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CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES AND COMMENTARY (ACI 350-06)

REPORTED BY ACI COMMITTEE 350

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REPORTED BY ACI COMMITTEE 350

The code portion of this document covers the structural design, materials selection, and construction of environmental engineering concrete structures. Such structures are used for conveying, storing, or treating liquid or other materials such as solid waste. They include ancillary structures for dams, spill-ways, and channels.

They are subject to uniquely different loadings, more severe exposure conditions, and more restrictive serviceability requirements than non-environmental building structures.

Loadings include normal dead and live loads and vibrating equipment or hydrodynamic forces. Exposures include concentrated chemicals, alternate wetting and drying, and freezing and thawing of saturated concrete. Serviceability requirements include liquid-tightness or gas-tightness.

Typical structures include conveyance, storage, and treatment structures.

Proper design, materials, and construction of environmental engineering concrete structures are required to produce serviceable concrete that is dense, durable, nearly impermeable, and resistant to chemicals, with limited deflections and cracking. Leakage must be controlled to minimize contamination of ground water or the environment, to minimize loss of product or infiltration, and to promote durability.

This code presents new material as well as modified portions of the ACI 318-02 Building Code that are applicable to environmental engineering concrete structures.

Because ACI 350-06 is written as a legal document, it may be adopted by reference in a general building code or in regulations governing the design and construction of environmental engineering concrete structures. Thus, it cannot present background details or suggestions for carrying out its requirements or intent. It is the function of the commentary to fill this need.

ACI 350-06 was adopted as a standard of the American Concrete Institute on July 3, 2006 to supersede ACI 350/350R-01 in accordance with the Institute's standardization procedure.

ACI Committee Reports, Guides, 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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The 2006 "Code Requirements for Environmental Engineering Concrete Structures 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.

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.

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

The chapter and section numbering of the code are followed throughout the commentary.

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

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

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

INTRODUCTION

The code and commentary includes excerpts from ACI 318-02 that are pertinent to ACI 350. The commentary discusses some of the considerations of Committee ACI 350 in developing "Code Requirements for Environmental Engineering Concrete Structures (ACI 350-06)," hereinafter called the code. Emphasis is given to the explanation of provisions that may be unfamiliar to users of the standard. Comments on specific provisions are made under the corresponding chapter and section numbers of the code and commentary.

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

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

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

Requirements more stringent than the code provisions may be desirable for unusual structures. This code and this commentary cannot replace sound engineering knowledge, experience, and judgment.

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

ACI 350 has no legal status unless it is adopted by government bodies having the power to regulate building design and construction. Where the code has not been adopted, it may serve as a reference to good practice.

The code provides a means of establishing minimum standards for acceptance of design and construction by a legally appointed building official or 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 ACI 350 in the job specifications should be avoided, since the contractor is rarely in a position to accept responsibility for design

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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 ACI 301, "Specifications for Structural Concrete," are written specifically for use as contract documents for construction.

Committee 350 recognizes the desirability of standards of performance for individual parties involved in the contract documents. Available for this purpose are the certification programs of the American Concrete Institute, the plant certification programs of the Precast/Prestressed Concrete Institute, the National Ready Mixed Concrete Association, and the qualification standards of the American Society of Concrete Constructors. Also available are "Standard Specification for Agencies Engaged in Construction Inspection and/or Testing" (ASTM E 329) and "Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation" (ASTM C 1077).

Design aids (general concrete design aids are listed in ACI 318-02):

"Rectangular Concrete Tanks," Portland Cement Association, Skokie, IL, 1994, 176 pp. (Presents data for design of rectangular tanks.)

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

"Concrete Manual," U.S. Department of Interior, Bureau of Reclamation, 8th edition, 1981, 627 pp. (Presents technical information for the control of concrete construction, including linings for tunnels, impoundments, and canals.)

GENERAL COMMENTARY

Because of stringent service requirements, environmental engineering concrete structures should be designed and detailed with care. The quality of concrete is important, and close quality control must be performed during construction to obtain impervious concrete.

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

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

a) The concrete mixture is well proportioned, well consolidated without segregation, and properly cured.
b) Crack widths and depths are minimized.
c) Joints are properly spaced, sized, designed, waterstopped, and constructed.
d) Adequate reinforcing steel is provided, properly detailed, fabricated, and placed.
e) Impervious protective coatings or barriers are used where required.

