An ACI Standard and Report

Building Code Requirements for Structural Concrete (ACI 318-14)

Commentary on Building Code Requirements for Structural Concrete (ACI 318R-14)

Reported by ACI Committee 318

ACI 318-14

American Concrete Institute
Always advancing

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An ACI Report

Reported by ACI Committee 318

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Building Code Requirements for Structural Concrete and Commentary

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PREFACE TO ACI 318-14

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 addresses structural systems, members, and connections, including cast-in-place, precast, 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. "Building Code Requirements for Concrete Thin Shells" (ACI 318.2) is adopted by reference in this Code.

The Code user will find that ACI 318-14 has been substantially reorganized and reformatted from previous editions. The principal objectives of this reorganization are 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 members are located in utility chapters.

The quality and testing of materials used in construction are covered by reference to the appropriate ASTM standard specifications. Welding of reinforcement is covered by reference to the appropriate American Welding Society (AWS) standard.

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 of the considerations of the committee in developing the Code are discussed within 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 318-11 to ACI 318-14 are outlined in the May 2014 issue of *Concrete International*.

Transition keys showing how the code was reorganized are provided on the ACI website on the 318 Resource Page under Topics in Concrete.

KEYWORDS

admixtures; aggregates; anchorage (structural); beam-column frame; beams (supports); building codes; cements; cold weather construction; columns (supports); combined stress; composite construction (concrete and steel); composite construction (concrete to concrete); compressive strength; concrete construction; concrete slabs; concretes; construction joints; continuity (structural); contract documents; contraction joints; cover; curing; deep beams; deflections; earthquake-resistant structures; embedded service ducts; flexural strength; floors; folded plates; footings; formwork (construction); frames; hot weather construction; inspection; isolation joints; joints (junctions); joists; lightweight concretes; load tests (structural); loads (forces); materials; mixing; mixture proportioning; modulus of elasticity; moments; pipe columns; pipes (tubing); placing; plain concrete; precast concrete; prestressed concrete; prestressing steels; quality control; reinforced concrete; reinforcing steels; roofs; serviceability; shear strength; shear walls; shells (structural forms); spans; splicing; strength; strength analysis; stresses; structural analysis; structural concrete; structural design; structural integrity; T-beams; torsion; walls; water; welded wire reinforcement.

NOTES FROM THE PUBLISHER

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This commentary (318R-14) 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 there from. Reference to this commentary shall not be made in contract documents. If items found in this commentary are desired by the Architect/ Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

The materials, processes, quality control measures, and inspections described in this document should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI Certification or equivalent.

ACI 318-14, Building Code Requirements for Structural Concrete, and ACI 318R-14, 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.

INTRODUCTION

This Commentary discusses some of the considerations of Committee 318 in developing the provisions contained in “Building Code Requirements for Structural Concrete (ACI 318-14),” hereinafter called the Code or the 2014 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.

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 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 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 provides a means of establishing minimum standards for acceptance of designs and construction by legally appointed building officials or their designated representatives. The Code and Commentary are not intended for use in settling disputes between the owner, engineer, architect, contractor, or their agents, subcontractors, material suppliers, or testing agencies. Therefore, the Code cannot define the contract responsibility of each of the parties in usual construction. General references requiring compliance with the Code in the project specifications should be avoided since the contractor is rarely in a position to accept responsibility for design details or construction requirements that depend on a detailed knowledge of the design. 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.

It is recommended to have testing and certification programs for the individual parties involved with the execution of work performed in accordance with this Code. Available for this purpose are the plant certification programs of the Precast/Prestressed Concrete Institute, the Post-Tensioning Institute, and the National Ready Mixed Concrete Association; the personnel certification programs of the American Concrete Institute and the Post-Tensioning Institute; and the Concrete Reinforcing Steel Institute’s Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants. In addition, “Standard Specification for Agencies Engaged in Construction Inspecting and/or Testing” (ASTM E329-09) specifies performance requirements for inspection and testing agencies.

Design reference materials illustrating applications of the Code requirements may be found in the following documents. The design aids listed may be obtained from the sponsoring organization.

Design aids:

“ACI Design Handbook,” Publication SP-17(11), American Concrete Institute, Farmington Hills, MI, 2011, 539 pp. (This provides tables and charts for design of eccentrically loaded columns by the Strength Design Method of the 2009 Code. Provides design aids for use in the engineering design and analysis of reinforced concrete slab systems carrying loads by two-way action. Design aids are also provided for the selection of slab thickness and for reinforcement required to control deformation and assure adequate shear and flexural strengths.)

For a history of the ACI Building Code, see Kerekes, F., and Reid, H. B., Jr., “Fifty Years of Development in Building Code Requirements for Reinforced Concrete,” ACI Journal*, V. 50, No. 6, Feb. 1954, p. 441. For a discussion of code philosophy, see Siess, C. P., “Research, Building Codes, and Engineering Practice,”* ACI Journal*, V. 56, No. 5, May 1960, p. 1105.*

"ACI Detailing Manual—2004," ACI Committee 315, Publication SP-66(04), American Concrete Institute, Farmington Hills, MI, 2004, 212 pp. (Includes the standard, ACI 315-99, and report, ACI 315R-04. Provides recommended methods and standards for preparing engineering drawings, typical details, and drawings placing reinforcing steel in reinforced concrete structures. Separate sections define responsibilities of both engineer and reinforcing bar detailer.)

"Guide to Durable Concrete (ACI 201.2R-08)," ACI Committee 201, American Concrete Institute, Farmington Hills, MI, 2008, 49 pp. (This describes specific types of concrete deterioration. It contains a discussion of the mechanisms involved in deterioration and the recommended requirements for individual components of the concrete, quality considerations for concrete mixtures, construction procedures, and influences of the exposure environment.)

"Guide for the Design and Construction of Durable Parking Structures (362.1R-12)," ACI Committee 362, American Concrete Institute, Farmington Hills, MI, 2012, 24 pp. (This summarizes practical information regarding design of parking structures for durability. It also includes information about design issues related to parking structure construction and maintenance.)

