

An ACI Standard

Building Code Requirements for Structural Concrete (ACI 318-19)

Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19)

Reported by ACI Committee 318

ACI 318-19



American Concrete Institute
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Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19)

Reported by ACI Committee 318

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David M. Rogowsky

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Building Code Requirements for Structural Concrete and Commentary

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American Concrete Institute
3880 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org



PREFACE TO ACI 318-19

The “Building Code Requirements for Structural Concrete” (“Code”) provides minimum requirements for the materials, design, and detailing of structural concrete buildings and, where applicable, nonbuilding structures. This Code was developed by an ANSI-approved consensus process and addresses structural systems, members, and connections, including cast-in-place, precast, shotcrete, plain, nonprestressed, prestressed, and composite construction. Among the subjects covered are: design and construction for strength, serviceability, and durability; load combinations, load factors, and strength reduction factors; structural analysis methods; deflection limits; mechanical and adhesive anchoring to concrete; development and splicing of reinforcement; construction document information; field inspection and testing; and methods to evaluate the strength of existing structures.

The Code was substantially reorganized and reformatted in 2014, and this Code continues and expands that same organizational philosophy. The principal objectives of the reorganization were to present all design and detailing requirements for structural systems or for individual members in chapters devoted to those individual subjects, and to arrange the chapters in a manner that generally follows the process and chronology of design and construction. Information and procedures that are common to the design of multiple members are located in utility chapters. Additional enhancements implemented in this Code to provide greater clarity and ease of use include the first use of color illustrations and the use of color to help the user navigate the Code and quickly find the information they need. Special thanks to Bentley Systems, Incorporated, for use of their ProConcrete software to produce many of the figures found in the Commentary.

Uses of the Code include adoption by reference in a general building code, and earlier editions have been widely used in this manner. The Code is written in a format that allows such reference without change to its language. Therefore, background details or suggestions for carrying out the requirements or intent of the Code provisions cannot be included within the Code itself. The Commentary is provided for this purpose.

Some considerations of the committee in developing the Code are discussed in the Commentary, with emphasis given to the explanation of new or revised provisions. Much of the research data referenced in preparing the Code is cited for the user desiring to study individual questions in greater detail. Other documents that provide suggestions for carrying out the requirements of the Code are also cited.

Technical changes from ACI 318-14 to ACI 318-19 are outlined in the August 2019 issue of *Concrete International* and are marked in the text of this Code with change bars in the margins.

KEYWORDS

admixtures; aggregates; anchorage (structural); beam-column frame; beams (supports); caissons; cements; cold weather; columns (supports); combined stress; composite construction (concrete to concrete); compressive strength; concrete; construction documents; construction joints; continuity (structural); contraction joints; cover; curing; deep beams; deep foundations; deflections; drilled piers; earthquake-resistant structures; flexural strength; floors; footings; formwork (construction); hot weather; inspection; isolation joints; joints (junctions); joists; lightweight concretes; load tests (structural); loads (forces); mixture proportioning; modulus of elasticity; moments; piles; placing; plain concrete; precast concrete; prestressed concrete; prestressing steels; quality control; reinforced concrete; reinforcing steels; roofs; serviceability; shear strength; shotcrete; spans; splicing; strength analysis; stresses; structural analysis; structural design; structural integrity; structural walls; T-beams; torsion; walls; water; welded wire reinforcement.

INTRODUCTION

ACI 318-19, “Building Code Requirements for Structural Concrete,” hereinafter called the Code or the 2019 Code, and ACI 318R-19, “Commentary,” are presented in a side-by-side column format. These are two separate but coordinated documents, with Code text placed in the left column and the corresponding Commentary text aligned in the right column. Commentary section numbers are preceded by an “R” to further distinguish them from Code section numbers. The two documents are bound together solely for the user’s convenience. Each document carries a separate enforceable and distinct copyright.

As the name implies, “Building Code Requirements for Structural Concrete” is meant to be used as part of a legally adopted building code and as such must differ in form and substance from documents that provide detailed specifications, recommended practice, complete design procedures, or design aids.

The Code is intended to cover all buildings of the usual types, both large and small. Requirements more stringent than the Code provisions may be desirable for unusual construction. The Code and Commentary cannot replace sound engineering knowledge, experience, and judgment.

A building code states only the minimum requirements necessary to provide for public health and safety. The Code is based on this principle. For any structure, the owner or the licensed design professional may require the quality of materials and construction to be higher than the minimum requirements necessary to protect the public as stated in the Code. However, lower standards are not permitted.

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

The Code and Commentary are not intended for use in settling disputes between the owner, engineer, architect, contractor, or their agents, subcontractors, material suppliers, or testing agencies. Therefore, the Code cannot define the contract responsibility of each of the parties in usual construction. General references requiring compliance with the Code in the 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 a detailed knowledge of the design. Design-build construction contractors, however, typically combine the design and construction responsibility. Generally, the 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 project specifications. Other ACI publications, such as “Specifications for Structural Concrete (ACI 301)” are written specifically for use as contract documents for construction.

The Commentary discusses some of the considerations of Committee 318 in developing the provisions contained in the Code. Emphasis is given to the explanation of new or revised provisions that may be unfamiliar to Code users. In addition, comments are included for some items contained in previous editions of the Code to make the present Commentary independent of the previous editions. Comments on specific provisions are made under the corresponding chapter and section numbers of the Code.

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

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

The Commentary is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations, and who will accept responsibility for the application of the information it contains. ACI disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom. Reference to the Commentary shall not be made in construction documents. If items found in the Commentary are desired by the licensed design professional to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the licensed design professional.

It is recommended to have the materials, processes, quality control measures, and inspections described in this document tested, monitored, or performed by individuals holding the appropriate ACI Certification or equivalent, when available. The personnel certification programs of the American Concrete Institute and the Post-Tensioning Institute; the plant certification programs of the Precast/Prestressed Concrete Institute, the Post-Tensioning Institute, and the National Ready Mixed Concrete Association; and the Concrete Reinforcing Steel Institute’s Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants are available for this purpose. In addition, “Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection” (ASTM E329-18) specifies performance requirements for inspection and testing agencies.

Design reference materials illustrating applications of the Code requirements are listed and described in the back of this document.

TABLE OF CONTENTS

PART 1: GENERAL**CHAPTER 1
GENERAL**

- 1.1—Scope of ACI 318, p. 9
- 1.2—General, p. 9
- 1.3—Purpose, p. 9
- 1.4—Applicability, p. 10
- 1.5—Interpretation, p. 12
- 1.6—Building official, p. 13
- 1.7—Licensed design professional, p. 13
- 1.8—Construction documents and design records, p. 13
- 1.9—Testing and inspection, p. 14
- 1.10—Approval of special systems of design, construction, or alternative construction materials, p. 14

**CHAPTER 2
NOTATION AND TERMINOLOGY**

- 2.1—Scope, p. 15
- 2.2—Notation, p. 15
- 2.3—Terminology, p. 31

**CHAPTER 3
REFERENCED STANDARDS**

- 3.1—Scope, p. 47
- 3.2—Referenced standards, p. 47

**CHAPTER 4
STRUCTURAL SYSTEM REQUIREMENTS**

- 4.1—Scope, p. 51
- 4.2—Materials, p. 51
- 4.3—Design loads, p. 51
- 4.4—Structural system and load paths, p. 52
- 4.5—Structural analysis, p. 54
- 4.6—Strength, p. 55
- 4.7—Serviceability, p. 56
- 4.8—Durability, p. 56
- 4.9—Sustainability, p. 56
- 4.10—Structural integrity, p. 56
- 4.11—Fire resistance, p. 57
- 4.12—Requirements for specific types of construction, p. 57
- 4.13—Construction and inspection, p. 59
- 4.14—Strength evaluation of existing structures, p. 59

PART 2: LOADS & ANALYSIS**CHAPTER 5
LOADS**

- 5.1—Scope, p. 61
- 5.2—General, p. 61
- 5.3—Load factors and combinations, p. 62

**CHAPTER 6
STRUCTURAL ANALYSIS**

- 6.1—Scope, p. 67
- 6.2—General, p. 67
- 6.3—Modeling assumptions, p. 72
- 6.4—Arrangement of live load, p. 73
- 6.5—Simplified method of analysis for nonprestressed continuous beams and one-way slabs, p. 74
- 6.6—Linear elastic first-order analysis, p. 75
- 6.7—Linear elastic second-order analysis, p. 84
- 6.8—Inelastic analysis, p. 85
- 6.9—Acceptability of finite element analysis, p. 86

PART 3: MEMBERS**CHAPTER 7
ONE-WAY SLABS**

- 7.1—Scope, p. 89
- 7.2—General, p. 89
- 7.3—Design limits, p. 89
- 7.4—Required strength, p. 91
- 7.5—Design strength, p. 91
- 7.6—Reinforcement limits, p. 92
- 7.7—Reinforcement detailing, p. 94

**CHAPTER 8
TWO-WAY SLABS**

- 8.1—Scope, p. 99
- 8.2—General, p. 99
- 8.3—Design limits, p. 100
- 8.4—Required strength, p. 103
- 8.5—Design strength, p. 109
- 8.6—Reinforcement limits, p. 110
- 8.7—Reinforcement detailing, p. 113
- 8.8—Nonprestressed two-way joist systems, p. 125

CHAPTER 9 BEAMS

- 9.1—Scope, p. 127
- 9.2—General, p. 127
- 9.3—Design limits, p. 128
- 9.4—Required strength, p. 130
- 9.5—Design strength, p. 133
- 9.6—Reinforcement limits, p. 135
- 9.7—Reinforcement detailing, p. 139
- 9.8—Nonprestressed one-way joist systems, p. 150
- 9.9—Deep beams, p. 152

CHAPTER 10 COLUMNS

- 10.1—Scope, p. 155
- 10.2—General, p. 155
- 10.3—Design limits, p. 155
- 10.4—Required strength, p. 156
- 10.5—Design strength, p. 157
- 10.6—Reinforcement limits, p. 157
- 10.7—Reinforcement detailing, p. 158

CHAPTER 11 WALLS

- 11.1—Scope, p. 165
- 11.2—General, p. 165
- 11.3—Design limits, p. 166
- 11.4—Required strength, p. 166
- 11.5—Design strength, p. 167
- 11.6—Reinforcement limits, p. 170
- 11.7—Reinforcement detailing, p. 171
- 11.8—Alternative method for out-of-plane slender wall analysis, p. 172

CHAPTER 12 DIAPHRAGMS

- 12.1—Scope, p. 175
- 12.2—General, p. 176
- 12.3—Design limits, p. 177
- 12.4—Required strength, p. 178
- 12.5—Design strength, p. 181
- 12.6—Reinforcement limits, p. 188
- 12.7—Reinforcement detailing, p. 188

CHAPTER 13 FOUNDATIONS

- 13.1—Scope, p. 191
- 13.2—General, p. 193
- 13.3—Shallow foundations, p. 197
- 13.4—Deep foundations, p. 199

CHAPTER 14 PLAIN CONCRETE

- 14.1—Scope, p. 203
- 14.2—General, p. 204
- 14.3—Design limits, p. 204
- 14.4—Required strength, p. 206
- 14.5—Design strength, p. 207
- 14.6—Reinforcement detailing, p. 210

PART 4: JOINTS/CONNECTIONS/ANCHORS

CHAPTER 15 BEAM-COLUMN AND SLAB-COLUMN JOINTS

- 15.1—Scope, p. 211
- 15.2—General, p. 211
- 15.3—Detailing of joints, p. 212
- 15.4—Strength requirements for beam-column joints, p. 213
- 15.5—Transfer of column axial force through the floor system, p. 214

