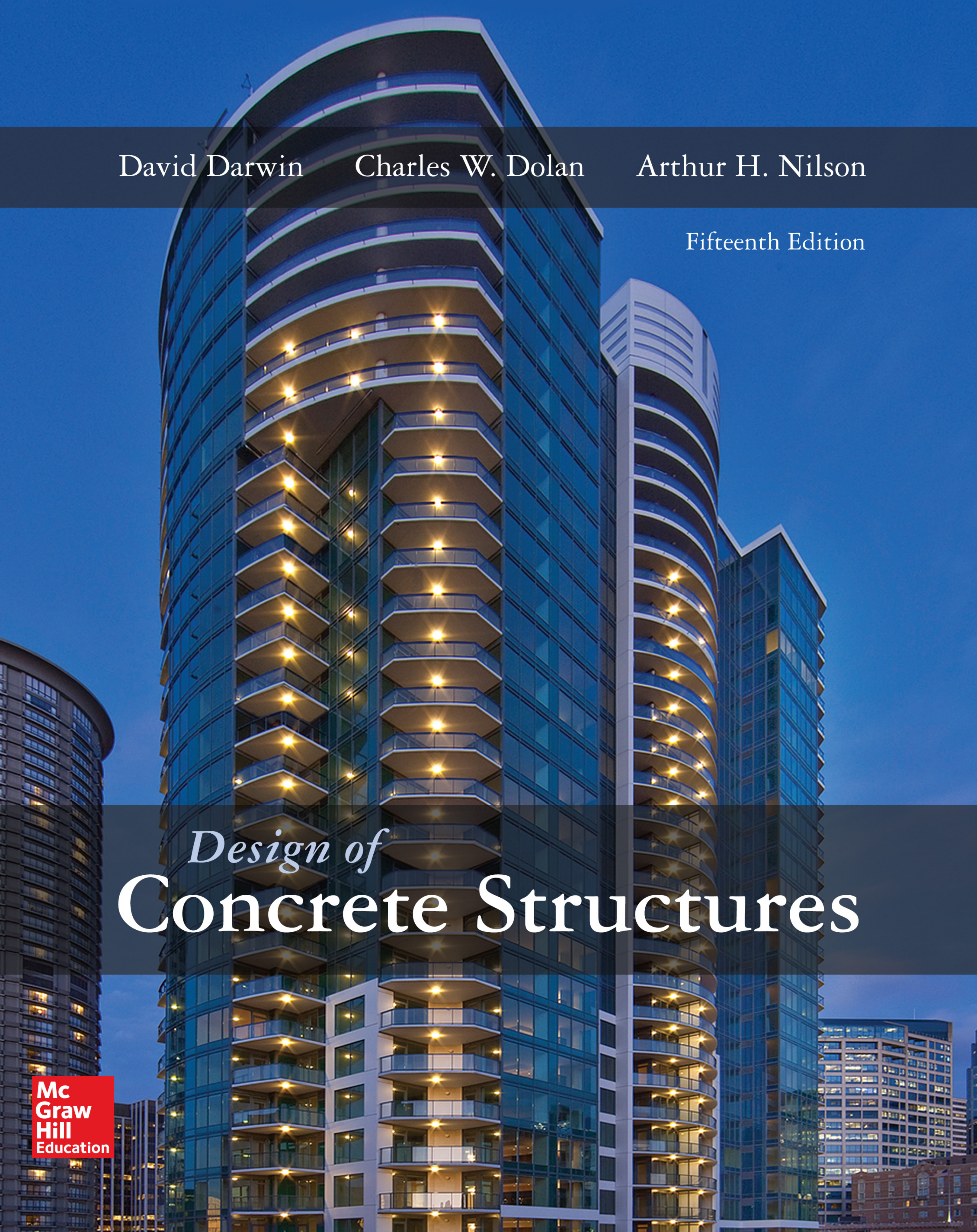
David Darwin Charles W. Dolan Arthur H. Nilson

Fifteenth Edition

Design of Concrete Structures



McGraw Hill Education

DESIGN of CONCRETE STRUCTURES

Fifteenth Edition

David Darwin

Ph.D., P.E., Distinguished Member of ASCE
Fellow of ACI, Fellow of SEI
Deane E. Ackers Distinguished Professor and Chair
of Civil, Environmental & Architectural Engineering
University of Kansas

Charles W. Dolan

Ph.D., P.E., Honorary Member of ACI
Fellow of PCI
H. T. Person Professor of Engineering, Emeritus
University of Wyoming

Arthur H. Nilson

Ph.D., P.E., Honorary Member of ACI
Fellow of ASCE
Late Professor of Structural Engineering
Cornell University

