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มาตรฐาน American Concrete Institute

รองศาสตราจารย์ ดร.ศักดา กตเวทวารักษ์

4 ธันวาคม 2567

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ACI Standards

- **ACI technical committees disseminate information through consensus-based publications within the scope of a committee's mission.**
  - Standardization is the most rigorous consensus process used by ACI. ACI standards are written in mandatory language. There are typically two types of ACI Standards – design codes and construction specifications.

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Design Codes

- Design codes are directed to the design professional, not the construction team. ACI design codes include, code requirements, code cases, acceptance criteria, and design specifications

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Construction Specifications

- ACI construction specifications are written to direct the producers, testing agencies, and construction team, not the design professional. ACI specifications include both construction and material specifications.

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Design Codes

- ACI CODE-216.1-14(19) Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies
- ACI CODE-307-23: Requirements for Reinforced Concrete Chimneys—Code and Commentary
- ACI CODE-318-11: Building Code Requirements for Structural Concrete and Commentary
- ACI CODE-318-14: Building Code Requirements for Structural Concrete and Commentary
- ACI CODE-318-19(22): Building Code Requirements for Structural Concrete and Commentary (Reapproved 2022)
- ACI CODE-318.2-14: Building Code Requirements for Concrete Thin Shells and Commentary
- ACI CODE-318.2-19: Building Code Requirements for Concrete Thin Shells (ACI 318.2-19) and Commentary

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Design Codes

- ACI CODE-332-20: Code Requirements for Residential Concrete and Commentary
- ACI CODE-350-20: Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20) and Commentary (ACI 350R-20)
- ACI CODE-350.3-20: Code Requirements for Seismic Analysis and Design of Liquid-Containing Concrete Structures (ACI 350.3-20) and Commentary
- ACI CODE-350M-06 Code Requirements for Environmental Engineering Concrete Structures & Commentary (Metric)
- ACI CODE-369.1-22: Seismic Evaluation and Retrofit of Existing Concrete Buildings—Code and Commentary

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Design Codes

- ACI CODE-376-23: Refrigerated Liquefied Gas Containment for Concrete Structures—Code Requirements and Commentary
- ACI CODE-437.2-22: Load Testing of Concrete Structures - Code and Commentary
- ACI CODE-440.11-22: Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary
- ACI CODE-550.3-13 Design Specification for Unbonded Post-Tensioned Precast Concrete Special Moment Frames Satisfying ACI 374.1 (Reapproved 2022)
- ACI CODE-550.4-18: Qualification of Precast Concrete Diaphragm Connections and Reinforcement at Joints for Earthquake Loading (ACI 550.4-18) and Commentary

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Design Codes

- ACI CODE-550.5-18:Code Requirements for the Design of Precast Concrete Diaphragms for Earthquake Motions (ACI 550.5) and Commentary (ACI 550.5R)
- ACI CODE-550.5M-18: Code Requirements for the Design of Precast Concrete Diaphragms for Earthquake Motions (Metric)
- ACI CODE-550.6-19: Acceptance Criteria for Special Unbonded Post-Tensioned Precast Structural Walls Based on Validation Testing and Commentary
- ACI CODE-562-21: Assessment, Repair, and Rehabilitation of Existing Concrete Structures - Code and Commentary
- ACI CODE-323-24: Low-Carbon Concrete—Code Requirements and Commentary.

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Construction Specifications

- ACI SPEC-117-10: Specification for Tolerances for Concrete Construction and Materials (ACI 117-10) and Commentary-Reapproved 2015
- ACI SPEC-301-20: Specifications for Concrete Construction
- ACI SPEC-305.1-14(20) Specification for Hot Weather Concreting
- ACI SPEC-308.1-11 Specification for Curing Concrete
- ACI SPEC-310.1-20: Specification for Polished Concrete Slab Finishes
- ACI SPEC-330.1-14: Specification for Unreinforced Concrete Parking Lots and Site Paving (Reapproved 2020)

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Construction Specifications

- ACI SPEC-350.1-10 Specification for Tightness Testing of Environmental Engineering Concrete Containment Structures & Commentary
- ACI SPEC-350.1-22: Tightness Testing of Environmental Engineering Concrete Structures—Specification
- ACI SPEC-350.5-12 Specifications for Environmental Concrete Structures
- ACI SPEC-351.4-14 Specification for Installation of Cementitious Grouting between Foundations and Equipment Bases
- ACI SPEC-351.5-15 Specification for Installation of Epoxy Grout between Foundations and Equipment Bases

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Construction Specifications

- ACI SPEC-440.12-22: Strengthening of Concrete Structures with Externally Bonded Fiber-Reinforced Polymer (FRP) Materials Using the Wet Layup Method—Specification
- ACI SPEC-440.5-22: Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars—Specification
- ACI SPEC-440.6-08(17)(22) Specification for Carbon Fiber-Reinforced Polymer Bar Material for Concrete Reinforcement (Reapproved 2022
- ACI SPEC-440.8-13 Specification for Carbon and Glass Fiber-Reinforced Polymer Materials Made by Wet Layup for External Strengthen (Reapproved 2023)

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Construction Specifications

- ACI SPEC-503.3-10 Specification for Producing a Skid-Resistant Surface on Concrete by the Use of Epoxy and Aggregate
- ACI SPEC-506.2-13 Specification for Shotcrete (Reapproved 2018)
- ACI SPEC-522.1-20: Specification for Construction of Pervious Concrete Pavement
- ACI SPEC-548.10-22: Type Methyl Methacrylate Slurry (MMS) Polymer Overlays for Bridge and Parking Garage Deck—Specification
- ACI SPEC-548.13-21: Multi-Component Epoxy Adhesive for Bonding to Concrete—Specification
- ACI SPEC-548.14-14 Specification for Repairing Concrete with Epoxy Mortar

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Construction Specifications

- ACI SPEC-548.15-20: Specification for Crack Repair by Epoxy Injection
- ACI SPEC-548.16-21: Epoxy and Aggregate High Friction Surface on Concrete—Specification
- ACI SPEC-548.4-11 Specification for Latex-Modified Concrete Overlays
- ACI SPEC-548.8-19: Construction Specification for Type EM (Epoxy Multi-Layer) Polymer Overlay for Bridge and Parking Garage Decks
- ACI SPEC-548.9-21: Type ES (Epoxy Slurry) Polymer Overlay for Bridge and Parking Garage Decks—Specification
- ACI SPEC-563-18: Specifications for Repair of Concrete in Buildings

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ACI 318

HISTORICAL HIGHLIGHTS OF ACI 318: “Building Code Requirements for Structural Concrete and Commentary”

1910
ACI (then known as National Association of Cement Users) publishes its first building code.

1920s-1930s
The ACI Building Code is widely used as the benchmark for concrete design and construction.