CHAPTER 16 CONNECTIONS BETWEEN MEMBERS

- 16.1—Scope, p. 217
- 16.2—Connections of precast members, p. 217
- 16.3—Connections to foundations, p. 222
- 16.4—Horizontal shear transfer in composite concrete flexural members, p. 225
- 16.5—Brackets and corbels, p. 227

CHAPTER 17 ANCHORING TO CONCRETE

- 17.1—Scope, p. 233
- 17.2—General, p. 234
- 17.3—Design Limits, p. 235
- 17.4—Required strength, p. 236
- 17.5—Design strength, p. 236
- 17.6—Tensile strength, p. 246
- 17.7—Shear strength, p. 261
- 17.8—Tension and shear interaction, p. 270
- 17.9—Edge distances, spacings, and thicknesses to preclude splitting failure, p. 270
- 17.10—Earthquake-resistant anchor design requirements, p. 272
- 17.11—Attachments with shear lugs, p. 277

PART 5: EARTHQUAKE RESISTANCE**CHAPTER 18
EARTHQUAKE-RESISTANT STRUCTURES**

- 18.1—Scope, p. 285
- 18.2—General, p. 285
- 18.3—Ordinary moment frames, p. 291
- 18.4—Intermediate moment frames, p. 292
- 18.5—Intermediate precast structural walls, p. 299
- 18.6—Beams of special moment frames, p. 299
- 18.7—Columns of special moment frames, p. 305
- 18.8—Joints of special moment frames, p. 311
- 18.9—Special moment frames constructed using precast concrete, p. 314
- 18.10—Special structural walls, p. 317
- 18.11—Special structural walls constructed using precast concrete, p. 336
- 18.12—Diaphragms and trusses, p. 336
- 18.13—Foundations, p. 343
- 18.14—Members not designated as part of the seismic-force-resisting system, p. 351

PART 6: MATERIALS & DURABILITY**CHAPTER 19
CONCRETE: DESIGN AND DURABILITY
REQUIREMENTS**

- 19.1—Scope, p. 355
- 19.2—Concrete design properties, p. 355
- 19.3—Concrete durability requirements, p. 357
- 19.4—Grout durability requirements, p. 369

**CHAPTER 20
STEEL REINFORCEMENT PROPERTIES,
DURABILITY, AND EMBEDMENTS**

- 20.1—Scope, p. 371
- 20.2—Nonprestressed bars and wires, p. 371
- 20.3—Prestressing strands, wires, and bars, p. 378
- 20.4—Headed shear stud reinforcement, p. 382
- 20.5—Provisions for durability of steel reinforcement, p. 382
- 20.6—Embedments, p. 390

PART 7: STRENGTH & SERVICEABILITY**CHAPTER 21
STRENGTH REDUCTION FACTORS**

- 21.1—Scope, p. 391
- 21.2—Strength reduction factors for structural concrete members and connections, p. 391

**CHAPTER 22
SECTIONAL STRENGTH**

- 22.1—Scope, p. 397
- 22.2—Design assumptions for moment and axial strength, p. 397
- 22.3—Flexural strength, p. 399
- 22.4—Axial strength or combined flexural and axial strength, p. 400
- 22.5—One-way shear strength, p. 401
- 22.6—Two-way shear strength, p. 411
- 22.7—Torsional strength, p. 420
- 22.8—Bearing, p. 428
- 22.9—Shear friction, p. 430

**CHAPTER 23
STRUT-AND-TIE METHOD**

- 23.1—Scope, p. 435
- 23.2—General, p. 436
- 23.3—Design strength, p. 443
- 23.4—Strength of struts, p. 443
- 23.5—Minimum distributed reinforcement, p. 445
- 23.6—Strut reinforcement detailing, p. 446
- 23.7—Strength of ties, p. 447
- 23.8—Tie reinforcement detailing, p. 447
- 23.9—Strength of nodal zones, p. 448
- 23.10—Curved-bar nodes, p. 449
- 23.11—Earthquake-resistant design using the strut-and-tie method, p. 452

**CHAPTER 24
SERVICEABILITY**

- 24.1—Scope, p. 455
- 24.2—Deflections due to service-level gravity loads, p. 455
- 24.3—Distribution of flexural reinforcement in one-way slabs and beams, p. 460
- 24.4—Shrinkage and temperature reinforcement, p. 461
- 24.5—Permissible stresses in prestressed concrete flexural members, p. 463

PART 8: REINFORCEMENT**CHAPTER 25
REINFORCEMENT DETAILS**

- 25.1—Scope, p. 467
- 25.2—Minimum spacing of reinforcement, p. 467
- 25.3—Standard hooks, seismic hooks, crossties, and minimum inside bend diameters, p. 469
- 25.4—Development of reinforcement, p. 471
- 25.5—Splices, p. 488
- 25.6—Bundled reinforcement, p. 493
- 25.7—Transverse reinforcement, p. 494
- 25.8—Post-tensioning anchorages and couplers, p. 504
- 25.9—Anchorage zones for post-tensioned tendons, p. 505

PART 9: CONSTRUCTION**CHAPTER 26
CONSTRUCTION DOCUMENTS AND
INSPECTION**

- 26.1—Scope, p. 515
- 26.2—Design criteria, p. 516
- 26.3—Member information, p. 517
- 26.4—Concrete materials and mixture requirements, p. 517
- 26.5—Concrete production and construction, p. 528
- 26.6—Reinforcement materials and construction requirements, p. 535
- 26.7—Anchoring to concrete, p. 540
- 26.8—Embedments, p. 542
- 26.9—Additional requirements for precast concrete, p. 543
- 26.10—Additional requirements for prestressed concrete, p. 544
- 26.11—Formwork, p. 546
- 26.12—Evaluation and acceptance of hardened concrete, p. 548
- 26.13—Inspection, p. 554

PART 10: EVALUATION**CHAPTER 27
STRENGTH EVALUATION OF EXISTING
STRUCTURES**

- 27.1—Scope, p. 559
- 27.2—General, p. 559
- 27.3—Analytical strength evaluation, p. 560
- 27.4—Strength evaluation by load test, p. 561
- 27.5—Monotonic load test procedure, p. 562
- 27.6—Cyclic load test procedure, p. 564

APPENDICES & REFERENCES**APPENDIX A
DESIGN VERIFICATION USING NONLINEAR
RESPONSE HISTORY ANALYSIS**

- A.1—Notation and terminology, p. 567
- A.2—Scope, p. 567
- A.3—General, p. 568
- A.4—Earthquake ground motions, p. 568
- A.5—Load factors and combinations, p. 569
- A.6—Modeling and analysis, p. 569
- A.7—Action classification and criticality, p. 570
- A.8—Effective stiffness, p. 571
- A.9—Expected material strength, p. 573
- A.10—Acceptance criteria for deformation-controlled actions, p. 574
- A.11—Expected strength for force-controlled actions, p. 576
- A.12—Enhanced detailing requirements, p. 577
- A.13—Independent structural design review, p. 578

**APPENDIX B
STEEL REINFORCEMENT INFORMATION****APPENDIX C
EQUIVALENCE BETWEEN SI-METRIC,
MKS-METRIC, AND U.S. CUSTOMARY UNITS OF
NONHOMOGENOUS EQUATIONS IN THE CODE****COMMENTARY REFERENCES****INDEX**

CHAPTER 1—GENERAL

CODE

COMMENTARY

1.1—Scope of ACI 318

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

- (a) General requirements of this Code
- (b) Purpose of this Code
- (c) Applicability of this Code
- (d) Interpretation of this Code
- (e) Definition and role of the building official and the licensed design professional
- (f) Construction documents
- (g) Testing and inspection
- (h) Approval of special systems of design, construction, or alternative construction materials

1.2—General

1.2.1 ACI 318, “Building Code Requirements for Structural Concrete,” is hereafter referred to as “this Code.”

1.2.2 In this Code, the general building code refers to the building code adopted in a jurisdiction. When adopted, this Code forms part of the general building code.

1.2.3 The official version of this Code is the English language version, using inch-pound units, published by the American Concrete Institute.

1.2.4 In case of conflict between the official version of this Code and other versions of this Code, the official version governs.

1.2.5 This Code provides minimum requirements for the materials, design, construction, and strength evaluation of structural concrete members and systems in any structure designed and constructed under the requirements of the general building code.

1.2.6 Modifications to this Code that are adopted by a particular jurisdiction are part of the laws of that jurisdiction, but are not a part of this Code.

1.2.7 If no general building code is adopted, this Code provides minimum requirements for the materials, design, construction, and strength evaluation of members and systems in any structure within the scope of this Code.

1.3—Purpose

1.3.1 The purpose of this Code is to provide for public health and safety by establishing minimum requirements for

R1.1—Scope of ACI 318

R1.1.1 This Code includes provisions for the design of concrete used for structural purposes, including plain concrete; concrete containing nonprestressed reinforcement, prestressed reinforcement, or both; and anchoring to concrete. This chapter includes a number of provisions that explain where this Code applies and how it is to be interpreted.

R1.2—General

R1.2.2 The American Concrete Institute recommends that this Code be adopted in its entirety.

R1.2.3 Committee 318 develops the Code in English, using inch-pound units. Based on that version, Committee 318 approved three other versions:

- (a) In English using SI units (ACI 318M)
- (b) In Spanish using SI units (ACI 318S)
- (c) In Spanish using inch-pound units (ACI 318SUS).

Jurisdictions may adopt ACI 318, ACI 318M, ACI 318S, or ACI 318SUS.

R1.2.5 This Code provides minimum requirements and exceeding these minimum requirements is not a violation of the Code.

The licensed design professional may specify project requirements that exceed the minimum requirements of this Code.

R1.3—Purpose

R1.3.1 This Code provides a means of establishing minimum requirements for the design and construction of

CHAPTER 2—NOTATION AND TERMINOLOGY

CODE COMMENTARY

2.1—Scope

2.1.1 This chapter defines notation and terminology used in this Code.

2.2—Notation

- a = depth of equivalent rectangular stress block, in.
- a_v = shear span, equal to distance from center of concentrated load to either: (a) face of support for continuous or cantilevered members, or (b) center of support for simply supported members, in.
- A_b = area of an individual bar or wire, in.²
- A_{bp} = area of the attachment base plate in contact with concrete or grout when loaded in compression, in.²
- A_{brg} = net bearing area of the head of stud, anchor bolt, or headed deformed bar, in.²
- A_c = area of concrete section resisting shear transfer, in.²
- A_{cf} = greater gross cross-sectional area of the two orthogonal slab-beam strips intersecting at a column of a two-way prestressed slab, in.²
- A_{ch} = cross-sectional area of a member measured to the outside edges of transverse reinforcement, in.²
- A_{cp} = area enclosed by outside perimeter of concrete cross section, in.²
- A_{cs} = cross-sectional area at one end of a strut in a strut-and-tie model, taken perpendicular to the axis of the strut, in.²
- A_{ct} = area of that part of cross section between the flexural tension face and centroid of gross section, in.²
- A_{cv} = gross area of concrete section bounded by web thickness and length of section in the direction of shear force considered in the case of walls, and gross area of concrete section in the case of diaphragms. Gross area is total area of the defined section minus area of any openings, in.²
- A_{cw} = area of concrete section of an individual pier, horizontal wall segment, or coupling beam resisting shear, in.²
- $A_{ef,sl}$ = effective bearing area of shear lug, in.²
- A_f = area of reinforcement in bracket or corbel resisting design moment, in.²
- A_g = gross area of concrete section, in.² For a hollow section, A_g is the area of the concrete only and does not include the area of the void(s)
- A_h = total area of shear reinforcement parallel to primary tension reinforcement in a corbel or bracket, in.²
- A_{hs} = total cross-sectional area of hooked or headed bars being developed at a critical section, in.²
- A_j = effective cross-sectional area within a joint in a plane parallel to plane of beam reinforcement generating shear in the joint, in.²
- A_ℓ = total area of longitudinal reinforcement to resist torsion, in.²
- $A_{\ell,min}$ = minimum area of longitudinal reinforcement to resist torsion, in.²

R2.2—Notation

CHAPTER 3—REFERENCED STANDARDS

CODE	COMMENTARY
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3.1—Scope

3.1.1 Standards, or specific sections thereof, cited in this Code, including Annex, Appendixes, or Supplements where prescribed, are referenced without exception in this Code, unless specifically noted. Cited standards are listed in the following with their serial designations, including year of adoption or revision.

