" (ASTM C 330).

Exception: Aggregates that have been shown by special test or actual service to produce concrete of adequate strength and durability and approved by the building official.

R3.3 — Aggregates

R3.3.1 — Aggregates conforming to the ASTM specifications are not always economically available and, in some instances, noncomplying materials have a long history of satisfactory performance. Such nonconforming materials are permitted with special approval when acceptable evidence of satisfactory performance is provided. Satisfactory performance in the past, however, does not guarantee good performance under other conditions and in other localities. Whenever possible, aggregates conforming to the designated specifications should be used.

3.3.2 — Nominal maximum size of coarse aggregate shall be not larger than:

(a) 1/5 the narrowest dimension between sides of forms, nor

(b) 1/3 the depth of slabs, nor

(c) 3/4 the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, individual tendons, bundled tendons, or ducts.

These limitations shall not apply if, in the judgment of the engineer, workability and methods of consolidation are such that concrete can be placed without honeycombs or voids.

R3.3.2 — The size limitations on aggregates are provided to ensure proper encasement of reinforcement and to minimize honeycombing. Note that the limitations on maximum size of the aggregate may be waived if, in the judgment of the engineer, the workability and methods of consolidation of the concrete are such that the concrete can be placed without honeycombs or voids.

3.4 — Water

3.4.1 — Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement.

3.4.2 — Mixing water for prestressed concrete or for concrete that will contain aluminum embedments, including that portion of mixing water contributed in the form of free moisture on aggregates, shall not contain deleterious amounts of chloride ion. See 4.4.1.

3.4.3 — Nonpotable water shall not be used in concrete unless the following are satisfied:

3.4.3.1 — Selection of concrete proportions shall be based on concrete mixes using water from the same source.

R3.4 — Water

R3.4.1 — Almost any natural water that is drinkable (potable) and has no pronounced taste or odor is satisfactory as mixing water for making concrete. Impurities in mixing water, when excessive, may affect not only setting time, concrete strength, and volume stability (length change), but may also cause efflorescence or corrosion of reinforcement. Where possible, water with high concentrations of dissolved solids should be avoided.

Salts or other deleterious substances contributed from the aggregate or admixtures are additive to the amount which might be contained in the mixing water. These additional amounts are to be considered in evaluating the acceptability of the total impurities that may be deleterious to concrete or steel.

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3.4.3.2 — Mortar test cubes made with nonpotable mixing water shall have 7-day and 28-day strengths equal to at least 90 percent of strengths of similar specimens made with potable water. Strength test comparison shall be made on mortars, identical except for the mixing water, prepared and tested in accordance with "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)" (ASTM C 109).

3.5 — Steel reinforcement

3.5.1 — Reinforcement shall be deformed reinforcement, except that plain reinforcement shall be permitted for spirals or prestressing steel; and reinforcement consisting of structural steel, steel pipe, or steel tubing shall be permitted as specified in this code.

3.5.2 — Welding of reinforcing bars shall conform to "Structural Welding Code — Reinforcing Steel," ANSI/AWS D1.4 of the American Welding Society. Type and location of welded splices and other required welding of reinforcing bars shall be indicated on the design drawings or in the project specifications. ASTM reinforcing bar specifications, except for ASTM A 706, shall be supplemented to require a report of material properties necessary to conform to the requirements in ANSI/AWS D1.4.

COMMENTARY

R3.5 — Steel reinforcement

R3.5.1 — Materials permitted for use as reinforcement are specified. Other metal elements, such as inserts, anchor bolts, or plain bars for dowels at isolation or contraction joints, are not normally considered to be reinforcement under the provisions of this code.

R3.5.2 — When welding of reinforcing bars is required, the weldability of the steel and compatible welding procedures need to be considered. The provisions in ANSI/AWS D1.4 Welding Code cover aspects of welding reinforcing bars, including criteria to qualify welding procedures.

Weldability of the steel is based on its chemical composition or carbon equivalent (CE). The Welding Code establishes preheat and interpass temperatures for a range of carbon equivalents and reinforcing bar sizes. Carbon equivalent is calculated from the chemical composition of the reinforcing bars. The Welding Code has two expressions for calculating carbon equivalent. A relatively short expression, considering only the elements carbon and manganese, is to be used for bars other than ASTM A 706 material. A more comprehensive expression is given for ASTM A 706 bars. The CE formula in the Welding Code for A 706 bars is identical to the CE formula in the ASTM A 706 specification.

The engineer should realize that the chemical analysis, for bars other than A 706, required to calculate the carbon equivalent is not routinely provided by the producer of the reinforcing bars. For welding reinforcing bars other than A 706 bars, the design drawings or project specifications should specifically require results of the chemical analysis to be furnished.

The ASTM A 706 specification covers low-alloy steel reinforcing bars intended for applications requiring controlled tensile properties or welding. Weldability is accomplished in the A 706 specification by limits or controls on chemical composition and on carbon equivalent.[3.2] The producer is required by the A 706 specification to report the chemical composition and carbon equivalent.

The ANSI/AWS D1.4 Welding Code requires the contractor to prepare written welding procedure specifications conforming to the requirements of the Welding Code.

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Appendix A of the Welding Code contains a suggested form that shows the information required for such a specification for each joint welding procedure.

