The Reinforced Concrete Design Manual

In Accordance with ACI 318-11

American Concrete Institute®

SP-17(11) Vol 1

ACI SP-17(11)
Volume 1

THE REINFORCED CONCRETE DESIGN MANUAL

in Accordance with ACI 318-11

Columns
Deflection
Flexure
Footings
Seismic
Shear
Strut-and-tie

Publication:
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Editors:
Ronald Janowiak
Michael Kreger
Antonio Nanni

American Concrete Institute®
Advancing concrete knowledge

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THE REINFORCED CONCRETE DESIGN MANUAL
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Most ACI standards and committee reports are gathered together in the annually revised *ACI Manual of Concrete Practice* (MCP).

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FOREWORD

The *Reinforced Concrete Design Manual* [SP-17(11)] is intended to provide guidance and assistance to professionals engaged in the design of cast-in-place reinforced concrete structures.

The first *Reinforced Concrete Design Manual* (formerly titled *ACI Design Handbook*) was developed in accordance with the design provisions of 1963 ACI 318 Building Code by ACI Committee 340, Design Aids for Building Codes, whose mission was to develop handbook editions in accordance with the ACI 318 Building Code. That committee published revised editions of the handbook in accordance with the 1971, 1977, 1983, and 1995 ACI 318 Building Codes. Many individuals and members of ACI Committee 340 contributed to the earlier editions of the handbook, which remains the basis for the current *Reinforced Concrete Design Manual*. Their contributions, as well as the administrative and technical assistance from ACI staff, are acknowledged. This earlier handbook format was a collection of design aids and illustrative examples, generated in the pre-calculator era. Many of these earlier design aids intended to carry out relatively simple design calculations were eliminated in the SP-17(09) edition. Explanatory text was added to each chapter, while maintaining relevant design aids and illustrative examples.

The 2012 edition of the *Reinforced Concrete Design Manual* [SP-17(11)] was developed in accordance with the design provisions of ACI 318-11, and is consistent with the format of SP-17(09). Chapters 1 through 6 were developed by individual authors, as indicated on the first page of those chapters, and updated to the content of ACI 318-11 as needed. Those authors were members of the former ACI Committee 340. SP-17(09) was reviewed and approved by ACI's Technical Activities Committee (TAC).

Three new chapters were developed by ACI staff engineers under the auspices of TAC for SP-17(11): Chapter 7 (Deflection); Chapter 8 (Strut-and-Tie Model); and Chapter 9 (Anchoring to Concrete). To provide immediate oversight and guidance for this project, TAC appointed three content editors: Ronald Janowiak, Michael Kreger, and Antonio Nanni. Their reviews and suggestions improved this publication and are appreciated. TAC also appreciates the comments provided by Ronald Cook, Catherine French, Gary Klein, and John Silva for Chapters 8 and 9.

SP-17(11) is published in two volumes: Chapters 1 through 8 are published in Volume 1 and Chapter 9 is published in Volume 2.

Khaled Nahlawi
Managing Editor

On the cover:

The Grand Rapids Art Museum (GRAM) received a Gold-level certification in the Leadership in Energy and Environmental Design (LEED®) Rating System™ of the U.S. Green Building Council (USGBC). With that achievement, the GRAM has earned the distinction of being the first newly built art museum certified under the LEED for New Construction (LEED-NC) Version 2.1 requirements. The second highest of the four levels in the LEED Rating System, Gold certification recognizes a superior level of energy and environmental performance.

Architects: wHY Architecture
Location: Grand Rapids, MI
Client: Grand Rapids Art Museum
Area: 125,000 ft^2
Construction start: 2004
Completion: 2007
General contractors: Rockford/Pepper Construction
Concrete contractor: Grand River Construction
Structural Engineer: Dewhurst Macfarlane and Partners
Environmental Engineer: Atelier Ten/Design Plus, Inc.
Lighting Consultant: Isometrix Lighting + Design
Curtain Wall Consultant: W.J. Higgins & Associates
Landscape Design: Design Plus

Photo courtesy of Steve Hall© Hedrich Blessing.

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Volume 1

Editors: Ronald Janowiak, Michael Kreger, and Antonio Nanni

CONTENTS

ACI SP-17(11) supersedes ACI SP-17(09) and was adopted and published August 2012.