"CRSI Handbook," Concrete Reinforcing Steel Institute, Schaumburg, IL, tenth edition, 2008, 777 pp. (This provides tabulated designs for structural elements and slab systems. Design examples are provided to show the basis and use of the load tables. Tabulated designs are given for beams; square, round, and rectangular columns; one-way slabs; and one-way joist construction. The design tables for two-way slab systems include flat plates, flat slabs, and waffle slabs. The chapters on foundations provide design tables for square footings, pile caps, drilled piers (caissons), and cantilevered retaining walls. Other design aids are presented for crack control and development of reinforcement and lap splices.)

"Reinforcement Anchorages and Splices," Concrete Reinforcing Steel Institute, Schaumburg, IL, fifth edition, 2008, 100 pp. (This provides accepted practices in splicing reinforcement. The use of lap splices, mechanical splices, and welded splices are described. Design data are presented for development and lap splicing of reinforcement.)

"Structural Welded Wire Reinforcement Manual of Standard Practice," Wire Reinforcement Institute, Hartford, CT, eighth edition, Apr. 2010, 35 pp. (This describes welded wire reinforcement material, gives nomenclature and wire size and weight tables. Lists specifications and properties and manufacturing limitations. Book has latest code requirements as code affects welded wire. Also gives development length and splice length tables. Manual contains customary units and soft metric units.)

"Structural Welded Wire Reinforcement Detailing Manual," Wire Reinforcement Institute, Hartford, CT, 1994, 252 pp. (The manual, in addition to including ACI 318 provisions and design aids, also includes: detailing guidance on welded wire reinforcement in one-way and two-way slabs; precast/prestressed concrete components; columns and beams; cast-in-place walls; and slabs-on-ground. In addition, there are tables to compare areas and spacings of high-strength welded wire with conventional reinforcing.)

"PCI Design Handbook—Precast and Prestressed Concrete," Precast/Prestressed Concrete Institute, Chicago, IL, seventh edition, 2010, 804 pp. (This provides load tables for common industry products, and procedures for design and analysis of precast and prestressed elements and structures composed of these elements. Provides design aids and examples.)

"Design and Typical Details of Connections for Precast and Prestressed Concrete," Precast/Prestressed Concrete Institute, Chicago, IL, second edition, 1988, 270 pp. (This updates available information on design of connections for both structural and architectural products, and presents a full spectrum of typical details. This provides design aids and examples.)

"Post-Tensioning Manual," Post-Tensioning Institute, Farmington Hills, MI, sixth edition, 2006, 354 pp. (This provides comprehensive coverage of post-tensioning systems, specifications, design aids, and construction concepts.)

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CODE

CHAPTER 1—GENERAL

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.

COMMENTARY

R1—GENERAL

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; composite columns with structural steel shapes, pipes, or tubing; and anchoring to concrete.

This Code is substantially reorganized from the previous version, ACI 318-11. 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.

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1.3—Purpose

1.3.1 The purpose of this Code is to provide for public health and safety by establishing minimum requirements for strength, stability, serviceability, durability, and integrity of concrete structures.

1.3.2 This Code does not address all design considerations.

1.3.3 Construction means and methods are not addressed in this Code.

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

1.4.3 The design of thin shells and folded plate concrete structures shall be in accordance with ACI 318.2, "Building Code Requirements for Concrete Thin Shells."

1.4.4 This Code shall apply to the design of slabs cast on stay-in-place, noncomposite steel decks.

1.4.5 For one- and two-family dwellings, multiple single-family dwellings, townhouses, and accessory structures to

COMMENTARY

R1.3—Purpose

R1.3.1 This Code provides a means of establishing minimum requirements for the design and construction of structural concrete, as well as for acceptance of design and construction of concrete structures by the building officials or their designated representatives.

This Code does not provide a comprehensive statement of all duties of all parties to a contract or all requirements of a contract for a project constructed under this Code.

R1.3.2 The minimum requirements in this Code do not replace sound professional judgment or the licensed design professional's knowledge of the specific factors surrounding a project, its design, the project site, and other specific or unusual circumstances to the project.

R1.4—Applicability

R1.4.2 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 349)
- "Code for Concrete Containments" (ACI 359)

R1.4.4 In its most basic application, the noncomposite steel deck serves as a form, and the concrete slab is designed to resist all loads, while in other applications the concrete slab may be designed to resist only the superimposed loads. The design of a steel deck in a load-resisting application is given in "Standard for Non-Composite Steel Floor Deck" (SDI NC). The SDI standard refers to this Code for the design and construction of the structural concrete slab.

R1.4.5 ACI 332 addresses only the design and construction of cast-in-place footings, foundation walls supported on

CODE

these types of dwellings, the design and construction of cast-in-place footings, foundation walls, and slabs-on-ground in accordance with ACI 332 shall be permitted.

1.4.6 This Code does not apply to the design and installation of concrete piles, drilled piers, and caissons embedded in ground, except as provided in (a) or (b):

(a) For portions in air or water, or in soil incapable of providing adequate lateral restraint to prevent buckling throughout their length
(b) For structures assigned to Seismic Design Categories D, E, and F

1.4.7 This Code does not apply to design and construction of slabs-on-ground, unless the slab transmits vertical loads or lateral forces from other portions of the structure to the soil.

1.4.8 This Code does not apply to the design and construction of tanks and reservoirs.

1.4.9 This Code does not apply to composite design slabs cast on stay-in-place composite steel deck. Concrete used in the construction of such slabs shall be governed by this Code, where applicable. Portions of such slabs designed as reinforced concrete are governed by this Code.

COMMENTARY

continuous footings, and slabs-on-ground for limited residential construction applications. Multiple single-family dwellings include structures such as townhomes.

R1.4.6 The design and installation of concrete piles fully embedded in the ground is regulated by the general building code. Recommendations for concrete piles are given in ACI 543R. Recommendations for drilled piers are given in ACI 336.3R. Recommendations for precast prestressed concrete piles are given in "Recommended Practice for Design, Manufacture, and Installation of Prestressed Concrete Piling" (PCI 1993).

Refer to 18.13.4 for supplemental requirements for concrete piles, drilled piers, and caissons in structures assigned to Seismic Design Categories D, E, and F.