3.2—Referenced standards

3.2.1 *American Association of State Highway and Transportation Officials (AASHTO)*

LRFDUS-8—LRFD Bridge Design Specifications, 8th Edition, 2017, Articles 5.8.4.4.2, 5.8.4.4.3, and 5.8.4.5

LRFDCONS-4—LRFD Bridge Construction Specifications, Fourth Edition, 2017, Article 10.3.2.3

3.2.2 *American Concrete Institute (ACI)*

301-16—Specifications for Structural Concrete, Article 4.2.3

318.2-19—Building Code Requirements for Concrete Thin Shells and Commentary

332-14—Residential Code Requirements for Structural Concrete and Commentary

355.2-19—Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary

355.4-11—Qualification of Post-Installed Adhesive Anchors in Concrete

369.1-17—Standard Requirements for Seismic Evaluation and Retrofit of Existing Concrete Buildings (369.1-17) and Commentary

374.1-05—Acceptance Criteria for Moment Frames Based on Structural Testing

423.7-14—Specification for Unbonded Single-Strand Tendon Materials

437.2-13—Code Requirements for Load Testing of Existing Concrete Structures and Commentary

550.3-13—Design Specification for Unbonded Post-Tensioned Precast Concrete Special Moment Frames Satisfying ACI 374.1 and Commentary

550.4-18—Qualification of Precast Concrete Diaphragm Connections and Reinforcement at Joints for Earthquake Loading and Commentary

550.5-18—Code Requirements for the Design of Precast Concrete Diaphragms for Earthquake Motions and Commentary

ITG-5.1-07—Acceptance Criteria for Special Unbonded Post-Tensioned Precast Structural Walls Based on Validation Testing

ITG-5.2-09—Requirements for Design of a Special Unbonded Post-Tensioned Precast Wall Satisfying ACI ITG-5.1 and Commentary

R3.1—Scope

R3.1.1 In this Code, references to standard specifications or other material are to a specific edition of the cited document. This is done by using the complete serial designation for the referenced standard including the title that indicates the subject and year of adoption. All standards referenced in this Code are listed in this chapter, with the title and complete serial designation. In other sections of the Code, referenced standards are abbreviated to include only the serial designation without a title or date. These abbreviated references correspond to specific standards listed in this chapter.

R3.2—Referenced standards

R3.2.1 *American Association of State Highway and Transportation Officials (AASHTO)*

Three articles of the AASHTO LRFD Specifications for Highway Bridge Design (AASHTO LRFDUS) and one article of the AASHTO LRFD Construction Specifications (AASHTO LRFDCONS) are cited in **Chapters 2 and 25** of this Code.

R3.2.2 *American Concrete Institute (ACI)*

Article 4.2.3 of ACI 301 is referenced for the method of mixture proportioning cited in **26.4.3.1(b)**.

Prior to 2014, the provisions of **ACI 318.2** were specified in Chapter 19 of the ACI 318 Building Code.

ACI 355.2 contains qualification requirements for testing and evaluating post-installed expansion, screw, and undercut anchors for use in both cracked and uncracked concrete.

ACI 355.4 contains qualification requirements for testing and evaluating adhesive anchors for use in both cracked and uncracked concrete.

ACI 423.7 requires the use of encapsulated tendon systems for applications subject to this Code.

CHAPTER 4—STRUCTURAL SYSTEM REQUIREMENTS

CODE COMMENTARY

4.1—Scope

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

4.2—Materials

4.2.1 Design properties of concrete shall be selected to be in accordance with [Chapter 19](#).

4.2.1.1 Design properties of shotcrete shall conform to the requirements for concrete except as modified by provisions of the Code.

4.2.2 Design properties of reinforcement shall be selected to be in accordance with [Chapter 20](#).

4.3—Design loads

4.3.1 Loads and load combinations considered in design shall be in accordance with [Chapter 5](#).

R4.1—Scope

This chapter was added to the 2014 Code to introduce structural system requirements. Requirements more stringent than the Code provisions may be desirable for unusual construction or construction where enhanced performance is appropriate. The Code and Commentary must be supplemented with sound engineering knowledge, experience, and judgment.

R4.2—Materials

[Chapter 3](#) identifies the referenced standards permitted for design. [Chapters 19](#) and [20](#) establish properties of concrete and steel reinforcement permitted for design. Chapter 26 presents construction requirements for concrete materials, proportioning, and acceptance of concrete.

R4.2.1.1 Shotcrete is considered to behave and have properties similar to concrete unless otherwise noted. Sections where use of shotcrete is specifically addressed in this Code are shown in Table R4.2.1.1. Additional information on shotcrete can be found in [ACI 506R](#) and [ACI 506.2](#).

Table R4.2.1.1—Sections in Code with shotcrete provisions

Topic covered	Section
Freezing and thawing	19.3.3.3 through 19.3.3.6
Reinforcement	25.2.7 through 25.2.10, 25.5.1.6, and 25.5.1.7
Where shotcrete is required or permitted	26.3.1, 26.3.2
Materials	26.4.1.2, 26.4.1.4, and 26.4.1.6
Proportioning mixtures	26.4.3
Documentation of mixtures	26.4.4.1
Placement and consolidation	26.5.2.1
Curing	26.5.3
Joints	26.5.6
Evaluation and acceptance	26.12

R4.3—Design loads

R4.3.1 The provisions in [Chapter 5](#) are based on [ASCE/SEI 7](#). The design loads include, but are not limited to, dead loads, live loads, snow loads, wind loads, earthquake effects, prestressing effects, crane loads, vibration, impact, shrinkage, temperature changes, creep, expansion of shrinkage-compensating concrete, and predicted unequal settlement of supports. Other project-specific loads may be specified by the licensed design professional.

CHAPTER 5—LOADS

CODE

COMMENTARY

5.1—Scope

5.1.1 This chapter shall apply to selection of load factors and combinations used in design, except as permitted in [Chapter 27](#).

5.2—General

5.2.1 Loads shall include self-weight; applied loads; and effects of prestressing, earthquakes, restraint of volume change, and differential settlement.

5.2.2 Loads and Seismic Design Categories (SDCs) shall be in accordance with the general building code, or determined by the building official.

R5.2—General

R5.2.1 Provisions in the Code are associated with dead, live, wind, and earthquake loads such as those recommended in [ASCE/SEI 7](#). The commentary to Appendix C of ASCE/SEI 7 provides service-level wind loads W_a for serviceability checks; however, these loads are not appropriate for strength design.

If the service loads specified by the general building code differ from those of ASCE/SEI 7, the general building code governs. However, if the nature of the loads contained in a general building code differs considerably from ASCE/SEI 7 loads, some provisions of this Code may need modification to reflect the difference.

R5.2.2 Seismic Design Categories (SDCs) in this Code are adopted directly from ASCE/SEI 7. Similar designations are used by the International Building Code ([2018 IBC](#)) and the National Fire Protection Association ([NFPA 5000 2012](#)). The BOCA National Building Code ([BOCA 1999](#)) and “The Standard Building Code” ([SBC 1999](#)) used seismic performance categories. The “Uniform Building Code” ([IBCO 1997](#)) relates seismic design requirements to seismic zones, whereas editions of ACI 318 prior to 2008 related seismic design requirements to seismic risk levels. Table R5.2.2 correlates SDC to seismic risk terminology used in ACI 318 for several editions before the 2008 edition, and to the various methods of assigning design requirements used in the United States under the various model building codes, the ASCE/SEI 7 standard, and the National Earthquake Hazard Reduction Program ([NEHRP 1994](#)).

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

In the absence of a general building code that prescribes earthquake effects and seismic zoning, it is the intent of Committee 318 that application of provisions for earthquake-resistant design be consistent with national standards or model building codes such as ASCE/SEI 7, 2012 IBC, and NFPA 5000. The model building codes also specify overstrength factors Ω_o that are related to the seismic-force-resisting system used for the structure and design of certain elements.

CHAPTER 6—STRUCTURAL ANALYSIS

CODE

COMMENTARY

6.1—Scope

6.1.1 This chapter shall apply to methods of analysis, modeling of members and structural systems, and calculation of load effects.

6.2—General

6.2.1 Members and structural systems shall be permitted to be modeled in accordance with 6.3.

6.2.2 All members and structural systems shall be analyzed to determine the maximum load effects including the arrangements of live load in accordance with 6.4.

6.2.3 Methods of analysis permitted by this chapter shall be (a) through (e):

- (a) The simplified method for analysis of continuous beams and one-way slabs for gravity loads in 6.5
- (b) Linear elastic first-order analysis in 6.6
- (c) Linear elastic second-order analysis in 6.7
- (d) Inelastic analysis in 6.8
- (e) Finite element analysis in 6.9

R6.1—Scope

The provisions of this chapter apply to analyses used to determine load effects for design.

Section 6.2 provides general requirements that are applicable for all analysis procedures.

Section 6.2.4 directs the licensed design professional to specific analysis provisions that are not contained in this chapter. Sections 6.2.4.1 and 6.2.4.2 identify analysis provisions that are specific to two-way slabs and walls.

Section 6.3 addresses modeling assumptions used in establishing the analysis model.

Section 6.4 prescribes the arrangements of live loads that are to be considered in the analysis.

Section 6.5 provides a simplified method of analysis for nonprestressed continuous beams and one-way slabs that can be used in place of a more rigorous analysis when the stipulated conditions are satisfied.

Section 6.6 includes provisions for a comprehensive linear elastic first-order analysis. The effects of cracked sections and creep are included in the analysis through the use of effective stiffnesses.

Section 6.7 includes provisions for linear elastic second-order analysis. Inclusion of the effects of cracking and creep is required.

Section 6.8 includes provisions for inelastic analysis.

Section 6.9 includes provisions for the use of the finite element method.

R6.2—General

R6.2.3 A first-order analysis satisfies the equations of equilibrium using the original undeformed geometry of the structure. When only first-order results are considered, slenderness effects are not accounted for. Because these effects can be important, 6.6 provides procedures to calculate both individual member slenderness ($P\delta$) effects and sidesway ($P\Delta$) effects for the overall structure using the first-order results.

A second-order analysis satisfies the equations of equilibrium using the deformed geometry of the structure. If the second-order analysis uses nodes along compression members, the analysis accounts for slenderness effects due to lateral deformations along individual members, as well as sidesway of the overall structure. If the second-order analysis uses nodes at the member intersections only, the analysis captures the sidesway effects for the overall structure but neglects individual member slenderness effects. In this case, the moment magnifier method (6.6.4) is used to determine individual member slenderness effects.