Mc Graw Hill Education

DESIGN OF CONCRETE STRUCTURES, FIFTEENTH EDITION

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 QVS/QVS 1 0 9 8 7 6 5

ISBN 978-0-07-339794-8
MHID 0-07-339794-6

Senior Vice President, Products & Markets: *Kurt L. Strand*
Vice President, General Manager, Products & Markets: *Michael Ryan*
Vice President, Content Design & Delivery: *Kimberly Meriwether David*
Managing Director: *Thomas Timp*
Director, Product Development: *Rose Koos*
Brand Manager: *Thomas Scaife, Ph.D.*
Product Developer: *Lorraine Buczek*
Marketing Manager: *Nick McFadden*
Director, Content Design & Delivery: *Terri Schiesl*
Full-Service Manager: *Faye Schilling*
Content Project Managers: *Melissa M. Leick & Sandy Schnee*
Buyer: *Laura M. Fuller*
Content Licensing Specialist: *Deanna Dausener*
Cover Image: Escala image: © Structural Engineer: Cary Kopczynski/photographer: Michael Walmsley; Marriott image: © Magnusson Klemencic Associates
Compositor: *Laserwords Private Limited*
Typeface: *10.5/12 Times Lt std*
Printer: *Quad/Graphics*

Library of Congress Cataloging-in-Publication Data

Darwin, David.
Design of concrete structures / David Darwin, Deane E. Ackers Distinguished Professor and chair of Civil, Environmental & Architectural Engineering, University of Kansas, Charles W. Dolan, H.T. Person Professor of Engineering, emeritus, University of Wyoming, Arthur H. Nilson, late professor of structural engineering, Cornell University.—Fifteenth edition.
pages cm
Primary author of previous edition: Arthur H. Nilson.
Includes bibliographical references and index.
ISBN 978-0-07-339794-8 (alk. paper)
1. Reinforced concrete construction. 2. Prestressed concrete construction. I. Dolan, Charles W. (Charles William), 1943- II. Nilson, Arthur H. III. Title.
TA683.2.N55 2016
624.1'834—dc23
2014038966

www.mhhe.com

About the Authors

David Darwin has been a member of the faculty at the University of Kansas since 1974, where he has served as director of the Structural Engineering and Materials Laboratory since 1982 and currently chairs the Department of Civil, Environmental, and Architectural Engineering. He was appointed the Deane E. Ackers Distinguished Professor of Civil Engineering in 1990. Dr. Darwin served as President of the American Concrete Institute in 2007–2008 and is a member and past chair of ACI Committees 224 on Cracking and 408 on Bond and Development of Reinforcement. He is also a member of ACI Building Code Subcommittee 318-B on Anchorage and Reinforcement and ACI-ASCE Committee 445 on Shear and Torsion. Dr. Darwin is an acknowledged expert on concrete crack control and bond between steel reinforcement and concrete. He received the ACI Arthur R. Anderson Award for his research efforts in plain and reinforced concrete, the ACI Structural Research Award, the ACI Joe W. Kelly Award for his contributions to teaching and design, and the ACI Foundation – Concrete Research Council Arthur J. Boase Award for his research on reinforcing steel and concrete cracking. He has also received a number of awards from the American Society of Civil Engineers, including the Walter L. Huber Civil Engineering Research Prize, the Moisseiff Award, and the State-of-the-Art of Civil Engineering Award twice, the Richard R. Torrens Award, and the Dennis L. Tewksbury Award, and has been honored for his teaching by both undergraduate and graduate students at the University of Kansas. He is past editor of the ASCE *Journal of Structural Engineering*. Professor Darwin is a Distinguished Member of ASCE and a Fellow of ACI and the Structural Engineering Institute of ASCE. He is a licensed professional engineer and serves as a consultant in the fields of concrete materials and structures. He has been honored with the Distinguished Alumnus Award from the University of Illinois Civil and Environmental Engineering Alumni Association. Between his M.S. and Ph.D. degrees, he served four years with the U.S. Army Corps of Engineers. He received the B.S. and M.S. degrees from Cornell University in 1967 and 1968 and the Ph.D. from the University of Illinois at Urbana-Champaign in 1974.

