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# Code Requirements for Residential Concrete (ACI 332-20) and Commentary

Reported by ACI Committee 332

ACI 332-20



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# Code Requirements for Residential Concrete and Commentary

An ACI Standard

Reported by ACI Committee 332

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*This code covers the design and construction of cast-in-place concrete for one- and two-family dwellings and multiple single-family dwellings (townhouses), and their accessory structures. Among the subjects covered are the design and construction requirements for plain and reinforced concrete footings; foundation walls; slabs-on-ground; and requirements for concrete, reinforcement, forms, and other related materials. The quality and testing of materials discussed in this document are covered by reference to the appropriate ASTM standards.*

*This code is written to allow for reference by adoption in a general building code without changing its language. Background details or suggestions for carrying out the requirements or intent of the code are provided in the commentary. The commentary discusses some of the considerations of the committee in developing the code with emphasis given to the explanation of provisions that may be unfamiliar to code users or where significant departure exists from other concrete codes.*

**Keywords:** admixtures; aggregate; backfill; cement; compressive strength; cover; flexural strength; footings; formwork (construction); foundations; loads (forces); slabs; structural analysis; reinforcement.

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## CONTENTS

### PREFACE, p. 3

### CHAPTER 1—GENERAL, p. 5

- 1.1—Scope, p. 5
- 1.2—Alternative systems, p. 6
- 1.3—Drawings and specifications, p. 7
- 1.4—Inspection, p. 7

### CHAPTER 2—NOTATION AND DEFINITIONS, p. 8

- 2.1—Notation, p. 8
- 2.2—Definitions, p. 9

### CHAPTER 3—REFERENCED STANDARDS, p. 11

### CHAPTER 4—MATERIALS, p. 13

- 4.1—Concrete, p. 13
- 4.2—Reinforcement, p. 13
- 4.3—Formwork, p. 14
- 4.4—Vapor retarder, p. 14

### CHAPTER 5—CONCRETE REQUIREMENTS, p. 16

- 5.1—Exposure categories and classes, p. 16
- 5.2—General requirements, p. 18
- 5.3—Requirements for concrete mixtures, p. 18
- 5.4—Additional requirements for freezing-and-thawing exposure, p. 20
- 5.5—Alternative cementitious materials for sulfate exposure, p. 21
- 5.6—Concrete cover, p. 21

### CHAPTER 6—DESIGN OF STRUCTURAL CONCRETE, p. 22

- 6.1—Scope, p. 22
- 6.2—Materials, p. 22
- 6.3—Load factors and combinations, p. 23
- 6.4—Strength reduction factors, p. 24
- 6.5—Plain concrete, p. 24
- 6.6—Sectional strength of reinforced sections, p. 26
- 6.7—Design limits, p. 30
- 6.8—Reinforcement detailing, p. 30

### CHAPTER 7—CONCRETE PRODUCTION AND PLACEMENT, p. 31

- 7.1—Concrete, p. 31
- 7.2—Placement, p. 31
- 7.3—Form removal, p. 31
- 7.4—Finishing, p. 31
- 7.5—Curing, p. 32
- 7.6—Protection of concrete during cold weather, p. 32
- 7.7—Temperature limits for concrete as delivered in hot weather, p. 33

### CHAPTER 8—FOOTINGS, p. 34

- 8.1—Scope, p. 34
- 8.2—General, p. 34
- 8.3—Design limits, p. 37
- 8.4—Required strength, p. 38
- 8.5—Design, p. 39
- 8.6—Prescriptive design tables, p. 39
- 8.7—Construction requirements, p. 45

### CHAPTER 9—FOUNDATION WALLS, p. 47

- 9.1—Scope, p. 47
- 9.2—General, p. 47
- 9.3—Design limits, p. 49
- 9.4—Required strength, p. 51
- 9.5—Design, p. 51
- 9.6—Connection to lateral support system, p. 62
- 9.7—Construction requirements, p. 62

### CHAPTER 10—ABOVE-GRADE WALLS, p. 64

- 10.1—Scope, p. 64
- 10.2—General, p. 64
- 10.3—Design limits, p. 64
- 10.4—Required strength, p. 64
- 10.5—Design, p. 64
- 10.6—Construction requirements, p. 65

### CHAPTER 11—LINTEL BEAMS, p. 66

- 11.1—Scope, p. 66
- 11.2—General, p. 66
- 11.3—Design limits, p. 67
- 11.4—Required strength, p. 67
- 11.5—Design, p. 67
- 11.6—Prescriptive design, p. 67

### CHAPTER 12—DESIGN FOR EXPANSIVE SOILS, p. 68

- 12.1—Scope, p. 68
- 12.2—General, p. 68
- 12.3—Expansive soil classification, p. 68
- 12.4—Design, p. 68

### CHAPTER 13—SLABS-ON-GROUND, p. 69

- 13.1—Scope, p. 69
- 13.2—Design, p. 69
- 13.3—Support, p. 69
- 13.4—Forms, p. 69
- 13.5—Thickness, p. 69
- 13.6—Joints, p. 69
- 13.7—Reinforcement, p. 70

### COMMENTARY REFERENCES, p. 72

- Authored documents, p. 73

## PREFACE

The commentary of this code discusses some of the considerations of ACI Committee 332 in developing the provisions contained herein. Explanation of the departure of this code from ACI 318 is emphasized. Comments on specific provisions are made under the corresponding chapter and section numbers of this code.

The commentary is not intended to provide a complete historical background concerning the development of this code, nor is it intended to provide a detailed résumé of the studies and research data reviewed by the committee in formulating this document.

This code is meant to be used as part of a legally adopted building code and, as such, must differ in form and substance from documents that provide detailed specifications, recommended practices, or complete design procedures. This code was developed by an ANSI-approved consensus process.

This code is intended to cover all residential structures that fall within the scope of IRC-2018. Requirements more stringent than the code provisions may be desirable for large, complex, or irregular structures; high-hazard areas; and other unusual construction. This code cannot replace sound engineering knowledge, experience, and judgment.

A building code states only the minimum requirements necessary to provide for public health and safety; this code is based on that principle. For any structure, the owner or the designer may require the quality of materials and construction to be higher than the minimum requirements necessary to protect the public as stated herein. Lower standards, however, are not permitted. The commentary directs attention to other documents that provide suggestions for carrying out the requirements and intent of this code.

This code has no legal status unless adopted by government bodies having authority to regulate building design and construction. Where this code has not been adopted, it may serve as a reference to good practice even though it has no legal status.