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

Minimum permeability of the concrete will be obtained by using water-cementitious materials ratios as low as possible, consistent with satisfactory workability and consolidation. Impermeability increases with the age of the concrete and is improved by extended periods of moist curing. Surface treatment is important and use of smooth forms or troweling improves impermeability. Air entrainment reduces segregation and bleeding, increases workability, and provides resistance to the effect of freeze-thaw cycles. Because of this, use of an air-entraining admixture results in better consolidated concrete. Other admixtures, such as water-reducing agents and pozzolans, are useful when they lead to increased workability and consolidation, and lower water-cementitious ratios. Pozzolans also reduce permeability.

Joint design should also account for movement resulting from thermal dimensional changes and differential settlements. Joints permitting movement along predetermined control planes, and which form a barrier to the passage of fluids, shall include waterstops in complete, closed circuits. Proper rate of concrete placement operations, adequate consolidation, and proper curing are also essential to control of cracking in environmental engineering concrete structures. Additional information on cracking is contained in ACI 224R and ACI 224.2R.

The design of the whole environmental engineering concrete structure as well as all individual members should be in accordance with ACI 350-06, which has been adapted from ACI 318-02. When all relevant loading conditions are considered, the design should provide adequate safety and serviceability, with a life expectancy of 50 to 60 years for the structural concrete. Some components of the structure, such as jointing materials, have a shorter life expectancy and will require maintenance or replacement.

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

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PART 1 — GENERAL

CHAPTER 1 — GENERAL REQUIREMENTS

CODE

1.1 — Scope

COMMENTARY

R1.1 — Scope

The American Concrete Institute **"Code Requirements for Environmental Engineering Concrete Structures (ACI 350-06),"** hereinafter referred to as the code, provide minimum requirements for environmental engineering concrete structural design and construction practices.

The 2006 edition of the code revised the previous code, "**Code Requirements of Environmental Engineering Concrete Structures (ACI 350-01)**." This code includes in one document the rules for all reinforced concrete used for environmental engineering structural purposes. This covers the spectrum of structural applications of concrete containing nonprestressed reinforcement, prestressing steel, or composite steel shapes, pipe, or tubing.

Prestressed concrete is included under the definition of reinforced concrete. Provisions of ACI 350-06 apply to prestressed concrete except in cases in which the provisions of the code 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.

Appendix I of the 2006 code, formerly Appendix A of the 2001 code, contains provisions for an alternate method of design for nonprestressed reinforced concrete members using service loads (without load factors) and permissible service load stresses. The strength design method of this code is intended to give design results similar to the Alternate Design Method.

Appendix A of the ACI 318-02 code has not yet been adopted for environmental engineering concrete structures. Applicability of strut-and-tie models to environmental structures may be addressed in future revisions to ACI 350.

Appendix B of the 2006 code contains provisions for reinforcement limits based on $\mathbf{0.75\rho_b}$, determination of the strength reduction factor $\boldsymbol{\phi}$, and moment redistribution that have been in the 318 codes for many years, including the 1999 318 code. The provisions are applicable to reinforced and prestressed concrete members. Designs made using the provisions of Appendix B are used in their entirety.

Appendix C of the 2006 code allows the use of load, environmental durability, strength reduction factors, and flexural reinforcement distribution provisions similar to those In Chapters 9 and 10 of ACI 350-01. Designs made using the provisions of Appendix C are equally acceptable for use

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CODE

1.1.1 — Except for primary containment of hazardous materials, this code provides minimum requirements for the design and construction of reinforced concrete structural elements of any environmental engineering concrete structure erected under the requirements of the legally adopted building code where this code has been adopted to be a part of such code. In areas without a legally adopted building code, this code defines minimum acceptable standards of design and construction practice.

For structural concrete, the specified concrete strength shall not be less than 4000 psi. No maximum specified compressive strength shall apply unless restricted by a specific code provision.

1.1.1.1 — Environmental engineering concrete structures are defined as concrete structures intended for conveying, storing, or treating water, wastewater, or other liquids and non-hazardous materials such as solid waste, and for secondary containment of hazardous liquids or solid waste. Ancillary structures for which liquid-tightness, gas-tightness, or enhanced durability are essential design considerations shall also conform to requirements of environmental engineering concrete structures. Precast concrete environmental structures designed and constructed in accordance with ASTM or AWWA standards, with the exception of circular tanks, are not covered in this code.

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

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

1.1.4 — The provisions of this code shall govern for tanks, reservoirs, and other reinforced concrete elements of any environmental engineering concrete structure. Special structures such as arches, bins and silos, blast-resistant structures, and chimneys are not covered in this code.