Charles W. Dolan is a consulting engineer and emeritus faculty member of the University of Wyoming. At the University of Wyoming from 1991 to 2012, he served as Department Head from 1998 to 2001 and as the first H. T. Person Chair of Engineering from 2002 to 2012, for which he received the University of Wyoming's John P. Ellbogen lifetime teaching award. A member of American Concrete Institute (ACI) Committee 318 Building Code for Concrete Structures for 12 years, he has chaired the Building Code Subcommittees on Prestressed Concrete and Code Reorganization. He has served as chair of the ACI Technical Activities Committee, ACI Committee

358 on Transit Guideways, and ACI-ASCE Committee 423 on Prestressed Concrete. A practicing engineer for over 40 years, including 20 years at Berger/ABAM, he was the project engineer on the Walt Disney World Monorail, the Detroit Downtown Peoplemover guideway, and the original Dallas–Fort Worth Airport transit system guideway. He developed the conceptual design of the Vancouver BC SkyTrain structure and the Dubai Palm Island monorail. He received the ASCE T. Y. Lin Award for outstanding contributions to the field of prestressed concrete, the ACI Arthur R. Anderson award for advancements in the design of reinforced and prestressed concrete structures, and the Prestress/Precast Concrete Institute's (PCI) Martin P. Korn award for advances in design and research in prestressed concrete. An Honorary Member of ACI and a Fellow of PCI, he is internationally recognized as a leader in the design of specialty transit structures and development of fiber-reinforced polymers for concrete reinforcement. Dr. Dolan is a registered professional engineer and lectures widely on the design and behavior of structural concrete. He received his B.S. from the University of Massachusetts in 1965 and his M.S. and Ph.D. from Cornell University in 1967 and 1989.

The late **Arthur H. Nilson** was engaged in research, teaching, and consulting relating to structural concrete for over 40 years. He was a member of the faculty of the College of Engineering at Cornell University from 1956 to 1991 when he retired and was appointed professor emeritus. At Cornell he was in charge of undergraduate and graduate courses in the design of reinforced concrete and prestressed concrete structures. He served as Chairman of the Department of Structural Engineering from 1978 to 1985. Dr. Nilson served on many professional committees, including American Concrete Institute (ACI) Building Code Subcommittee 318-D. His pioneering work on high-strength concrete has been widely recognized. He was awarded the ACI Wason Medal for materials research in 1974, the ACI Wason Medal for best technical paper in 1986 and 1987, and the ACI Structural Research Award in 1993. Professor Nilson was an Honorary Member of ACI and a Fellow in the American Society of Civil Engineers (ASCE). He was honored by the civil engineering student body at Cornell for outstanding teaching. Professor Nilson was a registered professional engineer in several states and, prior to entering teaching, was engaged in full-time professional practice. He received the B.S. degree from Stanford University in 1948, the M.S. from Cornell in 1956, and the Ph.D. from the University of California at Berkeley in 1967.

Contents

Preface

The fifteenth edition of *Design of Concrete Structures* continues the dual objectives of establishing a firm understanding of the behavior of structural concrete and of developing proficiency in the methods of design practice. It is generally recognized that mere training in special design skills and codified procedures is inadequate for a successful career in professional practice. As new research becomes available and new design methods are introduced, these procedures are subject to frequent changes. To understand and keep abreast of these rapid developments and to engage safely in innovative design, the engineer needs a thorough grounding in the fundamental performance of concrete and steel as structural materials and in the behavior of reinforced concrete members and structures. At the same time, the main business of the structural engineer is to design structures safely, economically, and efficiently. Consequently, with this basic understanding as a firm foundation, familiarity with current design procedures is essential. This edition, like the preceding ones, addresses both needs.

The text presents the basic mechanics of structural concrete and methods for the design of individual members subjected to bending, shear, torsion, and axial forces. It additionally addresses in detail applications of the various types of structural members and systems, including an extensive presentation of slabs, beams, columns, walls, footings, retaining walls, and the integration of building systems.

The 2014 ACI Building Code, which governs design practice in most of the United States and serves as a model code in many other countries, is significantly reorganized from previous editions and now focuses on member design and ease of access to code provisions. Strut-and-tie methods for design and anchoring to concrete have been moved from the appendixes into the body of the Code. The Code emphasis on member design reinforces the importance of understanding basic behavior.

To meet the challenges of a revised building Code and the objectives listed above, this edition is revised as follows:

- Every chapter is updated to account for the reorganization of the 2014 American Concrete Institute Building Code.
- The opening chapters explore the roles of design theory, codes, and practice.
- The process of developing building design and the connection between the chapters in the text and the ACI Code is added.
- A new chapter on anchoring to concrete is included.
- A chapter on walls is added, doubling the coverage and adding design examples.
- Diaphragms are included for the first time.
- Coverage of seismic design is updated.

- In addition to changes in the ACI Code, the text also includes the modified compression field theory method of shear design presented in the 2012 edition of the American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications.*
- Chapters on yield line and strip methods for slabs are moved to the McGraw-Hill Education Website (www.mhhe.com/darwin15e).

A strength of the text is the analysis chapter, which includes load combinations for use in design, a description of envelope curves for moment and shear, guidelines for proportioning members under both gravity and lateral loads, and procedures for developing preliminary designs of reinforced concrete structures. The chapter also includes the ACI moment and shear coefficients.