Often it is necessary to weld to existing reinforcing bars in a structure when no mill test report of the existing reinforcement is available. This condition is particularly common in alterations or building expansions. ANSI/AWS D1.4 states for such bars that a chemical analysis may be performed on representative bars. If the chemical composition is not known or obtained, the Welding Code requires a minimum preheat. For bars other than A 706 material, the minimum preheat required is 300 F for bars No. 6 or smaller, and 400 F for No. 7 bars or larger. The required preheat for all sizes of A 706 is to be the temperature given in the Welding Code's table for minimum preheat corresponding to the range of CE "over 45 percent to 55 percent." Welding of the particular bars should be performed in accordance with ANSI/AWS D 1.4. It should also be determined if additional precautions are in order, based on other considerations such as stress level in the bars, consequences of failure, and heat damage to existing concrete due to welding operations.

Welding of wire to wire, and of wire or welded wire fabric to reinforcing bars or structural steel elements is not covered by ANSI/AWS D1.4. If welding of this type is required on a project, the engineer should specify requirements or performance criteria for this welding. If cold drawn wires are to be welded, the welding procedures should address the potential loss of yield strength and ductility achieved by the cold working process (during manufacture) when such wires are heated by welding. Machine and resistance welding as used in the manufacture of welded wire fabrics is covered by ASTM A 185 and A 497 and is not part of this concern.

3.5.3 — Deformed reinforcement

3.5.3.1 — Deformed reinforcing bars shall conform to one of the following specifications:

(a) "Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement" (ASTM A 615);

(b) "Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement" (ASTM A 706);

(c) "Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement" (ASTM A 996). Bars from rail-steel shall be Type R.

R3.5.3 — Deformed reinforcement

R3.5.3.1 — ASTM A 615 covers deformed billet-steel reinforcing bars that are currently the most widely used type of steel bar in reinforced concrete construction in the United States. The specification requires that the bars be marked with the letter *S* for type of steel.

ASTM A 706 covers low-alloy steel deformed bars intended for applications where controlled tensile properties, restrictions on chemical composition to enhance weldability, or both, are required. The specification requires that the bars be marked with the letter *W* for type of steel.

Deformed bars produced to meet both ASTM A 615 and A 706 are required to be marked with the letters *S* and *W* for type of steel.

Rail-steel reinforcing bars used with this code are required to conform to ASTM A 996 including the provisions for Type R bars, and marked with the letter *R* for type of steel.

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3.5.3.2 — Deformed reinforcing bars with a specified yield strength f_y exceeding 60,000 psi shall be permitted, provided f_y shall be the stress corresponding to a strain of 0.35 percent and the bars otherwise conform to one of the ASTM specifications listed in 3.5.3.1. See 9.4.

3.5.3.3 — Bar mats for concrete reinforcement shall conform to "Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement" (ASTM A 184). Reinforcing bars used in bar mats shall conform to one of the specifications listed in 3.5.3.1.

3.5.3.4 — Deformed wire for concrete reinforcement shall conform to "Specification for Steel Wire, Deformed, for Concrete Reinforcement" (ASTM A 496), except that wire shall not be smaller than size D4 and for wire with a specified yield strength f_y exceeding 60,000 psi, f_y shall be the stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi.

3.5.3.5 — Welded plain wire fabric for concrete reinforcement shall conform to "Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement" (ASTM A 185), except that for wire with a specified yield strength f_y exceeding 60,000 psi, f_y shall be the stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi. Welded intersections shall not be spaced farther apart than 12 in. in direction of calculated stress, except for wire fabric used as stirrups in accordance with 12.13.2.

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Type R bars are required to meet more restrictive provisions for bend tests.

R3.5.3.2 — ASTM A 615 includes provisions for Grade 75 bars in sizes No. 6 through 18.

The 0.35 percent strain limit is necessary to ensure that the assumption of an elasto-plastic stress-strain curve in 10.2.4 will not lead to unconservative values of the member strength.

The 0.35 strain requirement is not applied to reinforcing bars having yield strengths of 60,000 psi or less. For steels having strengths of 40,000 psi, as were once used extensively, the assumption of an elasto-plastic stress-strain curve is well justified by extensive test data. For higher strength steels, up to 60,000 psi, the stress-strain curve may or may not be elasto-plastic as assumed in 10.2.4, depending on the properties of the steel and the manufacturing process. However, when the stress-strain curve is not elasto-plastic, there is limited experimental evidence to suggest that the actual steel stress at ultimate strength may not be enough less than the specified yield strength to warrant the additional effort of testing to the more restrictive criterion applicable to steels having f_y greater than 60,000 psi. In such cases, the f-factor can be expected to account for the strength deficiency.

R3.5.3.5 — Welded plain wire fabric should be made of wire conforming to "Specification for Steel Wire, Plain, for Concrete Reinforcement" (ASTM A 82). ASTM A 82 has a minimum yield strength of 70,000 psi. The code has assigned a yield strength value of 60,000 psi, but makes provision for the use of higher yield strengths provided the stress corresponds to a strain of 0.35 percent.

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3.5.3.6 — Welded deformed wire fabric for concrete reinforcement shall conform to "Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement" (ASTM A 497), except that for wire with a specified yield strength f_y exceeding 60,000 psi, f_y shall be the stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi. Welded intersections shall not be spaced farther apart than 16 in. in direction of calculated stress, except for wire fabric used as stirrups in accordance with 12.13.2.

3.5.3.7 — Galvanized reinforcing bars shall comply with "Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement" (ASTM A 767). Epoxy-coated reinforcing bars shall comply with "Specification for Epoxy-Coated Reinforcing Steel Bars" (ASTM A 775) or with "Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars" (ASTM A 934). Bars to be galvanized or epoxy-coated shall conform to one of the specifications listed in 3.5.3.1.