This code provides a means of establishing minimum standards for acceptance of designs and construction by legally appointed building officials or their designated representatives. This document is not intended for use in settling disputes between the owner; engineer; architect; contractor; or their agents, subcontractors, material suppliers, or testing agencies. Therefore, this code cannot define the contract responsibility of each of the parties in construction. General references requiring compliance with this code in the project specifications should be avoided because the contractor is rarely in a position to accept responsibility for design details or construction requirements that depend on detailed knowledge of the design. Design-build construction contractors, however, typically combine the design and construction responsibility. Generally, the drawings, specifications, and contract documents should contain all the necessary requirements to ensure compliance with the code. In part, this can be accomplished by reference to specific code sections in the project specifications. Other ACI publications, such as ACI 301, are written specifically for use as contract documents for construction. Requirements for testing and certification programs should be provided for the individual parties involved with the execution of work performed in accordance with this code.

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## CODE

## CHAPTER 1—GENERAL

## 1.1—Scope

1.1.1 This chapter addresses (a) through (f):

- (a) General requirements of this code
- (b) Purpose of this code
- (c) Applicability of this code
- (d) Alternative systems
- (e) Drawings and specifications
- (f) Inspection

1.1.2 This code, when legally adopted as part of a general building code, provides minimum requirements for design and construction of residential concrete members. In areas without a legally adopted building code, this code defines minimum acceptable standards of design and construction practice.

1.1.3 This code supplements the general building code and governs matters pertaining to design and construction of cast-in-place concrete construction for one- and two-family dwellings and multiple single-family dwellings (town-houses), and their accessory structures, except wherever this code conflicts with requirements in the legally adopted general building code.

1.1.4 Where this code conflicts with requirements contained in other standards referenced in this code, this code shall govern.

1.1.5 This code is limited to design and construction of concrete footings, including thickened slab footings, wall footings, and isolated footings; concrete basement or foundation walls and above-grade walls constructed with removable forms or with flat insulating concrete forms; and concrete slabs-on-ground.

1.1.6 Where the scope of this code and the scope of **ACI 318** coincide, design in accordance with ACI 318 shall be permitted for all buildings and structures, and all parts thereof, within the scope of this code.

1.1.7 *Seismic design*

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

1.1.8 This code does not govern design and construction of insulating concrete form walls with a waffle or screen configuration; precast wall members; cantilevered walls or retaining walls; deep foundation systems, such as piles, drilled piers, or caissons; and elevated concrete slabs.

## COMMENTARY

## CHAPTER R1—GENERAL

## R1.1—Scope

R1.1.1 This Code includes provisions for the design of residential concrete used for structural purposes, including plain concrete and concrete containing mild reinforcement.

This chapter includes numerous provisions that explain where this Code applies and how it is to be interpreted.

R1.1.2 The user of this code should consult the applicable general building code for all applied loads to determine the applicable values for design requirements. In the absence of a governing code, the user should consider the use of **ASCE/SEI 7** to determine applicable loads.

R1.1.4 **IRC-2018** references this code. Where the design of a member is initiated with this code from reference by the IRC, the entire design of the member must be completed using the provisions of this code.

R1.1.5 The design and construction requirements for footings, foundation walls, and slabs-on-ground are included in this code, together with requirements for concrete, reinforcement, forms, and other related materials.

R1.1.7 *Seismic design*

Provisions for application of precast wall members are found in IRC-2018. The provisions for above-grade concrete walls are currently available in IRC-2018 based on **PCA 100.03**.

R1.1.8 Guidance on the type and application of systems for drainage, waterproofing, dampproofing, and radon gas ventilation are commonly found in the general building code.

## CODE

## COMMENTARY

**1.1.9** This code does not govern the design and application of methods for top lateral wall support, surface drainage, waterproofing, dampproofing, or the ventilation of radon gases.

**1.1.10** When a building or structure contains concrete members that exceed the limits of this code or otherwise do not conform to this code, these concrete members shall be designed in accordance with **ACI 318**.

**1.1.11** Where permitted by the statutes of the jurisdiction where the project is to be constructed, construction documents for residences designed by the provisions of this code need not be prepared by a licensed design professional. Where required by the statutes of the jurisdiction where the project is to be constructed, a licensed design professional shall prepare the construction documents for residences.

**1.1.12** This code is intended to state only minimum requirements necessary to provide for public health and safety for the design of residences that fall within the scope of **IRC-2018**. The owner or the licensed design professional may require the quality of materials and construction to be higher than the minimum requirements stated in the code.

**1.1.13** All references to minimum and maximum dimensions or values in the code refer to those dimensions or values as specified.

**1.1.14** This code is not intended to define contractual responsibilities between all the parties involved in a project, nor is it intended to settle disputes regarding contractual responsibilities.

**1.1.15** The commentary text, tables, figures, or illustrations shall not be used to interpret the code in a way that conflicts with the plain meaning of the code text, or to create ambiguity within the code that would not otherwise exist.

**1.1.16** The English version in U.S. customary units is the official version of the code. In case of conflict between the official version and versions with SI units or in different languages, the official version governs.

### 1.2—Alternative systems

Sponsors of any system of design or construction or an alternative material to be applied within the scope of this code, the adequacy of which has been shown by successful use, analysis, or test, but which does not conform to or is not covered by this code, shall have the right to present the data on which their design is based to the building official or to a board of examiners appointed by the building official. This board shall 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, if approved by the building official

### R1.2—Alternative systems

New methods of design, materials, and uses of materials should undergo a period of development before being specifically covered in a code. Hence, acceptable systems or components might be excluded from use by implication if means were not available to obtain acceptance. For systems considered under this section, specific tests, load factors, deflection limits, and other pertinent requirements should be set by the board of examiners and should be consistent with the intent of this document.

**CODE****COMMENTARY**

and promulgated, shall be of the same force and effect as the provisions of this code.

**1.3—Drawings and specifications**

All designs for cast-in-place concrete construction not covered by the design provisions or prescriptive tables of this code shall require the seal of a licensed design professional.

**1.4—Inspection**

The construction of all concrete members covered by this code shall be inspected as required by the legally adopted general building code.