CHAPTER 1—DESIGN FOR FLEXURE

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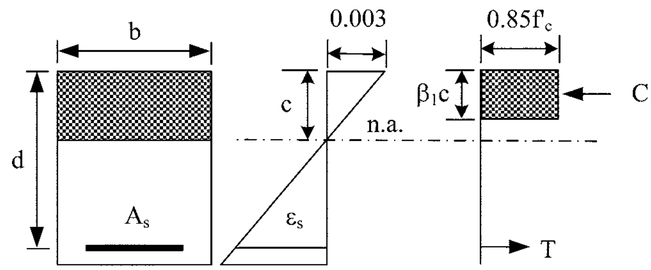
1.1—Introduction

The design of reinforced concrete elements for flexure involves sectional design and member detailing. Sectional design includes the determination of cross-sectional geometry and the required longitudinal reinforcement in accordance with Chapter 10 of ACI 318-11. Member detailing includes the determination of bar lengths, locations of cutoff points, and detailing of reinforcement as governed by the development, splice, and anchorage length requirements provided in Chapter 12 of ACI 318-11. This chapter deals with the sectional design of members for flexure on the basis of the Strength Design Method of ACI 318-11. The Strength Design Method requires the conditions of static equilibrium and strain compatibility across the depth of the section to be satisfied.

The following are the assumptions for Strength Design Method:

i. Strains in reinforcement and concrete are directly proportional to the distance from neutral axis. This implies that the variation of strains across the section is linear, and unknown values can be computed from the known values of strain through a linear relationship;
ii. Concrete sections are considered to have reached their flexural capacities when they develop 0.003 strain in the extreme compression fiber;
iii. Stress in reinforcement varies linearly with strain up to the specified yield strength. The stress remains constant beyond this point as strains continue increasing. This implies that the strain hardening of steel is ignored;
iv. Tensile strength of concrete is neglected; and
v. Compressive stress distribution of concrete is typically nonlinear. Various simplifications have been suggested for use in design. In this document, the rectangular stress distribution, in accordance with ACI 318-11, has been adopted as shown in Fig. 1.1.



$$\beta_1 = 0.85 \quad for\ f_c' \leq 4000\ psi$$

$$\beta_1 = 0.85 - 0.05(f_c' - 4000)/1000 \geq 0.65 \quad for\ f'_c > 4000\ psi$$

Fig. 1.1—Ultimate strain profile and corresponding rectangular stress distribution.

1.2—Nominal and design flexural strengths (M_n and ϕM_n)

Nominal moment strength M_n of a section is computed from internal forces at ultimate strain profile (when the extreme compressive fiber strain is equal to 0.003). Sections in flexure exhibit different modes of failure depending on the strain level in the extreme tension reinforcement. Tension-controlled sections have strains equal to or in excess of 0.005 (refer to Section 10.3.4 of ACI 318-11). Compression-controlled sections have strains equal to or less than the yield strain, which is equal to 0.002 for Grade 60 reinforcement (Section 10.3.3 of ACI 318-11). There exists a transition region between the tension-controlled and compression-controlled sections (Section 10.3.4 of ACI 318-11). Tension-controlled sections are desirable for their ductile behavior which allows redistribution of stresses and sufficient warning against an imminent failure. It is good practice to design reinforced concrete elements to behave in a ductile manner whenever possible. This can be ensured by limiting the amount of reinforcement such that the tension reinforcement yields before concrete crushing. The strain in extreme tension reinforcement of beams (where factored axial compression loads are less than $0.1 f_c' A_g$) shall not be less than 0.004 (Section 10.3.5 of ACI 318-11). The amount of reinforcement corresponding to this level of strain defines the maximum amount of tension reinforcement that balances the compression in the concrete. The ACI Code requires a lower strength reduction factor (ϕ-factor) for transition zone sections. This allows increased safety in sections with reduced ductility. Figure 1.2 illustrates the variation of ϕ-factors with tensile strain in reinforcement for Grade 60 steel, and the corresponding strain profiles at ultimate.

ACI 318-02 changed the traditional load factors of 1.4 and 1.7 for dead and live loads to 1.2 and 1.6 to be consistent with ASCE/SEI 7-02. Most of the ϕ-factors were reduced, but the ϕ-factor for flexure remained 0.90. These ϕ-factors appear in Chapter 9 of ACI 318-11. The ϕ-factors and the corresponding load factors in earlier editions of ACI 318 have been moved to Appendix C. The designer can use the ϕ-factors in the main body of the Code (Chapter 9) or those given in Appendix C, as long as ϕ-factors are used with the corresponding load factors. The basic design inequality remains the same, irrespective of which pair of ϕ and load factors is used:

factored (ultimate) moment ≤ reduced (design) strength

$$M_u \leq \phi M_n$$

1.2.1 *Rectangular sections with tension reinforcement*—Nominal moment strength of a rectangular section with tension reinforcement is computed from the internal force couple shown in Fig. 1.1. The required amount of reinforcement is computed from the equilibrium of forces. This