1941
ACI Building Code is renamed "ACI 318."

1963
ACI 318-63 includes a chapter on prestressed concrete.

Commentary is published to explain committee considerations and new provisions.

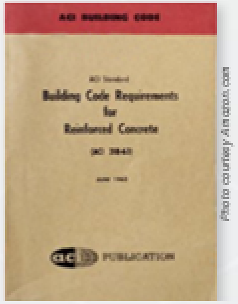


Photo courtesy Amazon.com

1971
Ultimate strength design philosophy is adopted.

Seismic design provisions are published.

1989
First metric version of 318 is published.

The Code and Commentary are published as a single document.

1995
ACI 318-95 includes a completely revised and expanded chapter on precast concrete.

2002
The First International Workshop on Structural Concrete in the Americas highlights the similarities and differences between ACI 318-02 and codes in other countries.

A unified design approach based on strain compatibility is used as a basis in the Code.

2003
International Standards Organization (ISO) recognizes ACI 318-02 as satisfying ISO 19338:2003, endorsing worldwide use of the Code.

ISO International Organization for Standardization

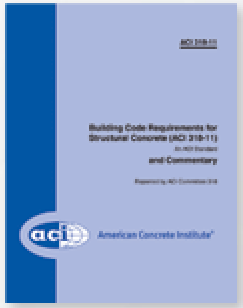
ACI 318

2004
ACI Committee 318 establishes a dedicated international subcommittee.

2005

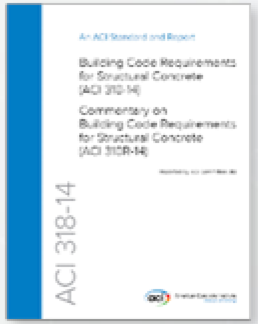

This is the first time Spanish and Chinese translations are published, and the first time 318 is published as a .pdf.

2008
ACI 318-08 is published; and includes new content on headed shear stud reinforcement and headed deformed bars, enhanced structural integrity reinforcement, a new seismic design requirement, and expanded provisions on anchoring to concrete.

2011


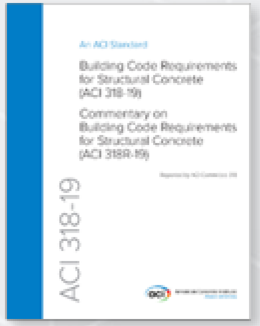
ACI 318-11 is published; includes new requirements on design, installation, and inspection of adhesive anchors. Includes new credentialing requirements for individuals who install adhesive anchors.

2014
ACI 318-14 is published in a completely reorganized format. Now organized from the designer's perspective, this 2014 edition includes more tables and charts, a consistent structure for each member chapter, fewer cross references, a dedicated chapter on construction requirements, and new chapters on structural systems and diaphragms. First electronic versions published for iPad, Kindle, and other tablet devices (in .epub and .mobi formats); .pdf versions enhanced with reference links and more.



2015
Spanish and Chinese versions of ACI 318-14 to be published. ACI will conduct 318 seminars and webinars. SP17: Reinforced Concrete Design Manual will be published, which will include explanations, analyses, examples, and design aids for reinforced concrete structures—an invaluable companion to the new ACI 318-14.

2019
ACI released the updated ACI 318-19: Building Code Requirements for Structural Concrete and Commentary. This latest edition includes new and updated code provisions along with updated color illustrations for added clarity.