Present-day design is performed using computer programs, either general-purpose commercially available software or individual programs written for special needs. Procedures given throughout the book guide the student and engineer through the increasingly complex methodology of design, with the emphasis on understanding the design process. Once mastered, these procedures are easily converted into flow charts to aid in preparing design aids or to validate commercial computer program output.

The text is suitable for either a one or two-semester course in the design of concrete structures. If the curriculum permits only a single course, probably taught in the fourth undergraduate year, the following will provide a good basis: the introduction and treatment of materials found in Chapters 1 through 3; the material on flexure, shear, and anchorage in Chapters 4, 5, and 6; Chapter 7 on serviceability; Chapter 9 on short columns; the introduction to one-way slabs found in Chapter 12; and footings in Chapter 15. Time may or may not permit classroom coverage of frame analysis or building systems, Chapters 11 and 19, but these could well be assigned as independent reading, concurrent with the earlier work of the course. In the authors' experience, such complementary outside reading tends to enhance student motivation.

The text is more than adequate for a second course, most likely taught in the senior year or the first year of graduate study. The authors have found that this is an excellent opportunity to provide students with a more general understanding of reinforced concrete structural design, often beginning with analysis and building systems, Chapters 11 and 19, followed by the increasingly important behavioral topics of torsion, Chapter 8; slender columns, Chapter 10; the strut-and-tie method of Chapter 17; and the design and detailing of joints, Chapter 18. It should also offer an opportunity for a much-expanded study of slabs, including Chapter 13, plus the methods for slab analysis and design based on plasticity theory found in Chapters 23 and 24 (available online), yield line analysis and the strip method of design. Other topics appropriate to a second course include retaining walls, Chapter 16, and the introduction to earthquake-resistant design in Chapter 20. Prestressed concrete in Chapter 22 is sufficiently important to justify a separate course in conjunction with anchoring to concrete, Chapter 21, and strut-and-tie methods, Chapter 17. If time constraints do not permit this, Chapter 22 provides an introduction and can be used as the text for a one-credit-hour course.

At the end of each chapter, the user will find extensive reference lists, which provide an entry into the literature for those wishing to increase their knowledge through individual study. For professors, the instructor's solution manual is available online at the McGraw-Hill Education Website.

A word must be said about units. In the United States customary inch-pound units remain prominent. Accordingly, inch-pound units are used throughout the text, although some graphs and basic data in Chapter 2 are given in dual units. Appendix B gives the SI equivalents of inch-pound units. An SI version of the ACI Building Code is available.

A brief historical note may be of interest. This book is the fifteenth edition of a textbook originated in 1923 by Leonard C. Urquhart and Charles E. O'Rourke, both professors of structural engineering at Cornell University. Over its remarkable 92-year history, new editions have kept pace with research, improved materials, and new methods of analysis and design. The second, third, and fourth editions firmly established the work as a leading text for elementary courses in the subject area. Professor George Winter, also of Cornell, collaborated with Urquhart in preparing the fifth and sixth editions. Winter and Professor Arthur H. Nilson were responsible for the seventh, eighth, and ninth editions, which substantially expanded both the scope and the depth of the presentation. The tenth, eleventh, and twelfth editions were prepared by Professor Nilson subsequent to Professor Winter's passing in 1982.

Professor Nilson was joined by Professor David Darwin of the University of Kansas and by Professor Charles Dolan of the University of Wyoming beginning with the thirteenth edition. All three have been deeply involved in research and teaching in the fields of reinforced and prestressed concrete, as well as professional Code-writing committees, and have spent significant time in professional practice, invaluable in developing the perspective and structural judgment that sets this book apart.

Special thanks are due to McGraw-Hill Education project team, notably, Lorraine Buczek, Developmental Editor, Melissa Leick, Project Manager, Thomas Scaife, Brand Manager, and Ramya Thirumavalavan, Full Service Project Manager.

We gladly acknowledge our indebtedness to the original authors. Although it is safe to say that neither Urquhart or O'Rourke would recognize much of the detail and that Winter would be impressed by the many changes, the approach to the subject and the educational philosophy that did so much to account for the success of the early editions would be familiar. With the passing of Arthur Nilson in the spring of 2014, we have lost a long-standing mentor, colleague, and friend.