3.5.3.8 — Epoxy-coated wires and welded wire fabric shall comply with "Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement" (ASTM A 884). Wires to be epoxy-coated shall conform to 3.5.3.4 and welded wire fabric to be epoxy-coated shall conform to 3.5.3.5 or 3.5.3.6.

3.5.4 — Plain reinforcement

3.5.4.1 — Plain bars for spiral reinforcement shall conform to the specification listed in 3.5.3.1(a) or (b).

3.5.4.2 — Plain wire for spiral reinforcement shall conform to "Specification for Steel Wire, Plain, for Concrete Reinforcement" (ASTM A 82), except that for wire with a specified yield strength f_y exceeding 60,000 psi, f_y shall be the stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi.

3.5.5 — Prestressing steel

3.5.5.1 — Steel for prestressing shall conform to one of the following specifications:

(a) Wire conforming to "Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete" (ASTM A 421);

(b) Low-relaxation wire conforming to "Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete" including Supplement "Low-Relaxation Wire" (ASTM A 421);

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R3.5.3.6 — Welded deformed wire fabric should be made of wire conforming to "Specification for Steel Wire, Deformed, for Concrete Reinforcement" (ASTM A 496). ASTM A 496 has a minimum yield strength of 70,000 psi. The code has assigned a yield strength value of 60,000 psi, but makes provision for the use of higher yield strengths provided the stress corresponds to a strain of 0.35 percent.

R3.5.3.7 — Galvanized reinforcing bars (A 767) and epoxy-coated reinforcing bars (A 775) were added to the 1983 code, and epoxy-coated prefabricated reinforcing bars (A 934) were added to the 1995 code recognizing their usage, especially for conditions where corrosion resistance of reinforcement is of particular concern. They have typically been used in parking decks, bridge decks, and other highly corrosive environments.

R3.5.4 — Plain reinforcement

Plain bars and plain wire are permitted only for spiral reinforcement (either as lateral reinforcement for compression members, for torsion members, or for confining reinforcement for splices).

R3.5.5 — Prestressing steel

R3.5.5.1 — Because low-relaxation prestressing steel is addressed in a supplement to ASTM A 421, which applies only when low-relaxation material is specified, the appropriate ASTM reference is listed as a separate entity.

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(c) Strand conforming to "Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete" (ASTM A 416);

(d) Bar conforming to "Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete" (ASTM A 722).

3.5.5.2 — Wire, strands, and bars not specifically listed in ASTM A 421, A 416, or A 722 are allowed provided they conform to minimum requirements of these specifications and do not have properties that make them less satisfactory than those listed in ASTM A 421, A 416, or A 722.

3.5.6 — Structural steel, steel pipe, or tubing

3.5.6.1 — Structural steel used with reinforcing bars in composite compression members meeting requirements of 10.16.7 or 10.16.8 shall conform to one of the following specifications:

(a) "Specification for Carbon Structural Steel" (ASTM A 36);

(b) "Specification for High-Strength Low-Alloy Structural Steel" (ASTM A 242);

(c) "Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel" (ASTM A 572);

(d) "Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick" (ASTM A 588).

3.5.6.2 — Steel pipe or tubing for composite compression members composed of a steel encased concrete core meeting requirements of 10.16.6 shall conform to one of the following specifications:

(a) Grade B of "Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless" (ASTM A 53);

(b) "Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes" (ASTM A 500);

(c) "Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing" (ASTM A 501).

3.6 — Admixtures

3.6.1 — Admixtures to be used in concrete shall be subject to prior approval by the engineer.

COMMENTARY

R3.6 — Admixtures

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3.6.2 — An admixture shall be shown capable of maintaining essentially the same composition and performance throughout the work as the product used in establishing concrete proportions in accordance with 5.2.

3.6.3 — Calcium chloride or admixtures containing chloride from other than impurities from admixture ingredients shall not be used in prestressed concrete, in concrete containing embedded aluminum, or in concrete cast against stay-in-place galvanized steel forms. See 4.3.2 and 4.4.1.

3.6.4 — Air-entraining admixtures shall conform to "Specification for Air-Entraining Admixtures for Concrete" (ASTM C 260).

3.6.5 — Water-reducing admixtures, retarding admixtures, accelerating admixtures, water-reducing and retarding admixtures, and water-reducing and accelerating admixtures shall conform to "Specification for Chemical Admixtures for Concrete" (ASTM C 494) or "Specification for Chemical Admixtures for Use in Producing Flowing Concrete" (ASTM C 1017).

3.6.6 — Fly ash or other pozzolans used as admixtures shall conform to "Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete" (ASTM C 618).

3.6.7 — Ground granulated blast-furnace slag used as an admixture shall conform to "Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars" (ASTM C 989).

COMMENTARY

R3.6.3 — Admixtures containing any chloride, other than impurities from admixture ingredients, should not be used in prestressed concrete or in concrete with aluminum embedments. Concentrations of chloride ion may produce corrosion of embedded aluminum (e.g., conduit), especially if the aluminum is in contact with embedded steel and the concrete is in a humid environment. Serious corrosion of galvanized steel sheet and galvanized steel stay-in-place forms occurs, especially in humid environments or where drying is inhibited by the thickness of the concrete or coatings or impermeable coverings. See 4.4.1 for specific limits on chloride ion concentration in concrete.