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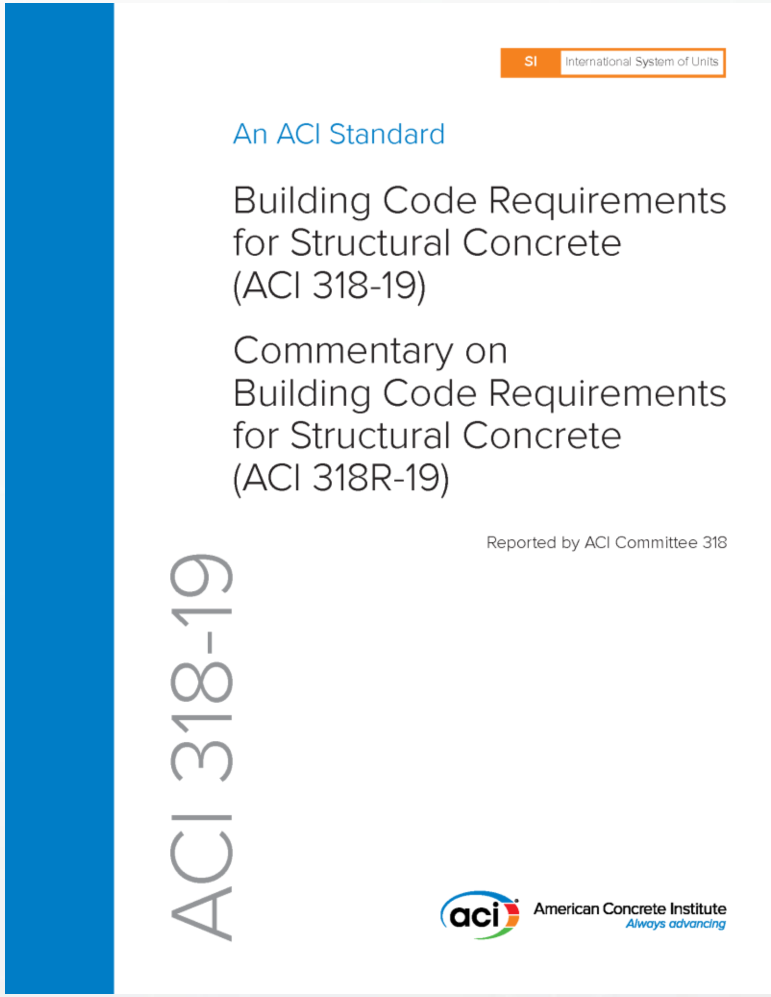
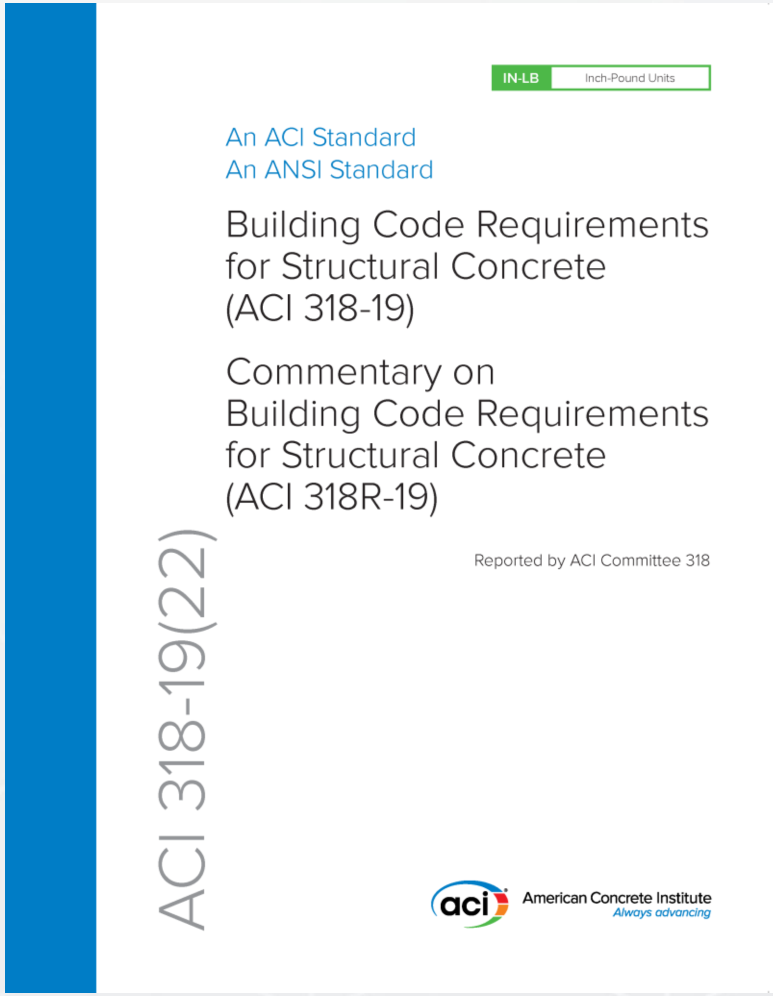
ACI CODE-318-19:

Building Code Requirements for Structural Concrete and Commentary





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ACI CODE-318-19

PART 1: GENERAL

CHAPTER 1 GENERAL

CHAPTER 2 NOTATION AND TERMINOLOGY

CHAPTER 3 REFERENCED STANDARDS

CHAPTER 4 STRUCTURAL SYSTEM REQUIREMENTS

Council of Engineers

ACI CODE-318-19

PART 2: LOADS & ANALYSIS

CHAPTER 5
LOADS

CHAPTER 6
STRUCTURAL ANALYSIS

PART 3: MEMBERS

CHAPTER 7
ONE-WAY SLABS

CHAPTER 8
TWO-WAY SLABS

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ACI CODE-318-19

CHAPTER 9 BEAMS

CHAPTER 10 COLUMNS

CHAPTER 11 WALLS

CHAPTER 12 DIAPHRAGMS

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ACI CODE-318-19

CHAPTER 13 FOUNDATIONS

CHAPTER 14 PLAIN CONCRETE

PART 4: JOINTS/CONNECTIONS/ANCHORS

CHAPTER 15 BEAM-COLUMN AND SLAB-COLUMN JOINTS

CHAPTER 16 CONNECTIONS BETWEEN MEMBERS

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ACI CODE-318-19

CHAPTER 17
ANCHORING TO CONCRETE

PART 5: EARTHQUAKE RESISTANCE

CHAPTER 18
EARTHQUAKE-RESISTANT STRUCTURES

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ACI CODE-318-19

PART 6: MATERIALS & DURABILITY

CHAPTER 19
CONCRETE: DESIGN AND DURABILITY REQUIREMENTS

CHAPTER 20
STEEL REINFORCEMENT PROPERTIES, DURABILITY, AND EMBEDMENTS

PART 7: STRENGTH & SERVICEABILITY

CHAPTER 21
STRENGTH REDUCTION FACTORS

CHAPTER 22
SECTIONAL STRENGTH

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ACI CODE-318-19

CHAPTER 23 STRUT-AND-TIE METHOD

CHAPTER 24 SERVICEABILITY

PART 8: REINFORCEMENT

CHAPTER 25 REINFORCEMENT DETAILS

Council of Engineers

ACI CODE-318-19

PART 9: CONSTRUCTION

CHAPTER 26
CONSTRUCTION DOCUMENTS AND INSPECTION

PART 10: EVALUATION

CHAPTER 27
STRENGTH EVALUATION OF EXISTING STRUCTURES

Council of Engineers

ACI CODE-318-19

APPENDICES & REFERENCES

APPENDIX A
DESIGN VERIFICATION USING NONLINEAR RESPONSE HISTORY ANALYSIS

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

Council of Engineers

ACI CODE-318-19

CHAPTER 1—GENERAL

CODE

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

COMMENTARY

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.

ACI CODE-318-19

1.4—Applicability

1.4.1 This Code shall apply to concrete structures designed and constructed under the requirements of the general building code.

1.4.2 Provisions of this Code shall be permitted to be used for the assessment, repair, and rehabilitation of existing structures.

1.4.3 Applicable provisions of this Code shall be permitted to be used for structures not governed by the general building code.