## CODE

## COMMENTARY

## CHAPTER 2—NOTATION AND DEFINITIONS

## CHAPTER R2—NOTATION AND DEFINITIONS

## 2.1—Notation

|              |   |                                                                                                                                                                     |
|--------------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $A_g$        | = | gross area of concrete section, in. <sup>2</sup>                                                                                                                    |
| $A_{st}$     | = | total area of longitudinal reinforcement, in. <sup>2</sup>                                                                                                          |
| $A_v$        | = | effective area of all bar legs or wires (ties, stirrups, or crossties) within spacing $s$ , in. <sup>2</sup>                                                        |
| $B_n$        | = | nominal bearing strength, psi                                                                                                                                       |
| $B_u$        | = | factored bearing strength, psi                                                                                                                                      |
| $b_w$        | = | web width, in.                                                                                                                                                      |
| $d$          | = | distance from extreme compression fiber to centroid of tension reinforcement, in.                                                                                   |
| $d_{agg}$    | = | nominal maximum size of coarse aggregate, in.                                                                                                                       |
| $d_b$        | = | diameter of steel reinforcing bar, in.                                                                                                                              |
| $D$          | = | effect of service dead load                                                                                                                                         |
| $E$          | = | effect of horizontal and vertical earthquake-induced forces                                                                                                         |
| $E_c$        | = | modulus of elasticity of concrete, psi                                                                                                                              |
| $E_s$        | = | modulus of elasticity of reinforcement and structural steel, psi                                                                                                    |
| $f'_c$       | = | specified compressive strength of concrete, psi                                                                                                                     |
| $f_r$        | = | modulus of rupture of concrete, psi                                                                                                                                 |
| $f_y$        | = | specified minimum yield strength of steel reinforcement, psi                                                                                                        |
| $H$          | = | effect of service load due to lateral earth pressure, groundwater pressure, or pressure of bulk materials, lb                                                       |
| $L$          | = | effect of service live load                                                                                                                                         |
| $L_r$        | = | effect of service roof live load                                                                                                                                    |
| $M_n$        | = | nominal flexural strength at section, in.-lb                                                                                                                        |
| $M_u$        | = | factored moment at section, in.-lb                                                                                                                                  |
| $P_n$        | = | nominal axial compressive strength at given eccentricity, psi                                                                                                       |
| $P_o$        | = | nominal axial load strength at zero eccentricity, psi                                                                                                               |
| $R$          | = | cumulative load effect of service rain load                                                                                                                         |
| $S$          | = | effect of service snow load                                                                                                                                         |
| $S_m$        | = | elastic section modulus, in. <sup>3</sup>                                                                                                                           |
| $T$          | = | cumulative effects of service temperature, creep, shrinkage, differential settlement, and shrinkage compensating concrete                                           |
| $U$          | = | strength of a member or cross section required to resist factored loads or related internal moments and forces in such combinations as stipulated in this code      |
| $V_c$        | = | nominal shear strength provided by concrete, lb                                                                                                                     |
| $V_n$        | = | nominal shear strength, lb                                                                                                                                          |
| $V_s$        | = | nominal shear strength provided by reinforcement, lb                                                                                                                |
| $V_u$        | = | factored shear force at section, lb                                                                                                                                 |
| $w_c$        | = | density, unit weight, of normalweight concrete, lb/ft <sup>3</sup>                                                                                                  |
| $\phi$       | = | strength reduction factor                                                                                                                                           |
| $\epsilon_t$ | = | net tensile strain in extreme layer of longitudinal tension reinforcement at nominal strength, excluding strains due to effective creep, shrinkage, and temperature |

## CODE

## COMMENTARY

$\epsilon_{fy}$  = value of net tensile strain in the extreme layer of longitudinal tension reinforcement used to define a compression-controlled section

**2.2—Definitions**

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

**above-grade walls**—a wall that is more than 50 percent above grade and that encloses occupiable or conditioned space.

**flat insulating concrete forms**—insulating concrete forming system that produces a solid concrete wall of uniform thickness.

**foundation walls**—a wall that is more than 50 percent below grade and that encloses a crawl space or encloses occupiable or conditioned space such as a basement.

**general residential code**—code adopted in each jurisdiction; when adopted, this code supplements and forms part of the general residential code.

**grade**—the plane considered as the entrance surface to a structure which defines a structural member as exposed either to soil pressure and groundwater (below grade), or to wind and snow loads (above grade); also the prepared surface to receive a slab.

**insulating concrete forms**—concrete forming system using stay-in-place forms of rigid foam plastic insulation, a hybrid of cement and foam insulation, a hybrid of cement and wood chips, or other insulating material for constructing cast-in-place concrete walls.

**macrofiber**—fiber with an equivalent diameter greater than or equal to 0.012 in. for use in concrete.

**plain concrete**—structural concrete with no reinforcement other than as required for temperature and shrinkage.

**reentrant corner**—an internal or inside corner where a concrete member turns or wraps around on itself, creating an inside corner flanked by two outside corners or lengths of concrete.

**reinforced concrete**—structural concrete reinforced with no less than the minimum amount required by this code for strength-design capacity.

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

**slump flow**—measure of the unconfined flow potential of freshly mixed self-consolidating concrete or grout.

**townhouse**—single-family dwelling unit constructed in a group of three or more attached units in which each unit extends from foundation to roof and with open space on at least two sides.

**unbalanced backfill height**—difference between the heights of the finished grade on each side of a wall.

**R2.2—Definitions**

**unbalanced backfill height**—Where an interior concrete slab is provided, the unbalanced backfill should be measured from the exterior finished grade level to the top of the interior concrete slab.



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**wall height**—distance from the top of the lower floor framing or slab to the bottom of the upper floor framing or slab.



## CODE

## COMMENTARY

## CHAPTER 3—REFERENCED STANDARDS

*American Concrete Institute*

ACI 318-19—Building Code Requirements for Structural Concrete and Commentary

*American Society of Civil Engineers*

ASCE/SEI 7-16—Minimum Design Loads for Buildings and Other Structures

*ASTM International*

ASTM A370-18—Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM A416/A416M-18—Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete

ASTM A615/A615M-18—Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A706/A706M-16—Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A820/A820M-16—Standard Specifications for Steel Fibers for Fiber-Reinforced Concrete

ASTM A996/A996M-16—Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

ASTM C33/C33M-18—Standard Specification for Concrete Aggregates

ASTM C94/C94M-18—Standard Specification for Ready-Mixed Concrete

ASTM C150/C150M-19—Standard Specification for Portland Cement

ASTM C260/C260M-10(2016)—Standard Specification for Air-Entraining Admixtures for Concrete

