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

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SP-17(11)1

Editors:
Ronald Janowiak
Michael Kreger
Antonio Nanni

American Concrete Institute®
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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 ft²
Construction start: 2004
Completion: 2007
General contractors: Rockford/Pepper Construction
Concrete contractor: Grand River Construction
Structural Engineer: Dewhurst Macfarlane and Partners
Lighting Consultant: Isometrix Lighting + Design
Curtain Wall Consultant: W.J. Higgins & Associates
Landscape Design: Design Plus

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ACI SP-17(11)1

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Volume 1

Editors: Ronald Janowiak, Michael Kreger, and Antonio Nanni

CONTENTS

Chapter 1—Design for flexure................................................................................................................................. 7
  1.1—Introduction .................................................................................................................................................................. 7
  1.2—Nominal and design flexural strengths (M_n and φM_n) .................................................................................................. 7
    1.2.1—Rectangular sections with tension reinforcement .................................................................................................. 7
    1.2.2—Rectangular sections with compression reinforcement ............................................................................................. 8
    1.2.3—T-sections ............................................................................................................................................................. 9
  1.3—Minimum flexural reinforcement .......................................................................................................................... 10
  1.4—Placement of reinforcement in sections ...................................................................................................................... 10
    1.4.1—Minimum spacing of longitudinal reinforcement .................................................................................................... 10
    1.4.2—Concrete protection for reinforcement .................................................................................................................. 10
    1.4.3—Maximum spacing of flexural reinforcement and crack control .............................................................................. 11
    1.4.4—Skin reinforcement ................................................................................................................................................ 11
  1.5—Flexure examples .................................................................................................................................................. 12
    Flexure Example 1: Calculation of tension reinforcement area for a rectangular tension-controlled cross section ........... 12
    Flexure Example 2: Calculation of nominal flexural strength of a rectangular beam subjected to positive bending .......... 13
    Flexure Example 3: Calculation of tension reinforcement area for a rectangular cross section in the transition zone ...... 14
    Flexure Example 4: Selection of slab thickness and area of flexural reinforcement .................................................... 15
    Flexure Example 5: Calculation of tension and compression reinforcement area for a rectangular beam section subjected to positive bending ................................................................. 16
    Flexure Example 6: Calculation of tension reinforcement area for a T-section subjected to positive bending, behaving as a rectangular section .................................................................................................................. 18
    Flexure Example 7: Computation of the tension reinforcement area for a T-section, subjected to positive bending, behaving as a tension-controlled T-section .................................................. 19
    Flexure Example 8: Calculation of the area of tension reinforcement for an L-beam section, subjected to positive bending, behaving as an L-section in the transition zone ............................................. 20
    Flexure Example 9: Placement of reinforcement in the rectangular beam section designed in Flexure Example 1 ............ 22
    Flexure Example 10: Placement of reinforcement in the slab section designed in Flexure Example 4 .......................... 23
Chapter 2—Design for shear ................................................................................................. 33

2.1—Introduction .................................................................................................................. 33

2.2—Shear strength of beams .............................................................................................. 33

2.3—Designing shear reinforcement for beams ..................................................................... 33

2.4—Shear strength of two-way slabs .................................................................................. 34

2.5—Shear strength with torsion and flexure ..................................................................... 35

2.6—Shear design examples ............................................................................................... 37

Shear Example 1: Determine stirrups required for simply supported beam ....................... 37
Shear Example 2: Determine beam shear strength of concrete by method of Section 11.2.2.1 ....................................................................................................................... 39
Shear Example 3: Vertical U-stirrups for beam with triangular shear diagram .................. 40
Shear Example 4: Vertical U-stirrups for beam with trapezoidal and triangular shear diagram ......................................................................................................................... 42
Shear Example 5: Determination of perimeter shear strength at an interior column supporting a flat slab ($\alpha_5 = 40$) .......................................................... 43
Shear Example 6: Determination of thickness required for perimeter shear strength of a flat slab at an interior rectangular column ............................................................. 44
Shear Example 7: Determination of perimeter shear strength at an interior rectangular column supporting a flat slab ($\beta_c > 4$) ............................................................. 45
Shear Example 8: Determination of required thickness of a footing to satisfy perimeter shear strength at a rectangular column ................................................................. 46
Shear Example 9: Determination of strength of a flat slab based on required perimeter shear strength at an interior round column ............................................................................ 47
Shear Example 10: Determination of thickness required for a flat slab based on required perimeter shear strength at an interior round column ........................................................................ 48
Shear Example 11: Determination of thickness of a square footing to satisfy perimeter shear strength under a circular column ................................................................................................................................. 49
Shear Example 12: Determination of closed ties required for the beam shown to resist flexural shear and indeterminate torque .............................................................. 50
Shear Example 13: Determination of closed ties required for the beam of Example 12 to resist flexural shear and indeterminate torque .............................................................. 52