R1.4—Applicability

R1.4.2 Specific provisions for assessment, repair, and rehabilitation of existing concrete structures are provided in ACI 562-19. Existing structures in ACI 562 are defined as structures that are complete and permitted for use.

R1.4.3 Structures such as arches, bins and silos, blast-resistant structures, chimneys, underground utility structures, gravity walls, and shielding walls involve design and construction requirements that are not specifically addressed by this Code. Many Code provisions, however, such as concrete quality and design principles, are applicable for these structures. Recommendations for design and construction of some of these structures are given in the following:

- "Code Requirements for Reinforced Concrete Chimneys and Commentary" (ACI 307-08)
- "Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials" (ACI 313-97)
- "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary" (ACI 349M)
- "Code for Concrete Containments" (ACI 359)

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ACI CODE-318-19

CHAPTER 2—NOTATION AND TERMINOLOGY

CODE

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, mm

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, mm

A_b = area of an individual bar or wire, mm^2

A_{bp} = area of the attachment base plate in contact with concrete or grout when loaded in compression, mm^2

A_{brg} = net bearing area of the head of stud, anchor bolt, or headed deformed bar, mm^2

A_c = area of concrete section resisting shear transfer, mm^2

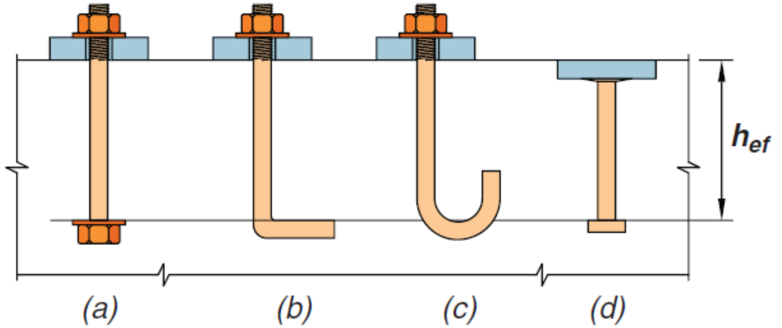
A_{cf} = greater gross cross-sectional area of the two orthogonal slab-beam strips intersecting at a column of a two-way prestressed slab, mm^2

COMMENTARY

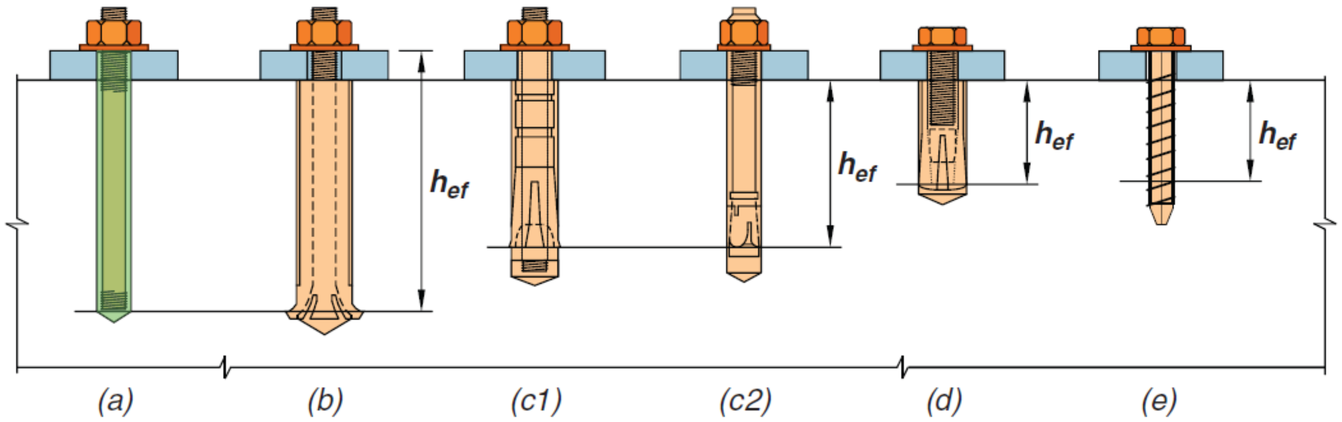
R2.2—Notation

ACI CODE-318-19

CODE | COMMENTARY



(A) Cast-in anchors: (a) hex head bolt with washer; (b) L-bolt; (c) J-bolt; and (d) welded headed stud.



(B) Post-installed anchors: (a) adhesive anchor; (b) undercut anchor; (c) torque-controlled expansion anchors [(c1) sleeve-type and (c2) stud-type]; (d) drop-in type displacement-controlled expansion anchor; and (e) screw anchor.

Fig. R2.1—*Types of anchors.*

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CHAPTER 3—REFERENCED STANDARDS

CODE

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

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.

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ACI CODE-318-19

CHAPTER 4—STRUCTURAL SYSTEM REQUIREMENTS

CODE

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.

COMMENTARY

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 506.2M.

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CHAPTER 5—LOADS

CODE

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.

COMMENTARY

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.

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CHAPTER 6—STRUCTURAL ANALYSIS

CODE

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.

COMMENTARY

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.