ASTM C330/330M-17a—Standard Specification for Lightweight Aggregates for Structural Concrete

ASTM C494/C494M-16—Standard Specification for Chemical Admixtures for Concrete

ASTM C595/C595M-19—Standard Specification for Blended Hydraulic Cements

ASTM C618-19—Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

ASTM C685/C685M-17—Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing

ASTM C989/C989M-18—Standard Specification for Slag Cement for Use in Concrete and Mortars

ASTM C1012/C1012M-18—Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

ASTM C1017/C1017M-13—Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

ASTM C1116/C1116M-10(2015)—Standard Specification for Fiber-Reinforced Concrete

**CODE****COMMENTARY**

ASTM C1157/C1157M-17—Standard Performance Specification for Hydraulic Cement

ASTM C1218/C1218M-17—Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C1240-15—Standard Specification for Silica Fume Used in Cementitious Mixtures

ASTM C1579-13—Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)

ASTM C1580-15—Standard Test Method for Water-Soluble Sulfate in Soil

ASTM C1602/C1602M-18—Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

ASTM C1798/C1798M-19—Standard Specification for Returned Fresh Concrete for Use in a New Batch of Ready-Mixed Concrete

ASTM D98-15—Standard Specification for Calcium Chloride

ASTM D422-63(2007)—Standard Test Method for Particle-Size Analysis of Soils

ASTM D516-16—Standard Test Method for Sulfate Ion in Water

ASTM D4130-15—Standard Test Method for Sulfate Ion in Brackish Water, Seawater, and Brines

ASTM D4318-17—Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

ASTM D4829-11—Standard Test Method for Expansion Index of Soils

ASTM D7508/D7508M-10(2015)—Standard Specification for Polyolefin Chopped Strands for Use in Concrete

*International Code Council*

IRC-2018—International Residential Code

## CODE

## COMMENTARY

## CHAPTER 4—MATERIALS

## CHAPTER R4—MATERIALS

## 4.1—Concrete

4.1.1 *Cementitious material*

4.1.1.1 Cement shall conform to ASTM C150/C150M, C595/C595M, or C1157/C1157M.

4.1.1.2 Fly ash and natural pozzolans shall conform to ASTM C618.

4.1.1.3 Slag cement shall conform to ASTM C989/C989M.

4.1.1.4 Silica fume shall conform to ASTM C1240.

4.1.2 *Aggregates*

4.1.2.1 Aggregates shall conform to ASTM C33/C33M or C330/C330M.

4.1.3 *Water*

4.1.3.1 Water used as mixing water in producing concrete shall conform to ASTM C1602/C1602M.

4.1.4 *Admixtures*

4.1.4.1 Air-entraining admixtures shall conform to ASTM C260/C260M.

4.1.4.2 Chemical admixtures shall conform to ASTM C494/C494M, except that admixtures for flowing concrete shall conform to ASTM C1017/C1017M.

4.1.4.3 Calcium chloride shall conform to ASTM D98.

4.1.5 *Recycled plastic concrete*

4.1.5.1 Recycled plastic concrete shall conform to ASTM C1798/C1798M.

## 4.2—Reinforcement

4.2.1 *Deformed reinforcement*

4.2.1.1 Deformed steel reinforcing bars shall conform to ASTM A615/A615M, A706/A706M, or A996/A996M. The yield strength of reinforcement shall be at least 40,000 psi.

## R4.2—Reinforcement

R4.2.1 *Deformed reinforcement*

Refer to Table R4.2.1 for bar information.

Table R4.2.1—Steel reinforcing bar information

| Bar size, no. | Nominal diameter, in. | Nominal area, in. <sup>2</sup> | Nominal weight, lb/ft | Hook size, in.  | Development length, in. |
|---------------|-----------------------|--------------------------------|-----------------------|-----------------|-------------------------|
|               |                       |                                |                       | 6d <sub>b</sub> | 36d <sub>b</sub>        |
| 3             | 0.375                 | 0.11                           | 0.376                 | 2.25            | 13.50                   |
| 4             | 0.500                 | 0.20                           | 0.668                 | 3               | 18.00                   |
| 5             | 0.625                 | 0.31                           | 1.043                 | 3.75            | 22.50                   |
| 6             | 0.750                 | 0.44                           | 1.502                 | 4.5             | 27.00                   |

## CODE

## COMMENTARY

**4.2.2** *Prestressing steel*

**4.2.2.1** Prestressing steel strand shall conform to **ASTM A416/A416M**.

**4.2.3** *Surface conditions of reinforcement*

**4.2.3.1** At the time concrete is placed, deformed bar and welded wire reinforcement shall be free of materials deleterious to development of bond strength between the reinforcement and the concrete.

**4.2.4** *Fiber reinforcement*

**4.2.4.1** Fiber-reinforced concrete shall conform to **ASTM C1116/C1116M**.

**4.2.4.2** Macrofiber or microfiber shall conform to **ASTM D7508/D7508M**.

**4.2.4.3** Steel fiber shall conform to **ASTM C1116/C1116M** and **ASTM A820/A820M**.

**4.3—Formwork**

**4.3.1** Forms shall result in a final structure that conforms to shapes, lines, and dimensions of the members as required by the design drawings and specifications.

**4.3.2** Forms shall provide a consistent surface and sufficiently tight joints so that leakage of concrete or mortar does not occur beyond the specified deviance for surface finish or which can be cleaned from the exposed concrete surface.

**4.3.3** Forms shall be braced, tied, or secured together to maintain position and shape.

**4.3.4** Forms and their supports shall be designed so as not to damage the previously placed structure.

**4.3.5** Design of formwork shall include consideration of the following factors:

- (a) Rate and method of placing concrete
- (b) Construction loads, including vertical, horizontal, and impact loads
- (c) Form requirements for construction of arches, blockouts, ledges, floor decks, or similar elements

**4.4—Vapor retarder**

**4.4.1** A vapor retarder shall be installed under slabs that will receive a moisture-sensitive floor covering, coating, or adhesive, or where moisture-sensitive items will be stored in direct contact with a slab surface.

**4.4.2** A 6 mil (0.006 in.) polyethylene or approved vapor retarder installed according to manufacturer's recommendations shall be placed between the concrete floor slab and the

**R4.2.3** *Surface conditions of reinforcement*

Common surface contaminants such as concrete splatter, rust, form oil, or other release agents have been found not to be deleterious to bond (**Taber et al. 2002**; **Suprenant and Malisch 1998**).