R1.4.7 Detailed recommendations for design and construction of slabs-on-ground and floors that do not transmit vertical loads or lateral forces from other portions of the structure to the soil, and residential post-tensioned slabs-on-ground, are given in the following publications:

- ACI 360R presents information on the design of slabs-on-ground, primarily industrial floors and the slabs adjacent to them. The report addresses the planning, design, and detailing of the slabs. Background information on the design theories is followed by discussion of the soil support system, loadings, and types of slabs. Design methods are given for structural plain concrete, reinforced concrete, shrinkage-compensating concrete, and post-tensioned concrete slabs.
- The Post-Tensioning Institute (DC 10.5-12) provides standard requirements for post-tensioned slab-on-ground foundations, soil investigation, design, and analysis of post-tensioned residential and light commercial slabs on expansive soils.

R1.4.8 Requirements and recommendations for the design and construction of tanks and reservoirs are given in ACI 350, ACI 334.1R, and ACI 372R.

R1.4.9 In this type of construction, the steel deck serves as the positive moment reinforcement. The design and construction of concrete-steel deck slabs is described in "Standard for Composite Steel Floor Deck-Slabs" (SDI C). The standard refers to the appropriate portions of this Code for the design and construction of the concrete portion of the composite assembly. SDI C also provides guidance for design of composite-concrete-steel deck slabs. The design of negative moment reinforcement to create continuity at supports is a common example where a portion of the slab is designed in conformance with this Code.

1.5—Interpretation

1.5.1 The principles of interpretation in this section shall apply to this Code as a whole unless otherwise stated.

R1.5—Interpretation

CODE

1.5.2 This Code consists of chapters and appendixes, including text, headings, tables, figures, footnotes to tables and figures, and referenced standards.

1.5.3 The Commentary consists of a preface, introduction, commentary text, tables, figures, and cited publications. The Commentary is intended to provide contextual information, but is not part of this Code, does not provide binding requirements, and shall not be used to create a conflict with or ambiguity in this Code.

1.5.4 This Code shall be interpreted in a manner that avoids conflict between or among its provisions. Specific provisions shall govern over general provisions.

1.5.5 This Code shall be interpreted and applied in accordance with the plain meaning of the words and terms used. Specific definitions of words and terms in this Code shall be used where provided and applicable, regardless of whether other materials, standards, or resources outside of this Code provide a different definition.

1.5.6 The following words and terms in this Code shall be interpreted in accordance with (a) through (e):

(a) The word "shall" is always mandatory.
(b) Provisions of this Code are mandatory even if the word "shall" is not used.
(c) Words used in the present tense shall include the future.
(d) The word "and" indicates that all of the connected items, conditions, requirements, or events shall apply.
(e) The word "or" indicates that the connected items, conditions, requirements, or events are alternatives, at least one of which shall be satisfied.

1.5.7 In any case in which one or more provisions of this Code are declared by a court or tribunal to be invalid, that ruling shall not affect the validity of the remaining provisions of this Code, which are severable. The ruling of a court or tribunal shall be effective only in that court's jurisdiction, and shall not affect the content or interpretation of this Code in other jurisdictions.

1.5.8 If conflicts occur between provisions of this Code and those of standards and documents referenced in Chapter 3, this Code shall apply.

1.6—Building official

1.6.1 All references in this Code to the building official shall be understood to mean persons who administer and enforce this Code.

1.6.2 Actions and decisions by the building official affect only the specific jurisdiction and do not change this Code.

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R1.5.4 General provisions are broad statements, such as a building needs to be serviceable. Specific provisions, such as explicit reinforcement distribution requirements for crack control, govern over the general provisions.

R1.5.5 ACI Concrete Terminology (2013) is the primary resource to help determine the meaning of words or terms that are not defined in the Code. Dictionaries and other reference materials commonly used by licensed design professionals may be used as secondary resources.

R.1.5.7 This Code addresses numerous requirements that can be implemented fully without modification if other requirements in this Code are determined to be invalid. This severability requirement is intended to preserve this Code and allow it to be implemented to the extent possible following legal decisions affecting one or more of its provisions.

R1.6—Building official

R1.6.1 Building official is defined in 2.3.

R1.6.2 Only the American Concrete Institute has the authority to alter or amend this Code.

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1.6.3 The building official shall have the right to order testing of any materials used in concrete construction to determine if materials are of the quality specified.

1.7—Licensed design professional

1.7.1 All references in this Code to the licensed design professional shall be understood to mean the person who is licensed and responsible for, and in charge of, the structural design or inspection.

1.8—Construction documents and design records

1.8.1 The licensed design professional shall provide in the construction documents the information required in Chapter 26 and that required by the jurisdiction.

1.8.2 Calculations pertinent to design shall be filed with the construction documents if required by the building official. Analyses and designs using computer programs shall be permitted provided design assumptions, user input, and computer-generated output are submitted. Model analysis shall be permitted to supplement calculations.

1.9—Testing and inspection

1.9.1 Concrete materials shall be tested in accordance with the requirements of Chapter 26.

1.9.2 Concrete construction shall be inspected in accordance with the general building code and in accordance with Chapters 17 and 26.

1.9.3 Inspection records shall include information required in Chapters 17 and 26.

1.10—Approval of special systems of design, construction, or alternative construction materials

1.10.1 Sponsors of any system of design, construction, or alternative construction materials within the scope of this Code, the adequacy of which has been shown by successful use or by analysis or test, but which does not conform to or is not covered by this Code, shall have the right to present the data on which their design is based to the building official

COMMENTARY

R1.7—Licensed design professional

R1.7.1 Licensed design professional is defined in 2.3.

R1.8—Construction documents and design records

R1.8.1 The provisions of Chapter 26 for preparing project drawings and specifications are, in general, consistent with those of most general building codes. Additional information may be required by the building official.

R1.8.2 Documented computer output is acceptable instead of manual calculations. The extent of input and output information required will vary according to the specific requirements of individual building officials. However, if a computer program has been used, only skeleton data should normally be required. This should consist of sufficient input and output data and other information to allow the building official to perform a detailed review and make comparisons using another program or manual calculations. Input data should be identified as to member designation, applied loads, and span lengths. The related output data should include member designation and the shears, moments, and reactions at key points in the span. For column design, it is desirable to include moment magnification factors in the output where applicable.