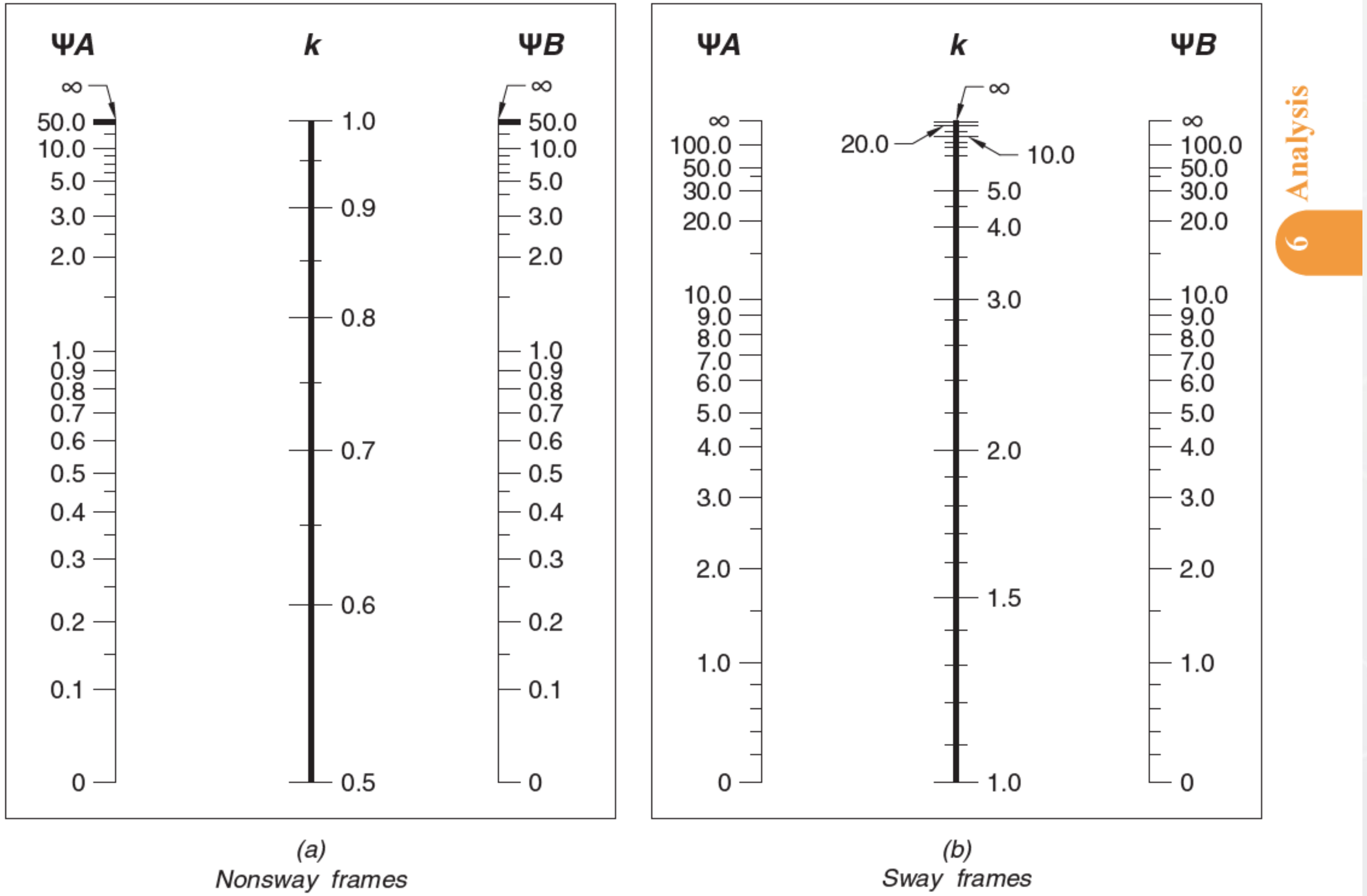
Section 6.3 addresses modeling assumptions used in establishing the analysis model.

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.

ACI CODE-318-19



Ψ = ratio of $\sum(EI/\ell_c)$ of all columns to $\sum(EI/\ell)$ of beams in a plane at one end of a column

ℓ = span length of of beam measured center to center of joints

Fig. R6.2.5.1—Effective length factor **k**.

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ACI CODE-318-19

CODE COMMENTARY

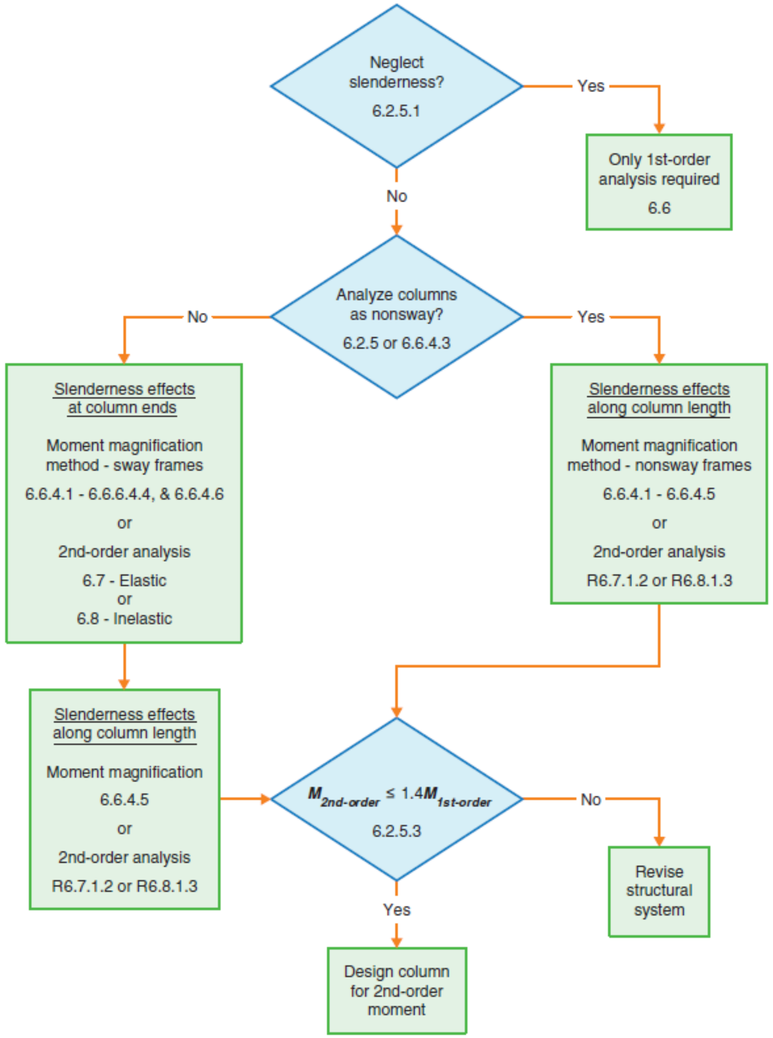

Fig. R6.2.5.3—Flowchart for determining column slenderness effects.