COMMENTARY

based on the body of the code, provided the provisions of Appendix C are used in their entirety.

Appendix D contains provisions for anchoring to concrete.

R1.1.1 — A hazardous material is defined as having one or more of the following characteristics: ignitable (NFPA 49), corrosive, reactive, or toxic. The Environmental Protection Agency (EPA)-listed wastes are organized into three categories under RCRA: source specific wastes, generic wastes, and commercial chemical products. Source specific wastes include sludges and wastewaters from treatment and production processes in specific industries such as petroleum refining and wood preserving. The list of generic wastes includes wastes from common manufacturing and industrial processes such as solvents used in degreasing operations. The third list contains specific chemical products such as benzine, creosote, mercury, and various pesticides.

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

R1.1.2 — 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, that general building code may modify some provisions of this code.

R1.1.4 — Environmental engineering projects can contain several types of structures. For example, a treatment plant can contain environmental engineering concrete structures such as tanks and reservoirs, as well and building structures. The ACI 350 code would apply to the environmental structures, while the ACI 318 code or the following ACI publications could apply to the other structures.

"Design and Construction of Reinforced Concrete Chimneys" reported by ACI Committee 307.[1.1] (Gives

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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.)

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

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

"Code Requirements for Nuclear Safety Related Concrete Structures" reported by ACI Committee 349.[1.3] (Provides minimum requirements for design and construction of concrete structures that form part of a nuclear power plant and which have nuclear safety related functions. The code does not cover concrete reactor vessels and concrete containment structures that are covered by ACI 359.)

"Code for Concrete Reactor Vessels and Containments" reported by Joint ACI-ASME Committee 359.[1.4] (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 and drilled piers 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.

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Recommendations for concrete piles are given in detail in **"Design, Manufacture, and Installation of Concrete Piles"** reported by ACI Committee 543.[1.5] (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.[1.6] (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.[1.7]

1.1.6 — This code governs the design and construction of soil-supported slabs as required by Appendix H. Slabs that transmit vertical loads from other portions of the structure to the soil shall meet the requirements of other chapters of this code as applicable.

R1.1.6 — Since tank floor slabs frequently directly transfer the loads from liquid contents to the soil below, Appendix H has been added to this code to provide appropriate requirements.

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, must 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).[1.8] 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 **"Standard Practice for the Construction and Inspection of Composite Slabs"** (ANSI/ASCE 9).[1.9]

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 ACI 318-71 Building Code and were continued without revision in ACI 318-77. 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 ACI 318-83 code edition to include new requirements for certain

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1.1.8.1 — In all regions of seismic risk, and all seismic performance or design categories, provisions of Chapter 21 shall be satisfied as described in 21.2.1.

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earthquake-resisting systems located in regions of moderate seismicity. In the 318-89 code, the special provisions were moved to Chapter 21.

R1.1.8.1 — Some structures and elements of structures will have their design governed by hydrodynamic forces, even when located in areas of low seismic risk, due to their configuration and position. Portions of Chapter 21 (21.2, 21.7, 21.8, and 21.9) apply to liquid-containing structures for all levels of seismic risk.

Aside from provisions given in 21.2, 21.7, 21.8, and 21.9, 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 environmental engineering concrete structures. It is the intent of this code that concrete structures proportioned by Chapters 1 to 18 of this code and the provisions given in 21.2, 21.7, 21.8, and 21.9 will provide a level of toughness adequate for low earthquake intensity.

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 earthquake effects require some 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 21 are considered to have sufficient toughness at anticipated drift levels for these structures.

For structures located in regions of high seismic risk, all structure components, structural and nonstructural, 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 provisions of Chapter 21 are intended to provide a monolithic reinforced concrete structure with adequate toughness to respond inelastically under severe earthquake motions. See also R21.2.1.

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1.1.8.2 — 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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R1.1.8.2 — Seismic risk levels (seismic zone maps) are under the jurisdiction of a general building code rather than ACI 350. This edition of ACI 350 adopts the changes in terminology made to the 1999 and 2002 editions of the 318 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)[1.10] and "Standard Building Code" (SBC),[1.11] which are based on the 1991 NEHRP,[1.12] 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)[1.13] also uses the two criteria of the NBC and SBC and also considers the effects of soil amplification on the ground motion when assigning a 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 R1.1.8.2 correlates low, moderate/intermediate, and high seismic risk, which has been the terminology used in the 318 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 350 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

TABLE R1.1.8.2—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.