2.7—Shear design aids ......................................................................................................... 53

Shear 1: Section limits based on required nominal shear stress $= V_d/(\phi_0 \alpha_0)$ .................. 53
Shear 2: Shear strength coefficients $K_{t0}$, $K_{vc}$, and $K_{vc}$ .................................................. 54
Shear 3: Minimum beam height to provide development length required for No. 6, No. 7, and No. 8 Grade 60 stirrups .......................................................................................... 56
Shear 4.1: Shear strength $V_s$ with Grade 40 U-stirrups ...................................................... 57
Shear 4.2: Shear strength $V_s$ with Grade 60 U-stirrups ...................................................... 58
Shear 5.1: Shear strength of slabs based on perimeter shear at interior rectangular columns ($\alpha_5 = 40$) when no shear reinforcement is used .............................................. 59
Shear 5.2: Shear strength of slabs based on perimeter shear at interior round columns when no shear reinforcement is used ............................................................ 60
Shear 6.1: Shear and torsion coefficients $K_1$ and $K_{tcr}$ ......................................................... 61
Shear 6.2: Shear and torsion coefficient $K_{tS}$ ..................................................................... 62
Chapter 3—Short column design ............................................................................................................. 63

3.1—Introduction ....................................................................................................................................... 63

3.2—Column sectional strength .................................................................................................................. 63

3.2.1—Column interaction diagrams ......................................................................................................... 63

3.2.2—Flexure with tension axial load ......................................................................................................... 65

3.3—Columns subjected to biaxial bending ................................................................................................. 65

3.3.1—Reciprocal load method ................................................................................................................... 65

3.3.2—Load contour method ...................................................................................................................... 66

3.4—Columns examples ............................................................................................................................. 68

Columns Example 1: Determination of required steel area for a rectangular tied column with bars on four faces with slenderness ratio below critical value ......................................................................................... 68

Columns Example 2: For a specified reinforcement ratio, select a column size for a rectangular tied column with bars on end faces only ......................................................................................................................... 69

Columns Example 3: Selection of reinforcement for a square spiral column with slenderness ratio below critical value ......................................................................................................................................................... 70

Columns Example 4: Design of square column section subject to biaxial bending using resultant moment ........................................................................................................................................................................... 71

Columns Example 5: Design of circular spiral column section subject to small design moment ........................................................................................................................................................................... 73

3.5—Columns design aids .......................................................................................................................... 75

Chapter 4—Design of slender columns ........................................................................................................ 171

4.1—Introduction ....................................................................................................................................... 171

4.2—Slenderness ratio ................................................................................................................................. 171

4.2.1—Unsupported length $l_0$ .................................................................................................................. 171

4.2.2—Effective length factor $k$ ................................................................................................................ 172

4.2.3—Radius of gyration $r$ ...................................................................................................................... 173

4.3—Lateral bracing and designation of frames as nonsway .................................................................... 173

4.4—Design of slender columns .................................................................................................................. 173

4.4.1—Slender columns in nonsway frames .............................................................................................. 173

4.4.2—Slender columns in sway frames .................................................................................................. 174

4.4.3—Upper limit on second-order effects .............................................................................................. 175

4.5—Slender columns examples ................................................................................................................ 176

Slender Columns Example 1: Design of an interior column braced against sidesway ......................................... 176

Slender Columns Example 2: Design of an exterior column in a sway frame using the moment magnification method ......................................................................................................................................................... 180

