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

REPORTED BY ACI COMMITTEE 350

ACI Committee 350
Environmental Engineering Concrete Structures

Satish K. Sachdev
Chair

Jon B. Ardahl
Vice Chair

John W. Baker
Secretary

Walter N. Bennett
Lucian I. Bogdan
Steven R. Close
Patrick J. Creegan
Robert E. Doyle
Anthony L. Felder
Carl A. Gentry
Gautam Ghosh
Charles S. Hanskat
Keith W. Jacobson
M. Reza Kianoush
Nicholas A. Legatos
Ramon E. Lucero
Andrew R. Minogue
Lawrence G. Mrazek
Javeed A. Munshi
Jerry Parnes
Andrew R. Philip
Risto Protic
William C. Sherman
Lawrence M. Tabat

Voting Subcommittee Members

Iyad (Eli) M. Alsamsam
Paul Hedli
Lawrence E. Kaiser
Salvatore Marques
Daniel J. McCarthy
Carl H. Moon
Rolf P. Pawski
Paul J. St. John

Consulting Members

William Irwin
Dov Kaminetzky
David G. Kittridge
Dennis C. Kohl
Terry Patzias
Narayan M. Prachand

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

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, spillways, 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 5, 2006 to supersede ACI 350/350R-01 in accordance with the Institute's standardization procedure.

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 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.

CONTENTS

PART 1—GENERAL

CHAPTER 1—GENERAL REQUIREMENTS 9

1.1—Scope
1.2—Drawings and specifications
1.3—Inspection
1.4—Approval of special systems of design or construction

CHAPTER 2—DEFINITIONS 21

PART 2—STANDARDS FOR TESTS AND MATERIALS

CHAPTER 3—MATERIALS 31

3.0—Notation
3.1—Tests of materials
3.2—Cements
3.3—Aggregates
3.4—Water
3.5—Steel reinforcement
3.6—Admixtures
3.7—Storage of materials
3.8—Reference standards

PART 3—CONSTRUCTION REQUIREMENTS

CHAPTER 4—DURABILITY REQUIREMENTS 47

4.0—Notation
4.1—Water-cementitious materials ratio and cementitious material content
4.2—Freezing and thawing exposures
4.3—Sulfate exposures
4.4—Corrosion protection of metals
4.5—Chemical effects
4.6—Protection against erosion
4.7—Coatings and liners
4.8—Joints

CHAPTER 5—CONCRETE QUALITY, MIXING, AND PLACING 63

5.0—Notation
5.1—General
5.2—Selection of concrete proportions
5.3—Proportioning on the basis of field experience, trial mixtures, or both
5.4—Average strength reduction
5.5—Evaluation and acceptance of concrete
5.6—Preparation of equipment and place of deposit
5.7—Mixing
5.8—Conveying
5.9—Depositing
5.10—Curing
5.11—Cold weather requirements
5.12—Hot weather requirements

CHAPTER 6—FORMWORK, EMBEDDED PIPES, AND CONSTRUCTION AND MOVEMENT JOINTS 79

6.1—Design of formwork
6.2—Removal of forms, shores, and reshoring
6.3—Conduits and pipes embedded in concrete
6.4—Construction joints
6.5—Movement joints

CHAPTER 7—DETAILS OF REINFORCEMENT 85

7.0—Notation
7.1—Standard hooks
7.2—Minimum bend diameters
7.3—Bending
7.4—Surface conditions of reinforcement
7.5—Placing reinforcement
7.6—Spacing limits for reinforcement
7.7—Concrete protection for reinforcement
7.8—Special reinforcement details for columns
7.9—Connections
7.10—Lateral reinforcement for compression members
7.11—Lateral reinforcement for flexural members
7.12—Shrinkage and temperature reinforcement
7.13—Requirements for structural integrity

PART 4—GENERAL REQUIREMENTS

CHAPTER 8—ANALYSIS AND DESIGN—GENERAL CONSIDERATIONS 101

8.0—Notation
8.1—Design methods
8.2—Loading
8.3—Methods of analysis
8.4—Redistribution of negative moments in continuous flexural members
8.5—Modulus of elasticity
8.6—Stiffness
8.7—Span length
8.8—Columns
8.9—Arrangement of live load
8.10—T-beam construction
8.11—Joist construction
8.12—Separate floor finish

CHAPTER 9—STRENGTH AND SERVICEABILITY REQUIREMENTS 111

9.0—Notation
9.1—General
9.2—Required strength
9.3—Design strength
9.4—Design strength for reinforcement
9.5—Control of deflections