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1.1.9 — For prestressed concrete environmental structures, Chapters 1 through 21 cover prestressing in general. Chapters 1 through 21 plus Appendix G cover the use of circular wire and strand wrapped prestressed concrete environmental structures.

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 licensed engineer or architect. These drawings, details, and specifications shall show:

(a) Name and date of issue of the applicable building code and supplement to which design conforms;

(b) Live load and other loads used in design;

(c) Specified compressive strength of concrete at stated ages or stages of construction for which each part of structure is designed;

(d) Specified strength or grade of reinforcement;

(e) Size and location of all structural elements and reinforcement and anchors;

(f) Provision for dimensional changes resulting from creep, shrinkage, and change in 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 welded splices and mechanical connections of reinforcement;

(j) The design liquid level for any structure designed to contain liquid;

(k) Stressing sequence for post-tensioning tendons;

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

(m) Design gas pressure for structural elements subjected to pressurized gas or liquid;

(n) Concrete properties and ingredients including type of cement, water-cementitious materials ratio, and, if allowed, admixtures, additives, and pozzolans;

(o) Additional requirements, such as limitations on drying shrinkage;

(p) Requirements for liquid-tightness testing, including liquid-tightness testing before backfilling.

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maps, such as recommended in References 1.9, 1.14, and 1.15, are suitable for correlating seismic risk.

R1.1.9 — Appendix G is incorporated to address those aspects of circular wrapped prestressed concrete environmental structures that are not directly covered within the main body of the code. Thus, Appendix G deals with items that are unique to circular wrapped prestressed structures, such as steel diaphragm, wrapped prestressing, and shotcrete.

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 must 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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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 requirements, concrete construction shall be inspected throughout the various work stages by or under the supervision of a licensed design professional or by a qualified inspector.

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

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. Such terms as "building commissioner" or "building inspector," however, are variations of the title, and the term "building official" as used in this code is intended to include those variations as well as others that are used in the same sense.

R1.3 — Inspection

The quality of concrete structures depends largely on workmanship in construction. The best of materials and design practice will not be effective unless the construction is performed well. Inspection is provided to assure satisfactory work in accordance with the design drawings and specifications. Proper performance of the structure depends on construction that accurately represents the design and meets code requirements within the tolerances allowed. In the public interest, local building ordinances should require the owner to provide inspections.

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

Qualified inspectors should establish their qualifications by becoming certified to inspect and record the results of concrete construction, including preplacement, placement, and postplacement operations through the Reinforced

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Concrete Special Inspection program sponsored by ACI, ICBO, BOCA, and SBCCI or equivalent.

When inspection is done independently of the licensed design professional responsible for the design, it is recommended that the licensed design professional responsible for the design be employed to oversee inspection and observe the work to see that his 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, licensed 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, and contractor. Adequate fees should be provided consistent with the work and equipment necessary to properly perform the inspection.

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 completed floors, members, or walls;

(h) Description and results of tightness testing of liquid and/or gas-containing structures;

(i) General progress of work.

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 is 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 implicitly 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/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 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.

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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.

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.

COMMENTARY

Recommended procedures for organization and conduct of concrete inspection are given in detail in **"Guide for Concrete Inspection."**[1.16] (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.[1.17] (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.)

ACI 311.5 provides the "Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete."[1.18]

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

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

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

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

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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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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.

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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]

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 must be stated, with interpolation when partial sand replacement is used.

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.

A number of definitions for loads are given as the code contains requirements that must be met at various load levels. The terms "dead load" and "live load" refer to the unfactored loads (service loads) specified or defined by the general building code. Service loads (loads without load factors) are to be used where specified in the code to proportion or investigate members for adequate serviceability as in 9.5, Control of Deflections. Loads used to proportion a member for adequate strength are defined as "factored loads." Factored loads are service loads multiplied by the appropriate load factors specified in 9.2 for required strength. The term "design loads," as used in the ACI 318-71 code to refer to loads multiplied by appropriate load factors, was discontinued in the ACI 318-77 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 ACI 318-77 code, clarifies when the load factors are applied to a particular load, moment, or shear value as used in the code provisions.

Reinforced concrete is defined to include prestressed concrete. Although the behavior of a prestressed member with unbonded tendons may vary from that of members with continuously bonded tendons, bonded and unbonded prestressed concrete are combined with conventionally reinforced concrete under the generic term "reinforced

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concrete." Provisions common to both prestressed and conventionally reinforced concrete are integrated to avoid overlapping and conflicting provisions.

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 ϕ.