The Code permits model analysis to be used to supplement structural analysis and design calculations. Documentation of the model analysis should be provided with the related calculations. Model analysis should be performed by an individual having experience in this technique.

R1.10—Approval of special systems of design, construction, or alternative construction materials

R1.10.1 New methods of design, new materials, and new uses of materials should undergo a period of development before being covered in a code. Hence, good systems or components might be excluded from use by implication if means were not available to obtain acceptance.

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or to a board of examiners appointed by the building official. This board shall be composed of competent engineers and shall have authority to investigate the data so submitted, require tests, and formulate rules governing design and construction of such systems to meet the intent of this Code. These rules, when approved by the building official and promulgated, shall be of the same force and effect as the provisions of this Code.

COMMENTARY

For special systems considered under this section, specific tests, load factors, deflection limits, and other pertinent requirements should be set by the board of examiners, and should be consistent with the intent of the Code.

The provisions of this section do not apply to model tests used to supplement calculations under 1.8.2 or to strength evaluation of existing structures under Chapter 27.

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CHAPTER 2—NOTATION AND TERMINOLOGY

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_{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 slab-beam strips of the two orthogonal equivalent frames intersecting at a column of a two-way 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, not to exceed the thickness times the width of the diaphragm, in.^{2}

A_{cw} = area of concrete section of an individual pier, horizontal wall segment, or coupling beam resisting shear, 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_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}

A_n = area of reinforcement in bracket or corbel resisting factored tensile force N_{uc}, in.^{2}

A_{nz} = area of a face of a nodal zone or a section through a nodal zone, in.^{2}

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R2—NOTATION AND TERMINOLOGY

R2.2—Notation

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COMMENTARY

A_{Na} = projected influence area of a single adhesive anchor or group of adhesive anchors, for calculation of bond strength in tension, in.^{2}

A_{Nao} = projected influence area of a single adhesive anchor, for calculation of bond strength in tension if not limited by edge distance or spacing, in.^{2}

A_{Nc} = projected concrete failure area of a single anchor or group of anchors, for calculation of strength in tension, in.^{2}

A_{Nco} = projected concrete failure area of a single anchor, for calculation of strength in tension if not limited by edge distance or spacing, in.^{2}

A_o = gross area enclosed by torsional shear flow path, in.^{2}

A_{oh} = area enclosed by centerline of the outermost closed transverse torsional reinforcement, in.^{2}

A_{pd} = total area occupied by duct, sheathing, and prestressing reinforcement, in.^{2}

A_{ps} = area of prestressed longitudinal tension reinforcement, in.^{2}

A_{pt} = total area of prestressing reinforcement, in.^{2}

A_s = area of nonprestressed longitudinal tension reinforcement, in.^{2}

A_s' = area of compression reinforcement, in.^{2}

A_{sc} = area of primary tension reinforcement in a corbel or bracket, in.^{2}

$A_{se,N}$ = effective cross-sectional area of anchor in tension, in.^{2}

$A_{se,V}$ = effective cross-sectional area of anchor in shear, in.^{2}

A_{sh} = total cross-sectional area of transverse reinforcement, including crossties, within spacing s and perpendicular to dimension b_c, in.^{2}

A_{si} = total area of surface reinforcement at spacing s_i in the i-th layer crossing a strut, with reinforcement at an angle α_i to the axis of the strut, in.^{2}

$A_{s,min}$ = minimum area of flexural reinforcement, in.^{2}

A_{st} = total area of nonprestressed longitudinal reinforcement including bars or steel shapes, and excluding prestressing reinforcement, in.^{2}

A_{sx} = area of steel shape, pipe, or tubing in a composite section, in.^{2}

A_t = area of one leg of a closed stirrup, hoop, or tie resisting torsion within spacing s, in.^{2}

A_{tp} = area of prestressing reinforcement in a tie, in.^{2}

A_{tr} = total cross-sectional area of all transverse reinforcement within spacing s that crosses the potential plane of splitting through the reinforcement being developed, in.^{2}

A_{ts} = area of nonprestressed reinforcement in a tie, in.^{2}

A_v = area of shear reinforcement within spacing s, in.^{2}

A_{vd} = total area of reinforcement in each group of diagonal bars in a diagonally reinforced coupling beam, in.^{2}

A_{vf} = area of shear-friction reinforcement, in.^{2}

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A_{vh} = area of shear reinforcement parallel to flexural tension reinforcement within spacing s_2, in.^{2}

$A_{v,min}$ = minimum area of shear reinforcement within spacing s, in.^{2}

A_{Vc} = projected concrete failure area of a single anchor or group of anchors, for calculation of strength in shear, in.^{2}

A_{Vco} = projected concrete failure area of a single anchor, for calculation of strength in shear, if not limited by corner influences, spacing, or member thickness, in.^{2}

A_1 = loaded area for consideration of bearing strength, in.^{2}

A_2 = area of the lower base of the largest frustum of a pyramid, cone, or tapered wedge contained wholly within the support and having its upper base equal to the loaded area. The sides of the pyramid, cone, or tapered wedge shall be sloped one vertical to two horizontal, in.^{2}

b = width of compression face of member, in.

b_c = cross-sectional dimension of member core measured to the outside edges of the transverse reinforcement composing area A_{sh}, in.

b_f = effective flange width of T section, in.

b_o = perimeter of critical section for two-way shear in slabs and footings, in.

b_s = width of strut, in.

b_{slab} = effective slab width resisting $\gamma_f M_{sc}$, in.

b_t = width of that part of cross section containing the closed stirrups resisting torsion, in.

b_v = width of cross section at contact surface being investigated for horizontal shear, in.

b_w = web width or diameter of circular section, in.

b_1 = dimension of the critical section b_o measured in the direction of the span for which moments are determined, in.

b_2 = dimension of the critical section b_o measured in the direction perpendicular to b_1, in.

B_n = nominal bearing strength, lb

B_u = factored bearing load, lb

c = distance from extreme compression fiber to neutral axis, in.

c_{ac} = critical edge distance required to develop the basic strength as controlled by concrete breakout or bond of a post-installed anchor in tension in uncracked concrete without supplementary reinforcement to control splitting, in.