CHAPTER 7—ONE-WAY SLABS

CODE

COMMENTARY

7.1—Scope

7.1.1 This chapter shall apply to the design of nonprestressed and prestressed slabs reinforced for flexure in one direction, including:

- (a) Solid slabs
- (b) Slabs cast on stay-in-place, noncomposite steel deck
- (c) Composite slabs of concrete elements constructed in separate placements but connected so that all elements resist loads as a unit
- (d) Precast, prestressed hollow-core slabs

7.2—General

7.2.1 The effects of concentrated loads, slab openings, and voids within the slab shall be considered in design.

7.2.2 Materials

7.2.2.1 Design properties for concrete shall be selected to be in accordance with **Chapter 19**.

7.2.2.2 Design properties for steel reinforcement shall be selected to be in accordance with **Chapter 20**.

7.2.2.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with 20.6.

7.2.3 Connection to other members

7.2.3.1 For cast-in-place construction, beam-column and slab-column joints shall satisfy **Chapter 15**.

7.2.3.2 For precast construction, connections shall satisfy the force transfer requirements of **16.2**.

7.3—Design limits**7.3.1 Minimum slab thickness**

7.3.1.1 For solid nonprestressed slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections, overall slab thickness h shall not be less than the limits in Table 7.3.1.1, unless the calculated deflection limits of 7.3.2 are satisfied.

R7.1—Scope

R7.1.1 The design and construction of composite slabs on steel deck is described in “Standard for Composite Steel Floor Deck – Slabs” (**SDI C**).

Provisions for one-way joist systems are provided in **Chapter 9**.

R7.2—General

R7.2.1 Concentrated loads and slab openings create local moments and shears and may cause regions of one-way slabs to have two-way behavior. The influence of openings through the slab and voids within the slab (for example ducts) on flexural and shear strength as well as deflections is to be considered, including evaluating the potential for critical sections created by the openings and voids.

R7.3—Design limits**R7.3.1 Minimum slab thickness**

The basis for minimum thickness for one-way slabs is the same as that for beams. Refer to **R9.3.1** for additional information.

CHAPTER 8—TWO-WAY SLABS

CODE

COMMENTARY

8.1—Scope

8.1.1 This chapter shall apply to the design of nonprestressed and prestressed slabs reinforced for flexure in two directions, with or without beams between supports, including (a) through (d):

- (a) Solid slabs
- (b) Slabs cast on stay-in-place, noncomposite steel deck
- (c) Composite slabs of concrete elements constructed in separate placements but connected so that all elements resist loads as a unit
- (d) Two-way joist systems in accordance with 8.8

8.2—General

8.2.1 A slab system shall be permitted to be designed by any procedure satisfying equilibrium and geometric compatibility, provided that design strength at every section is at least equal to required strength, and all serviceability requirements are satisfied. The direct design method or the equivalent frame method is permitted.

R8.1—Scope

The design methods given in this chapter are based on analysis of the results of an extensive series of tests (Burns and Hemakom 1977; Gamble et al. 1969; Gerber and Burns 1971; Guralnick and LaFraugh 1963; Hatcher et al. 1965, 1969; Hawkins 1981; Jirsa et al. 1966; PTI DC20.8; Smith and Burns 1974; Scordelis et al. 1959; Vanderbilt et al. 1969; Xanthakis and Sozen 1963) and the well-established performance records of various slab systems. The fundamental design principles are applicable to all planar structural systems subjected to transverse loads. Several specific design rules, as well as historical precedents, limit the types of structures to which this chapter applies. General slab systems that may be designed according to this chapter include flat slabs, flat plates, two-way slabs, and waffle slabs. Slabs with paneled ceilings are two-way, wide-band, beam systems.

Slabs-on-ground that do not transmit vertical loads from other parts of the structure to the soil are excluded.

For slabs with beams, the explicit design procedures of this chapter apply only when the beams are located at the edges of the panel and when the beams are supported by columns or other essentially nondeflecting supports at the corners of the panel. Two-way slabs with beams in one direction, with both slab and beams supported by girders in the other direction, may be designed under the general requirements of this chapter. Such designs should be based upon analysis compatible with the deflected position of the supporting beams and girders.

For slabs supported on walls, the explicit design procedures in this chapter treat the wall as a beam of infinite stiffness; therefore, each wall should support the entire length of an edge of the panel (refer to 8.4.1.7). Walls of width less than a full panel length can be treated as columns.

R8.2—General

R8.2.1 This section permits a design to be based directly on fundamental principles of structural mechanics, provided it can be demonstrated explicitly that all strength and serviceability criteria are satisfied. The design of the slab may be achieved through the combined use of classic solutions based on a linearly elastic continuum, numerical solutions based on discrete elements, or yield-line analyses, including, in all cases, evaluation of the stress conditions around the supports in relation to shear, torsion, and flexure, as well as the effects of reduced stiffness of elements due to cracking and support geometry. The design of a slab system involves more than its analysis; any deviations in physical dimensions of the slab from common practice should be justified on the basis of knowledge of the expected loads and the reliability of the calculated stresses and deformations of the structure.

The direct design method and the equivalent frame method are limited in application to orthogonal frames subject to gravity loads only.

CHAPTER 9—BEAMS

CODE

COMMENTARY

9.1—Scope

9.1.1 This chapter shall apply to the design of nonprestressed and prestressed beams, including:

- (a) Composite beams of concrete elements constructed in separate placements but connected so that all elements resist loads as a unit
- (b) One-way joist systems in accordance with 9.8
- (c) Deep beams in accordance with 9.9

9.2—General**9.2.1 Materials**

9.2.1.1 Design properties for concrete shall be selected to be in accordance with **Chapter 19**.

9.2.1.2 Design properties for steel reinforcement shall be selected to be in accordance with **Chapter 20**.

9.2.1.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with **20.6**.

9.2.2 Connection to other members

9.2.2.1 For cast-in-place construction, beam-column and slab-column joints shall satisfy **Chapter 15**.

9.2.2.2 For precast construction, connections shall satisfy the force transfer requirements of **16.2**.

9.2.3 Stability

9.2.3.1 If a beam is not continuously laterally braced, (a) and (b) shall be satisfied:

- (a) Spacing of lateral bracing shall not exceed 50 times the least width of compression flange or face.
- (b) Spacing of lateral bracing shall take into account effects of eccentric loads.

9.2.3.2 In prestressed beams, buckling of thin webs and flanges shall be considered. If there is intermittent contact between prestressed reinforcement and an oversize duct, member buckling between contact points shall be considered.

9.2.4 T-beam construction**R9.1—Scope**

R9.1.1 Composite structural steel-concrete beams are not covered in this chapter. Design provisions for such composite beams are covered in **AISC 360**.

R9.2—General**R9.2.3 Stability**

R9.2.3.1 Tests (**Hansell and Winter 1959**; **Sant and Bletzacker 1961**) have shown that laterally unbraced reinforced concrete beams, even when very deep and narrow, will not fail prematurely by lateral buckling, provided the beams are loaded without lateral eccentricity that causes torsion.

Laterally unbraced beams are frequently loaded eccentrically or with slight inclination. Stresses and deformations by such loading become detrimental for narrow, deep beams with long unsupported lengths. Lateral supports spaced closer than **50b** may be required for such loading conditions.

R9.2.3.2 In post-tensioned members where the prestressed reinforcement has intermittent contact with an oversize duct, the member can buckle due to the axial prestressing force, as the member can deflect laterally while the prestressed reinforcement does not. If the prestressed reinforcement is in continuous contact with the member being prestressed or is part of an unbonded tendon with the sheathing not excessively larger than the prestressed reinforcement, the prestressing force cannot buckle the member.

R9.2.4 T-beam construction

CHAPTER 10—COLUMNS

CODE

COMMENTARY

10.1—Scope

10.1.1 This chapter shall apply to the design of nonprestressed and prestressed columns, including reinforced concrete pedestals.

10.1.2 Design of plain concrete pedestals shall be in accordance with [Chapter 14](#).

10.2—General**10.2.1 Materials**

10.2.1.1 Design properties for concrete shall be selected to be in accordance with [Chapter 19](#).

10.2.1.2 Design properties for steel reinforcement shall be selected to be in accordance with [Chapter 20](#).

10.2.1.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with [20.6](#).

10.2.2 Connection to other members

10.2.2.1 For cast-in-place construction, beam-column and slab-column joints shall satisfy [Chapter 15](#).

10.2.2.2 For precast construction, connections shall satisfy the force transfer requirements of [16.2](#).

10.2.2.3 Connections of columns to foundations shall satisfy [16.3](#).

10.3—Design limits**10.3.1 Dimensional limits**

10.3.1.1 For columns with a square, octagonal, or other shaped cross section, it shall be permitted to base gross area considered, required reinforcement, and design strength on a circular section with a diameter equal to the least lateral dimension of the actual shape.

10.3.1.2 For columns with cross sections larger than required by considerations of loading, it shall be permitted to base gross area considered, required reinforcement, and design strength on a reduced effective area, not less than one-half the total area. This provision shall not apply to columns in special moment frames or columns not part of the seismic-force-resisting system required to be designed in accordance with [Chapter 18](#).

10.3.1.3 For columns built monolithically with a concrete wall, the outer limits of the effective cross section of the

R10.1—Scope

R10.1.1 Composite structural steel-concrete columns are not covered in this chapter. Composite columns include both structural steel sections encased in reinforced concrete and hollow structural steel sections filled with concrete. Design provisions for such composite columns are covered in [AISC 360](#).

R10.3—Design limits**R10.3.1 Dimensional limits**

Explicit minimum sizes for columns are not specified to permit the use of reinforced concrete columns with small cross sections in lightly loaded structures, such as low-rise residential and light office buildings. If small cross sections are used, there is a greater need for careful workmanship, and shrinkage stresses have increased significance.

R10.3.1.2 In some cases, the gross area of a column is larger than necessary to resist the factored load. In those cases, the minimum reinforcement percentage may be calculated on the basis of the required area rather than the provided area, but the area of reinforcement cannot be less than 0.5 percent of the actual cross-sectional area.

CHAPTER 11—WALLS

CODE

COMMENTARY

11.1—Scope

11.1.1 This chapter shall apply to the design of nonprestressed and prestressed walls including (a) through (c):

- (a) Cast-in-place
- (b) Precast in-plant
- (c) Precast on-site including tilt-up

11.1.2 Design of special structural walls shall be in accordance with **Chapter 18**.

11.1.3 Design of plain concrete walls shall be in accordance with **Chapter 14**.

11.1.4 Design of cantilever retaining walls shall be in accordance with **Chapter 13**.

11.1.5 Design of walls as grade beams shall be in accordance with **13.3.5**.

11.1.6 Cast-in-place walls with insulating forms shall be permitted by this Code for use in one- or two-story buildings.

11.2—General**11.2.1 Materials**

11.2.1.1 Design properties for concrete shall be selected to be in accordance with **Chapter 19**.

11.2.1.2 Design properties for steel reinforcement shall be selected to be in accordance with **Chapter 20**.

11.2.1.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with **20.6**.

11.2.2 Connection to other members

11.2.2.1 For precast walls, connections shall be designed in accordance with **16.2**.

11.2.2.2 Connections of walls to foundations shall satisfy **16.3**.

R11.1—Scope

R11.1.1 This chapter applies generally to walls as vertical and lateral force-resisting members. Provisions for in-plane shear in ordinary structural walls, as opposed to special structural walls conforming to **18.10**, are included in this chapter.