David Darwin
Charles W. Dolan

1 Introduction

1.1 CONCRETE, REINFORCED CONCRETE, AND PRESTRESSED CONCRETE

Concrete is a stonelike material obtained by permitting a carefully proportioned mixture of cement, sand and gravel or other coarse aggregate, and water to harden in forms of the shape and dimensions of the desired structure. The bulk of the material consists of fine and coarse aggregate. Cement and water interact chemically to bind the aggregate particles into a solid mass. Additional water, over and above that needed for this chemical reaction, is necessary to give the mixture the workability that enables it to fill the forms and surround the embedded reinforcing steel prior to hardening. Concretes with a wide range of properties can be obtained by appropriate adjustment of the proportions of the constituent materials. Special cements (such as high early strength cements), special aggregates (such as various lightweight or heavyweight aggregates), admixtures (such as plasticizers, air-entraining agents, silica fume, and fly ash), and special curing methods (such as steam-curing) permit an even wider variety of properties to be obtained.

These properties depend to a very substantial degree on the proportions of the mixture, on the thoroughness with which the various constituents are intermixed, and on the conditions of humidity and temperature in which the mixture is maintained from the moment it is placed in the forms until it is fully hardened. The process of controlling conditions after placement is known as *curing*. To protect against the unintentional production of substandard concrete, a high degree of skillful control and supervision is necessary throughout the process, from the proportioning by weight of the individual components, through mixing and placing, until the completion of curing.

The factors that make concrete a universal building material are so pronounced that it has been used, in more primitive kinds and ways than at present, for thousands of years, starting with lime mortars from 12,000 to 6000 BCE in Crete, Cyprus, Greece, and the Middle East. The facility with which, while plastic, it can be deposited and made to fill forms or molds of almost any practical shape is one of these factors. Its high fire and weather resistance is an evident advantage. Most of the constituent materials, with the exception of cement and additives, are usually available at low cost locally or at small distances from the construction site. Its compressive strength, like that of natural stones, is high, which makes it suitable for members primarily subject to compression, such as columns and arches. On the other hand, again as in natural stones, it is a relatively brittle material whose tensile strength is low compared with its compressive strength. This prevents its economical use as the sole building material in structural members that are subject to tension either entirely (such as in tie-rods) or over part of their cross sections (such as in beams or other flexural members).

To offset this limitation, it was found possible, in the second half of the nineteenth century, to use steel with its high tensile strength to reinforce concrete, chiefly in those places where its low tensile strength would limit the carrying capacity of the member. The reinforcement, usually round steel rods with appropriate surface deformations to provide interlocking, is placed in the forms in advance of the concrete. When completely surrounded by the hardened concrete mass, it forms an integral part of the member. The resulting combination of two materials, known as *reinforced concrete*, combines many of the advantages of each: the relatively low cost, good weather and fire resistance, good compressive strength, and excellent formability of concrete and the high tensile strength and much greater ductility and toughness of steel. It is this combination that allows the almost unlimited range of uses and possibilities of reinforced concrete in the construction of buildings, bridges, dams, tanks, reservoirs, and a host of other structures.

It is possible to produce steels, at relatively low cost, whose yield strength is 3 to 4 times and more that of ordinary reinforcing steels. Likewise, it is possible to produce concrete 4 to 5 times as strong in compression as the more ordinary concretes. These high-strength materials offer many advantages, including smaller member cross sections, reduced dead load, and longer spans. However, there are limits to the strengths of the constituent materials beyond which certain problems arise. To be sure, the strength of such a member would increase roughly in proportion to those of the materials. However, the high strains that result from the high stresses that would otherwise be permissible would lead to large deformations and consequently large deflections of such members under ordinary loading conditions. Equally important, the large strains in such high-strength reinforcing steel would induce large cracks in the surrounding low tensile strength concrete, cracks that not only would be unsightly but also could significantly reduce the durability of the structure. This limits the useful yield strength of high-strength reinforcing steel to 100 ksi[†] according to many codes and specifications; 60 ksi steel is most commonly used.

Construction known as *prestressed concrete*, however, does use steels and concretes of very high strength in combination. The steel, in the form of wires, strands, or bars, is embedded in the concrete under high tension that is held in equilibrium by compressive stresses in the concrete after hardening. Because of this precompression, the concrete in a flexural member will crack on the tension side at a much larger load than when not so precompressed. Prestressing greatly reduces both the deflections and the tensile cracks at ordinary loads in such structures and thereby enables these high-strength materials to be used effectively. Prestressed concrete has extended, to a very significant extent, the range of spans of structural concrete and the types of structures for which it is suited.

1.2 STRUCTURAL FORMS

The figures that follow show some of the principal structural forms of reinforced concrete. Pertinent design methods for many of them are discussed later in this volume.

Floor support systems for buildings include the monolithic slab-and-beam floor shown in Fig. 1.1, the one-way joist system of Fig. 1.2, and the flat plate floor, without beams or girders, shown in Fig. 1.3. The flat slab floor of Fig. 1.4, frequently used for more heavily loaded buildings such as warehouses, is similar to the flat plate floor, but makes use of increased slab thickness in the vicinity of the columns, as well as

[†]Abbreviation for kips per square inch, or thousands of pounds per square inch.