R3.6.7 — Ground granulated blast-furnace slag conforming to ASTM C 989 is used as an admixture in concrete in much the same way as fly ash. Generally, it should be used with portland cements conforming to ASTM C 150, and only rarely would it be appropriate to use ASTM C 989 slag with an ASTM C 595 blended cement that already contains a pozzolan or slag. Such use with ASTM C 595 cements might be considered for massive concrete placements where slow strength gain can be tolerated and where low heat of hydration is of particular importance. ASTM C 989 includes appendices which discuss effects of ground granulated blast-furnace slag on concrete strength, sulfate resistance, and alkali-aggregate reaction.

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3.6.8 — Admixtures used in concrete containing C 845 expansive cements shall be compatible with the cement and produce no deleterious effects.

3.6.9 — Silica fume used as an admixture shall conform to ASTM C 1240.

3.7 — Storage of materials

3.7.1 — Cementitious materials and aggregates shall be stored in such manner as to prevent deterioration or intrusion of foreign matter.

3.7.2 — Any material that has deteriorated or has been contaminated shall not be used for concrete.

3.8 — Referenced standards

3.8.1 — Standards of the American Society for Testing and Materials referred to in this code are listed below with their serial designations, including year of adoption or revision, and are declared to be part of this code as if fully set forth herein:

A 36/ A 36M-00a	Standard Specification for Carbon Structural Steel
A 53/ A 53M-99b	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A 82-97a	Standard Specification for Steel Wire, Plain, for Concrete Reinforcement
A 108-99	Standard Specification for Steel Bars, Carbon, Cold-Finished, Standard Quality
A 184/ A 184M-96	Standard Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
A 185-97	Standard Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement
A 242/ A 242M-00a	Standard Specification for High-Strength Low-Alloy Structural Steel
A 307-97	Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength
A 416/ A 416M-99	Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete

COMMENTARY

R3.6.8 — The use of admixtures in concrete containing C 845 expansive cements has reduced levels of expansion or increased shrinkage values. See ACI 223.[3.3]

R3.8 — Referenced standards

The ASTM standard specifications listed are the latest editions at the time these code provisions were adopted. Since these specifications are revised frequently, generally in minor details only, the user of the code should check directly with the sponsoring organization if it is desired to reference the latest edition. However, such a procedure obligates the user of the specification to evaluate if any changes in the later edition are significant in the use of the specification.

Standard specifications or other material to be legally adopted by reference into a building code should refer to a specific document. This can be done by simply using the complete serial designation since the first part indicates the subject and the second part the year of adoption. All standard documents referenced in this code are listed in 3.8, with the title and complete serial designation. In other sections of the code, the designations do not include the date so that all may be kept up-to-date by simply revising 3.8.

ASTM standards are available from ASTM, 100 Barr Harbor Drive, West Conshohocken, Pa., 19428.

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A 421/ A 421M-98a	Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete
A 496-97a	Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement
A 497-99	Standard Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement
A 500-99	Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
A 501-99	Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing
A 572/ A 572M-00	Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
A 588/ A 588M-00	Standard Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick
A 615/ A 615M-00	Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
A 706/ A 706M-00	Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A 722/ A 722M-98	Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete
A 767/ A 767M-00b	Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
A 775/ A 775M-00	Standard Specification for Epoxy-Coated Steel Reinforcing Bars
A 884/ A 884M-99	Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement
A 934/ A 934M-00	Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
A 996/ A 996M-00	Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

Type R rail-steel bars are considered a mandatory requirement whenever ASTM A 996 is referenced in the code.

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C 31/ C 31M-98	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 33-99a$^{\varepsilon 1}$	Standard Specification for Concrete Aggregates
C 39/ C 39M-99	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 42/ C 42M-99	Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C 94/ C 94M-00	Standard Specification of Ready-Mixed Concrete
C 109/ C 109M-99	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)
C 144-99	Standard Specification for Aggregate for Masonry Mortar
C 150-99a	Standard Specification for Portland Cement
C 172-99	Standard Practice for Sampling Freshly-Mixed Concrete
C 192/ C 192M-98	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 260-00	Standard Specification for Air-Entraining Admixtures for Concrete
C 330-99	Standard Specification for Lightweight Aggregates for Structural Concrete
C 494/ C 494M-99a	Standard Specification for Chemical Admixtures for Concrete
C 496-96	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
C 567-99a	Standard Test Method for Density of Structural Lightweight Concrete
C 595-00	Standard Specification for Blended Hydraulic Cements
C 618-99	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete

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C 685-98a	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
C 845-96	Standard Specification for Expansive Hydraulic Cement
C 989-99	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
C 1017/ C 1017M-98	Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C 1157-00	Standard Performance Specification for Hydraulic Cement
C 1218/ C 1218M-99	Standard Test Method for Water-Soluble Chloride in Mortar and Concrete
C 1240-00$^{\varepsilon 1}$	Standard Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout

3.8.2 — "Structural Welding Code—Reinforcing Steel" (ANSI/AWS D1.4-98) of the American Welding Society is declared to be part of this code as if fully set forth herein.

3.8.3 — Section 2.3 Combining Factored Loads Using Strength Design of "Minimum Design Loads for Buildings and Other Structures" (ASCE 7-98) is declared to be part of this code as if fully set forth herein, for the purpose cited in 9.2.4.