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:

$$\text{Design strength} \geq \text{Required strength}$$

$$\phi P_n \geq P_u$$

$$\phi M_n \geq M_u$$

$$\phi V_n \geq V_u$$

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

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.

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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.

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.

COMMENTARY

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

Composite concrete flexural members — Concrete flexural members of precast and/or cast-in-place concrete elements constructed in separate placements but so interconnected that all elements respond to loads as a unit.

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 normalweight sand is termed "sand-lightweight concrete."

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 18.15.

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.

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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.

Load, live — Live load specified by general building code of which this code forms a part (without load factor).

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 categorized 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.

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

Pedestal — Upright compression member with a ratio of unsupported height to average least lateral dimension of less than 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.

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.

Reshores — Shores placed snugly under a concrete slab or other structural member after the original form 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.

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

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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).

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 ϕ. 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.

COMMENTARY

Sheathing—Typically, sheathing is a continuous, seamless, high-density polyethylene material extruded directly on the coated prestressing steel. In environmental concrete structures, only seamless, extruded sheathing is acceptable for use in unbonded, monostrand 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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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.
>
> ***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.

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.

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

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2.2 — The following additional terms are defined for general use in this code

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

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

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

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

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

COMMENTARY

R2.2

An ideal **backer rod** will permit compression to one-half its original width and will re-expand to fill the joint when the adjacent members contract. Neoprene and open or closed cell plastic foams are satisfactory materials for backer rods. The backer rod should be compatible with the adjacent joint sealant.

Refer to Chapter 9 of this Code for rules on the application of this factor. When the **environmental durability factor** is used, members proportioned using the strength design approach are similar to those proportioned using the alternate design method (Appendix I).

Cork, neoprene, rubber, foam, and other materials conforming to ASTM D 1056 and D 1752 are satisfactory **joint fillers**. The preformed filler should be compatible with adjacent joint sealant.

Sealants used in water treatment plants, reservoirs, and other structural facilities that will be in contact with potable water should be certified as compliant with ANSI/NSF 61. In addition, the sealant should be resistant to chlorinated water and suitable for immersion service.

Waterstops are available in various sizes, shapes, and materials. Environmental concrete structures commonly use waterstops of preformed rubber or polyvinyl chloride with a minimum thickness of 3/8 in. They should normally be at least 9 in. wide for expansion joints and 6 in. wide for other types of joints to provide adequate embedment in the concrete. Metal waterstops are used for special exposure environments. Expansive rubber or adhesive waterstops may be used in joints cast against previously placed concrete, or in new construction when approved by the engineer. Chemical resistance, joint movement capacity, and design temperature range are among the items that should be investigated when selecting waterstops. Joint movement capacity and design temperature range are among the items that should be investigated when selecting waterstops. Joint details are further described in ACI 350.4R.

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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 — 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).

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 must be preserved 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 preservation of such records.

R3.2 — Cements

R3.2.1 — Different cements or cements from different producers should not be used interchangeably in the same element or portion of the work. Additional guidance on cement may be found in ACI 225R.[3.1]

Concrete made with expansive cement can be used to reduce drying-shrinkage cracking in environmental engineering concrete structures, but the ACI 350 committee is not yet in a position to recommend detailed requirements for its use. For the design to be successful, the engineer must recognize the characteristics and properties of shrinkage compensating concrete and cement as described in ACI 223 and ASTM C 845 (Type E1-K), respectively. Type K cement has historically shown very satisfactory resistance to sulfate attack in both the laboratory and the field. Additional care and control should be exercised during design and construction. Detailed information on shrinkage-compensating concrete is contained in ACI 223.[3.2]

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[3.3] of strength tests used in establishing the required strength margin was based on a cement from a particular source. If the standard deviation was based on tests involving a given type of cement obtained from several sources, the former interpretation may apply.

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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.

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

(a) 1/5 the narrowest dimension between sides of form; 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 honeycomb or voids.

3.3.3 — Where aggregates are alkali-reactive, impose restrictions on materials to minimize deterioration.

COMMENTARY

R3.3 — Aggregates

R3.3.1 — It is recognized that aggregates conforming to the ASTM specifications are not always economically available and that, 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. It should be noted, however, that satisfactory performance in the past does not guarantee good performance under other conditions and in other localities. Whenever possible, aggregates conforming to the designated specifications should be used.

R3.3.2 — The size limitations on aggregates are provided to ensure proper encasement of reinforcement and to minimize honeycomb. 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 honeycomb or voids. In this instance, the engineer must decide whether or not the limitations on maximum size of aggregate may be waived.