FIGURE 1.1
One-way reinforced concrete floor slab with monolithic supporting beams. (*Portland Cement Association.*)

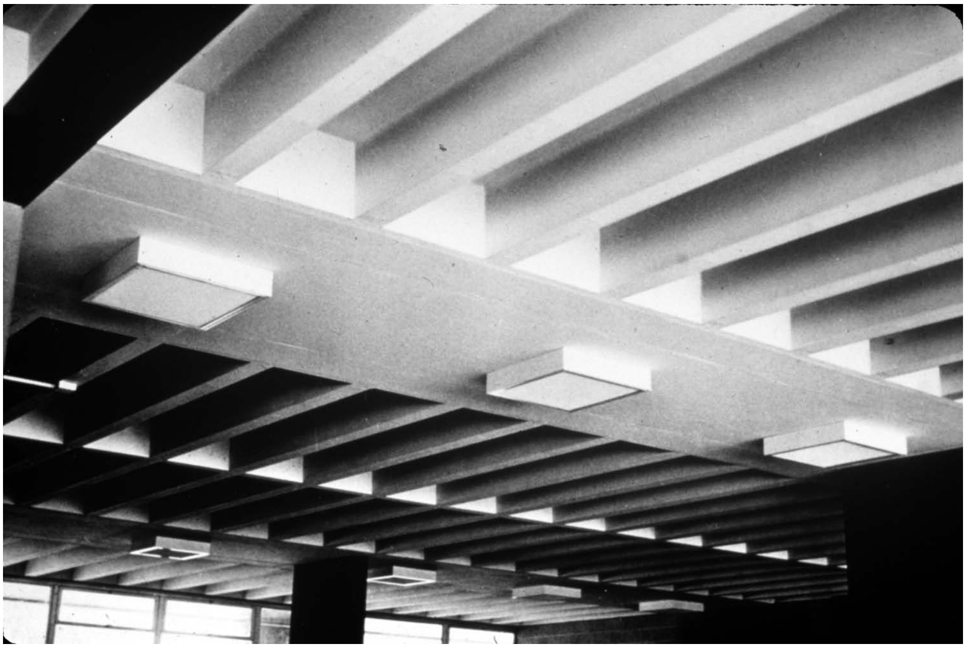


FIGURE 1.2
One-way joist floor system, with closely spaced ribs supported by monolithic concrete beams; transverse ribs provide for lateral distribution of localized loads. (*Portland Cement Association.*)

flared column tops, to reduce stresses and increase strength in the support region. The choice among these and other systems for floors and roofs depends upon functional requirements, loads, spans, and permissible member depths, as well as on cost and esthetic factors.

Where long clear spans are required for roofs, concrete shells permit use of extremely thin surfaces, often thinner, relatively, than an eggshell. The folded plate roof of Fig. 1.5 is simple to form because it is composed of flat surfaces; such roofs have been employed for spans of 200 ft and more. The cylindrical shell of Fig. 1.6 is also relatively easy to form because it has only a single curvature; it is similar to the folded plate in its structural behavior and range of spans and loads. Shells of this type were once quite popular in the United States and remain popular in other parts of the world.

Doubly curved shell surfaces may be generated by simple mathematical curves such as circular arcs, parabolas, and hyperbolas, or they may be composed of complex combinations of shapes. The hyperbolic paraboloid shape, defined by a concave downward parabola moving along a concave upward parabolic path, has been widely

FIGURE 1.3
Flat plate floor slab, carried directly by columns without beams or girders. (*Portland Cement Association.*)

FIGURE 1.4
Flat slab floor, without beams but with slab thickness increased at the columns and with flared column tops to provide for local concentration of forces. (*Portland Cement Association.*)

used. It has the interesting property that the doubly curved surface contains two systems of straight-line generators, permitting straight-form lumber to be used. The complex dome of Fig. 1.7, which provides shelter for performing arts events, consists essentially of a circular dome but includes monolithic, upwardly curved edge surfaces to provide stiffening and strengthening in that critical region.