**R4.3—Formwork**

**R4.3.1** Refer to **ACI 347R** and **ACI SP-4** for guidance on design and construction of formwork.

**R4.4—Vapor retarder**

**R4.4.1** Vapor retarders are used to minimize moisture vapor transmission through slabs.

**R4.4.2** Vapor retarder performance depends on its composition and the way it is installed. **ASTM E1744** defines three classes of vapor retarders—Class A, B, and C—in

**CODE**

base course or the prepared subgrade where no base course exists.

**4.4.3** Vapor retarder shall be installed as follows:

- (a) Base material shall be leveled and installed in a manner to minimize future settlement.
- (b) Vapor retarder material shall be installed in an orientation to minimize joints/seams in the system.
- (c) Vapor retarder shall be installed over footings and sealed to the foundation wall, grade beam, or slab, at an elevation consistent with the top of the slab.
- (d) Vapor retarder shall be sealed around all penetrations using manufacturer's recommendations to create a continuous membrane between the bottom of the concrete slab and the base course or the prepared subgrade where no base course exists.
- (e) Joints shall be lapped a minimum of 6 in. or as instructed by the manufacturer, and taped, sealed, or both, in accordance with manufacturer's recommendations.
- (f) All damage to the vapor retarder shall be repaired prior to the concrete placement. Repairs shall conform to manufacturer's recommendations.

**COMMENTARY**

order of highest to lowest requirements. Class C requirements are:

- a) Water vapor permeance of 0.1 perms
- b) Tensile strength of 13.6 lbf/in.
- c) Puncture resistance of 475 g.

Membranes (greater than 6 mil) incorporating an adhesive layer to create a continuous bond to the concrete should be considered when there is possible settlement of the subgrade and loss of support of the membrane. Full adhesion of the membrane to the bottom of the slab prevents lateral vapor transmission.

**R4.4.3** Vapor retarder placement requirements are intended to minimize the potential for water vapor to reach the concrete slab from the bottom or sides, when proper detailing is provided at slab edges and around isolated interior footing per manufacturer's recommendations, and when protected during concrete forming, placement, and finishing activities to help prevent damage to the membrane during construction. **ASTM E1643** covers procedures for installing vapor retarders.

## CODE

## CHAPTER 5—CONCRETE REQUIREMENTS

**5.1—Exposure categories and classes**

**5.1.1** Exposure classes shall be assigned to concrete members based on the severity of the anticipated exposure for each category according to Table 5.1.1 or as determined by the local building official.

## COMMENTARY

## CHAPTER R5—CONCRETE REQUIREMENTS

**R5.1—Exposure categories and classes**

**R5.1.1** For Exposure Category RF, Exposure Class RF0 should be assigned to interiors and to footings, foundations, and basement walls that are constructed below grade. Concrete deteriorates when exposed to freezing-and-thawing cycles when any portion of the member is in a critically saturated condition during freezing weather. Basement and foundation walls that extend above grade less than 12 in. are unlikely to be saturated and could generally be assigned Exposure Class RF0. Exposure Class RF1 or RF2 should be assigned to vertical concrete members where excessive accumulation of ice and snow is not anticipated. Examples include above-grade walls, and columns. Exposure Class RF2 should be assigned to elevated or on-grade horizontal structurally reinforced concrete members that have a likelihood for prolonged contact with water to achieve a saturation state. Exposure class RF3 shall apply to nonstructurally reinforced soil-supported exterior slabs that are subject to freezing-and-thawing cycling and deicing chemicals. Exposure Class RF4 should be assigned to the same type of structurally reinforced members as in Exposure Class RF2 but also when exposure to deicing chemicals is anticipated. Examples include above-grade columns and structural slabs exposed to salts in a marine environment. Depending on exposure conditions, garage floors can be classified as RF0 to RF3, but not RF4.

Exposure Category RS should be based on a measurement or knowledge of the concentration of soluble sulfates in soil or water that will be in contact with the relevant concrete member. The referenced test methods should be used to measure the sulfate concentrations. Other test methods can provide different results compared with the test methods referenced. Where the predominant soil sulfates are in the form of gypsum, the measured sulfate content will be higher, and these criteria will be conservative. In these cases, it is preferable that a test method that has a history of successful use in the geographic area of the project be permitted and approved by the local building official. Even though concentration of soluble sulfates in seawater will be high, members exposed to seawater should be assigned to Exposure Class RS1.

Exposure Category RC is only applicable to concrete members with structural reinforcement and not to plain concrete. The corrosion of the small amount of reinforcement used as temperature and shrinkage steel in plain or lightly reinforced (temperature and shrinkage steel) concrete members does not represent a problem whereby the structural safety of the member will be compromised.

The user of this document is encouraged to develop a table to assign exposure classes for each concrete member on a project as shown in Table R5.1.1.

## CODE

## COMMENTARY

Table 5.1.1—Exposure categories and classes

| Category                                           | Severity       | Class | Condition                                                                                                                                                                                          |                                                     |
|----------------------------------------------------|----------------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| RF<br>freezing and<br>thawing                      | Not applicable | RF0   | Concrete not exposed to freezing-and-thawing cycles                                                                                                                                                |                                                     |
|                                                    | Moderate       | RF1   | Concrete exposed to moisture but not likely to be in a saturated condition when exposed to freezing-and-thawing cycles                                                                             |                                                     |
|                                                    | Severe         | RF2   | Reinforced concrete exposed to moisture and with the potential of being in a saturated condition when exposed to freezing-and-thawing cycles                                                       |                                                     |
|                                                    | Very severe    | RF3   | Plain concrete exposed to moisture and deicing chemicals with the potential of being saturated when exposed to freezing-and-thawing cycles                                                         |                                                     |
|                                                    | Most severe    | RF4   | Reinforced concrete exposed to moisture and deicing chemicals with the potential of being saturated when exposed to freezing-and-thawing cycles                                                    |                                                     |
| RS<br>sulfate                                      |                |       | Water-soluble sulfate (SO <sub>4</sub> ) in soil, percent by mass*                                                                                                                                 | Dissolved sulfate (SO <sub>4</sub> ) in water, ppm† |
|                                                    | Not applicable | RS0   | SO <sub>4</sub> < 0.10                                                                                                                                                                             | SO <sub>4</sub> < 150                               |
|                                                    | Moderate       | RS1   | 0.10 ≤ SO <sub>4</sub> < 0.20                                                                                                                                                                      | 150 ≤ SO <sub>4</sub> < 1500<br>Seawater            |
|                                                    | Severe         | RS2   | 0.20 ≤ SO <sub>4</sub> ≤ 2.00                                                                                                                                                                      | 1500 ≤ SO <sub>4</sub> ≤ 10,000                     |
|                                                    | Very severe    | RS3   | SO <sub>4</sub> > 2.00                                                                                                                                                                             | SO <sub>4</sub> > 10,000                            |
| RC‡<br>corrosion<br>protection of<br>reinforcement | Not applicable | RC0   | Concrete dry or protected from moisture                                                                                                                                                            |                                                     |
|                                                    | Moderate       | RC1   | Concrete containing structural steel reinforcement and exposed to moisture but not to external sources of chlorides                                                                                |                                                     |
|                                                    | Severe         | RC2   | Concrete containing structural steel reinforcement and exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources |                                                     |

\*Percent sulfate by mass in soil shall be determined by ASTM C1580.