R11.1.2 Special structural walls are detailed according to the provisions of **18.10**. This Code uses the term “structural wall” as being synonymous with “shear wall.” While the term “shear wall” is not defined in this Code, the definition of a structural wall in Chapter 2 states “a shear wall is a structural wall.”

ASCE/SEI 7 defines a structural wall as a wall that meets the definition for a bearing wall or a shear wall. A bearing wall is defined as a wall that supports vertical load beyond a certain threshold value. A shear wall is defined as a wall, bearing or nonbearing, designed to resist lateral forces acting in the plane of the wall. **ASCE/SEI 7** definitions are widely accepted.

R11.1.6 Specific design recommendations for cast-in-place walls constructed with insulating concrete forms are not provided in this Code. Guidance can be found in **ACI 506R** and **PCA 100**.

R11.2—General

CHAPTER 12—DIAPHRAGMS

CODE

12.1—Scope

12.1.1 This chapter shall apply to the design of nonprestressed and prestressed diaphragms, including (a) through (d):

- (a) Diaphragms that are cast-in-place slabs
- (b) Diaphragms that comprise a cast-in-place topping slab on precast elements
- (c) Diaphragms that comprise precast elements with end strips formed by either a cast-in-place concrete topping slab or edge beams
- (d) Diaphragms of interconnected precast elements without cast-in-place concrete topping

COMMENTARY

R12.1—Scope

R12.1.1 Diaphragms typically are horizontal or nearly horizontal planar elements that serve to transfer lateral forces to vertical elements of the lateral-force-resisting system (Fig. R12.1.1). Diaphragms also tie the building elements together into a complete three-dimensional system and provide lateral support to those elements by connecting them to the lateral-force-resisting system. Typically, diaphragms also serve as floor and roof slabs, or as parking structure ramps and, therefore, support gravity loads. A diaphragm may include chords and collectors.

When subjected to lateral loads, such as the in-plane inertial loads acting on the roof diaphragm of Fig. R12.1.1, a diaphragm acts essentially as a beam spanning horizontally between vertical elements of the lateral-force-resisting system. The diaphragm thus develops in-plane bending moments, shears, and possibly other actions. Where vertical elements of the lateral-force-resisting system do not extend along the full depth of the diaphragm, collectors may be required to collect the diaphragm shear and transfer it to the vertical elements. The term “distributor” is sometimes used to describe a collector that transfers force from a vertical element of the lateral-force-resisting system into the diaphragm. This chapter describes minimum requirements for diaphragm and collector design and detailing, including configuration, analysis models, materials, and strength.

This chapter covers only the types of diaphragms listed in this provision. Other diaphragm types, such as horizontal trusses, are used successfully in buildings, but this chapter does not include prescriptive provisions for those other types.

CHAPTER 13—FOUNDATIONS

CODE

COMMENTARY

13.1—Scope

13.1.1 This chapter shall apply to the design of nonprestressed and prestressed foundations, including shallow foundations (a) through (f), deep foundations (g) through (i), and retaining walls (j) and (k):

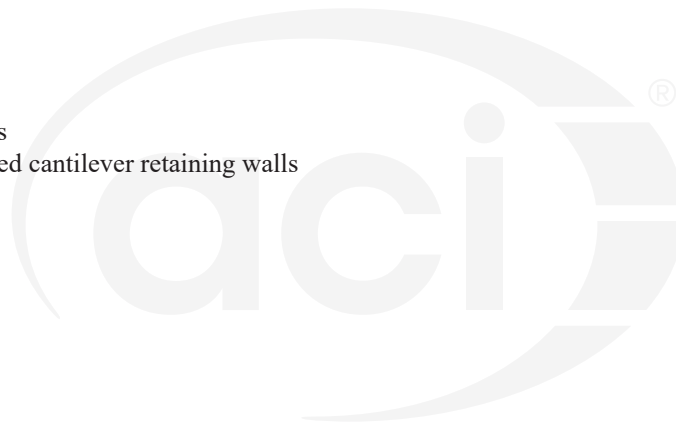
- (a) Strip footings
- (b) Isolated footings
- (c) Combined footings
- (d) Mat foundations
- (e) Grade beams
- (f) Pile caps
- (g) Piles
- (h) Drilled piers
- (i) Caissons
- (j) Cantilever retaining walls
- (k) Counterfort and buttressed cantilever retaining walls

R13.1—Scope

While requirements applicable to foundations are provided in this chapter, the majority of requirements used for foundation design are found in other chapters of the Code. These other chapters are referenced in Chapter 13. However, the applicability of the specific provisions within these other chapters may not be explicitly defined for foundations.

R13.1.1 Examples of foundation types covered by this chapter are illustrated in Fig. R13.1.1. Stepped and sloped footings are considered to be subsets of other footing types.

The 2019 edition of the Code contains provisions for the design of deep foundations. These provisions are based in part on similar provisions that were previously included in [ASCE/SEI 7](#) and the [IBC](#).



CHAPTER 14—PLAIN CONCRETE

CODE

COMMENTARY

14.1—Scope

14.1.1 This chapter shall apply to the design of plain concrete members, including (a) and (b):

- (a) Members in building structures
- (b) Members in non-building structures such as arches, underground utility structures, gravity walls, and shielding walls

14.1.2 This chapter shall not govern the design of cast-in-place concrete piles and piers embedded in ground.

14.1.3 Plain concrete shall be permitted only in cases (a) through (d):

- (a) Members that are continuously supported by soil or supported by other structural members capable of providing continuous vertical support
- (b) Members for which arch action provides compression under all conditions of loading
- (c) Walls
- (d) Pedestals

14.1.4 Plain concrete shall be permitted for a structure assigned to Seismic Design Category (SDC) D, E, or F, only in cases (a) and (b):

- (a) Footings supporting cast-in-place reinforced concrete or reinforced masonry walls, provided the footings are reinforced longitudinally with at least two continuous reinforcing bars. Bars shall be at least No. 4 and have a total area of not less than 0.002 times the gross cross-sectional area of the footing. Continuity of reinforcement shall be provided at corners and intersections.
- (b) Foundation elements (i) through (iii) for detached one- and two-family dwellings not exceeding three stories and constructed with stud bearing walls:
 - (i) Footings supporting walls
 - (ii) Isolated footings supporting columns or pedestals
 - (iii) Foundation or basement walls not less than 7-1/2 in. thick and retaining no more than 4 ft of unbalanced fill.

14.1.5 Plain concrete shall not be permitted for columns and pile caps.

R14.1—Scope

R14.1.2 Structural elements, such as cast-in-place plain concrete piles and piers in ground or other material sufficiently stiff to provide adequate lateral support to prevent buckling, are not covered by the Code. Such elements are covered by the general building code.

R14.1.3 Because the strength and structural integrity of structural plain concrete members is based solely on the member size, concrete strength, and other concrete properties, use of structural plain concrete should be limited to members:

- (a) That are primarily in a state of compression
- (b) That can tolerate random cracks without detriment to their structural integrity
- (c) For which ductility is not an essential feature of design

The tensile strength of concrete can be used in design of structural plain concrete members. Tensile stresses due to restraint from creep, shrinkage, or temperature effects are to be considered to avoid uncontrolled cracks or structural failure. For residential construction within the scope of **ACI 332**, refer to **1.4.6**.

R14.1.5 Because plain concrete lacks the necessary ductility that columns should possess, and because a random crack in an unreinforced column will most likely endanger

CHAPTER 15—BEAM-COLUMN AND SLAB-COLUMN JOINTS

CODE COMMENTARY

15.1—Scope

15.1.1 This chapter shall apply to the design and detailing of cast-in-place beam-column and slab-column joints.

15.2—General

15.2.1 Beam-column joints shall satisfy the detailing provisions of 15.3 and strength requirements of 15.4.

15.2.2 Beam-column and slab-column joints shall satisfy 15.5 for transfer of column axial force through the floor system.

15.2.3 If gravity load, wind, earthquake, or other lateral forces cause transfer of moment at beam-column joints, the shear resulting from moment transfer shall be considered in the design of the joint.

15.2.4 At corner joints between two members, the effects of closing and opening moments within the joint shall be considered.

15.2.5 If a beam framing into the joint and generating joint shear has depth exceeding twice the column depth, analysis and design of the joint shall be based on the strut-and-tie method in accordance with **Chapter 23** and (a) and (b) shall be satisfied:

- (a) Design joint shear strength determined in accordance with Chapter 23 shall not exceed ϕV_n calculated in accordance with 15.4.2.
- (b) Detailing provisions of 15.3 shall be satisfied.

15.2.6 A column extension assumed to provide continuity through a beam-column joint in the direction of joint shear considered shall satisfy (a) and (b):

- (a) The column extends above the joint at least one column depth, h , measured in the direction of joint shear considered.
- (b) Longitudinal and transverse reinforcement from the column below the joint is continued through the extension.

15.2.7 A beam extension assumed to provide continuity through a beam-column joint in the direction of joint shear considered shall satisfy (a) and (b):

R15.1—Scope

A joint is the portion of a structure common to intersecting members, whereas a connection is comprised of a joint and portions of adjoining members. Chapter 15 is focused on design requirements for beam-to-column and slab-to-column joints.

For structures assigned to Seismic Design Categories (SDC) B through F, joints may be required to withstand several reversals of loading. **Chapter 18** provides requirements for earthquake-resistant structures that are applied in addition to the basic requirements for joints in Chapter 15.

R15.2—General

Tests of joints with extensions of beams with lengths at least equal to their depths have indicated similar joint shear strengths to those of joints with continuous beams. These findings suggest that extensions of beams and columns, when properly dimensioned and reinforced with longitudinal and transverse bars, provide effective confinement to the joint faces (**Meinheit and Jirsa 1981**). Extensions that provide beam and column continuity through a joint do not contribute to joint shear force if they do not support externally applied loads.

Tests (**Hanson and Conner 1967**) have shown that beam-column joints laterally supported on four sides by beams of approximately equal depth exhibit superior behavior compared to joints without all four faces confined by beams under reversed cyclic loading.

Corner joints occur where two non-colinear members transfer moment and terminate at the joint. A roof-level exterior joint is an example of a corner joint between two members, also referred to as a knee joint. Corner joints are vulnerable to flexural failure from either closing or opening moments even if flexural strengths at the joint faces are sufficient. Considering transfer of moment across a diagonal section through a corner joint connecting to a cantilevered member is critical because the moment acting through the joint cannot be redistributed.

Chapter 23 provides requirements for design and detailing of corner joints when using the strut-and-tie method. **Klein (2008)** provides additional guidance on design of frame corners using the strut-and-tie method. The requirements for transverse reinforcement in corner joints are given in 15.3. **ACI 352R** provides additional guidance on detailing of joints.

For joints in which the beam depth is significantly greater than the column depth a diagonal strut between the joint corners may not be effective. Therefore, the Code requires that joints in which the beam depth exceeds twice the column depth be designed using the strut-and-tie method of Chapter 23.

Transfer of bending through joints between slabs and corner or edge columns is covered in **Chapter 8**.

In the 2019 Code, classification of beam and column members framing into joint faces was modified to distin-

CHAPTER 16—CONNECTIONS BETWEEN MEMBERS

CODE COMMENTARY

16.1—Scope

16.1.1 This chapter shall apply to the design of joints and connections at the intersection of concrete members and for load transfer between concrete surfaces, including (a) through (d):

- (a) Connections of precast members
- (b) Connections between foundations and either cast-in-place or precast members
- (c) Horizontal shear strength of composite concrete flexural members
- (d) Brackets and corbels

16.2—Connections of precast members

16.2.1 *General*

16.2.1.1 Transfer of forces by means of grouted joints, shear keys, bearing, anchors, mechanical connectors, steel reinforcement, reinforced topping, or a combination of these, shall be permitted.