R3.3.3 — Alkali-aggregate reactions can cause an expansive action when reactive aggregates come in contact with alkali hydroxides in the hardened concrete. These reactions can result in long-term deterioration of concrete, usually the interior of the concrete. It is recommended to specify testing and quality aggregates conforming to ASTM C 33.

Reactivity testing of aggregates should be required when local aggregates are suspected of being alkali reactive. Unless all local aggregates are known to be nonreactive, a low-alkali cement should be used. Pozzolans and lithium hydroxide admixtures may also be considered. The use of lithium hydroxide admixtures to control reactive aggregates, however, is technology that is not widely accepted at this time.

Alkali-aggregate reactivity potential should be determined for local aggregates when local aggregates are suspected of being alkali reactive. On projects where alkali reactivity is a known problem, prescreening of aggregate sources before completing design of the project may be advisable.

Aggregates that do not indicate a potential for alkali reactivity or reactive constituents may be used without further testing. Aggregates that indicate a potential for alkali reactivity should be tested for potential reactivity using the mortar-bar test, ASTM C 227 and C 289. Nonreactive aggregates may need to be imported if local aggregates exhibit unacceptable potential reactivity.

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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, 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.

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

R3.4 — 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 that might be contained in the mixing water. These additional amounts must be considered in evaluating the acceptability of the total impurities that may be deleterious to concrete or steel.

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. The welder needs to be certified to the requirements of ANSI/AWS D1.4.

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. CE is calculated from

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the chemical composition of the reinforcing bars. The Welding Code has two expressions for calculating CE. 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 CE is not routinely provided by the producer of the reinforcing bars. Hence, for welding reinforcing bars other than A 706 bars, the contract documents 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.[3.4] 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. Appendix A of the Welding Code contains a suggested form that shows the information required for such a specification for each joint welding procedure.

It is often 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 must then 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.

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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.

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).

COMMENTARY

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.

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.

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

Previous standards ASTM A 616 and ASTM A 617 have been replaced by ASTM A 996.

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. When the stress-strain curve is not elasto-plastic, however, 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 ϕ-factor can be expected to account for the strength deficiency.

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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.

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

COMMENTARY

R3.5.3.5 — Welded plain wire fabric must 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.

R3.5.3.6 — Welded deformed wire fabric must 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 ACI 318-83 Code, and epoxy-coated prefabricated reinforcing bars (A 934) were added to the ACI 318-95 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).

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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);

(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) "Standard Specification for Structural Steel Shapes" (ASTM A 992);

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

(c) "Specification for High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality" (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).

COMMENTARY

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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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.

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 ion other than from impurities in admixture ingredients shall not be used.

3.6.4 — Air-entraining admixtures shall conform to "Specification for Air-Entraining Admixtures for Concrete" (ASTM C 260). All air-entraining admixtures that are not vinsol resin or vinsol rosin based shall be tested in accordance with ASTM C 260 at the highest percent air allowed in the specifications.

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).

COMMENTARY

R3.6 — Admixtures

R3.6.3 — Admixtures containing any chloride, other than from impurities in admixture ingredients, should not be used in concrete. Calcium chloride in concrete is particularly detrimental in the wet conditions encountered in environmental engineering concrete structures.

R3.6.4 — Vinsol resin based air-entraining admixtures have been used in the concrete industry since the 1960s or earlier. They have performed the function of entraining air in concrete with few problems. The use of non-vinsol resin or non-vinsol rosin based air-entraining admixtures in concrete have on occasion, especially at specified air contents of 6 percent or higher, resulted in problems such as unacceptable reduction in compressive strength, increase in shrinkage, and surface weakness (similar to scaling).

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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).

3.6.8 — Admixtures used in concrete containing ASTM 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 "Specification for Silica Fume for Use in Hydraulic-Cement Concrete and Mortar" (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 — Reference standards

COMMENTARY

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 that discuss effects of ground-granulated blast-furnace slag on concrete strength, sulfate resistance, and alkali-aggregate reaction.

R3.6.8 — The use of admixtures in concrete containing ASTM 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. Because 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. Such a procedure, however, 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 must refer to a specific document. This can be done by simply using the complete serial designation because 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.