4.6—Slender columns design aids .............................................................................................................. 186

Slender Columns 4.1: Effective length factor—Jackson and Moreland alignment chart for columns in braced (nonsway) frames (Column Research Council 1966) ......................................................................................... 186

Slender Columns 4.2: Effective length factor—Jackson and Moreland alignment chart for columns in unbraced (sway) frames (Column Research Council 1966) ......................................................................................... 187

Slender Columns 4.3: Recommended flexural rigidities (EI) for use in first-order and second-order analyses of frames for design of slender columns ......................................................................................... 188

Slender Columns 4.4: Effective length factor $k$ for columns in braced frames ........................................................................................................................................................................... 189

Slender Columns 4.5: Moment of inertia of reinforcement about sectional centroid ..................................... 190

Chapter 5—Footing design .......................................................................................................................... 191

5.1—Introduction ....................................................................................................................................... 191

5.2—Foundation types ............................................................................................................................... 191

5.3—Allowable stress design and strength design ..................................................................................... 191

5.4—Structural design ............................................................................................................................... 191

5.5—Footings subject to eccentric loading ............................................................................................... 191
Chapter 6—Seismic design ..................................................................................................................... 207

6.1—Introduction ..................................................................................................................................... 207

6.2—Limitations on materials .................................................................................................................. 207

6.3—Flexural members of special moment frames .................................................................................... 208
   6.3.1—Flexural design ............................................................................................................................ 208
   6.3.2—Shear design .................................................................................................................................. 208

6.4—Special moment frame members subjected to bending and axial load ................................................ 208
   6.4.1—Flexural design ............................................................................................................................ 208
   6.4.2—Strong-column weak-beam concept ............................................................................................ 209
   6.4.3—Confinement reinforcement ........................................................................................................ 209

6.5—Joints of special moment frames ...................................................................................................... 210
   6.5.1—Joint shear strength ....................................................................................................................... 210
   6.5.2—Joint reinforcement ....................................................................................................................... 210

6.6—Members of intermediate moment frames ......................................................................................... 210
   6.6.1—Flexural design ............................................................................................................................ 210
   6.6.2—Shear design .................................................................................................................................. 210

6.7—Members not designed as part of the lateral-force-resisting system .................................................. 211

6.8—Seismic design examples .................................................................................................................. 212
   Seismic Design Example 1: Adequacy of beam flexural design for a special moment frame ................. 212
   Seismic Design Example 2: Design of the critical end regions of a beam in a special moment frame for shear and confinement ................................................................. 213
   Seismic Design Example 3: Design of a column of a special moment frame for longitudinal and confinement reinforcement .................................................................................................. 215
   Seismic Design Example 4: Shear strength of a monolithic beam-column joint ................................... 218

6.9—Seismic design aids .......................................................................................................................... 220
   Seismic 1: Requirements for flexural members of special moment frames ............................................ 220
   Seismic 2: Details of transverse reinforcement for flexural members of special moment frames .................. 221
   Seismic 3: Probable moment strength for flexural members ................................................................. 222
   Seismic 4: Shear strength for flexural members and members subjected to bending and axial load of special moment frames .................................................................................... 223
   Seismic 5: Requirements for members subjected to bending and axial load of special moment frames .......... 224
   Seismic 6: Volumetric ratio of spiral reinforcement $\rho_s$ for concrete confinement .................................. 225
   Seismic 7: Area ratio of rectilinear confinement reinforcement $\rho_c$ for concrete ..................................... 226
   Seismic 8: Joint shear $V_j$ in an interior beam-column joint .................................................................... 227
   Seismic 9: Joint shear $V_j$ in an exterior beam-column joint ................................................................. 228
   Seismic 10: Requirements for flexural members and members subjected to bending and axial load of intermediate moment frames ......................................................................... 229
   Seismic 11: Shear strength for flexural members and members subjected to bending and axial load of intermediate frames ......................................................................................... 230

Chapter 7—Deflection ............................................................................................................................. 231

7.1—Introduction ..................................................................................................................................... 231

7.2—Limitations on member thickness .................................................................................................... 231