3.8.4 — "Specification for Unbonded Single Strand Tendons (ACI 423.6-01) and Commentary (423.6R-01)" is declared to be part of this code as if fully set forth herein.

3.8.5 — 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 16th Edition, 1996) are declared to be a part of this code as if fully set forth herein.

3.8.6 — "Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-01)" is declared to be part of this code as if fully set forth herein, for the purpose cited in Appendix D.

COMMENTARY

R3.8.3 — ASCE 7 is available from ASCE Book Orders, Box 79404, Baltimore, Md., 21279-0404.

R3.8.5 — The 1996 16th Edition of the AASHTO "Standard Specification for Highway Bridges" is available from AASHTO, 444 North Capitol Street, N.W., Suite 249, Washington, D.C., 20001.

R3.8.6 — Parallel to development of the ACI 318-02 provisions for anchoring to concrete, ACI 355 developed a test method to define the level of performance required for post-installed anchors. This test method, ACI 355.2, contains requirements for the testing and evaluation of post-installed anchors for both cracked and uncracked concrete applications.

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3.8.7 — "Structural Welding Code—Steel (AWS D 1.1:2000)" of the American Welding Society is declared to be part of this code as if fully set forth herein.

3.8.8 — "Acceptance Criteria for Moment Frames Based on Structural Testing (ACI T1.1-01)," is declared to be part of this code as if fully set forth herein.

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PART 3 — CONSTRUCTION REQUIREMENTS

CHAPTER 4 — DURABILITY REQUIREMENTS

CODE

4.0 — Notation

f_c' = specified compressive strength of concrete, psi

COMMENTARY

Chapters 4 and 5 of earlier editions of the code were reformatted in 1989 to emphasize the importance of considering durability requirements before the designer selects f_c' and cover over the reinforcing steel.

Maximum water-cementitious materials ratios of 0.40 to 0.50 that may be required for concretes exposed to freezing and thawing, sulfate soils or waters, or for preventing corrosion of reinforcement will typically be equivalent to requiring an f_c' of 5000 to 4000 psi, respectively. Generally, the required average concrete strengths, f_{cr}', will be 500 to 700 psi higher than the specified compressive strength, f_c'. Since it is difficult to accurately determine the water-cementitious materials ratio of concrete during production, the f_c' specified should be reasonably consistent with the water-cementitious materials ratio required for durability. Selection of an f_c' that is consistent with the water-cementitious materials ratio selected for durability will help ensure that the required water-cementitious materials ratio is actually obtained in the field. Because the usual emphasis on inspection is for strength, test results substantially higher than the specified strength may lead to a lack of concern for quality and production of concrete that exceeds the maximum water-cementitious materials ratio. Thus an f_c' of 3000 psi and a maximum water-cementitious materials ratio of 0.45 should not be specified for a parking structure, if the structure will be exposed to deicing salts.

The code does not include provisions for especially severe exposures, such as acids or high temperatures, and is not concerned with aesthetic considerations such as surface finishes. These items are beyond the scope of the code and should be covered specifically in the project specifications. Concrete ingredients and proportions are to be selected to meet the minimum requirements stated in the code and the additional requirements of the contract documents.

4.1 — Water-cementitious materials ratio

4.1.1 — The water-cementitious materials ratios specified in Tables 4.2.2 and 4.3.1 shall be calculated using the weight of cement meeting ASTM C 150, C 595, C 845, or C 1157 plus the weight of fly ash and other pozzolans meeting ASTM C 618, slag meeting ASTM C 989, and silica fume meeting ASTM C 1240, if any, except that when concrete is exposed to deicing chemicals, 4.2.3 further limits the amount of fly ash, pozzolans, silica fume, slag, or the combination of these materials.

R4.1 — Water-cementitious materials ratio

R4.1.1 — For concrete exposed to deicing chemicals the quantity of fly ash, other pozzolans, silica fume, slag, or blended cements used in the concrete is subject to the percentage limits in 4.2.3. Further, in 4.3 for sulfate exposures,[4.1] the pozzolan should be Class F by ASTM C 618, or have been tested by ASTM C 1012[4.2] or determined by service record to improve sulfate resistance.

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4.2 — Freezing and thawing exposures

4.2.1 — Normalweight and lightweight concrete exposed to freezing and thawing or deicing chemicals shall be air-entrained with air content indicated in Table 4.2.1. Tolerance on air content as delivered shall be ± 1.5 percent. For specified compressive strength f'_c greater than 5000 psi, reduction of air content indicated in Table 4.2.1 by 1.0 percent shall be permitted.

TABLE 4.2.1—TOTAL AIR CONTENT FOR FROST-RESISTANT CONCRETE

Nominal maximum aggregate size, in.*	Air content, percent	
	Severe exposure	Moderate exposure
3/8	7.5	6
1/2	7	5.5
3/4	6	5
1	6	4.5
1-1/2	5.5	4.5
2†	5	4
3†	4.5	3.5

* See ASTM C 33 for tolerance on oversize for various nominal maximum size designations.

† These air contents apply to total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than 1-1/2 in. is removed by handpicking or sieving and air content is determined on the minus 1-1/2 in. fraction of mix (tolerance on air content as delivered applies to this value.). Air content of total mix is computed from value determined on the minus 1-1/2 in. fraction.

4.2.2 — Concrete that will be subject to the exposures given in Table 4.2.2 shall conform to the corresponding maximum water-cementitious materials ratios and minimum specified concrete compressive strength requirements of that table. In addition, concrete that will be exposed to deicing chemicals shall conform to the limitations of 4.2.3.