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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 992/ A 992M-02	Standard Specification for Structural Steel Shapes
A 53/ A 53M-02	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-01	Standard Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
A 185-97	Standard Specification for Steel Welded Wire Fabric, Plain, for Concrete
A 227/ A 227M-99	Specification for Steel Wire, Cold-Drawn for Mechanical Springs
A 242/ A 242M-03a	Standard Specification for High-Strength Low-Alloy Structural Steel
A 307-03	Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength
A 336/ A 336M-03	Standard Specification for Alloy Steel Forgings for Pressure and High Temperature Parts
A 416/ A 416M-02	Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
A 421/ A 421M-02	Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete
A 475-98	Specification for Zinc-Coated Steel Wire Strand
A 496-97a	Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement
A 497/ A 497M-02	Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete
A 500-03a	Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
A 501-01	Standard Specification for Hot-Formed

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	Welded and Seamless Carbon Steel Structural Tubing
A 572/ A 572M-03	Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
A 586-98	Standard Specification for Zinc-Coated Parallel and Helical Steel Wire Structural Strand and Zinc-Coated Wire for Spun-In-Place Structural Strand
A 588/ A 588M-03	Standard Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick
A 603-98	Standard Specification for Zinc-Coated Steel Structural Wire Rope
A 615/ A 615M-03	Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
A 648-95	Standard Specification for Steel Wire, Hard Drawn for Prestressing Concrete Pipe
A 653/ A 653M-03	Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
A 706/ A 706M-03	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 Bar for Prestressing Concrete
A 767/ A 767M-00b	Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
A 775/ A 775M-01	Standard Specification for Epoxy-Coated Steel Reinforcing Bars
A 821/ A 821M-99	Standard Specification for Steel Wire, Hard Drawn for Prestressing Concrete Tanks
A 881/ A 881M-02	Standard Specification for Steel Wire, Deformed, Stress-Relieved or Low-Relaxation for Prestressed Concrete Railroad Ties
A 882/ A 882M-02a	Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand
A 884/ A 884M-02	Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement

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A 934/ A 934M-03	Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
A 996/ A 996M-03	Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement
C 31/ C 31M-03a	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 33-03	Standard Specification for Concrete Aggregates
C 39/ C 39M-03a	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 42/ C 42M-03	Standard Test Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C 94/ C 94M-03	Standard Specification for Ready-Mixed Concrete
C 109/ C 109M-02	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in.or (50-mm) Cube Specimens)
C 144-03	Standard Specification for Aggregate for Masonry Mortar
C 150-02a$^{\varepsilon 1}$	Standard Specification for Portland Cement
C 172-99	Standard Practice for Sampling Freshly Mixed Concrete
C 192/ C 192M-02	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 260-01	Standard Specification for Air-Entraining Admixtures for Concrete
C 295-03	Standard Guide for Petrographic Examination of Aggregates for Concrete
C 330-03	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 567-00	Standard Test Method for Determining Density of Structural Lightweight Concrete
C 595-03	Standard Specification for Blended Hydraulic Cements
C 618-03	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

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C 685/C 685M-01 Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing

C 845-96 Standard Specification for Expansive Hydraulic Cement

C 920-02 Specification for Elastomeric Joint Sealants

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 1064/C 1064M-03 Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete

C 1077-03 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

C 1138-97 Test Method for Abrasion Resistance of Concrete (Underwater Method)

C 1218/C 1218M-99 Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

C 1240-03a Standard Specification for Silica Fume Used in Cementitious Mixtures

D 395-03 Standard Test Methods for Rubber Property Compression Set

D 412-98a$^{\varepsilon 1}$ Standard Test Methods for Rubber Properties in Tension

D 570-98 Standard Test Method for Water Absorption of Plastics

D 746-98 Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact

D 1056-00 Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber

D 1149-99 Standard Test Method for Rubber Deterioration-Surface Ozone Cracking in a Chamber

D 1752-84 Specification for Preformed Sponge Rubber and Cork Expansion Joint (Reapproved 1996)$^{\varepsilon 1}$ Fillers for Concrete Paving and Structural Construction

D 2000-03 Classification System for Rubber Products in Automotive Applications

D 2240-03 Test Method for Rubber Property—Durometer Hardness

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E 96-00 Test Methods for Water Vapor Transmission of Materials

E 329-03 Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction

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 7-05) is declared to be part of this standard 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 — "Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-04)" is declared to be part of this code as if fully set forth herein, for the purpose cited in Appendix D.

3.8.6 — "Structural Welding Code—Steel (AWS D 1.1/D 1.1M: 2004)" of the American Welding Society is declared to be part of this code as if fully set forth herein.

3.8.7 — "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.