CHAPTER 10—FLEXURE AND AXIAL LOADS 127

10.0—Notation
10.1—Scope
10.2—Design assumptions
10.3—General principles and requirements
10.4—Distance between lateral supports of flexural members
10.5—Minimum reinforcement of flexural members
10.6—Distribution of flexural reinforcement
10.7—Deep beams
10.8—Design dimensions for compression members
10.9—Limits for reinforcement of compression members
10.10—Slenderness effects in compression members
10.11—Magnified moments—General
10.12—Magnified moments—Nonsway frames
10.13—Magnified moments—Sway frames
10.14—Axially loaded members supporting slab system
10.15—Transmission of column loads through floor system
10.16—Composite compression members
10.17—Bearing strength

CHAPTER 11—SHEAR AND TORSION 159

11.0—Notation
11.1—Shear strength
11.2—Lightweight concrete
11.3—Shear strength provided by concrete for nonprestressed members
11.4—Shear strength provided by concrete for prestressed members
11.5—Shear strength provided by shear reinforcement
11.6—Design for torsion
11.7—Shear-friction
11.8—Deep beams
11.9—Special provisions for brackets and corbels
11.10—Special provisions for walls
11.11—Transfer of moments to columns
11.12—Special provisions for slabs and footings

CHAPTER 12—DEVELOPMENT AND SPLICES OF REINFORCEMENT 205

12.0—Notation
12.1—Development of reinforcement—General
12.2—Development of deformed bars and deformed wire in tension
12.3—Development of deformed bars and deformed wire in compression
12.4—Development of bundled bars
12.5—Development of standard hooks in tension
12.6—Mechanical anchorage
12.7—Development of welded deformed wire fabric in tension
12.8—Development of welded plain wire fabric in tension
12.9—Development of prestressing strand
12.10—Development of flexural reinforcement—General
12.11—Development of positive moment reinforcement
12.12—Development of negative moment reinforcement
12.13—Development of web reinforcement
12.14—Splices of reinforcement—General
12.15—Splices of deformed bars and deformed wire in tension
12.16—Splices of deformed bars in compression
12.17—Special splice requirements for columns
12.18—Splices of welded deformed wire fabric in tension
12.19—Splices of welded plain wire fabric in tension

PART 5—STRUCTURAL SYSTEMS OR ELEMENTS

CHAPTER 13—TWO-WAY SLAB SYSTEMS 233

13.0—Notation
13.1—Scope
13.2—Definitions
13.3—Slab reinforcement
13.4—Openings in slab systems
13.5—Design procedures
13.6—Direct design method
13.7—Equivalent frame method

CHAPTER 14—WALLS 253

14.0—Notation
14.1—Scope
14.2—General
14.3—Minimum reinforcement
14.4—Walls designed as compression members
14.5—Empirical design method
14.6—Minimum wall thickness
14.7—Walls as grade beams
14.8—Alternative design of slender walls

CHAPTER 15—FOOTINGS 259

15.0—Notation
15.1—Scope
15.2—Loads and reactions
15.3—Footings supporting circular or regular polygon shaped columns or pedestals
15.4—Moment in footings
15.5—Shear in footings
15.6—Development of reinforcement in footings
15.7—Minimum footing depth
15.8—Transfer of force at base of column, wall, or reinforced pedestal
15.9—Sloped or stepped footings
15.10—Combined footings and mats

CHAPTER 16—PRECAST CONCRETE.. 267

16.0—Notation
16.1—Scope
16.2—General
16.3—Distribution of forces among members
16.4—Member design
16.5—Structural integrity
16.6—Connection and bearing design
16.7—Items embedded after concrete placement
16.8—Marking and identification
16.9—Handling
16.10—Strength evaluation of precast construction

CHAPTER 17—COMPOSITE CONCRETE FLEXURAL MEMBERS 275

17.0—Notation
17.1—Scope
17.2—General
17.3—Shoring
17.4—Vertical shear strength
17.5—Horizontal shear strength
17.6—Ties for horizontal shear