TABLE 4.2.2—REQUIREMENTS FOR SPECIAL EXPOSURE CONDITIONS

Exposure condition	Maximum water-cementitious materials ratio*, by weight, normalweight aggregate concrete	Minimum f'_c, normalweight and lightweight aggregate concrete, psi*
Concrete intended to have low permeability when exposed to water	0.50	4000
Concrete exposed to freezing and thawing in a moist condition or to deicing chemicals	0.45	4500
For corrosion protection of reinforcement in concrete exposed to chlorides from deicing chemicals, salt, salt water, brackish water, seawater, or spray from these sources.	0.40	5000

* When both Table 4.3.1 and Table 4.2.2 are considered, the lowest applicable maximum *w/cm* and highest applicable minimum f'_c shall be used.

COMMENTARY

R4.2 — Freezing and thawing exposures

R4.2.1 — A table of required air contents for frost-resistant concrete is included in the code, based on **"Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete"** (ACI 211.1).[4.3] Values are provided for both severe and moderate exposures depending on the exposure to moisture or deicing salts. Entrained air will not protect concrete containing coarse aggregates that undergo disruptive volume changes when frozen in a saturated condition. In Table 4.2.1, a severe exposure is where the concrete in a cold climate may be in almost continuous contact with moisture prior to freezing, or where deicing salts are used. Examples are pavements, bridge decks, sidewalks, parking garages, and water tanks. A moderate exposure is where the concrete in a cold climate will be only occasionally exposed to moisture prior to freezing, and where no deicing salts are used. Examples are certain exterior walls, beams, girders, and slabs not in direct contact with soil. Section 4.2.1 permits 1 percent lower air content for concrete with f'_c greater than 5000 psi. Such high-strength concretes will have lower water-cementitious materials ratios and porosity and, therefore, improved frost resistance.

R4.2.2 — Maximum water-cementitious materials ratios are not specified for lightweight aggregate concrete because determination of the absorption of these aggregates is uncertain, making calculation of the water-cementitious materials ratio uncertain. The use of a minimum specified strength will ensure the use of a high-quality cement paste. For normalweight aggregate concrete, use of both minimum strength and maximum water-cementitious materials ratio provide additional assurance that this objective is met.

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4.2.3 — For concrete exposed to deicing chemicals, the maximum weight of fly ash, other pozzolans, silica fume, or slag that is included in the concrete shall not exceed the percentages of the total weight of cementitious materials given in Table 4.2.3.

TABLE 4.2.3—REQUIREMENTS FOR CONCRETE EXPOSED TO DEICING CHEMICALS

Cementitious materials	Maximum percent of total cementitious materials by weight*
Fly ash or other pozzolans conforming to ASTM C 618	25
Slag conforming to ASTM C 989	50
Silica fume conforming to ASTM C 1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50†
Total of fly ash or other pozzolans and silica fume	35†

* The total cementitious material also includes ASTM C 150, C 595, C 845, and C 1157 cement.
The maximum percentages above shall include:
(a) Fly ash or other pozzolans present in Type IP or I(PM) blended cement, ASTM C 595, or ASTM C 1157;
(b) Slag used in the manufacture of a IS or I(SM) blended cement, ASTM C 595, or ASTM C 1157;
(c) Silica fume, ASTM C 1240, present in a blended cement.
† Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

COMMENTARY

R4.2.3 — Section 4.2.3 and Table 4.2.3 establish limitations on the amount of fly ash, other pozzolans, silica fume, and slag that can be included in concrete exposed to deicing chemicals.[4.4-4.6] Recent research has demonstrated that the use of fly ash, slag, and silica fume produce concrete with a finer pore structure and, therefore, lower permeability.[4.7-4.9]

4.3 — Sulfate exposures

4.3.1 — Concrete to be exposed to sulfate-containing solutions or soils shall conform to requirements of Table 4.3.1 or shall be concrete made with a cement that provides sulfate resistance and that has a maximum water-cementitious materials ratio and minimum compressive strength from Table 4.3.1.

R4.3 — Sulfate exposures

R4.3.1 — Concrete exposed to injurious concentrations of sulfates from soil and water should be made with a sulfate-resisting cement. Table 4.3.1 lists the appropriate types of cement and the maximum water-cementitious materials ratios and minimum strengths for various exposure conditions. In selecting a cement for sulfate resistance, the principal consideration is its tricalcium aluminate (C_3A) content. For moderate exposures, Type II cement is limited to a maximum C_3A content of 8.0 percent under ASTM C 150. The blended cements under ASTM C 595 with the MS designation are appropriate for use in moderate sulfate exposures. The appropriate types under ASTM C 595 are IP(MS), IS(MS), I(PM)(MS), and I(SM)(MS). For severe exposures, Type V cement with a maximum C_3A content of 5 percent is specified. In certain areas, the C_3A content of other avail-

TABLE 4.3.1—REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-CONTAINING SOLUTIONS

Sulfate exposure	Water soluble sulfate (SO_4) in soil, percent by weight	Sulfate (SO_4) in water, ppm	Cement type	Maximum water-cementitious materials ratio, by weight, normalweight aggregate concrete*	Minimum f'_c, normalweight and lightweight aggregate concrete, psi*
Negligible	$0.00 \le SO_4 < 0.10$	$0 \le SO_4 < 150$	—	—	—
Moderate†	$0.10 \le SO_4 < 0.20$	$150 \le SO_4 < 1500$	II, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	4000
Severe	$0.20 \le SO_4 \le 2.00$	$1500 \le SO_4 \le 10{,}000$	V	0.45	4500
Very severe	$SO_4 > 2.00$	$SO_4 > 10{,}000$	V plus pozzolan‡	0.45	4500

* When both Table 4.3.1 and Table 4.2.2 are considered, the lowest applicable maximum *w/cm* and highest applicable minimum f'_c shall be used.
† Seawater.
‡ Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.