†Concentration of dissolved sulfates in water in ppm shall be determined by ASTM D516 or ASTM D4130.

‡Exposure Category RC applies to concrete members designed with reinforcing steel to resist loads. Does not apply to members with minimum steel reinforcement used for control of cracking due to temperature and shrinkage or to steel fiber-reinforced concrete.

The terms “plain concrete” and “reinforced concrete” refer to the use of structural reinforcement as found in 2.1 and 6.5.

Table R5.1.1—Assigned exposure classes for concrete members

| Concrete member*                                                                                        | Exposure class                |               |                                                   |
|---------------------------------------------------------------------------------------------------------|-------------------------------|---------------|---------------------------------------------------|
|                                                                                                         | RF<br>freezing and<br>thawing | RS<br>sulfate | RC<br>corrosion<br>protection of<br>reinforcement |
| Footings, foundations, and basement walls not exposed to weather                                        | RF*†                          | RS*†          | RC*†                                              |
| Basement slabs and interior slabs on grade                                                              | RF*†                          | RS*†          | RC*†                                              |
| Footings, foundations, basement walls, and exterior walls exposed to weather                            | RF*†                          | RS*†          | RC*†                                              |
| Driveways, curbs, walks, patios, porches, steps, stairs, and unheated garage floors exposed to weather. | RF*†                          | RS*†          | RC*†                                              |

\*Depending on the project and or exposure conditions, fewer or additional concrete members may need to be defined for purposes of assigning exposure classes.

†For each concrete member, the corresponding exposure classifications should be placed in the appropriate cell and compared to determine the most restrictive requirements for concrete per 5.3.2.

## CODE

## COMMENTARY

**5.2—General requirements**

**5.2.1** The value of  $f'_c$  shall be the greatest of the values required by Table 5.1.1 based on exposure class or as required for structural strength. Concrete mixtures shall be proportioned to achieve the strength and to comply with the slump, air content, and cementitious materials limitations in this chapter.

**5.3—Requirements for concrete mixtures**

**5.3.1** *Coarse aggregate size*—The nominal maximum size of coarse aggregate shall not exceed the smallest of (a), (b), and (c):

- (a) one-fifth of the minimum wall thickness
- (b) one-third of the cross-sectional dimension of a member
- (c) three-fourths of the specified minimum clear spacing between reinforcing bars or clear cover

**5.3.2** Based on the exposure classes assigned from 5.1.1, concrete mixtures shall comply with the most restrictive requirements according to Table 5.3.2.

**R5.2—General requirements**

**R5.2.1** The specifier can require a higher specified strength than indicated in this code. The concrete supplier proportions concrete mixtures to achieve an average strength higher than the specified strength. The purchaser may request documentation demonstrating that the concrete being supplied will achieve the specified strength requirements. **ACI 301** provides guidance for proportioning mixtures to meet specified compressive strength. If strength verification is required, cylinders shall be taken by an ACI Certified Field Technician or technician certified by an equivalent program during time of placement and shall be tested according **ASTM C39/C39M**. The concrete strength is considered satisfactory as long as averages of any three consecutive strength tests remain above the specified  $f'_c$  and no individual strength test falls below the specified  $f'_c$  by more than 500 psi.

**R5.3—Requirements for concrete mixtures**

**R5.3.1** These aggregate size limitations do not apply (may be waived) if workability and consolidation methods facilitate the placement of concrete without honeycombs or voids. Selecting the largest maximum aggregate size consistent with workability and placement can reduce the paste and water content, resulting in reduced volume change, and typically results in a more economical mixture design.

**R5.3.2** Concrete durability is improved by the introduction of air entrainment for resistance to freezing and thawing, the use of a  $w/cm$  less than or equal to 0.45 to reduce the permeability of concrete to water and deleterious chemicals, and proper curing (refer to **6.5**).

The type and performance of water-reducing admixtures are selected based on the intended application and include both high-range water-reducing admixtures (HRWRAs) and mid-range water-reducing admixtures (MRWRAs). HRWRAs and MRWRAs result in large to moderate water reductions, respectively, in mixtures while maintaining greater workability (slump) without causing undue set retardation or increased air entrainment. If slump verification is required, slump testing shall be in accordance with **ASTM C143/C143M**. A traditional slump limit is not appropriate for self-consolidated concrete, where the consistency of the concrete is measured in terms of slump flow in accordance with **ASTM C1611/C1611M**. Slump flow in the range of 20 to 28 in. is generally used for residential concrete. Refer to ACI 237R for additional information.

For Exposure Class RS3, it is permitted to use cementitious materials in concrete mixtures that have a good service record in similar exposure conditions. When typical concrete mixtures used in the region have had good service history that exceeds approximately 5 years, testing mixtures in accordance with 5.4.2 to establish the additional quantity of pozzolans and slag cement is not necessary. The MS and HS designations for blended cements complying with **ASTM C595/C595M** and **ASTM C1157/C1157M** are permitted to comply with the requirements of Table 5.4.2.