6 Analysis

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ACI CODE-318-19

CHAPTER 7—ONE-WAY SLABS

CODE

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.

COMMENTARY

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.

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ACI CODE-318-19

CHAPTER 8—TWO-WAY SLABS

CODE

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

COMMENTARY

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

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CHAPTER 9—BEAMS

CODE

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.

COMMENTARY

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

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ACI CODE-318-19

CHAPTER 10—COLUMNS

CODE

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.

COMMENTARY

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.

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

R10.3—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.

CODE

column shall not be taken greater than 40 mm outside the transverse reinforcement.

10.3.1.4 For columns with two or more interlocking spirals, outer limits of the effective cross section shall be taken at a distance outside the spirals equal to the minimum required concrete cover.

10.3.1.5 If a reduced effective area is considered according to 10.3.1.1 through 10.3.1.4, structural analysis and design of other parts of the structure that interact with the column shall be based on the actual cross section.

10.4—Required strength

10.4.1 *General*

10.4.1.1 Required strength shall be calculated in accordance with the factored load combinations in Chapter 5.

10.4.1.2 Required strength shall be calculated in accordance with the analysis procedures in Chapter 6.

10.4.2 *Factored axial force and moment*

10.4.2.1 P_u and M_u occurring simultaneously for each applicable factored load combination shall be considered.

COMMENTARY

R10.4—Required strength

R10.4.2 *Factored axial force and moment*

R10.4.2.1 The critical load combinations may be difficult to discern without methodically checking each combination. As illustrated in Fig. R10.4.2.1, considering only the factored load combinations associated with maximum axial force (LC1) and with maximum bending moment (LC2) does not necessarily provide a code-compliant design for other load combinations such as LC3.

Council of Engineers

ACI CODE-318-19

CODE

COMMENTARY

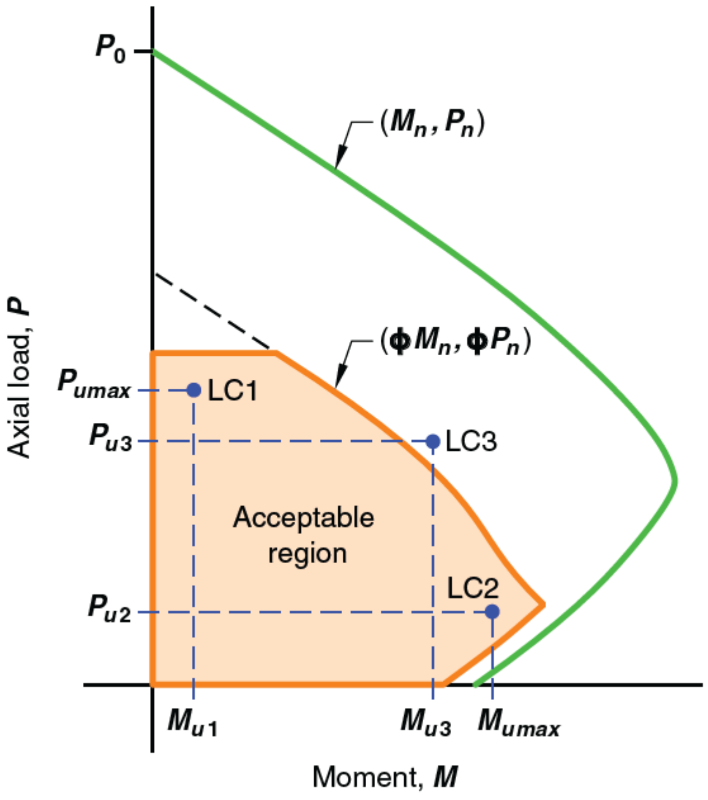

Fig. R10.4.2.1—Critical column load combination.

10.5—Design strength

10.5.1 *General*

R10.5—Design strength

R10.5.1 *General*

10.5—Design strength

10.5.1 *General*

10.5.1.1 For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$, including (a) through (d). Interaction between load effects shall be considered:

(a) $\phi P_n \geq P_u$

(b) $\phi M_n \geq M_u$

(c) $\phi V_n \geq V_u$

(d) $\phi T_n \geq T_u$

10.5.1.2 ϕ shall be determined in accordance with 21.2.

10.5.2 *Axial force and moment*

10.5.2.1 P_n and M_n shall be calculated in accordance with 22.4.

10.5.3 *Shear*

10.5.3.1 V_n shall be calculated in accordance with 22.5.

10.5.4 *Torsion*

10.5.4.1 If $T_u \geq \phi T_{th}$, where T_{th} is given in 22.7, torsion shall be considered in accordance with Chapter 9.

R10.5—Design strength

R10.5.1 *General*

R10.5.1.1 Refer to R9.5.1.1.

R10.5.4 *Torsion*

Torsion acting on columns in buildings is typically negligible and is rarely a governing factor in the design of columns.

Council of Engineers

ACI CODE-318-19

CODE

10.6—Reinforcement limits

10.6.1 *Minimum and maximum longitudinal reinforcement*

10.6.1.1 For nonprestressed columns and for prestressed columns with average f_{pe} < **1.6 MPa**, area of longitudinal reinforcement shall be at least $\mathbf{0.01}A_g$ but shall not exceed $\mathbf{0.08}A_g$.

COMMENTARY

R10.6—Reinforcement limits

R10.6.1 *Minimum and maximum longitudinal reinforcement*

R10.6.1.1 Limits are provided for both the minimum and maximum longitudinal reinforcement ratios.

Minimum reinforcement—Reinforcement is necessary to provide resistance to bending, which may exist regardless of analytical results, and to reduce the effects of creep and shrinkage of the concrete under sustained compressive stresses. Creep and shrinkage tend to transfer load from the concrete to the reinforcement, and the resultant increase in reinforcement stress becomes greater as the reinforcement ratio decreases. Therefore, a minimum limit is placed on the reinforcement ratio to prevent reinforcement from yielding under sustained service loads (Richart 1933).