16.2.1.2 Adequacy of connections shall be verified by analysis or test.

16.2.1.3 Connection details that rely solely on friction caused by gravity loads shall not be permitted.

16.2.1.4 Connections, and regions of members adjacent to connections, shall be designed to resist forces and accommodate deformations due to all load effects in the precast structural system.

16.2.1.5 Design of connections shall consider structural effects of restraint of volume change in accordance with 5.3.6.

16.2.1.6 Design of connections shall consider the effects of tolerances specified for fabrication and erection of precast members.

R16.2—Connections of precast members

R16.2.1 *General*

Connection details should be arranged to minimize the potential for cracking due to restrained creep, shrinkage, and temperature movements. The Precast/Prestressed Concrete Institute ([MNL 123](#)) provides information on recommended connection details for precast concrete structures.

R16.2.1.1 If two or more connection methods are used to satisfy the requirements for force transfer, their individual load-deformation characteristics should be considered to confirm that the mechanisms work together as intended.

R16.2.1.4 The structural behavior of precast members may differ substantially from that of similar members that are cast-in-place. Design of connections to minimize or transmit forces due to shrinkage, creep, temperature change, elastic deformation, differential settlement, wind, and earthquake require particular consideration in precast construction.

R16.2.1.5 Connections should be designed to either permit the displacements or resist the forces induced by lack of fit, volume changes caused by shrinkage, creep, thermal, and other environmental effects. Connections intended to resist the forces should do so without loss of strength. Restraint assumptions should be consistent in all interconnected members. There are also cases in which the intended force may be in one direction, but it may affect the strength of the connection in another. For example, shrinkage-induced longitudinal tension in a precast beam may affect the vertical shear strength on the corbel supporting it.

R16.2.1.6 Refer to [R26.9.1\(a\)](#).

CHAPTER 17—ANCHORING TO CONCRETE

CODE

COMMENTARY

17.1—Scope

17.1.1 This chapter shall apply to the design of anchors in concrete used to transmit loads by means of tension, shear, or a combination of tension and shear between: (a) connected structural elements; or (b) safety-related attachments and structural elements. Safety levels specified are intended for in-service conditions rather than for short-term handling and construction conditions.

17.1.2 Provisions of this chapter shall apply to the following anchor types (a) through (g):

- (a) Headed studs and headed bolts having a geometry that has been demonstrated to result in a pullout strength in uncracked concrete equal to or exceeding $1.4N_p$, where N_p is given in Eq. (17.6.3.2.2a).
- (b) Hooked bolts having a geometry that has been demonstrated to result in a pullout strength without the benefit of friction in uncracked concrete equal to or exceeding $1.4N_p$, where N_p is given in Eq. (17.6.3.2.2b)
- (c) Post-installed expansion (torque-controlled and displacement-controlled) anchors that meet the assessment criteria of **ACI 355.2**.
- (d) Post-installed undercut anchors that meet the assessment criteria of **ACI 355.2**.
- (e) Post-installed adhesive anchors that meet the assessment criteria of **ACI 355.4**.
- (f) Post-installed screw anchors that meet the assessment criteria of **ACI 355.2**.
- (g) Attachments with shear lugs.

17.1.3 The removal and resetting of post-installed mechanical anchors is prohibited.

17.1.4 This chapter does not apply for load applications that are predominantly high-cycle fatigue or due to impact.

R17.1—Scope

R17.1.1 This chapter is restricted in scope to structural anchors that transmit loads related to strength, stability, or life safety. Two types of applications are envisioned. The first is connections between structural elements where the failure of an anchor or anchor group could result in loss of equilibrium or stability of any portion of the structure. The second is where safety-related attachments that are not part of the structure (such as sprinkler systems, heavy suspended pipes, or barrier rails) are attached to structural elements. The levels of safety defined by the factored load combinations and ϕ -factors are appropriate for structural applications. Other standards may require more stringent safety levels during temporary handling.

The format for this chapter was revised in 2019 to be more consistent with the other chapters of this Code.

R17.1.2 Typical cast-in headed studs and headed bolts with head geometries consistent with **ASME B1.1**, **B18.2.1**, and **B18.2.6** have been tested and proven to behave predictably; therefore, calculated pullout strengths are acceptable.

Post-installed expansion, screw, and undercut anchors do not have predictable pullout strengths, and therefore qualification tests to establish the pullout strengths according to **ACI 355.2** are required. For post-installed expansion, screw, and undercut anchors to be used in conjunction with the requirements of this chapter, the results of the **ACI 355.2** tests have to indicate that pullout failures exhibit acceptable load-displacement characteristics or that pullout failures are precluded by another failure mode.

For adhesive anchors, the characteristic bond stress and suitability for structural applications are established by testing in accordance with **ACI 355.4**. Adhesive anchors are particularly sensitive to a number of factors including installation direction and load type. If adhesive anchors are used to resist sustained tension, the provisions include testing requirements for horizontal or upwardly inclined installations in 17.2.3, design requirements in 17.5.2.2, certification requirements in 26.7, and inspection requirements in 26.13. Adhesive anchors qualified in accordance with **ACI 355.4** are tested in concrete with compressive strengths within two ranges: 2500 to 4000 psi and 6500 to 8500 psi. Bond strength is, in general, not highly sensitive to concrete compressive strength.

R17.1.3 **ACI 355.2** prohibits reuse of post-installed mechanical anchors.

R17.1.4 The exclusion of load applications producing high-cycle fatigue or extremely short duration impact (such as blast or shock wave) from the scope of this chapter is not meant to exclude earthquake loads. Section 17.10 presents additional requirements for design when earthquake loads are included.

CHAPTER 18—EARTHQUAKE-RESISTANT STRUCTURES

CODE COMMENTARY

18.1—Scope

18.1.1 This chapter shall apply to the design of nonprestressed and prestressed concrete structures assigned to Seismic Design Categories (SDC) B through F, including, where applicable:

- (a) Structural systems designated as part of the seismic-force-resisting system, including diaphragms, moment frames, structural walls, and foundations
- (b) Members not designated as part of the seismic-force-resisting system but required to support other loads while undergoing deformations associated with earthquake effects

18.1.2 Structures designed according to the provisions of this chapter are intended to resist earthquake motions through ductile inelastic response of selected members.

18.2—General

18.2.1 *Structural systems*

18.2.1.1 All structures shall be assigned to a SDC in accordance with [4.4.6.1](#).

R18.1—Scope

Chapter 18 does not apply to structures assigned to Seismic Design Category (SDC) A. For structures assigned to SDC B and C, Chapter 18 applies to structural systems designated as part of the seismic-force-resisting system. For structures assigned to SDC D through F, Chapter 18 applies to both structural systems designated as part of the seismic-force-resisting system and structural systems not designated as part of the seismic-force-resisting system.

Chapter 18 contains provisions considered to be the minimum requirements for a cast-in-place or precast concrete structure capable of sustaining a series of oscillations into the inelastic range of response without critical deterioration in strength. The integrity of the structure in the inelastic range of response should be maintained because the design earthquake forces defined in documents such as [ASCE/SEI 7](#), the [2018 IBC](#), the UBC ([ICBO 1997](#)), and the NEHRP ([FEMA P749](#)) provisions are considered less than those corresponding to linear response at the anticipated earthquake intensity ([FEMA P749](#); [Blume et al. 1961](#); [Clough 1960](#); [Gulkan and Sozen 1974](#)).

The design philosophy in Chapter 18 is for cast-in-place concrete structures to respond in the nonlinear range when subjected to design-level ground motions, with decreased stiffness and increased energy dissipation but without critical strength decay. Precast concrete structures designed in accordance with Chapter 18 are intended to emulate cast-in-place construction, except [18.5](#), [18.9.2.3](#), and [18.11.2.2](#), which permit precast construction with alternative yielding mechanisms. The combination of reduced stiffness and increased energy dissipation tends to reduce the response accelerations and lateral inertia forces relative to values that would occur were the structure to remain linearly elastic and lightly damped ([Gulkan and Sozen 1974](#)). Thus, the use of design forces representing earthquake effects such as those in [ASCE/SEI 7](#) requires that the seismic-force-resisting system retain a substantial portion of its strength into the inelastic range under displacement reversals.

The provisions of Chapter 18 relate detailing requirements to type of structural framing and SDC. Seismic design categories are adopted directly from [ASCE/SEI 7](#), and relate to considerations of seismic hazard level, soil type, occupancy, and use. Before the 2008 Code, low, intermediate, and high seismic risk designations were used to delineate detailing requirements. For a qualitative comparison of seismic design categories and seismic risk designations, refer to [Table R5.2.2](#). The assignment of a structure to a SDC is regulated by the general building code (refer to [4.4.6.1](#)).

R18.2—General

Structures assigned to SDC A need not satisfy requirements of Chapter 18 but must satisfy all other applicable requirements of this Code. Structures assigned to Seismic Design Categories B through F must satisfy requirements of

CHAPTER 19—CONCRETE: DESIGN AND DURABILITY REQUIREMENTS CODE COMMENTARY

19.1—Scope

19.1.1 This chapter shall apply to concrete, including:

- (a) Properties to be used for design
- (b) Durability requirements

19.1.2 This chapter shall apply to durability requirements for grout used for bonded tendons in accordance with 19.4.

19.2—Concrete design properties

19.2.1 Specified compressive strength

19.2.1.1 The value of f'_c shall be in accordance with (a) through (d):

- (a) Limits for f'_c in Table 19.2.1.1. Limits apply to both normalweight and lightweight concrete.
- (b) Durability requirements in Table 19.3.2.1
- (c) Structural strength requirements
- (d) f'_c for lightweight concrete in special moment frames and special structural walls, and their foundations, shall not exceed 5000 psi, unless demonstrated by experimental evidence that members made with lightweight concrete provide strength and toughness equal to or exceeding those of comparable members made with normalweight concrete of the same strength.

Application	Minimum f'_c , psi
General	2500
Foundations for structures assigned to SDC A, B, or C	2500
Foundations for Residential and Utility use and occupancy classification with stud bearing wall construction two stories or less assigned to SDC D, E, or F	2500
Foundations for structures assigned to SDC D, E, or F other than Residential and Utility use and occupancy classification with stud bearing wall construction two stories or less	3000
Special moment frames	3000
Special structural walls with Grade 60 or 80 reinforcement	3000
Special structural walls with Grade 100 reinforcement	5000
Precast-nonprestressed driven piles Drilled shafts	4000
Precast-prestressed driven piles	5000

19.2.1.2 The specified compressive strength shall be used for proportioning of concrete mixtures in 26.4.3 and for testing and acceptance of concrete in 26.12.3.

19.2.1.3 Unless otherwise specified, f'_c shall be based on 28-day tests. If other than 28 days, test age for f'_c shall be indicated in the construction documents.

19.2.2 Modulus of elasticity

R19.2—Concrete design properties

R19.2.1 Specified compressive strength

Requirements for concrete mixtures are based on the philosophy that concrete should provide both adequate strength and durability. The Code defines a minimum value of f'_c for structural concrete. There is no limit on the maximum value of f'_c except as required by specific Code provisions.