7.3—Deflection behavior of beams ......................................................................................................... 231
Chapter 8—Strut-and-tie model ................................................................. 257

8.1—Introduction .................................................................................. 257
8.2—Concept ....................................................................................... 257
8.3—Design .......................................................................................... 257
8.4—Struts ........................................................................................... 258
8.5—Ties ............................................................................................... 260
8.6—Nodal zones .................................................................................. 260
8.7—Usual calculation steps and modeling consideration to apply strut-and-tie model ................................................................. 262
8.8—References ................................................................................... 262
8.9—Strut-and-tie examples ................................................................. 263
Strut-and-tie Example 1: Strut-and-tie model of a deep beam without shear reinforcement ....................................................... 263
Strut-and-tie Example 2: Strut-and-tie model of a deep beam with shear reinforcement ................................................................. 270
Strut-and-tie Example 3: Design of one-sided corbel using strut-and-tie method ............................................................... 282
Strut-and-tie Example 4: Design of double corbel ....................................................................................................................... 291
Strut-and-tie Example 5: Design a pile cap subjected to the dead and live load axial forces and to axial forces and overturning moment ................................................................. 298

References ........................................................................................................... 311

Referenced standards and reports ........................................................................... 311
Cited references....................................................................................................... 311

Appendix A—Reference tables ......................................................................... 313

Table A-1: Nominal cross section area, weight, and nominal diameter of ASTM standard reinforcing bars ....................................................... 313
Table A-2: Area of bars in a section 1 ft wide .................................................................313
Table A-3: Minimum beam web widths required for two or more bars in one layer for cast-in-place non-prestressed concrete ........................................................................................................314
Table A-4: Minimum beam web widths for various bar combinations (interior exposure) ........................................315
Table A-5: Properties of bundled bars ........................................................................316
Table A-6: Minimum beam web widths $b_{ww}$ for various combinations of bundled bars (interior exposure) ..........................................................317
Table A-7: Basic development length ratios of bars in tension ........................................318
Table A-8: Basic development length $l_{dh}$ of standard hooks in tension .........................320

Appendix B—Analysis tables ..................................................................................................................323
Table B-1: Beam diagrams .........................................................................................................................323
Table B-2: Moments and reactions in continuous beams under uniformly distributed loads ........................................................................................................330
Table B-3: Moments and reactions in continuous beams under central point loads .........................331
Table B-4: Moments and reactions in continuous beams, point loads at third points of span ................332
Table B-5: Approximate moments and shears for continuous beams and one-way slabs ..........................................................333
Table B-6: Beams with prismatic haunch at one end ................................................................................334
Table B-7: Beams with prismatic haunch at both ends ........................................................................335
Table B-8: Prismatic member with equal infinitely stiff end regions ................................................336
Table B-9: Prismatic member with infinitely stiff region at one end .......................................................336
Table B-10: Prismatic member with unequal infinitely stiff end regions ........................................336

Appendix C—Sectional properties ........................................................................................................337
Table C-1: Properties of sections .........................................................................................................337
Table C-2: Properties of sections .........................................................................................................338
CHAPTER 1—DESIGN FOR FLEXURE

by Murat Saatcioglu
Professor and University Research Chair, Department of Civil Engineering, University of Ottawa, Ottawa, ON, Canada

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.

1.2—Nominal and design flexural strengths ($M_n$ and $\phi M_n$)

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 ($\phi$-factor) for transition zone sections. This allows increased safety in sections with reduced ductility. Figure 1.2 illustrates the variation of $\phi$-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 $\phi$-factors were reduced, but the $\phi$-factor for flexure remained 0.90. These $\phi$-factors appear in Chapter 9 of ACI 318-11. The $\phi$-factors and the corresponding load factors in earlier editions of ACI 318 have been moved to Appendix C. The designer can use the $\phi$-factors in the main body of the Code (Chapter 9) or those given in Appendix C, as long as $\phi$-factors are used with the corresponding load factors. The basic design inequality remains the same, irrespective of which pair of $\phi$ and load factors is used:

$$\text{factored (ultimate) moment } \leq \text{ reduced (design) strength}$$

$$M_u \leq \phi M_n$$

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...