FIGURE 1.5
Folded plate roof of 125 ft span that, in addition to carrying ordinary roof loads, carries the second floor as well using a system of cable hangers; the ground floor is kept free of columns. (*Photograph by Arthur H. Nilson.*)

FIGURE 1.6
Cylindrical shell roof providing column-free interior space. (*Photograph by Arthur H. Nilson.*)

Bridge design has provided the opportunity for some of the most challenging and creative applications of structural engineering. The award-winning Napoleon Bonaparte Broward Bridge, shown in Fig. 1.8, is a six-lane, cable-stayed structure that spans St. John's River at Dame Point, Jacksonville, Florida. It has a 1300 ft

FIGURE 1.7
Spherical shell in Lausanne, Switzerland. Upwardly curved edges provide stiffening for the central dome. (*Photograph by Arthur H. Nilson.*)

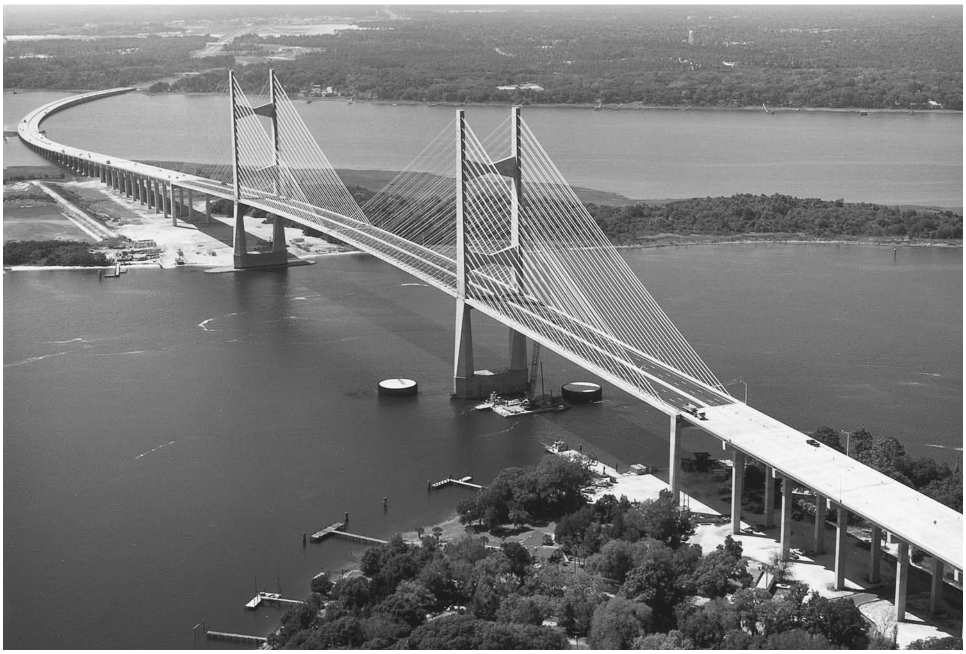


FIGURE 1.8
Napoleon Bonaparte Broward Bridge, with a 1300 ft center span at Dame Point, Jacksonville, Florida. (*HNTB Corporation, Kansas City, Missouri.*)

center span. Figure 1.9 shows the Bennett Bay Centennial Bridge, a four-span continuous, segmentally cast-in-place box girder structure. Special attention was given to esthetics in this award-winning design. The spectacular Natchez Trace Parkway Bridge in Fig. 1.10, a two-span arch structure using hollow precast concrete elements, carries a two-lane highway 155 ft above the valley floor. This structure has won many honors,