CHAPTER 18—PRESTRESSED CONCRETE 279

18.0—Notation
18.1—Scope
18.2—General
18.3—Design assumptions
18.4—Serviceability requirements—Flexural members
18.5—Permissible stresses in prestressing steel
18.6—Loss of prestress
18.7—Flexural strength
18.8—Limits for reinforcement of flexural members
18.9—Minimum bonded reinforcement
18.10—Statically indeterminate structures
18.11—Compression members—Combined flexure and axial loads
18.12—Slab systems
18.13—Post-tensioned tendon anchorage zones
18.14—Design of anchorage zones for monostrand or single 5/8 in. diameter bar tendons
18.15—Design of anchorage zone for multistrand tendons
18.16—Corrosion protection for unbonded single-strand prestressing tendons
18.17—Post-tensioning ducts
18.18—Grout for bonded tendons
18.19—Protection for prestressing steel
18.20—Application and measurement of prestressing force
18.21—Post-tensioning anchorages and couplers
18.22—External post-tensioning

CHAPTER 19—SHELLS AND FOLDED PLATE MEMBERS 311

19.0—Notation
19.1—Scope and definitions
19.2—Analysis and design
19.3—Design strength of materials
19.4—Shell reinforcement
19.5—Construction

PART 6—SPECIAL CONSIDERATIONS

CHAPTER 20—STRENGTH EVALUATION OF EXISTING STRUCTURES 319

20.0—Notation
20.1—Strength evaluation—General
20.2—Determination of required dimensions and material properties
20.3—Load test procedure
20.4—Loading criteria
20.5—Acceptance criteria
20.6—Provision for lower load rating
20.7—Safety

CHAPTER 21—SPECIAL PROVISIONS FOR SEISMIC DESIGN 325

21.0—Notation
21.1—Definitions
21.2—General requirements
21.3—Flexural members of special moment frames
21.4—Special moment frame members subjected to bending and axial load
21.5—Joints of special moment frames
21.6—Special moment frames constructed using precast concrete
21.7—Special reinforced concrete structural walls and coupling beams
21.8—Special structural walls constructed using precast concrete
21.9—Structural diaphragms and trusses
21.10—Foundations
21.11—Frame members not proportioned to resist forces induced by earthquake motions
21.12—Requirements for intermediate moment frames
21.13—Intermediate precast structural walls

PART 7—STRUCTURAL PLAIN CONCRETE

CHAPTER 22—NOT USED 367

COMMENTARY REFERENCES 369

APPENDIXES

APPENDIX A—NOT USED 387

APPENDIX B—ALTERNATE PROVISIONS FOR REINFORCED AND PRESTRESSED CONCRETE FLEXURAL AND COMPRESSION MEMBERS 389

B.0—Notation
B.1—Scope

APPENDIX C—ALTERNATE LOAD FACTORS, STRENGTH REDUCTION FACTORS, AND DISTRIBUTION OF FLEXURAL REINFORCEMENT 393

C.1—General

APPENDIX D—ANCHORING TO CONCRETE 401

D.0—Notation
D.1—Definitions
D.2—Scope
D.3—General requirements
D.4—General requirements for strength of anchors
D.5—Design requirements for tensile loading
D.6—Design requirements for shear loading
D.7—Interaction of tensile and shear forces
D.8—Required edge distances, spacings, and thicknesses to preclude splitting failure
D.9—Installation of anchors

APPENDIX E—NOTATION 427

APPENDIX F—METAL REINFORCEMENT INFORMATION 441

APPENDIX G—CIRCULAR WIRE AND STRAND WRAPPED PRESTRESSED CONCRETE ENVIRONMENTAL STRUCTURES 443

G.0—Notation
G.1—Scope
G.2—Design
G.3—Materials
G.4—Construction procedures

APPENDIX H—SLABS ON SOIL 459

H.1—Scope
H.2—Subgrade
H.3—Slab thickness
H.4—Reinforcement
H.5—Joints
H.6—Hydrostatic uplift
H.7—Curing

APPENDIX I—ALTERNATE DESIGN METHOD 463

I.0—Notation
I.1—Scope
I.2—General
I.3—Permissible service load stresses
I.4—Development and splices of reinforcement
I.5—Flexure
I.6—Compression members with or without flexure
I.7—Shear and torsion

INDEX 475

SUMMARY OF CHANGES FOR 350-06 CODE 481

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 ϕ, 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 as those

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.

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.

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.

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.

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.

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.

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.

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.

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

CODE

COMMENTARY

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.

CODE / **COMMENTARY**

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

CODE

COMMENTARY

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

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.

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.

CODE

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.

COMMENTARY

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

	Level of seismic risk or assigned seismic performance or design categories as defined in the code section		
Code, standard, or resource document and edition	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.