Maximum reinforcement—The amount of longitudinal reinforcement is limited to ensure that concrete can be effectively consolidated around the bars and to ensure that columns designed according to the Code are similar to the test specimens by which the Code was calibrated. The 0.08 limit applies at all sections, including splice regions, and can also be considered a practical maximum for longitudinal reinforcement in terms of economy and requirements for placing. Longitudinal reinforcement in columns should usually not exceed 4 percent if the column bars are required to be lap spliced, as the lap splice zone will have twice as much reinforcement if all lap splices occur at the same location.

ACI CODE-318-19

10.6.2 *Minimum shear reinforcement*

10.6.2.1 A minimum area of shear reinforcement, $A_{v,min}$, shall be provided in all regions where $V_u > 0.5\phi V_c$.

10.6.2.2 If shear reinforcement is required, $A_{v,min}$ shall be the greater of (a) and (b):

(a) $0.062\sqrt{f_c'}\dfrac{b_w s}{f_{yt}}$

(b) $0.35\dfrac{b_w s}{f_{yt}}$

R10.6.2 *Minimum shear reinforcement*

R10.6.2.1 The basis for the minimum shear reinforcement is the same for columns and beams. Refer to R9.6.3 for more information.

10.7—Reinforcement detailing

10.7.1 *General*

10.7.1.1 Concrete cover for reinforcement shall be in accordance with 20.5.1.

10.7.1.2 Development lengths of deformed and prestressed reinforcement shall be in accordance with 25.4.

R10.7—Reinforcement detailing

ACI CODE-318-19

CODE

10.7.1.3 Along development and lap splice lengths of longitudinal bars with $f_y \geq 550$ **MPa**, transverse reinforcement shall be provided such that K_{tr} shall not be smaller than $0.5d_b$.

10.7.1.4 Bundled bars shall be in accordance with 25.6.

10.7.2 *Reinforcement spacing*

10.7.2.1 Minimum spacing s shall be in accordance with 25.2.

10.7.3 *Longitudinal reinforcement*

10.7.3.1 For nonprestressed columns and for prestressed columns with average $f_{pe} < 1.6$ **MPa**, the minimum number of longitudinal bars shall be (a), (b), or (c):

(a) Three within triangular ties
(b) Four within rectangular or circular ties
(c) Six enclosed by spirals or for columns of special moment frames enclosed by circular hoops

COMMENTARY

R10.7.3 *Longitudinal reinforcement*

R10.7.3.1 At least four longitudinal bars are required when bars are enclosed by rectangular or circular ties. For other tie shapes, one bar should be provided at each apex or corner and proper transverse reinforcement provided. For example, tied triangular columns require at least three longitudinal bars, with one at each apex of the triangular ties. For bars enclosed by spirals, at least six bars are required.

If the number of bars in a circular arrangement is less than eight, the orientation of the bars may significantly affect the moment strength of eccentrically loaded columns and should be considered in design.

10.7.4 *Offset bent longitudinal reinforcement*

10.7.4.1 The slope of the inclined portion of an offset bent longitudinal bar relative to the longitudinal axis of the column shall not exceed 1 in 6. Portions of bar above and below an offset shall be parallel to axis of column.

10.7.4.2 If the column face is offset 75 mm or more, longitudinal bars shall not be offset bent and separate dowels, lap spliced with the longitudinal bars adjacent to the offset column faces, shall be provided.

10.7.5 *Splices of longitudinal reinforcement*

10.7.5.1 *General*

10.7.5.1.1 Lap splices, mechanical splices, butt-welded splices, and end-bearing splices shall be permitted.

10.7.5.1.2 Splices shall satisfy requirements for all factored load combinations.

10.7.5.1.3 Splices of deformed reinforcement shall be in accordance with 25.5 and, if applicable, shall satisfy the requirements of 10.7.5.2 for lap splices or 10.7.5.3 for end-bearing splices.

R10.7.5 *Splices of longitudinal reinforcement*

R10.7.5.1 *General*

R10.7.5.1.2 Frequently, the basic gravity load combination will govern the design of the column itself, but a load combination including wind or earthquake effects may induce greater tension in some column bars. Each bar splice should be designed for the maximum calculated bar tensile force.

R10.7.5.1.3 For the purpose of calculating ℓ_d for tension lap splices in columns with offset bars, Fig. R10.7.5.1.3 illustrates the clear spacing to be used.

ACI CODE-318-19

CHAPTER 11—WALLS

CODE

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.

COMMENTARY

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.

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ACI CODE-318-19

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.

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ACI CODE-318-19

CHAPTER 13—FOUNDATIONS

CODE

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

COMMENTARY

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.

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ACI CODE-318-19

CHAPTER 14—PLAIN CONCRETE

CODE

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

COMMENTARY

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

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ACI CODE-318-19

CHAPTER 15—BEAM-COLUMN AND SLAB-COLUMN JOINTS

CODE

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.

COMMENTARY

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.

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ACI CODE-318-19

CHAPTER 16—CONNECTIONS BETWEEN MEMBERS

CODE

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.

COMMENTARY

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.

ACI CODE-318-19

CHAPTER 17—ANCHORING TO CONCRETE

CODE

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.

COMMENTARY

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.

ACI CODE-318-19

CHAPTER 18—EARTHQUAKE-RESISTANT STRUCTURES

CODE

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.

COMMENTARY

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).

Council of Engineers

ACI CODE-318-19

CHAPTER 19—CONCRETE: DESIGN AND DURABILITY REQUIREMENTS

CODE

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 35 MPa, 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.

COMMENTARY

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

Council of Engineers

ACI CODE-318-19

CHAPTER 20—STEEL REINFORCEMENT PROPERTIES, DURABILITY, & EMBEDMENTS

CODE

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-kneed or well-defined yield point

COMMENTARY

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-kneed (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

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ACI CODE-318-19

CHAPTER 21—STRENGTH REDUCTION FACTORS

CODE

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.

COMMENTARY

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.

Council of Engineers

ACI CODE-318-19

CHAPTER 22—SECTIONAL STRENGTH

CODE

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.

COMMENTARY

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.

Council of Engineers

ACI CODE-318-19

CHAPTER 23—STRUT-AND-TIE METHOD

CODE

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.

COMMENTARY

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.

ACI CODE-318-19

CHAPTER 24—SERVICEABILITY

CODE

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)

COMMENTARY

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.