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able types such as Type III or Type I may be less than 8 or 5 percent and are usable in moderate or severe sulfate exposures. Note that sulfate-resisting cement will not increase resistance to some chemically aggressive solutions, for example ammonium nitrate. The project specifications should cover all special cases.

Using fly ash (ASTM C 618, Class F) also has been shown to improve the sulfate resistance of concrete.[4.9] Certain Type IP cements made by blending Class F pozzolan with portland cement having a C_3A content greater than 8 percent can provide sulfate resistance for moderate exposures.

A note to Table 4.3.1 lists seawater as moderate exposure, even though it generally contains more than 1500 ppm SO_4. In seawater exposures, other types of cement with C_3A up to 10 percent may be used if the maximum water-cementitious materials ratio is reduced to 0.40.

ASTM test method C 1012[4.2] can be used to evaluate the sulfate resistance of mixtures using combinations of cementitious materials.

In addition to the proper selection of cement, other requirements for durable concrete exposed to concentrations of sulfate are essential, such as, low water-cementitious materials ratio, strength, adequate air entrainment, low slump, adequate consolidation, uniformity, adequate cover of reinforcement, and sufficient moist curing to develop the potential properties of the concrete.

4.3.2 — Calcium chloride as an admixture shall not be used in concrete to be exposed to severe or very severe sulfate-containing solutions, as defined in Table 4.3.1.

4.4 — Corrosion protection of reinforcement

4.4.1 — For corrosion protection of reinforcement in concrete, maximum water soluble chloride ion concentrations in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall not exceed the limits of Table 4.4.1. When testing is performed to determine water soluble chloride ion content, test procedures shall conform to ASTM C 1218.

R4.4 — Corrosion protection of reinforcement

R4.4.1 — Additional information on the effects of chlorides on the corrosion of reinforcing steel is given in **"Guide to Durable Concrete"** reported by ACI Committee 201[4.10] and **"Corrosion of Metals in Concrete"** reported by ACI Committee 222.[4.11] Test procedures should conform to those given in ASTM C 1218. An initial evaluation may be obtained by testing individual concrete ingredients for total chloride ion content. If total chloride ion content, calculated on the basis of concrete proportions, exceeds those permitted in Table 4.4.1, it may be necessary to test samples of the hardened concrete for water soluble chloride ion content described in the ACI 201 guide. Some of the total chloride ions present in the ingredients will either be insoluble or will react with the cement during hydration and become insoluble under the test procedures described in ASTM C 1218.

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TABLE 4.4.1—MAXIMUM CHLORIDE ION CONTENT FOR CORROSION PROTECTION OF REINFORCEMENT

Type of member	Maximum water soluble chloride ion (Cl^-) in concrete, percent by weight of cement
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

4.4.2 — If concrete with reinforcement will be exposed to chlorides from deicing chemicals, salt, salt water, brackish water, seawater, or spray from these sources, requirements of Table 4.2.2 for water-cementitious materials ratio and concrete strength, and the minimum concrete cover requirements of 7.7 shall be satisfied. See 18.16 for unbonded tendons.

COMMENTARY

When concretes are tested for soluble chloride ion content the tests should be made at an age of 28 to 42 days. The limits in Table 4.4.1 are to be applied to chlorides contributed from the concrete ingredients, not those from the environment surrounding the concrete.

The chloride ion limits in Table 4.4.1 differ from those recommended in ACI 201.2R[4.10] and ACI 222R.[4.11] For reinforced concrete that will be dry in service, a limit of 1 percent has been included to control total soluble chlorides. Table 4.4.1 includes limits of 0.15 and 0.30 percent for reinforced concrete that will be exposed to chlorides or will be damp in service, respectively. These limits compare to 0.10 and 0.15 recommended in ACI 201.2R.[4.10] ACI 222R[4.11] recommends limits of 0.08 and 0.20 percent by weight of cement for chlorides in prestressed and reinforced concrete, respectively, based on tests for acid soluble chlorides, not the test for water soluble chlorides required here.

When epoxy or zinc-coated bars are used, the limits in Table 4.4.1 may be more restrictive than necessary.

R4.4.2 — When concretes are exposed to external sources of chlorides, the water-cementitious materials ratio and specified compressive strength f'_c of 4.2.2 are the minimum requirements that are to be considered. The designer should evaluate conditions in structures where chlorides may be applied, in parking structures where chlorides may be tracked in by vehicles, or in structures near seawater. Epoxy- or zinc-coated bars or cover greater than the minimum required in 7.7 may be desirable. Use of slag meeting ASTM C 989 or fly ash meeting ASTM C 618 and increased levels of specified strength provide increased protection. Use of silica fume meeting ASTM C 1240 with an appropriate high-range water reducer, ASTM C 494, Types F and G, or ASTM C 1017 can also provide additional protection.[4.12] The use of ASTM C 1202[4.13] to test concrete mixtures proposed for use will provide additional information on the performance of the mixtures.