3.8.8 — Standards of the following organizations are referred to in this code and 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:

3.8.8.1 — American Water Works Association

C 652-92 Disinfection of Water Storage Facilities

3.8.8.2 — U.S. Army Corps of Engineers Specifications

CRD C 572 U.S. Army Corps of Engineers Specification for Polyvinyl Chloride Waterstops (1999)

3.8.8.3 — Federal Specifications

TT-S-227e(3) (1969) Sealing Compound, Elastomeric Type, Multi-Component (for Calking, Sealing, and Glazing in Buildings and Other Structures)

COMMENTARY

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

R3.8.5 — 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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TT-S-230c(2) (1970) Sealing Compound, Elastomeric Type, Single Component (for Calking, Sealing, and Glazing in Buildings and Other Structures)

3.8.8.4 — American Concrete Institute

ACI 350.3/350.3R-06 "Seismic Design of Liquid-Containing Concrete Structures"

3.8.8.5 — American Association of State Highway and Transportation Officials

T260-84 Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials

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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

Chapter 4 of ACI 318 has been expanded herein for environmental concrete structures. Chapter 4 of earlier editions of ACI 318 was reformatted in 1989 to emphasize the importance of considering durability requirements before the designer selected f_c' and cover over the reinforcing steel.

Specified compressive concrete strength f_c' should correspond to maximum water-cementitious materials ratios of 0.40 to 0.42 for concretes exposed to freezing and thawing, water, wastewater, and to corrosive gases or for preventing corrosion of reinforcement, as shown in Table 4.2.2 and Table 4.3.1.

Generally, f_{cr}', defined as the required average compressive strength of concrete used as the basis for selection of concrete proportions, will be 500 to 700 psi higher than the specified compressive strength f_c'. Because it is difficult to accurately determine the water-cementitious materials ratio of concrete during production, the f_c' should be reasonably consistent with the specified 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, a minimum f_c' of 4000 psi and a maximum water-cementitious materials ratio of 0.42 should be specified for an environmental structure exposed to freezing and thawing in a moist condition.

The code includes provisions for especially severe exposure where high resistance to chemical attack, alternate wetting and drying, freezing-and-thawing cycles, and exposure to the elements are required. It also includes special requirements for concrete cover and spacing of reinforcing bars (Chapter 7) for concrete in such environments.

The code requires the addition of protective coatings or liners in the case of severe exposures such as acids or other chemicals, and exposures to erosion by abrasion and cavitation.

Concrete ingredients and proportions must be selected to meet the minimum requirements stated in the code and the additional requirements of the contract documents.

Lightweight concrete may be used for environmental structures provided attention is given to durability requirements in general and protection against freezing and thawing, abrasion, and sulfate and chemical attack in particular.

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4.1 — Water-cementitious materials ratio and cementitious material content

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, or C 845 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.

4.1.2 — Minimum cementitious materials content shall be as indicated in Table 4.1.2.1.

TABLE 4.1.2.1 — MINIMUM CEMENTITIOUS MATERIAL CONTENT

Nominal maximum aggregate size, in.	Coarse aggregate (ASTM C 33) size no.*	Minimum cementitious materials (lb/yd^3)
1-1/2	467	515
1	57	535
3/4	67	560
1/2	7	580
3/8	8	600

*For nominal maximum coarse aggregate size not indicated, interpolate the minimum cementitious material content between nominal sizes shown.

4.2 — Freezing and thawing exposures

4.2.1 — 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.

COMMENTARY

The code requires the use of an environmental durability factor S_d when using strength design. See R9.2.6.

R4.1 — Water-cementitious materials ratio and cementitious material content

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.

R4.1.2 — The 350 Code includes the requirements for environmental structures constructed of concrete with properties and characteristics that are suitable for long-term durability. Concrete mixtures using different types of cement, pozzolans, and admixtures should demonstrate low permeability, acceptable durability, workability, compactability, and finishability characteristics based on the requirements in the code. Upper and lower limits on the percentage of pozzolans that would be advisable for the durability of environmental structures need to be considered.

R4.2 — Freezing and thawing exposures

R4.2.1 — A table of required air contents for freezing-and-thawing 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 exposure, 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 before freezing, or where deicing salts are used. Examples are water tanks, tanks storing brackish water, and pavements. 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 tanks containing water or wastewater and certain exterior walls, beams, girders, and slabs not in direct contact with soil. Examples of severe exposure for water tanks are aeration basins and clarifier tanks, which incorporate walkways that are subject to the application of deicing chemicals. Section 4.2.1 permits an air content of 1 percentage point lower for concrete with f_c' greater than 5000 psi. Such high-strength

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