$c_{a,max}$ = maximum distance from center of an anchor shaft to the edge of concrete, in.

$c_{a,min}$ = minimum distance from center of an anchor shaft to the edge of concrete, in.

c_{a1} = distance from the center of an anchor shaft to the edge of concrete in one direction, in. If shear is applied to anchor, c_{a1} is taken in the direction of the applied shear. If tension is applied to the anchor, c_{a1} is the minimum edge distance. Where anchors

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subject to shear are located in narrow sections of limited thickness, see 17.5.2.4

c_{a2} = distance from center of an anchor shaft to the edge of concrete in the direction perpendicular to c_{a1}, in.

c_b = lesser of: (a) the distance from center of a bar or wire to nearest concrete surface, and (b) one-half the center-to-center spacing of bars or wires being developed, in.

c_c = clear cover of reinforcement, in.

c_{Na} = projected distance from center of an anchor shaft on one side of the anchor required to develop the full bond strength of a single adhesive anchor, in.

c_t = distance from the interior face of the column to the slab edge measured parallel to c_1, but not exceeding c_1, in.

c_1 = dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direction of the span for which moments are being determined, in.

c_2 = dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direction perpendicular to c_1, in.

C = cross-sectional constant to define torsional properties of slab and beam

C_m = factor relating actual moment diagram to an equivalent uniform moment diagram

d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in.

d' = distance from extreme compression fiber to centroid of longitudinal compression reinforcement, in.

d_a = outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt, in.

d_a' = value substituted for d_a if an oversized anchor is used, in.

d_{agg} = nominal maximum size of coarse aggregate, in.

d_b = nominal diameter of bar, wire, or prestressing strand, in.

d_p = distance from extreme compression fiber to centroid of prestressing reinforcement, in.

d_{pile} = diameter of pile at footing base, in.

D = effect of service dead load

e_h = distance from the inner surface of the shaft of a J- or L-bolt to the outer tip of the J- or L-bolt, in.

e'_N = distance between resultant tension load on a group of anchors loaded in tension and the centroid of the group of anchors loaded in tension, in.; e_N' is always positive

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c'_{a1} = limiting value of c_{a1} where anchors are located less than $1.5c_{a1}$ from three or more edges, in.; see Fig. R17.5.2.4

C = compressive force acting on a nodal zone, lb

d_{burst} = distance from the anchorage device to the centroid of the bursting force, T_{burst}, in.

e_{anc} = eccentricity of the anchorage device or group of devices with respect to the centroid of the cross section, in.

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e'_V = distance between resultant shear load on a group of anchors loaded in shear in the same direction, and the centroid of the group of anchors loaded in shear in the same direction, in.; e_V' is always positive

E = effect of horizontal and vertical earthquake-induced forces

E_c = modulus of elasticity of concrete, psi

E_{cb} = modulus of elasticity of beam concrete, psi

E_{cs} = modulus of elasticity of slab concrete, psi

EI = flexural stiffness of member, in.^{2}-lb

$(EI)_{eff}$ = effective flexural stiffness of member, in.^{2}-lb

E_p = modulus of elasticity of prestressing reinforcement, psi

E_s = modulus of elasticity of reinforcement and structural steel, excluding prestressing reinforcement, psi

f_c' = specified compressive strength of concrete, psi

$\sqrt{f_c'}$ = square root of specified compressive strength of concrete, psi

f_{ci}' = specified compressive strength of concrete at time of initial prestress, psi

$\sqrt{f_{ci}'}$ = square root of specified compressive strength of concrete at time of initial prestress, psi

f_{ce} = effective compressive strength of the concrete in a strut or a nodal zone, psi

f_{cm} = measured average compressive strength of concrete, psi

f_{ct} = measured average splitting tensile strength of lightweight concrete, psi

f_d = stress due to unfactored dead load, at extreme fiber of section where tensile stress is caused by externally applied loads, psi

f_{dc} = decompression stress; stress in the prestressing reinforcement if stress is zero in the concrete at the same level as the centroid of the prestressing reinforcement, psi

f_{pc} = compressive stress in concrete, after allowance for all prestress losses, at centroid of cross section resisting externally applied loads or at junction of web and flange where the centroid lies within the flange, psi. In a composite member, f_{pc} is the resultant compressive stress at centroid of composite section, or at junction of web and flange where the centroid lies within the flange, due to both prestress and moments resisted by precast member acting alone

f_{pe} = compressive stress in concrete due only to effective prestress forces, after allowance for all prestress losses, at extreme fiber of section if tensile stress is caused by externally applied loads, psi

f_{ps} = stress in prestressing reinforcement at nominal flexural strength, psi

f_{pu} = specified tensile strength of prestressing reinforcement, psi

f_{py} = specified yield strength of prestressing reinforcement, psi

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f_r = modulus of rupture of concrete, psi

f_s = tensile stress in reinforcement at service loads, excluding prestressing reinforcement, psi

f_s' = compressive stress in reinforcement under factored loads, excluding prestressing reinforcement, psi

f_{se} = effective stress in prestressing reinforcement, after allowance for all prestress losses, psi

f_t = extreme fiber stress in the precompressed tension zone calculated at service loads using gross section properties after allowance of all prestress losses, psi

f_{uta} = specified tensile strength of anchor steel, psi

f_y = specified yield strength for nonprestressed reinforcement, psi

f_{ya} = specified yield strength of anchor steel, psi

f_{yt} = specified yield strength of transverse reinforcement, psi

F = effect of service lateral load due to fluids with well-defined pressures and maximum heights

F_{nn} = nominal strength at face of a nodal zone, lb

F_{ns} = nominal strength of a strut, lb

F_{nt} = nominal strength of a tie, lb

F_{un} = factored force on the face of a node, lb

F_{us} = factored compressive force in a strut, lb

F_{ut} = factored tensile force in a tie, lb

h = overall thickness, height, or depth of member, in.

h_a = thickness of member in which an anchor is located, measured parallel to anchor axis, in.

h_{ef} = effective embedment depth of anchor, in.

h_{sx} = story height for story x, in.

h_u = laterally unsupported height at extreme compression fiber of wall or wall pier, in., equivalent to ℓ_u for compression members

h_v = depth of shearhead cross section, in.

h_w = height of entire wall from base to top, or clear height of wall segment or wall pier considered, in.

h_x = maximum center-to-center spacing of longitudinal bars laterally supported by corners of crossties or hoop legs around the perimeter of the column, in.