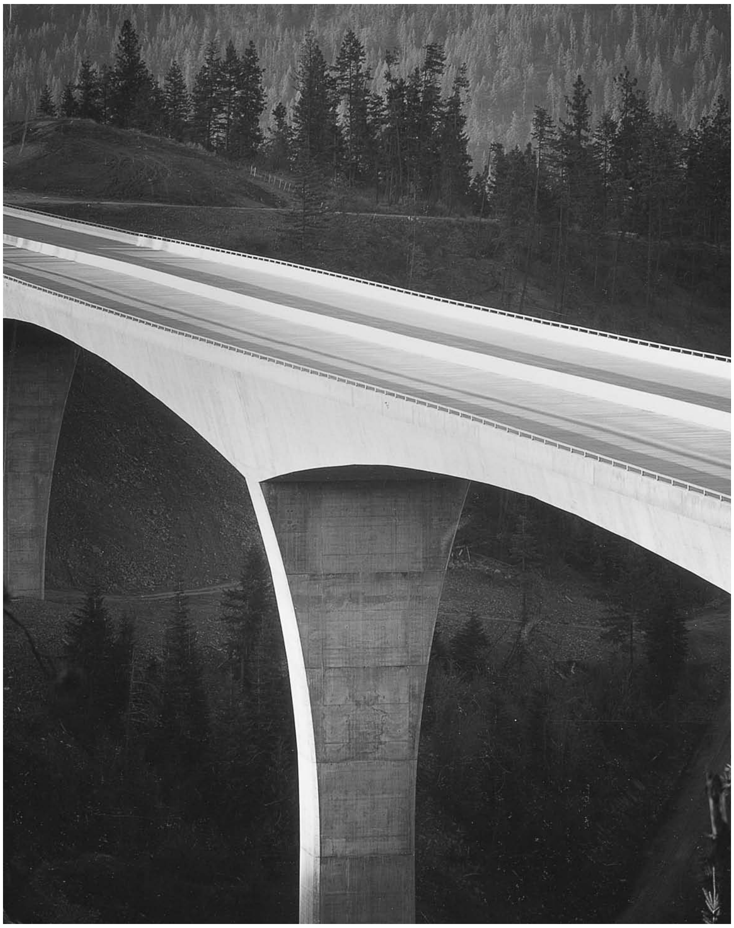


FIGURE 1.9
Bennett Bay Centennial Bridge, Coeur d'Alene, Idaho, a four-span continuous concrete box girder structure of length 1730 ft. (*HNTB Corporation, Kansas City, Missouri.*)

FIGURE 1.10
Natchez Trace Parkway Bridge near Franklin, Tennessee, an award-winning two-span concrete arch structure rising 155 ft above the valley floor. (*Designed by Figg Engineering Group.*)

FIGURE 1.11
The Dakota Dome is a 10,000 seat multipurpose stadium with a concrete frame and ring girder to support the roof. (*Photograph by Charles W. Dolan.*)

including awards from the American Society of Civil Engineers and the National Endowment for the Arts.

The durability and sustainability of concrete structures is evident in the 10,000 seat multipurpose Dakota Dome shown in Fig. 1.11. Originally constructed in 1979 as an inflatable roof dome, the entire concrete structure was retained and a steel roof installed in 2001.

Concrete structures may be designed to provide a wide array of surface textures, colors, and structural forms. Figure 1.12 shows a precast concrete building containing both color changes and architectural finishes.

The forms shown in Figs. 1.1 to 1.12 hardly constitute a complete inventory but are illustrative of the shapes appropriate to the properties of reinforced or prestressed concrete. They illustrate the adaptability of the material to a great variety of one-dimensional (beams, girders, columns), two-dimensional (slabs, arches, rigid frames), and three-dimensional (shells, tanks) structures and structural components. This variability allows the shape of the structure to be adapted to its function in an economical manner, and furnishes the architect and design engineer with a wide variety of possibilities for esthetically satisfying structural solutions.

1.3 LOADS

Loads that act on structures can be divided into three broad categories: dead loads, live loads, and environmental loads.

Dead loads are those that are constant in magnitude and fixed in location throughout the lifetime of the structure. Usually the major part of the dead load is the weight of the structure itself. This can be calculated with good accuracy from the design configuration, dimensions of the structure, and density of the material. For buildings, floor fill, finish floors, and plastered ceilings are usually included as dead loads, and an allowance is made for suspended loads such as piping and lighting fixtures. For bridges, dead loads may include wearing surfaces, sidewalks, and curbs, and an allowance is made for piping and other suspended loads.

Live loads consist chiefly of occupancy loads in buildings and traffic loads on bridges. They may be either fully or partially in place or not present at all, and may also change in location. Their magnitude and distribution at any given time are uncertain, and even their maximum intensities throughout the lifetime of the structure are not known with precision. The minimum live loads for which the floors and roof of

FIGURE 1.12
Concrete structures can be produced in a wide range of colors, finishes, and architectural detailing. (*Courtesy of Rocky Mountain Prestress, LLC.*)

a building should be designed are usually specified in the building code that governs at the site of construction. Representative values of minimum live loads to be used in a wide variety of buildings are found in *Minimum Design Loads for Buildings and Other Structures* (Ref. 1.1), a portion of which is reprinted in Table 1.1. The table gives uniformly distributed live loads for various types of occupancies; these include impact provisions where necessary. These loads are expected maxima and considerably exceed average values.

In addition to these uniformly distributed loads, it is recommended that, as an alternative to the uniform load, floors be designed to support safely certain concentrated loads if these produce a greater stress. For example, according to Ref. 1.1, office floors are to be designed to carry a load of 2000 lb distributed over an area 2.5 ft square (6.25 ft^2), to allow for the weight of a safe or other heavy equipment, and stair treads must safely support a 300 lb load applied on the center of the tread. Certain reductions are often permitted in live loads for members supporting large areas with the understanding that it is unlikely that the entire area would be fully loaded at one time (Refs. 1.1 and 1.2).

Tabulated live loads cannot always be used. The type of occupancy should be considered and the probable loads computed as accurately as possible. Warehouses for heavy storage may be designed for loads as high as 500 psf or more; unusually heavy operations in manufacturing buildings may require an increase in the 250 psf value specified in Table 1.1; special provisions must be made for all definitely located heavy concentrated loads.