Concrete mixtures proportioned in accordance with 26.4.3 should achieve an average compressive strength that exceeds the value of f'_c used in the structural design calculations. The amount by which the average strength of concrete exceeds f'_c is based on statistical concepts. When concrete is designed to achieve a strength level greater than f'_c , it ensures that the concrete strength tests will have a high probability of meeting the strength acceptance criteria in 26.12.3. The durability requirements prescribed in Table 19.3.2.1 are to be satisfied in addition to meeting the minimum f'_c of 19.2.1. Under some circumstances, durability requirements may dictate a higher f'_c than that required for structural purposes.

Available test data do not include lower strength concrete with Grade 100 reinforcement in special structural walls (refer to R18.2.6).

For design of special moment frames and special structural walls used to resist earthquake forces, the Code limits the maximum f'_c of lightweight concrete to 5000 psi. This limit is imposed primarily because of a paucity of experimental and field data on the behavior of members made with lightweight concrete subjected to displacement reversals in the nonlinear range.

Minimum concrete strengths are increased for special seismic systems with $f_y > 80,000$ psi to enhance bar anchorage and reduce the neutral axis depth for improved performance.

The Code also limits f'_c for design of anchors to concrete. The requirements are in 17.3.1.

R19.2.2 Modulus of elasticity

CHAPTER 20—STEEL REINFORCEMENT PROPERTIES, DURABILITY, & EMBEDMENTS

CODE

COMMENTARY

20.1—Scope

20.1.1 This chapter shall apply to steel reinforcement, and shall govern (a) through (c):

- (a) Material properties
- (b) Properties to be used for design
- (c) Durability requirements, including minimum specified cover requirements

20.1.2 Provisions of 20.6 shall apply to embedments.

20.2—Nonprestressed bars and wires

20.2.1 *Material properties*

20.2.1.1 Nonprestressed bars and wires shall be deformed, except plain bars or wires are permitted for use in spirals.

20.2.1.2 Yield strength of nonprestressed 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 nonprestressed bar or wire has a sharp-knead or well-defined yield point

20.2.1.3 Deformed bars shall conform to (a), (b), (c), (d), or (e), except bar sizes larger than No. 18 shall not be permitted:

- (a) [ASTM A615](#) – carbon steel, including requirements specified in Table 20.2.1.3(a)
- (b) [ASTM A706](#) – low-alloy steel, including requirements specified in (i), (ii), and (iii):
 - (i) Tensile property requirements for ASTM A706 Grade 100 reinforcement shall be as specified in Table 20.2.1.3(b), and bend test requirements for ASTM A706 Grade 100 reinforcement shall be the same as the bend test requirements for ASTM A706 Grade 80 reinforcement.

R20.1—Scope

R20.1.1 Materials permitted for use as reinforcement are specified. Other metal elements, such as inserts, anchor bolts, or plain bars for dowels at isolation or contraction joints, are not normally considered reinforcement under the provisions of this Code. Fiber-reinforced polymer (FRP) reinforcement is not addressed in this Code. ACI Committee 440 has developed guidelines for the use of FRP reinforcement ([ACI 440.1R](#) and [ACI 440.2R](#)).

R20.2—Nonprestressed bars and wires

R20.2.1 *Material properties*

R20.2.1.2 The majority of nonprestressed steel bar reinforcement exhibits actual stress-strain behavior that is sharply yielding or sharp-knead (elasto-plastic stress-strain behavior). However, reinforcement products such as bars of higher strength grade, steel wire, coiled steel bar, and stainless steel bars and wire generally do not exhibit sharply-yielding stress-strain behavior, but instead are gradually-yielding. The method used to measure yield strength of reinforcement needs to provide for both types of reinforcement stress-strain relationships.

A study ([Paulson et al. 2013](#)) considering reinforcement manufactured during 2008 through 2012 found that the offset method, using an offset of 0.2 percent, provides for a reasonable estimate of the strength of reinforced concrete structures.

The yield strength is determined by the manufacturer during tensile tests performed at the mill on samples of reinforcement. Test methods for determining yield strength of steel, including the offset method and yield point by halt-of-force method, are referenced either in the ASTM standards for nonprestressed bars and wire or in ASTM A370 Test Methods and Definitions.

R20.2.1.3 The requirements specified in 20.2.1.3(a) and (b), and in Tables 20.2.1.3(a) through (c), are necessary because the referenced standards in [Chapter 3](#), [ASTM A615-18](#)^{e1} and [ASTM A706-16](#), do not include these requirements. For project specifications, these requirements should be specified along with the corresponding ASTM requirements. The requirements provide for harmonization of minimum tensile strength requirements between ASTM A615 and ASTM A706, add new ductility requirements to both ASTM A615 and ASTM A706, and introduce Grade 100 reinforcement for ASTM A706. These requirements accommodate the introduction of higher strength reinforcement into the Code for special seismic applications and have been developed considering both structural safety and

CHAPTER 21—STRENGTH REDUCTION FACTORS CODE

COMMENTARY

21.1—Scope

21.1.1 This chapter shall apply to the selection of strength reduction factors used in design, except as permitted by Chapter 27.

21.2—Strength reduction factors for structural concrete members and connections

21.2.1 Strength reduction factors ϕ shall be in accordance with Table 21.2.1, except as modified by 21.2.2, 21.2.3, and 21.2.4.

Table 21.2.1—Strength reduction factors ϕ

Action or structural element	ϕ	Exceptions
(a) Moment, axial force, or combined moment and axial force	0.65 to 0.90 in accordance with 21.2.2	Near ends of pretensioned members where strands are not fully developed, ϕ shall be in accordance with 21.2.3.
(b) Shear	0.75	Additional requirements are given in 21.2.4 for structures designed to resist earthquake effects.
(c) Torsion	0.75	—
(d) Bearing	0.65	—
(e) Post-tensioned anchorage zones	0.85	—
(f) Brackets and corbels	0.75	—
(g) Struts, ties, nodal zones, and bearing areas designed in accordance with strut-and-tie method in Chapter 23	0.75	—
(h) Components of connections of precast members controlled by yielding of steel elements in tension	0.90	—
(i) Plain concrete elements	0.60	—
(j) Anchors in concrete elements	0.45 to 0.75 in accordance with Chapter 17	—

21.2.2 Strength reduction factor for moment, axial force, or combined moment and axial force shall be in accordance with Table 21.2.2.

R21.1—Scope

R21.1.1 The purposes of strength reduction factors ϕ are: (1) to account for the probability of under-strength members due to variations in material strengths and dimensions; (2) to account for inaccuracies in the design equations; (3) to reflect the available ductility and required reliability of the member under the load effects being considered; and (4) to reflect the importance of the member in the structure (MacGregor 1976; Winter 1979).

R21.2—Strength reduction factors for structural concrete members and connections

R21.2.1 The strength reduction factors in this Code are compatible with the ASCE/SEI 7 load combinations, which are the basis for the required factored load combinations in Chapter 5:

- (e) Laboratory tests of post-tensioned anchorage zones (Breen et al. 1994) indicate a wide range of scatter in the results. This observation is addressed with a ϕ -factor of 0.85 and by limiting the nominal compressive strength of unconfined concrete in the general zone to $0.7\lambda f_{ci}'$ in 25.9.4.5.2, where λ is defined in 19.2.4. Thus, the effective design strength of unconfined concrete is $0.85 \times 0.7\lambda f_{ci}' = 0.6\lambda f_{ci}'$ in the general zone.
- (f) Bracket and corbel behavior is predominantly controlled by shear; therefore, a single value of $\phi = 0.75$ is used for all potential modes of failure.
- (i) The strength reduction factor ϕ for plain concrete members is the same for all potential modes of failure. Because both the flexural tension strength and shear strength for plain concrete depend on the tensile strength of the concrete, without the reserve strength or ductility that might otherwise be provided by reinforcement, equal strength reduction factors for moment and shear are considered to be appropriate.

R21.2.2 The nominal strength of a member that is subjected to moment or combined moment and axial force is determined for the condition where the strain in the extreme compression fiber is equal to the assumed strain limit of 0.003. The net tensile strain ϵ_t is the tensile strain calculated in the extreme tension reinforcement at nominal strength,

CHAPTER 22—SECTIONAL STRENGTH

CODE	COMMENTARY
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22.1—Scope

22.1.1 This chapter shall apply to calculating nominal strength at sections of members, including (a) through (g):

- (a) Flexural strength
- (b) Axial strength or combined flexural and axial strength
- (c) One-way shear strength
- (d) Two-way shear strength
- (e) Torsional strength
- (f) Bearing
- (g) Shear friction

22.1.2 Sectional strength requirements of this chapter shall be satisfied unless the member or region of the member is designed in accordance with **Chapter 23**.

22.1.3 Design strength at a section shall be taken as the nominal strength multiplied by the applicable strength reduction factor ϕ given in **Chapter 21**.

22.2—Design assumptions for moment and axial strength

22.2.1 *Equilibrium and strain compatibility*

22.2.1.1 Equilibrium shall be satisfied at each section.

22.2.1.2 Strain in concrete and nonprestressed reinforcement shall be assumed proportional to the distance from neutral axis.

22.2.1.3 Strain in prestressed concrete and in bonded and unbonded prestressed reinforcement shall include the strain due to effective prestress.

22.2.1.4 Changes in strain for bonded prestressed reinforcement shall be assumed proportional to the distance from neutral axis.

R22.1—Scope

R22.1.1 The provisions in this chapter apply where the strength of the member is evaluated at critical sections.

R22.1.2 **Chapter 23** provides methods for designing discontinuity regions where section-based methods do not apply.

R22.2—Design assumptions for moment and axial strength

R22.2.1 *Equilibrium and strain compatibility*

The flexural and axial strength of a member calculated by the strength design method of the Code requires that two basic conditions be satisfied: 1) equilibrium; and 2) compatibility of strains. Equilibrium refers to the balancing of forces acting on the cross section at nominal strength. The relationship between the stress and strain for the concrete and the reinforcement at nominal strength is established within the design assumptions allowed by 22.2.

R22.2.1.2 It is reasonable to assume a linear distribution of strain across a reinforced concrete cross section (plane sections remain plane), even near nominal strength except in cases as described in **Chapter 23**.

The strain in both nonprestressed reinforcement and in concrete is assumed to be directly proportional to the distance from the neutral axis. This assumption is of primary importance in design for determining the strain and corresponding stress in the reinforcement.

R22.2.1.4 The change in strain for bonded prestressed reinforcement is influenced by the change in strain at the section under consideration. For unbonded prestressed reinforcement, the change in strain is influenced by external load, reinforcement location, and boundary conditions along the length of the reinforcement. Current Code equations for calculating f_{ps} for unbonded tendons, as provided in **20.3.2.4**, have been correlated with test results.

CHAPTER 23—STRUT-AND-TIE METHOD

<h3>CODE</h3>	<h3>COMMENTARY</h3>
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23.1—Scope

23.1.1 This chapter shall apply to the design of structural concrete members, or regions of members, where load or geometric discontinuities cause a nonlinear distribution of longitudinal strains within the cross section.

23.1.2 Any structural concrete member, or discontinuity region in a member, shall be permitted to be designed by modeling the member or region as an idealized truss in accordance with this chapter.

R23.1—Scope

A discontinuity in the stress distribution occurs at a change in the geometry of a structural element or at a concentrated load or reaction. St. Venant's principle indicates that the stresses due to axial force and bending approach a linear distribution at a distance approximately equal to the overall depth of the member, h , away from the discontinuity. For this reason, discontinuity regions are assumed to extend a distance h from the section where the load or change in geometry occurs.