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ACI CODE-318-19

CHAPTER 25—REINFORCEMENT DETAILS

CODE

25.1—Scope

25.1.1 This chapter shall apply to reinforcement details, including:

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

COMMENTARY

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 mass per meter 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.

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ACI CODE-318-19

CHAPTER 26—CONSTRUCTION DOCUMENTS AND INSPECTION

CODE

26.1—Scope

COMMENTARY

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.

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ACI CODE-318-19

CHAPTER 27—STRENGTH EVALUATION OF EXISTING STRUCTURES

CODE

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.

COMMENTARY

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.

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ACI CODE-318-19

APPENDIX A—DESIGN VERIFICATION USING NONLINEAR RESPONSE HISTORY ANALYSIS

CODE

A.1—Notation and terminology

A.1.1 *Notation*

B = bias factor to adjust nominal strength to seismic target reliabilities

D_u = ultimate deformation capacity; the largest deformation at which the hysteresis model is deemed valid given available laboratory data or other substantiating evidence

f_{ce}' = expected compressive strength of concrete, MPa

f_{ue} = expected tensile strength for nonprestressed reinforcement, MPa

f_{ye} = expected yield strength for nonprestressed reinforcement, MPa

ℓ_p = plastic-hinge length for analysis purposes, mm

R_{ne} = expected yield strength

V_{ne} = expected shear strength, N

θ_y = yield rotation, radians

ϕ_s = seismic resistance factor for force-controlled actions

COMMENTARY

RA.1—Notation and terminology

ACI CODE-318-19

APPENDIX B—STEEL REINFORCEMENT INFORMATION

As an aid to users of the ACI Building Code, information on sizes, areas, and masses of various steel reinforcement is presented.

ASTM STANDARD REINFORCING BARS

Bar size, no.*	Nominal diameter, mm	Nominal area, mm^2	Nominal mass, kg/m
10	9.5	71	0.560
13	12.7	129	0.994
16	15.9	199	1.552
19	19.1	284	2.235
22	22.2	387	3.042
25	25.4	510	3.973
29	28.7	645	5.060
32	32.3	819	6.404
36	35.8	1006	7.907
43	43.0	1452	11.38
57	57.3	2581	20.24

*Bar numbers approximate the number of millimeters of the nominal diameter of the bar

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ACI CODE-318-19

APPENDIX C—EQUIVALENCE BETWEEN SI-METRIC, MKS-METRIC, AND U.S. CUSTOMARY UNITS OF NONHOMOGENOUS EQUATIONS IN THE CODE

Provision number	SI-metric stress in MPa	mks-metric stress in kgf/cm²	U.S. Customary units stress in pounds per square inch (psi)
	1 MPa	10 kgf/cm²	145 psi
	$f_c' = 21$ MPa	$f_c' = 210$ kgf/cm²	$f_c' = 3000$ psi
	$f_c' = 28$ MPa	$f_c' = 280$ kgf/cm²	$f_c' = 4000$ psi
	$f_c' = 35$ MPa	$f_c' = 350$ kgf/cm²	$f_c' = 5000$ psi
	$f_c' = 40$ MPa	$f_c' = 420$ kgf/cm²	$f_c' = 6000$ psi
	$f_y = 280$ MPa	$f_y = 2800$ kgf/cm²	$f_y = 40{,}000$ psi
	$f_y = 420$ MPa	$f_y = 4200$ kgf/cm²	$f_y = 60{,}000$ psi
	$f_y = 550$ MPa	$f_y = 5600$ kgf/cm²	$f_y = 80{,}000$ psi
	$f_y = 690$ MPa	$f_y = 7000$ kgf/cm²	$f_y = 100{,}000$ psi
	$f_{pu} = 1725$ MPa	$f_{pu} = 17{,}600$ kgf/cm²	$f_{pu} = 250{,}000$ psi
	$f_{pu} = 1860$ MPa	$f_{pu} = 19{,}000$ kgf/cm²	$f_{pu} = 270{,}000$ psi
	$\sqrt{f_c'}$ in MPa	$3.18\sqrt{f_c'}$ in kgf/cm²	$12\sqrt{f_c'}$ in psi

Council of Engineers

ACI CODE-318-19

Provision number	SI-metric stress in MPa	mks-metric stress in kgf/cm²	U.S. Customary units stress in pounds per square inch (psi)
8.7.5.6.3.1(a) and (b)	$A_s = \frac{0.37\sqrt{f_c'}c_2 d}{f_y}$ $A_s = \frac{2.1 c_2 d}{f_y}$	$A_s = \frac{1.2\sqrt{f_c'}c_2 d}{f_y}$ $A_s = \frac{21 c_2 d}{f_y}$	$A_s = \frac{4.5\sqrt{f_c'}c_2 d}{f_y}$ $A_s = \frac{300 c_2 d}{f_y}$
8.7.7.1.2	$\phi 0.5\sqrt{f_c'}$	$\phi 1.6\sqrt{f_c'}$	$\phi 6\sqrt{f_c'}$
9.3.1.1.1	$\left(0.4+\frac{f_y}{700}\right)$	$\left(0.4+\frac{f_y}{7000}\right)$	$\left(0.4+\frac{f_y}{100{,}000}\right)$
9.3.1.1.2	$(1.65 - 0.0003w_c)$	$(1.65 - 0.0003w_c)$	$(1.65 - 0.005w_c)$
9.6.1.2(a) and (b)	$\frac{0.25\sqrt{f_c'}}{f_y}b_w d$ $\frac{1.4}{f_y}b_w d$	$\frac{0.80\sqrt{f_c'}}{f_y}b_w d$ $\frac{14}{f_y}b_w d$	$\frac{3\sqrt{f_c'}}{f_y}b_w d$ $\frac{200}{f_y}b_w d$

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ACI CODE-318-19

COMMENTARY REFERENCES

ACI Committee documents and documents published by other organizations that are cited in the commentary are listed first by document number, year of publication, and full title, followed by authored documents listed alphabetically.

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Council of Engineers

ACI CODE-318-19

INDEX

Council of Engineers

ACI CODE-318-19

Thank you