

Reinforced Concrete Structures

About the Author

David A. Fanella, Ph.D., S.E., P.E., F.ASCE, F.ACI, is Principal at TGRWA, LLC, in Chicago, Illinois. He earned a Ph.D. in structural engineering from the University of Illinois at Chicago and is a licensed Structural Engineer in the State of Illinois and a licensed Professional Engineer in numerous states. Dr. Fanella is a past-president of the Structural Engineers Association of Illinois. He is an active member of a number of American Concrete Institute (ACI) committees, is an Associate Member of the ASCE 7 Committee, and served on the board of the Applied Technology Council. Dr. Fanella has authored or co-authored many structural publications, most recently an ICC publication on the determination of loads and a CRSI publication on the vibration of reinforced concrete floor systems. In 2014, he received the Alfred E. Lindau Award from ACI.

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Reinforced Concrete Structures

Analysis and Design

David A. Fanella

Second Edition



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Contents

Preface to the Second Edition	ix
Preface to the First Edition	xi
1 Introduction	1
1.1 Reinforced Concrete	1
1.2 Building Codes and Standards	3
1.3 Strength and Serviceability	4
1.4 Reinforced Concrete Members in Building Structures	4
1.5 Drawings and Specifications	12
1.6 Construction of Reinforced Concrete Buildings	15
References	20
2 Materials	21
2.1 Introduction	21
2.2 Concrete	21
2.3 Reinforcement	54
References	65
Problems	67
Problems in SI Units	67
3 General Considerations for Analysis and Design	71
3.1 Introduction	71
3.2 Loading	72
3.3 Structural Analysis	92
References	110
Problems	111
Problems in SI Units	111
4 General Requirements for Strength and Serviceability	113
4.1 Introduction	113
4.2 Required Strength	114
4.3 Design Strength	123
4.4 Control of Deflections	127
References	130
Problems	131
Problems in SI Units	132
5 General Principles of the Strength Design Method	135
5.1 Introduction	135
5.2 Design Assumptions	136
5.3 General Principles and Requirements	139
5.4 One-Way Slabs, Two-Way Slabs, and Beams	142

vi Contents

5.5	Columns	177
5.6	Tension Members	180
5.7	Members Subjected to Flexure and Axial Load	181
	References	189
	Problems	189
	Problems in SI Units	193
6	Beams and One-Way Slabs	197
6.1	Introduction	197
6.2	Mechanics and Behavior of Reinforced Concrete Beams	198
6.3	Design for Flexure	211
6.4	Design for Shear	272
6.5	Design for Torsion	295
6.6	Deflections	323
	References	334
	Problems	336
	Problems in SI Units	342
7	Two-Way Slabs	347
7.1	Introduction	347
7.2	Two-Way Slab Systems	348
7.3	Minimum Thickness Requirements	353
7.4	Analysis Methods	369
7.5	Design for Flexure	412
7.6	Design for Shear	427
7.7	Design Procedure	460
	References	472
	Problems	473
	Problems in SI Units	476
8	Columns	481
8.1	Introduction	481
8.2	Preliminary Column Sizing	483
8.3	Analysis and Design Methods	486
8.4	Interaction Diagrams	488
8.5	Slenderness Effects	513
8.6	Biaxial Loading	541
8.7	Reinforcement Details	544
8.8	Shear Requirements	562
8.9	Design Procedure	567
	References	569
	Problems	570
	Problems in SI Units	574
9	Walls	579
9.1	Introduction	579
9.2	Design Methods for Axial Loads and Flexure	582
9.3	Design for Shear	604