H = effect of service load due to lateral earth pressure, ground water pressure, or pressure of bulk materials, lb

I = moment of inertia of section about centroidal axis, in.^{4}

I_b = moment of inertia of gross section of beam about centroidal axis, in.^{4}

I_{cr} = moment of inertia of cracked section transformed to concrete, in.^{4}

I_e = effective moment of inertia for calculation of deflection, in.^{4}

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f_{si} = stress in the *i*-th layer of surface reinforcement, psi

h_{anc} = dimension of anchorage device or single group of closely spaced devices in the direction of bursting being considered, in.

h'_{ef} = limiting value of h_{ef} where anchors are located less than $1.5h_{ef}$ from three or more edges, in.; refer to Fig. R17.4.2.3

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I_g = moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement, in.^{4}

I_s = moment of inertia of gross section of slab about centroidal axis, in.^{4}

I_{se} = moment of inertia of reinforcement about centroidal axis of member cross section, in.^{4}

I_{sx} = moment of inertia of structural steel shape, pipe, or tubing about centroidal axis of composite member cross section, in.^{4}

k = effective length factor for compression members

k_c = coefficient for basic concrete breakout strength in tension

k_{cp} = coefficient for pryout strength

k_f = concrete strength factor

k_n = confinement effectiveness factor

K_{tr} = transverse reinforcement index, in.

ℓ = span length of beam or one-way slab; clear projection of cantilever, in.

ℓ_a = additional embedment length beyond centerline of support or point of inflection, in.

ℓ_c = length of compression member, measured center-to-center of the joints, in.

ℓ_d = development length in tension of deformed bar, deformed wire, plain and deformed welded wire reinforcement, or pretensioned strand, in.

ℓ_{dc} = development length in compression of deformed bars and deformed wire, in.

ℓ_{db} = debonded length of prestressed reinforcement at end of member, in.

ℓ_{dh} = development length in tension of deformed bar or deformed wire with a standard hook, measured from outside end of hook, point of tangency, toward critical section, in.

ℓ_{dt} = development length in tension of headed deformed bar, measured from the bearing face of the head toward the critical section, in.

ℓ_e = load bearing length of anchor for shear, in.

ℓ_{ext} = straight extension at the end of a standard hook, in.

ℓ_n = length of clear span measured face-to-face of supports, in.

ℓ_o = length, measured from joint face along axis of member, over which special transverse reinforcement must be provided, in.

ℓ_{sc} = compression lap splice length, in.

ℓ_{st} = tension lap splice length, in.

ℓ_t = span of member under load test, taken as the shorter span for two-way slab systems, in. Span is the lesser of: (a) distance between centers of supports, and (b) clear distance between supports plus thickness h of member. Span for a cantilever shall be

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K_t = torsional stiffness of member; moment per unit rotation

K_{05} = coefficient associated with the 5 percent fractile

ℓ_{anc} = length along which anchorage of a tie must occur, in.

ℓ_b = width of bearing, in.

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taken as twice the distance from face of support to cantilever end

ℓ_{tr} = transfer length of prestressed reinforcement, in.

ℓ_u = unsupported length of column or wall, in.

ℓ_v = length of shearhead arm from centroid of concentrated load or reaction, in.

ℓ_w = length of entire wall, or length of wall segment or wall pier considered in direction of shear force, in.

ℓ_1 = length of span in direction that moments are being determined, measured center-to-center of supports, in.

ℓ_2 = length of span in direction perpendicular to ℓ_1, measured center-to-center of supports, in.

L = effect of service live load

L_r = effect of service roof live load

M_a = maximum moment in member due to service loads at stage deflection is calculated, in.-lb

M_c = factored moment amplified for the effects of member curvature used for design of compression member, in.-lb

M_{cr} = cracking moment, in.-lb

M_{cre} = moment causing flexural cracking at section due to externally applied loads, in.-lb

M_{max} = maximum factored moment at section due to externally applied loads, in.-lb

M_n = nominal flexural strength at section, in.-lb

M_{nb} = nominal flexural strength of beam including slab where in tension, framing into joint, in.-lb

M_{nc} = nominal flexural strength of column framing into joint, calculated for factored axial force, consistent with the direction of lateral forces considered, resulting in lowest flexural strength, in.-lb

M_o = total factored static moment, in.-lb

M_p = required plastic moment strength of shearhead cross section, in.-lb

M_{pr} = probable flexural strength of members, with or without axial load, determined using the properties of the member at joint faces assuming a tensile stress in the longitudinal bars of at least $1.25f_y$ and a strength reduction factor ϕ of 1.0, in.-lb

M_{sa} = maximum moment in wall due to service loads, excluding $P\Delta$ effects, in.-lb

M_{sc} = factored slab moment that is resisted by the column at a joint, in.-lb

M_u = factored moment at section, in.-lb

M_{ua} = moment at midheight of wall due to factored lateral and eccentric vertical loads, not including $P\Delta$ effects, in.-lb

M_v = moment resistance contributed by shearhead reinforcement, in.-lb

M_1 = lesser factored end moment on a compression member, in.-lb

M_{1ns} = factored end moment on a compression member at the end at which M_1 acts, due to loads that cause no

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M = moment acting on anchor or anchor group, in.-lb

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appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb

M_{1s} = factored end moment on compression member at the end at which M_1 acts, due to loads that cause appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb

M_2 = greater factored end moment on a compression member. If transverse loading occurs between supports, M_2 is taken as the largest moment occurring in member. Value of M_2 is always positive, in.-lb

$M_{2,min}$ = minimum value of M_2, in.-lb

M_{2ns} = factored end moment on compression member at the end at which M_2 acts, due to loads that cause no appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb

M_{2s} = factored end moment on compression member at the end at which M_2 acts, due to loads that cause appreciable sidesway, calculated using a first-order elastic frame analysis, in.-lb

n = number of items, such as, bars, wires, monostrand anchorage devices, anchors, or shearhead arms

n_ℓ = number of longitudinal bars around the perimeter of a column core with rectilinear hoops that are laterally supported by the corner of hoops or by seismic hooks. A bundle of bars is counted as a single bar