The shaded regions in Fig. R23.1(a) and (b) show typical D-regions (Schlaich et al. 1987). The plane sections assumption of 9.2.1 is not applicable in such regions. In general, any portion of a member outside a D-region is a B-region where the plane sections assumptions of flexural theory can be applied. The strut-and-tie design method, as described in this chapter, is based on the assumption that D-regions can be analyzed and designed using hypothetical pin-jointed trusses consisting of struts and ties connected at nodes.

The idealized truss specified in 23.2.1, which forms the basis of the strut-and-tie method, is not intended to apply to structural systems configured as actual trusses because secondary effects, such as moments, are not included in the model.

CHAPTER 24—SERVICEABILITY

CODE

COMMENTARY

24.1—Scope

24.1.1 This chapter shall apply to member design for minimum serviceability, including (a) through (d):

- (a) Deflections due to service-level gravity loads (24.2)
- (b) Distribution of flexural reinforcement in one-way slabs and beams to control cracking (24.3)
- (c) Shrinkage and temperature reinforcement (24.4)
- (d) Permissible stresses in prestressed flexural members (24.5)

24.2—Deflections due to service-level gravity loads

24.2.1 Members subjected to flexure shall be designed with adequate stiffness to limit deflections or deformations that adversely affect strength or serviceability of a structure.

R24.1—Scope

This chapter prescribes serviceability requirements that are referenced by other chapters of the Code, or are otherwise applicable to provide adequate performance of structural members. This chapter does not stand on its own as a complete and cohesive compilation of serviceability requirements for the design of structural members. This chapter has no specific requirements for vibrations.

Cast-in-place floor systems designed in accordance with the minimum thickness and deflection requirements of 7.3, 8.3, 9.3, and 24.2 have generally been found, through experience, to provide vibration performance suitable for human comfort under typical service conditions. However, there may be situations where serviceability conditions are not satisfied, for example:

- (a) Long spans and open floor plans
- (b) Floors with strict vibration performance requirements such as precision manufacturing and laboratory spaces
- (c) Facilities subject to rhythmic loadings or vibrating mechanical equipment

Prestressed floor systems are not subject to the minimum thickness requirements of 7.3, 8.3, and 9.3, and if precast they are frequently simple span systems. Consequently, these floor systems can be more susceptible to vibration.

Guidance on the consideration of vibrations in the design of floor systems and the evaluation of vibration frequency and amplitude for concrete floor systems is contained in the *PCI Design Handbook (PCI MNL 120)*, *ATC Design Guide 1 (Applied Technology Council 1999)*, *Mast (2001)*, *Fanella and Mota (2014)*, and *Wilford and Young (2006)*. An example application is described by *West et al. (2008)*.

R24.2—Deflections due to service-level gravity loads

This section is concerned only with deflections or deformations that may occur at service load levels. When time-dependent deflections are calculated, only the dead load and those portions of other loads that are sustained need be considered.

Two methods are given in the Code for controlling deflections (*Sabnis et al. 1974*). For nonprestressed one-way slabs and beams, including composite members, the minimum overall thickness required by 7.3.1 and 9.3.1 is considered to satisfy the requirements of the Code for members not supporting or attached to nonstructural elements likely to be damaged by large deflections. For nonprestressed two-way construction, the minimum thickness required by 8.3.1 is considered to satisfy the requirements of the Code.

For nonprestressed members that do not meet these minimum thickness requirements, for nonprestressed one-way members that support or are attached to nonstructural elements likely to be damaged by large deflections, and for prestressed flexural members, deflections are required to be calculated by 24.2.3 through 24.2.5. Calculated deflections are limited to the values in Table 24.2.2.

CHAPTER 25—REINFORCEMENT DETAILS

CODE	COMMENTARY
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25.1—Scope

25.1.1 This chapter shall apply to reinforcement details, including:

- (a) Minimum spacing
- (b) Standard hooks, seismic hooks, and cross-ties
- (c) Development of reinforcement
- (d) Splices
- (e) Bundled reinforcement
- (f) Transverse reinforcement
- (g) Post-tensioning anchorages and couplers

25.1.2 Provisions of 25.9 shall apply to anchorage zones for post-tensioned tendons.

25.2—Minimum spacing of reinforcement

25.2.1 For parallel nonprestressed reinforcement in a horizontal layer, clear spacing shall be at least the greatest of 1 in., d_b , and $(4/3)d_{agg}$.

25.2.2 For parallel nonprestressed reinforcement placed in two or more horizontal layers, reinforcement in the upper layers shall be placed directly above reinforcement in the bottom layer with a clear spacing between layers of at least 1 in.

25.2.3 For longitudinal reinforcement in columns, pedestals, struts, and boundary elements in walls, clear spacing between bars shall be at least the greatest of 1.5 in., $1.5d_b$, and $(4/3)d_{agg}$.

25.2.4 For pretensioned strands at ends of a member, minimum center-to-center spacing s shall be the greater of the value in Table 25.2.4, and $[(4/3)d_{agg} + d_b]$.

R25.1—Scope

Recommended methods and standards for preparing design drawings, typical details, and drawings for the fabrication and placing of steel reinforcement in reinforced concrete structures are given in the *ACI Detailing Manual (SP-66)*.

All provisions in the Code relating to bar, wire, or strand diameter (and area) are based on the nominal dimensions of the reinforcement as given in the appropriate ASTM specification. Nominal dimensions are equivalent to those of a circular area having the same weight per foot as the ASTM designated bar, wire, or strand sizes. Cross-sectional area of reinforcement is based on nominal dimensions.

R25.1.1 In addition to the requirements in this chapter that affect detailing of reinforcement, detailing specific to particular members is given in the corresponding member chapters. Additional detailing associated with structural integrity requirements is covered in 4.10.

R25.2—Minimum spacing of reinforcement

The minimum limits are set to permit concrete to flow readily into spaces between bars and between bars and forms without honeycombs, and to ensure against concentration of bars on a line that may cause shear or shrinkage cracking. Use of nominal bar diameter to define minimum spacing permits a uniform criterion for all bar sizes. In 2014, the size limitations on aggregates were translated to minimum spacing requirements, and are provided to promote proper encasement of reinforcement and to minimize honeycombing. The limitations associated with aggregate size need not be satisfied if, in the judgment of the licensed design professional, the workability and methods of consolidation of the concrete are such that the concrete can be placed without creating honeycombs or voids.

The development lengths given in 25.4 are a function of the bar spacing and cover. As a result, it may be desirable to use larger than minimum bar spacing or cover in some cases.

R25.2.4 The decreased spacing for transfer strengths of 4000 psi or greater is based on [Deatherage et al. \(1994\)](#) and [Russell and Burns \(1996\)](#).

CHAPTER 26—CONSTRUCTION DOCUMENTS AND INSPECTION CODE COMMENTARY

26.1—Scope

R26.1—Scope

This chapter establishes the minimum requirements for information that must be included in the construction documents as applicable to the project. The requirements include information developed in the structural design that must be conveyed to the contractor, provisions directing the contractor on required quality, and inspection requirements to verify compliance with the construction documents. Construction and inspection provisions for anchors were located in Chapter 17 of the 2014 Code. These provisions were moved to Chapter 26 of the 2019 Code.

This chapter is directed to the licensed design professional responsible for incorporating project requirements into the construction documents. The construction documents should contain all of the necessary design and construction requirements for the contractor to achieve compliance with the Code. It is not intended that the Contractor will need to read and interpret the Code.

A general reference in the construction documents requiring compliance with this Code is to 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. References to specific Code provisions should be avoided as well because it is the intention of the Code that all necessary provisions be included in the construction documents. For example, references to specific provisions within Chapter 26 are expected to be replaced with the appropriate references within the project construction documents. Reference to ACI and ASTM standards as well as to other documents is expected.

This chapter includes provisions for some of the information that is to be in the construction documents. This chapter is not intended as an all-inclusive list; additional items may be applicable to the Work or required by the building official. **ACI 301** is a reference construction specification that is written to be consistent with the requirements of this Code.

Chapter 26 is organized as shown below:

Section	Coverage
26.1	Scope
26.2	Design criteria
26.3	Member information
26.4	Concrete materials and mixture requirements
26.5	Concrete production and construction
26.6	Reinforcement materials and construction requirements
26.7	Anchoring to concrete
26.8	Embedments
26.9	Additional requirements for precast concrete
26.10	Additional requirements for prestressed concrete
26.11	Formwork
26.12	Evaluation and acceptance of hardened concrete
26.13	Inspection

CHAPTER 27—STRENGTH EVALUATION OF EXISTING STRUCTURES

CODE COMMENTARY

27.1—Scope

27.1.1 Provisions of this chapter shall apply to strength evaluation of existing structures by analytical means or by load testing.

27.2—General

27.2.1 If there is doubt that a part or all of a structure meets the safety requirements of this Code and the structure is to remain in service, a strength evaluation shall be carried out as required by the licensed design professional or building official.

27.2.2 If the effect of a strength deficiency is well understood and it is practical to measure the dimensions and determine the material properties of the members required for analysis, an analytical evaluation of strength based on this information is permitted. Required data shall be determined in accordance with 27.3.

27.2.3 If the effect of a strength deficiency is not well understood or it is not practical to measure the dimensions and determine the material properties of the members required for analysis, a load test is required in accordance with 27.4.

27.2.4 If uncertainty about the strength of part or all of a structure involves deterioration, and if the observed response during the load test satisfies the acceptance criteria in 27.5 or 27.6 for the selected load test procedure, the structure or part of the structure is permitted to remain in service for a time period specified by the licensed design professional. If deemed necessary by the licensed design professional, periodic reevaluations shall be conducted.

R27.1—Scope

R27.1.1 Provisions of this chapter may be used to evaluate whether a structure or a portion of a structure satisfies the safety requirements of the Code. A strength evaluation may be required if the materials are considered to be deficient in quality, if there is evidence indicating faulty construction, if a building will be used for a new function, or if, for any reason, a structure or a portion of it does not appear to satisfy the requirements of the Code. In such cases, this chapter provides guidance for investigating the safety of the structure. This chapter does not cover load testing for the approval of new design or construction methods. Acceptance of alternative materials or systems is covered in 1.10.

R27.2—General

R27.2.1 If a load test is described as part of the strength evaluation process, it is desirable for all parties to agree on the region to be loaded, the magnitude of the load, the load test procedure, and acceptance criteria before any load tests are conducted. If the safety concerns are related to an assemblage of members or an entire structure, it is not feasible to load test every member and section. In such cases, it is appropriate that an investigation plan be developed to address the specific safety concerns.

R27.2.2 Strength considerations related to axial load, flexure, and combined axial load and flexure are well understood. There are reliable theories relating strength and short-term displacement to load in terms of member dimensional and material data. To determine the strength of the structure by analysis, calculations should be based on data gathered on the actual dimensions of the structure, properties of the materials in place, and all pertinent details.

R27.2.3 If the shear or bond strength of a member is critical in relation to the doubt expressed about safety, a test may be the most efficient solution to eliminate or confirm the doubt. A test may also be appropriate if it is not feasible to determine the material and dimensional properties required for analysis, even if the cause of the concern relates to flexure or axial load. Wherever possible and appropriate, the results of the load test should be supported by analysis.

R27.2.4 For a deteriorating structure, acceptance provided by the load test is, by necessity, limited in terms of future service life. In such cases, a periodic inspection program is useful. A program that involves physical tests and periodic inspection can justify a longer period in service. Another option for maintaining the structure in service, while the periodic inspection program continues, is to limit the live load to a level determined to be appropriate in accordance with 27.2.5. The length of the specified time period between inspections should be based on consideration of: a) the nature of the deterioration; b) environmental and load effects; c) service history of the structure; and d) scope of the