## CODE

## COMMENTARY

Table 5.3.2—Concrete design requirements for exposure categories and classes

| Exposure class | Maximum $w/cm$ | Minimum $f_c'$ ,<br>psi* | Additional minimum requirements                                                                                                                           |                                                                       |                                           |                                  |
|----------------|----------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------|----------------------------------|
|                |                |                          | Air content                                                                                                                                               |                                                                       |                                           | Limits on cementitious materials |
| RF0            | N/A            | 2500                     | N/A                                                                                                                                                       |                                                                       |                                           | N/A                              |
| RF1            | 0.55           | 3500                     | Table 5.4.1                                                                                                                                               |                                                                       |                                           | N/A                              |
| RF2            | 0.45           | 4500                     | Table 5.4.1                                                                                                                                               |                                                                       |                                           | N/A                              |
| RF3            | 0.45           | 4500                     | Table 5.4.1                                                                                                                                               |                                                                       |                                           | Table 5.4.2                      |
| RF4            | 0.40           | 5000                     | Table 5.4.1                                                                                                                                               |                                                                       |                                           | Table 5.4.2                      |
|                |                |                          | Cementitious materials <sup>†</sup> —types                                                                                                                |                                                                       |                                           | Calcium chloride admixture       |
|                |                |                          | ASTM C150/C150M                                                                                                                                           | ASTM C595/C595M                                                       | ASTM C1157/C1157M                         |                                  |
| RS0            | N/A            | 2500                     | No type restriction                                                                                                                                       | No type restriction                                                   | No type restriction                       | No restriction                   |
| RS1            | 0.50           | 2500                     | II                                                                                                                                                        | Types with (MS) designation                                           | MS                                        | No restriction                   |
| RS2            | 0.45           | 3000                     | V <sup>‡</sup>                                                                                                                                            | Types with (HS) designation                                           | HS                                        | Not permitted                    |
| RS3            | 0.45           | 3000                     | V + pozzolan or slag <sup>§</sup>                                                                                                                         | Types with (HS) designation plus pozzolan or slag cement <sup>§</sup> | HS + pozzolan or slag cement <sup>§</sup> | Not permitted                    |
|                |                |                          | Maximum water-soluble chloride ion (Cl <sup>-</sup> ) content in concrete, percent by mass of cementitious materials <sup>  </sup> in reinforced concrete |                                                                       |                                           |                                  |
| RC0            | N/A            | 2500                     | 1.00                                                                                                                                                      |                                                                       |                                           |                                  |
| RC1            | N/A            | 2500                     | 0.30                                                                                                                                                      |                                                                       |                                           |                                  |
| RC2            | 0.40           | 4000                     | 0.15                                                                                                                                                      |                                                                       |                                           |                                  |

\*Concrete compressive strength specified  $f_c'$  shall be based on 28-day tests per ASTM C39/C39M.

<sup>†</sup>Alternative combinations of cementitious materials of those listed in Table 5.4.2 shall be permitted when tested for sulfate resistance and meeting the criteria in 5.5.

<sup>‡</sup>Other available types of cement such as Type III or Type I are permitted in Exposure Classes RS1 or RS2 if the  $C_3A$  contents are less than 8 or 5 percent, respectively.

<sup>§</sup>The amount of the specific source of the pozzolan or slag to be used shall not be less than the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag to be used shall not be less than the amount tested in accordance with ASTM C1012/C1012M and meeting the criteria in 5.5.1.

<sup>||</sup>Water-soluble chloride ion content that is contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall be determined on the concrete mixture by ASTM C1218/C1218M between 28 and 42 days.

Calcium chloride is a common and effective chemical admixture used to accelerate the setting time and rate of strength gain in cold weather construction. Its use is not permitted for members assigned with Exposure Classes RS2 and RS3 because of the potential for reducing the sulfate resistance of concrete. Its use may also be restricted for members with structural reinforcement assigned to Exposure Category RC. The limits for calcium chloride are stated in terms of chloride ions. When there is no other source of chlorides in the concrete ingredients, the limit on calcium chloride is approximately double the chloride ion limit (a 1 percent chloride ion limit is roughly equivalent to 2 percent calcium chloride). When calcium chloride use is restricted, non-chloride-based accelerating admixtures may be used for the same purpose.

## CODE

## COMMENTARY

**5.4—Additional requirements for freezing-and-thawing exposure**

**5.4.1** Normalweight concrete subject to Exposure Category RF1 through RF4 shall be air entrained with a total air content as indicated in Table 5.4.1. Tolerance on air content as delivered shall be  $\pm 1.5$  percent. For  $f'_c$  greater than 5000 psi, reduction of air content indicated in Table 5.4.1 by 1.0 percent shall be permitted.

**Table 5.4.1—Total air content for concrete assigned to exposure category RF**

| Nominal maximum aggregate size, in.* | Total air content, percent† |                                    |
|--------------------------------------|-----------------------------|------------------------------------|
|                                      | Exposure Class RF1          | Exposure Classes RF2, RF3, and RF4 |
| 3/8                                  | 6                           | 7.5                                |
| 1/2                                  | 5.5                         | 7                                  |
| 3/4                                  | 5                           | 6                                  |
| 1                                    | 4.5                         | 6                                  |
| 1-1/2                                | 4.5                         | 5.5                                |
| 2                                    | 4                           | 5                                  |
| 3                                    | 3.5                         | 4.5                                |

\*Refer to ASTM C33/C33M for tolerance on oversized aggregate for various nominal maximum size designations.

†Tolerance on air content of  $\pm 1.5$  percent shall be permissible.

**5.4.2** The quantity of pozzolans, including fly ash and silica fume, and slag in concrete subject to Exposure Class RF3 shall not exceed the limits in Table 5.4.2.

**Table 5.4.2—Requirements for concrete subject to exposure class RF3 and RF4**

| Cementitious materials                                     | Maximum percent of total cementitious materials by weight* |
|------------------------------------------------------------|------------------------------------------------------------|
| Fly ash or other pozzolans conforming to ASTM C618         | 25                                                         |
| Slag conforming to ASTM C989/C989M                         | 50                                                         |
| Silica fume conforming to ASTM C1240                       | 10                                                         |
| Total of fly ash or other pozzolans, slag, and silica fume | 50†                                                        |
| Total of fly ash or other pozzolans and silica fume        | 35†                                                        |

\*The total cementitious material also includes ASTM C150/C150M, C595/C595M, C845, and C1157/C1157M cement.

The maximum percentages above shall include:

- (a) Fly ash or other pozzolans in Type IP blended cement, ASTM C595/C595M, or ASTM C1157/C1157M
- (b) Slag used in the manufacture of an IS blended cement, ASTM C595/C595M, or ASTM C1157/C1157M
- (c) ASTM C1240 silica fume present in a blended cement

†Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

**R5.4—Additional requirements for freezing-and-thawing exposure**

**R5.4.1** Air-entrained concrete is essential for durability of concrete exposed to freezing-and-thawing cycles. A lower air content is justified for members assigned an Exposure Class RF1 because of the reduced likelihood that these members will be in a saturated condition when exposed to freezing and thawing cycles. Higher air contents than indicated in Table 5.4.1 will reduce strength and will not improve durability. If verification of air content is specified, testing shall be performed by an ACI Certified Field Technician or technician certified by an equivalent program and in accordance with **ASTM C231/C231M** or **C173/C173M**, as appropriate. If concrete fails to meet the required air entrainment at the lower end of the tolerance, steps should be taken to increase the air content.