N_a = nominal bond strength in tension of a single adhesive anchor, lb

N_{ag} = nominal bond strength in tension of a group of adhesive anchors, lb

N_b = basic concrete breakout strength in tension of a single anchor in cracked concrete, lb

N_{ba} = basic bond strength in tension of a single adhesive anchor, lb

N_c = resultant tensile force acting on the portion of the concrete cross section that is subjected to tensile stresses due to the combined effects of service loads and effective prestress, lb

N_{cb} = nominal concrete breakout strength in tension of a single anchor, lb

N_{cbg} = nominal concrete breakout strength in tension of a group of anchors, lb

N_{cp} = basic concrete pryout strength of a single anchor, lb

N_{cpg} = basic concrete pryout strength of a group of anchors, lb

N_n = nominal strength in tension, lb

N_p = pullout strength in tension of a single anchor in cracked concrete, lb

N_{pn} = nominal pullout strength in tension of a single anchor, lb

N_{sa} = nominal strength of a single anchor or individual anchor in a group of anchors in tension as governed by the steel strength, lb

N_{sb} = side-face blowout strength of a single anchor, lb

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n_t = number of threads per inch

N = tension force acting on anchor or anchor group, lb

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N_{sbg} = side-face blowout strength of a group of anchors, lb

N_u = factored axial force normal to cross section occurring simultaneously with V_u or T_u; to be taken as positive for compression and negative for tension, lb

N_{ua} = factored tensile force applied to anchor or individual anchor in a group of anchors, lb

$N_{ua,g}$ = total factored tensile force applied to anchor group, lb

$N_{ua,i}$ = factored tensile force applied to most highly stressed anchor in a group of anchors, lb

$N_{ua,s}$ = factored sustained tension load, lb

N_{uc} = factored horizontal tensile force applied at top of bracket or corbel acting simultaneously with V_u, to be taken as positive for tension, lb

p_{cp} = outside perimeter of concrete cross section, in.

p_h = perimeter of centerline of outermost closed transverse torsional reinforcement, in.

P_c = critical buckling load, lb

P_n = nominal axial compressive strength of member, lb

$P_{n,max}$ = maximum nominal axial compressive strength of a member, lb

P_{nt} = nominal axial tensile strength of member, lb

$P_{nt,max}$ = maximum nominal axial tensile strength of member, lb

P_o = nominal axial strength at zero eccentricity, lb

P_{pu} = factored prestressing force at anchorage device, lb

P_s = unfactored axial load at the design, midheight section including effects of self-weight, lb

P_u = factored axial force; to be taken as positive for compression and negative for tension, lb

$P\Delta$ = secondary moment due to lateral deflection, in.-lb

q_{Du} = factored dead load per unit area, lb/ft^2

q_{Lu} = factored live load per unit area, lb/ft^2

q_u = factored load per unit area, lb/ft^2

Q = stability index for a story

r = radius of gyration of cross section, in.

R = cumulative load effect of service rain load

s = center-to-center spacing of items, such as longitudinal reinforcement, transverse reinforcement, tendons, or anchors, in.

s_i = center-to-center spacing of reinforcement in the i-th direction adjacent to the surface of the member, in.

s_o = center-to-center spacing of transverse reinforcement within the length ℓ_o, in.

s_s = sample standard deviation, psi

s_w = clear distance between adjacent webs, in.

s_2 = center-to-center spacing of longitudinal shear or torsional reinforcement, in.

S = effect of service snow load

S_e = moment, shear, or axial force at connection corresponding to development of probable strength at intended yield locations, based on the governing

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$P\delta$ = secondary moment due to individual member slenderness, in.-lb

R = reaction, lb

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mechanism of inelastic lateral deformation, considering both gravity and earthquake effects

S_m = elastic section modulus, in.^{3}

S_n = nominal moment, shear, axial, torsional, or bearing strength

S_y = yield strength of connection, based on f_y of the connected part, for moment, shear, or axial force, psi

t = wall thickness of hollow section, in.

t_f = thickness of flange, in.

T = cumulative effects of service temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete

T_{cr} = cracking torsional moment, in.-lb

T_t = total test load, lb

T_{th} = threshold torsional moment, in.-lb

T_n = nominal torsional moment strength, in.-lb

T_u = factored torsional moment at section, in.-lb

U = strength of a member or cross section required to resist factored loads or related internal moments and forces in such combinations as stipulated in this Code

v_c = stress corresponding to nominal two-way shear strength provided by concrete, psi

v_n = equivalent concrete stress corresponding to nominal two-way shear strength of slab or footing, psi

v_s = equivalent concrete stress corresponding to nominal two-way shear strength provided by reinforcement, psi

v_u = maximum factored two-way shear stress calculated around the perimeter of a given critical section, psi

v_{ug} = factored shear stress on the slab critical section for two-way action due to gravity loads without moment transfer, psi

V_b = basic concrete breakout strength in shear of a single anchor in cracked concrete, lb

V_c = nominal shear strength provided by concrete, lb

V_{cb} = nominal concrete breakout strength in shear of a single anchor, lb

V_{cbg} = nominal concrete breakout strength in shear of a group of anchors, lb

V_{ci} = nominal shear strength provided by concrete where diagonal cracking results from combined shear and moment, lb

V_{cp} = nominal concrete pryout strength of a single anchor, lb

V_{cpg} = nominal concrete pryout strength of a group of anchors, lb

V_{cw} = nominal shear strength provided by concrete where diagonal cracking results from high principal tensile stress in web, lb

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T = tension force acting on a nodal zone in a strut-and-tie model, lb (T is also used to define the cumulative effects of service temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete in the load combinations defined in 5.3.6.)

T_{burst} = tensile force in general zone acting ahead of the anchorage device caused by spreading of the anchorage force, in.