9.4	Reinforcement Details	612
9.5	Design Procedure	612
	References	614
	Problems	614
	Problems in SI Units	615
10	Foundations	617
10.1	Introduction	617
10.2	Footings	624
10.3	Mat Foundations	682
10.4	Pile Caps	691
10.5	Drilled Piers	700
	References	705
	Problems	705
	Problems in SI Units	708
11	Design and Detailing for Earthquake Effects	711
11.1	Introduction	711
11.2	Seismic Design Criteria	712
11.3	Seismic-Force-Resisting Systems	722
11.4	Design and Detailing Requirements	729
11.5	Ordinary Moment Frames	732
11.6	Intermediate Moment Frames	733
11.7	Special Moment Frames	762
11.8	Special Structural Walls	845
11.9	Diaphragms	889
11.10	Foundations	901
11.11	Members Not Designated as Part of the SFRS	905
	References	908
	Problems	909
	Problems in SI Units	918
A	Steel Reinforcement Information	925
A.1	ASTM Standard Reinforcing Bars	925
A.2	Wire Reinforcement Institute (WRI) Standard Wire Reinforcement	926
A.3	ASTM Standard Wire Reinforcement	927
B	Critical Section Properties for Two-Way Shear	929
B.1	Derivation of Critical Section Properties	929
B.2	Tabulated Values of Critical Shear Constants	940
	Index	947

Preface to the Second Edition

The second edition of this publication is based on the provisions of the 2015 edition of the *International Building Code*[®]. That document references ACI 318-14, *Building Code Requirements for Structural Concrete and Commentary*, for the design of reinforced concrete structures. A major structural reorganization occurred in going from the 2011 edition to the 2014 edition of ACI 318, the first such reorganization since 1971. In short, requirements in ACI 318-14 are organized mainly by member type (one-way slabs, beams, two-way slabs, columns, etc.), which is a major change of how the document was organized in earlier editions.

It was initially anticipated that the number of technical changes to ACI 318-14 would be kept to a minimum because of the effort that would be needed in the reorganization of the document. However, it did not end up that way, and some major revisions were made to the provisions themselves.

In the second edition of this text, all referenced provisions have been updated to the new chapter and section numbers in ACI 318-14 and all modifications and additions to the provisions have been addressed as well. The first edition of this text was organized essentially the same as ACI 318-14 is organized now, so readers familiar with the first edition will see that the structure of the second edition remains fundamentally the same.

Additional content, examples, problems, and design aids, including more flowcharts that guide the reader through the provisions, have been included in this edition to enhance the overall learning experience. In particular, content has been added to the first part of Chap. 6, which covers beams and one-way slabs. A review of the mechanics and behavior of reinforced concrete beams is provided as an externally applied load is gradually increased from zero to a magnitude that will cause failure. Examples illustrate the mechanics of an elastic, uncracked section through the nominal flexural strength of the section.

The most significant change to the second edition has been the addition of Chap. 11, which is a new chapter that covers the earthquake design provisions in Chap. 18 of ACI 318-14. All of the provisions in this chapter are covered in detail, and numerous tables, figures, design aids, flowcharts, and completely worked-out examples are provided that help illustrate the code requirements for design and detailing the structural members of intermediate moment frames, special moment frames, special structural walls (including

X Preface to the Second Edition

coupling beams and wall piers), diaphragms, foundations, and members not designated as part of the seismic-force-resisting system.

Another significant change to this edition has been the introduction of SI units. Equations from the 2015 IBC and ACI 318-14 in SI units have been included immediately after the equations in inch-pound units where applicable. The figures, tables, and flowcharts throughout the text also include quantities and equations in SI units, and numerous worked-out examples and problems in SI units have been included as well.

Like the first edition, this book is geared to both undergraduate and graduate students. The content in Chaps. 1 through 10 can be covered in two semester courses, the first a fundamental course for undergraduate students and the second course for advanced undergraduate and graduate students. The material in Chap. 11 can be accommodated in a semester course for advanced undergraduate students and graduate students as well. Practicing engineers who need to become familiar with the new structure of ACI 318-14 along with the current design and detailing requirements will also find this book to be very useful.

David A. Fanella

Preface to the First Edition

This book presents subject matter related to the analysis and design of reinforced concrete structural members. The focus is on the design of elements in reinforced concrete buildings where the primary reinforcement is steel reinforcing bars or steel wire reinforcement that is not prestressed.