**R5.4.2** Table 5.4.2 establishes limitations on the amount of fly ash, other pozzolans, silica fume, and slag cement that can be included in concrete members assigned to Exposure Category RF3 and RF4. The quantity of these materials includes those in blended cements (**ASTM C595/C595M** and **C1157/C1157M**), separately added when batching concrete, or both. Exceeding these limitations may increase the potential for surface scaling. These limits on supplementary cementitious materials should not be applied to concrete members that are Class RF0, RF1, or RF2.

## CODE

**5.5—Alternative cementitious materials for sulfate exposure**

**5.5.1** Alternative combinations of cementitious materials to those listed in Table 5.1.1 shall be permitted when tested for sulfate resistance and meeting the criteria in Table 5.5.1.

**Table 5.5.1—Requirements for establishing suitability of cementitious materials combinations exposed to water-soluble sulfate**

| Exposure class | Maximum expansion when tested using ASTM C1012/C1012M |               |              |
|----------------|-------------------------------------------------------|---------------|--------------|
|                | At 6 months                                           | At 12 months  | At 18 months |
| RS1            | 0.10 percent                                          | —             | —            |
| RS2            | 0.05 percent                                          | 0.10 percent* | —            |
| RS3            | —                                                     | —             | 0.10 percent |

\*The 12-month expansion limit applies only when the measured expansion exceeds the 6-month maximum expansion limit.

**5.6—Concrete cover**

**5.6.1** Concrete cover shall have a tolerance of  $\pm 3/8$  in.

**5.6.2** Concrete cover for slabs-on-ground shall be in accordance with 10.6.1.

**5.6.3** Clear cover to reinforcement in concrete footings and walls shall be in accordance with 5.6.4 through 5.6.7.

**5.6.4** Cover to reinforcement for concrete cast against earth shall be at least 3 in.

**5.6.5** Cover to reinforcement for concrete not exposed to earth or weather shall be at least 3/4 in.

**5.6.6** Cover to reinforcement, with a size not larger than a No. 5 bar or W31 or D31 wire, for concrete exposed to earth or weather shall be at least 1-1/2 in.

**5.6.7** Cover to reinforcement, with a size not smaller than a No. 6 bar, for concrete exposed to earth or weather shall be at least 2 in.

## COMMENTARY

**R5.5—Alternative cementitious materials for sulfate exposure**

**R5.5.1** Testing required to qualify cementitious materials in Table 5.5.1 takes considerable time and may not be possible with typical project schedules. It is permitted to use concrete mixtures with good service records in these circumstances. The expansion criteria for Exposure Classes RS1 and RS2 are the same as those for the MS and HS designations, respectively, for cements manufactured in accordance with ASTM C595/C595M and C1157/C1157M. Therefore, these blended cements may be an option in these exposure conditions.

**R5.6—Concrete cover**

**R5.6.4** In some instances, it is advantageous or necessary for one or more sides of the formed concrete to be cast against an excavated earth surface. This section refers to these instances where the placing operation results in the concrete directly contacting the earth. Exceptions to this coverage limit include the placement of footing dowels in accordance with 8.2.2.1.1 when the dowels are not continuous as or are lap spliced with vertical reinforcement.

## CODE

## CHAPTER 6—DESIGN OF STRUCTURAL CONCRETE

## 6.1—Scope

**6.1.1** This chapter shall apply to design of structural concrete in structures or portions of structures defined in [Chapter 1](#).

**6.1.2** It shall be permitted to design a structural system comprising structural members not in accordance with this chapter, provided the structural system is approved in accordance with [1.2](#).

## 6.2—Materials

**6.2.1** *Concrete design properties*

**6.2.1.1** Modulus of elasticity,  $E_c$ , for concrete shall be permitted to be calculated as (a) or (b):

(a) For values of  $w_c$  between 90 and 160 lb/ft<sup>3</sup>

$$E_c = w_c^{1.5} 33 \sqrt{f'_c} \quad (\text{in psi}) \quad (6.2.1.1a)$$

(b) For normalweight concrete:

$$E_c = 57,000 \sqrt{f'_c} \quad (\text{in psi}) \quad (6.2.1.1b)$$

**6.2.1.2** Modulus of rupture,  $f_r$ , for concrete shall be calculated by

$$f_r = 7.5 \lambda \sqrt{f'_c} \quad (6.2.1.2)$$

where,  $\lambda$  is 1 for normalweight concrete.

Alternatively, performance-based procedures may be employed as permitted in [1.2](#) to determine  $f_r$ .

**6.2.2** *Steel reinforcement design properties*

**6.2.2.1** Yield strength of bars and wires shall be determined by either (a) or (b):

(a) The offset method, using an offset of 0.2 percent in accordance with [ASTM A370](#)

(b) The yield point by the halt-of-force method, provided the bar or wire has a sharp-kneed or well-defined yield point

**6.2.2.2** The stress below  $f_y$  shall be  $E_s$  times steel strain. For strains greater than that corresponding to  $f_y$ , stress shall be considered independent of strain and equal to  $f_y$ .

## COMMENTARY

## CHAPTER R6—DESIGN OF STRUCTURAL CONCRETE

## R6.1—Scope

**R6.1.2** Some materials, structural members, or systems that may not be recognized in the provisions of the code may still be acceptable if they meet the intent of the code. [Section 1.2](#) outlines the procedures for obtaining approval of alternative materials and systems.

## R6.2—Materials

**R6.2.2** *Steel reinforcement design properties*

**R6.2.2.2** For deformed reinforcement, it is reasonably accurate to assume that the stress in reinforcement is proportional to strain below the specified yield strength  $f_y$ . The increase in strength due to the effect of strain hardening of the reinforcement is neglected for nominal strength calculations. In nominal strength calculations, the force developed in tension or compression reinforcement is calculated as:

if  $\epsilon_s < \epsilon_y$  (yield strain)

$$A_s f_s = A_s E_s \epsilon_s$$