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CHAPTER 5 — CONCRETE QUALITY, MIXING, AND PLACING

CODE

5.0 — Notation

f_c' = specified compressive strength of concrete, psi
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
s = standard deviation, psi

5.1 — General

5.1.1 — Concrete shall be proportioned to provide an average compressive strength as prescribed in 5.3.2 and shall satisfy the durability criteria of Chapter 4. Concrete shall be produced to minimize the frequency of strengths below f_c', as prescribed in 5.6.3.3. For concrete designed and constructed in accordance with the code, f_c' shall not be less than 2500 psi.

5.1.2 — Requirements for f_c' shall be based on tests of cylinders made and tested as prescribed in 5.6.3.

5.1.3 — Unless otherwise specified, f_c' shall be based on 28-day tests. If other than 28 days, test age for f_c' shall be as indicated in design drawings or specifications.

5.1.4 — Where design criteria in 9.5.2.3, 11.2, and 12.2.4 provide for use of a splitting tensile strength value of concrete, laboratory tests shall be made in accordance with "Specification for Lightweight Aggregates for Structural Concrete" (ASTM C 330) to establish value of f_{ct} corresponding to specified value of f_c'.

5.1.5 — Splitting tensile strength tests shall not be used as a basis for field acceptance of concrete.

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The requirements for proportioning concrete mixtures are based on the philosophy that concrete should provide both adequate durability (Chapter 4) and strength. The criteria for acceptance of concrete are based on the philosophy that the code is intended primarily to protect the safety of the public. Chapter 5 describes procedures by which concrete of adequate strength can be obtained, and provides procedures for checking the quality of the concrete during and after its placement in the work.

Chapter 5 also prescribes minimum criteria for mixing and placing concrete.

The provisions of 5.2, 5.3, and 5.4, together with Chapter 4, establish required mixture proportions. The basis for determining the adequacy of concrete strength is in 5.6.

R5.1 — General

R5.1.1 — The basic premises governing the designation and evaluation of concrete strength are presented. It is emphasized that the average strength of concrete produced should always exceed the specified value of f_c' used in the structural design calculations. This is based on probabilistic concepts, and is intended to ensure that adequate concrete strength will be developed in the structure. The durability requirements prescribed in Chapter 4 are to be satisfied in addition to attaining the average concrete strength in accordance with 5.3.2.

R5.1.4 — Sections 9.5.2.3 (modulus of rupture), 11.2 (concrete shear strength) and 12.2.4 (development of reinforcement) require modification in the design criteria for the use of lightweight aggregate concrete. Two alternative modification procedures are provided. One alternative is based on laboratory tests to determine the relationship between splitting tensile strength f_{ct} and specified compressive strength f_c' for the lightweight concrete. For a lightweight aggregate from a given source, it is intended that appropriate values of f_{ct} be obtained in advance of design.

R5.1.5 — Tests for splitting tensile strength of concrete (as required by 5.1.4) are not intended for control of, or acceptance of, the strength of concrete in the field. Indirect control will

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be maintained through the normal compressive strength test requirements provided by 5.6.

5.2 — Selection of concrete proportions

R5.2 — Selection of concrete proportions

Recommendations for selecting proportions for concrete are given in detail in **"Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete"** (ACI 211.1).[5.1] (Provides two methods for selecting and adjusting proportions for normalweight concrete: the estimated weight and absolute volume methods. Example calculations are shown for both methods. Proportioning of heavyweight concrete by the absolute volume method is presented in an appendix.)

Recommendations for lightweight concrete are given in **"Standard Practice for Selecting Proportions for Structural Lightweight Concrete"** (ACI 211.2).[5.2] (Provides a method of proportioning and adjusting structural grade concrete containing lightweight aggregates.)

5.2.1 — Proportions of materials for concrete shall be established to provide:

(a) Workability and consistency to permit concrete to be worked readily into forms and around reinforcement under conditions of placement to be employed, without segregation or excessive bleeding;

(b) Resistance to special exposures as required by Chapter 4;

(c) Conformance with strength test requirements of 5.6.

R5.2.1 — The selected water-cementitious materials ratio should be low enough, or in the case of lightweight concrete the compressive strength high enough to satisfy both the strength criteria (see 5.3 or 5.4) and the special exposure requirements (Chapter 4). The code does not include provisions for especially severe exposures, such as acids or high temperatures, and is not concerned with aesthetic considerations such as surface finishes. These items are beyond the scope of the code and should be covered specifically in the project specifications. Concrete ingredients and proportions are to be selected to meet the minimum requirements stated in the code and the additional requirements of the contract documents.

5.2.2 — Where different materials are to be used for different portions of proposed work, each combination shall be evaluated.

5.2.3 — Concrete proportions shall be established in accordance with 5.3 or, alternatively, 5.4, and shall meet applicable requirements of Chapter 4.

R5.2.3 — The code emphasizes the use of field experience or laboratory trial mixtures (see 5.3) as the preferred method for selecting concrete mixture proportions.

5.3 — Proportioning on the basis of field experience or trial mixtures, or both

R5.3 — Proportioning on the basis of field experience or trial mixtures, or both

In selecting a suitable concrete mixture there are three basic steps. The first is the determination of the standard deviation. The second is the determination of the required average strength. The third is the selection of mixture proportions required to produce that average strength, either by conventional trial mixture procedures or by a suitable experience record. Fig. R5.3 is a flow chart outlining the mixture selection and documentation procedure.

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