V = shear force acting on anchor or anchor group, lb

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V_d = shear force at section due to unfactored dead load, lb

V_e = design shear force for load combinations including earthquake effects, lb

V_i = factored shear force at section due to externally applied loads occurring simultaneously with M_{max}, lb

V_n = nominal shear strength, lb

V_{nh} = nominal horizontal shear strength, lb

V_p = vertical component of effective prestress force at section, lb

V_s = nominal shear strength provided by shear reinforcement, lb

V_{sa} = nominal shear strength of a single anchor or individual anchor in a group of anchors as governed by the steel strength, lb,

V_u = factored shear force at section, lb

V_{ua} = factored shear force applied to a single anchor or group of anchors, lb

$V_{ua,g}$ = total factored shear force applied to anchor group, lb

$V_{ua,i}$ = factored shear force applied to most highly stressed anchor in a group of anchors, lb

V_{uh} = factored shear force along contact surface in composite concrete flexural member, lb

V_{us} = factored horizontal shear in a story, lb

w_c = density, unit weight, of normalweight concrete or equilibrium density of lightweight concrete, lb/ft^3

w_u = factored load per unit length of beam or one-way slab, lb/in.

w/cm = water-cementitious material ratio

W = effect of wind load

x = shorter overall dimension of rectangular part of cross section, in

y = longer overall dimension of rectangular part of cross section, in

y_t = distance from centroidal axis of gross section, neglecting reinforcement, to tension face, in.

α = angle defining the orientation of reinforcement

α_c = coefficient defining the relative contribution of concrete strength to nominal wall shear strength

α_f = ratio of flexural stiffness of beam section to flexural stiffness of a width of slab bounded laterally by centerlines of adjacent panels, if any, on each side of the beam

COMMENTARY

$V_{||}$ = maximum shear force that can be applied parallel to the edge, lb

$V_{\perp}$ = maximum shear force that can be applied perpendicular to the edge, lb

w_s = width of a strut perpendicular to the axis of the strut, in.

w_t = effective height of concrete concentric with a tie, used to dimension nodal zone, in.

$w_{t,max}$ = maximum effective height of concrete concentric with a tie, in.

W_a = service-level wind load, lb

CODE **COMMENTARY**

α_{fm} = average value of α_f for all beams on edges of a panel

α_{f1} = α_f in direction of ℓ_1

α_{f2} = α_f in direction of ℓ_2

α_i = angle between the axis of a strut and the bars in the *i*-th layer of reinforcement crossing that strut

α_s = constant used to calculate V_c in slabs and footings

α_v = ratio of flexural stiffness of shearhead arm to that of the surrounding composite slab section

α_1 = orientation of distributed reinforcement in a strut

α_2 = orientation of reinforcement orthogonal to α_1 in a strut

β = ratio of long to short dimensions: clear spans for two-way slabs, sides of column, concentrated load or reaction area; or sides of a footing

β_b = ratio of area of reinforcement cut off to total area of tension reinforcement at section

β_{dns} = ratio used to account for reduction of stiffness of columns due to sustained axial loads

β_{ds} = the ratio of maximum factored sustained shear within a story to the maximum factored shear in that story associated with the same load combination

β_n = factor used to account for the effect of the anchorage of ties on the effective compressive strength of a nodal zone

β_s = factor used to account for the effect of cracking and confining reinforcement on the effective compressive strength of the concrete in a strut

β_t = ratio of torsional stiffness of edge beam section to flexural stiffness of a width of slab equal to span length of beam, center-to-center of supports

β_1 = factor relating depth of equivalent rectangular compressive stress block to depth of neutral axis

γ_f = factor used to determine the fraction of M_{sc} transferred by slab flexure at slab-column connections

γ_p = factor used for type of prestressing reinforcement

γ_s = factor used to determine the portion of reinforcement located in center band of footing

γ_v = factor used to determine the fraction of M_{sc} transferred by eccentricity of shear at slab-column connections

δ = moment magnification factor used to reflect effects of member curvature between ends of a compression member

δ_s = moment magnification factor used for frames not braced against sidesway, to reflect lateral drift resulting from lateral and gravity loads

δ_u = design displacement, in.

Δ_{cr} = calculated out-of-plane deflection at midheight of wall corresponding to cracking moment M_{cr}, in.

Δ_n = calculated out-of-plane deflection at midheight of wall corresponding to nominal flexural strength M_n, in.

Δ_o = relative lateral deflection between the top and bottom of a story due to V_{us}, in.

CODE

Δf_p = increase in stress in prestressing reinforcement due to factored loads, psi

Δf_{ps} = stress in prestressing reinforcement at service loads less decompression stress, psi

Δ_r = residual deflection measured 24 hours after removal of the test load. For the first load test, residual deflection is measured relative to the position of the structure at the beginning of the first load test. For the second load test, residual deflection is measured relative to the position of the structure at the beginning of the second load test, in.

Δ_s = out-of-plane deflection due to service loads, in.

Δ_u = calculated out-of-plane deflection at midheight of wall due to factored loads, in.

Δ_x = design story drift of story x, in.

Δ_1 = maximum deflection, during first load test, measured 24 hours after application of the full test load, in.

Δ_2 = maximum deflection, during second load test, measured 24 hours after application of the full test load. Deflection is measured relative to the position of the structure at the beginning of the second load test, in.

ε_t = net tensile strain in extreme layer of longitudinal tension reinforcement at nominal strength, excluding strains due to effective prestress, creep, shrinkage, and temperature

ε_{ty} = value of net tensile strain in the extreme layer of longitudinal tension reinforcement used to define a compression-controlled section

θ = angle between axis of strut, compression diagonal, or compression field and the tension chord of the members

λ = modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength

λ_a = modification factor to reflect the reduced mechanical properties of lightweight concrete in certain concrete anchorage applications

λ_Δ = multiplier used for additional deflection due to long-term effects

μ = coefficient of friction

ξ = time-dependent factor for sustained load

ρ = ratio of A_s to bd

ρ' = ratio of A_s' to bd

ρ_ℓ = ratio of area of distributed longitudinal reinforcement to gross concrete area perpendicular to that reinforcement

COMMENTARY

Δf_{pt} = difference between the stress that can be developed in the strand at the section under consideration and the stress required to resist factored bending moment at section, M_u/ϕ, psi

ε_{cu} = maximum usable strain at extreme concrete compression fiber