To safely and economically design reinforced concrete structures, a thorough understanding of the mechanics of reinforced concrete and the design provisions of current codes is essential. The purpose of this book is to present and explain the following in a simple and straightforward manner: (1) the underlying principles of reinforced concrete design and (2) the analysis, design, and detailing requirements in the 2008 edition of *Building Code Requirements for Structural Concrete and Commentary* by the American Concrete Institute (ACI) and the 2009 edition of the *International Building Code* by the International Code Council (ICC). Frequent reference is made to the sections of these documents (especially those in the ACI Building Code), and it is assumed that the reader will have access to them while using this book.

Information on the properties of the materials that constitute reinforced concrete and a basic understanding of the mechanics of reinforced concrete must be acquired prior to exploring code provisions. Design and detailing provisions given in the code change frequently, and it is important to have an understanding of the core elements of reinforced concrete design in order to correctly apply these provisions in practice.

Presented in Chap. 1 are a definition of reinforced concrete and a basic synopsis of the mechanics of reinforced concrete. Typical reinforced concrete members and the fundamental roles they play in buildings are discussed. The main purpose of this discussion is twofold: (1) to introduce the types of concrete elements that are covered in the chapters that follow and (2) to illustrate how all of the members in a structure are assembled. A brief overview of construction documents and the main events that occur in the construction of a cast-in-place concrete building are also covered. Again, the purpose is to make the reader aware of the important topics that are encountered in any building project.

Mechanical properties of concrete and reinforcing steel are summarized in Chap. 2. Basic information on the mechanics of concrete deterioration and failure is provided, which gives insight into the strengths and weaknesses of concrete. Also covered in this

chapter are (1) methodologies for proportioning concrete mixtures, (2) durability requirements, and (3) evaluation and acceptance criteria.

General information that is applicable to the analysis and design of any reinforced concrete building is provided in Chap. 3. Included are the loads that must be considered in design and analysis methods pertinent to reinforced concrete structures. Approximate methods of analysis and moment redistribution are also covered.

Chapter 4 contains the general requirements that must be satisfied for strength and serviceability. These requirements form the basis of design of all reinforced concrete members. Concepts of the strength design method of analysis are introduced, including required strength and design strength. Load factors, load combinations, and strength reduction factors are also covered, as are general provisions for deflection control.

General principles and requirements of the strength design method are presented in Chap. 5. The design assumptions of this method and the basic techniques to determine nominal strength of a reinforced concrete section subjected to flexure, axial load, or a combination of both are covered in detail. A thorough understanding of the material presented in this chapter is essential before continuing on to subsequent chapters.

Chapters 6 through 10 contain design and detailing requirements for the following reinforced concrete members: (1) beams and one-way slabs, (2) two-way slabs, (3) columns, (4) walls, and (5) foundations. Each chapter contains techniques on how to size the cross-section, calculate the required amount of reinforcement, and detail the reinforcement. Design procedures and flowcharts provide road maps that guide the reader through the requirements of the code. Also included are numerous design aids and comprehensive worked-out examples that facilitate and demonstrate the proper application of the design provisions. The examples follow the steps of the referenced design procedures and flowcharts and have been formulated using structural layouts that are found in typical concrete buildings. These examples further help the reader to understand how members work together and how loads are transferred through a structure.

Throughout the discussions and in the examples, the practical aspects of reinforced concrete design are stressed at length. These fundamental concepts are presented to familiarize the reader with important aspects of design (other than those that are theoretical) that need to be considered in everyday practice. Emphasis is placed on sizing concrete members on the basis of formwork considerations and detailing reinforcement so that they adequately fit within a section.

The content of this book is geared to both undergraduate and graduate students, as well as to practicing engineers who need to become familiar with current code design requirements or need an update on reinforced concrete design. Engineers studying for licensing exams will also find the material presented here to be very useful.

My sincere thanks to John R. Henry, PE, Principal Staff Engineer, International Code Council, Inc., for review of this text. His insightful suggestions for improvement are most appreciated. I also wish to thank Adugna Fanuel, SE, LEED AP, and Angelo Cicero of Klein and Hoffman, Inc., for reviewing Chap. 2 and producing some of the figures, respectively. Their help was invaluable.

David A. Fanella