混凝土结构设计

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(美)尼尔森(Nilson,A.H.) 编

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Arthur H . Nilson, David Darwin, Charles W . Dolan
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缩编说明

本书是“混凝土结构设计”一书的第13版，根据美国混凝土学会ACI 2002年修订的建筑规范进行了内容的更新。

与前面版本的目的一样，本书的目的首先是建立对结构混凝土性能的扎实理解，然后熟练地掌握当前工程实践中使用的设计方法。因此，本书不仅提供了结构混凝土的基本力学特性以及单一构件在弯、剪、扭以及轴力作用下的设计方法，而且进一步详细给出了它们在各种结构体系中的应用，如板、基础以及挡土墙，还包括节点设计等。有关抗震设计的内容被更新，并包含了预应力混凝土的内容。

与前面版本不同的是，由于ACI 2002建筑规范发生了重大改变，荷载系数和强度折减系数被全面修订，以便与美国土木工程师学会ASCE的建议一致。有关钢筋混凝土和预应力混凝土构件基于应变的抗弯设计“统一方法”，该法在ACI 1999版的附录中作为可供选择的方法，被放入ACI 2002正文。这些变化要求重写本版中相应的重要章节，并修改例子和习题，规范和详文中删去了“替代设计方法”(或被称为“容许应力方法”)。

本书的一个重要特点是全面介绍了板设计的所有内容。前一版中有关双向边支承和柱支承两章的内容被合成一章，删去了在实践中已经很少使用的系数法。本教材继续保留了基于塑性理论的板分析和设计方法，即板分析的屈服线法和板设计的条带法，两种方法对新型的结构尤其重要。

发源于欧洲的拉压杆模型被介绍到美国的实践中，且被包含在ACI 2002规范的附录中。这一方法提供了节点和连接部位，以及特殊构件如深梁等合理的设计方法。因此，有全新的一整章来详细介绍这一方法。

目前的大多数设计都采用计算机程序，如一般用途的商用软件或者特殊用途的单个程序。因此本书非常注重具体的计算，引导学生和工程技术人员逐步掌握复杂的设计方法，重点放在理解设计过程上。一旦掌握了这些过程，那么这些步骤就很容易地

被变成有助于编程的流程图。

本书为钢筋混凝土结构设计的著名教材之一,经过长期的发展和锤炼,已经成为同类中的经典。同时,各章后面列出的参考文献为希望深入钻研相关问题的读者提供了极大的方便。因此,本教材不仅适用于本科生、研究生的课程教学以及有一定基础的学生自学,而且还可作为科研、工程技术人员的重要参考资料。

本书作用 A. H. 尼尔逊教授从事与结构混凝土相关的研究、教学、工程咨询已经 40 余年。他 1948 年在斯坦福大学获得学士学位,1956 年在康奈尔大学获得硕士学位,1967 年在加州大学伯克利分校获得博士学位。从 1956 年起直至 1991 年退休,他作为康奈尔大学工学院的教师,一直负责本科生、研究生有关钢筋混凝土和预应力混凝土结构设计的课程。1978 年至 1985 年,他任结构工程系主任。他在高强混凝土领域中的开创性工作获得了广泛的认同,1974 年获得 ACI 材料研究的 Wason 奖章,1986 年和 1987 年获得 ACI 技术论文的 Wason 奖章,1993 年获得结构研究的 Wason 奖章。尼尔逊教授在许多学术委员会担任职务,他是美国混凝土学会(ACI)和美国土木工程师学会 ASCE 的资深会员,由于教学工作杰出而被康乃尔大学土木工程学生团体表彰。1991 年被选为名誉教授。他还在英国曼彻斯特大学、萨尔福特大学、意大利米兰工业大学等学校担任研究和讲学工作。他是数个州的注册工程师,在开始教学生涯之前,一直从事全职的工程实践。

由于篇幅限制,本书对原书进行了适当的删节。考虑到与我国目前混凝土结构设计教材内容的对应程度,删除了原书中的第 12 章(不静定梁和框架的分析)、第 15 章(板的条带法)、第 16 章(基础)、第 17 章(挡土墙)、第 18 章(混凝土建筑体系)、以及第 20 章(抗震设计)的内容。相应地,对原书的内容进行了重新排序和变更。编者希望这样的做法不致于对原书的特色有较大的影响。不当之处,敬请批评指正。

张　川

2005 年 9 月

About the Authors

Arthur H. Nilson was engaged in research, teaching, and consulting relating to structural concrete for over 40 years. He has been a member of the faculty of the College of Engineering at Cornell University since 1956, in charge of undergraduate and graduate courses in the design of reinforced concrete and prestressed concrete structures until his retirement in 1991. He served as Chairman of the Department of Structural Engineering from 1978 to 1985. Dr. Nilson has served on many professional committees, including Building Code Subcommittee 318-D of the American Concrete Institute (ACI) . 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 has been elected to the grade of fellow in ACI and the American Society of Civil Engineers (ASCE) and has been honored by the civil engineering student body at Cornell for outstanding teaching. He was elected Professor Emeritus in 1991. He has held research appointments or lectureships at the University of Manchester, Salford University, and the Technical University of Milan. He is 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.

David Darwin has been a member of the faculty at the University of Kansas since 1974 and has been director of the Structural Engineering and Materials Laboratory since 1982. He was appointed the Deane E. Ackers Distinguished Professor of Civil Engineering in 1990. Dr. Darwin is a member and past chairman of ACI Committee 224 on Cracking, and is the current chairman of ACI Committee 408 on Bond and Development of Reinforcement. He is also a member of ACI-ASCE Committee 445 on Shear and Torsion. He is an acknowledged expert on concrete crack control and bond between steel reinforcement and concrete. He received the ACI Arthur R. Anderson Award in 1992, for his research efforts in plain and reinforced concrete, and the ACI Structural Research Award in 1996. He has also received a number of awards from the American Society of Civil Engineers, including the Walter L. Huber Civil Engineering Research Prize in 1985, the Moisseiff Award in 1991, and the State-of-the-Art of Civil Engineering Award in 1996 and 2000. He is past editor of the ASCE Journal of Structural Engineering. Professor Darwin is a Fellow of ACI and ASCE. He is a licensed professional engineer and serves as a consultant in the fields of concrete materials and structures. 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 has been on the faculty at the University of Wyoming since 1991, serving as Department Head from 1998 to 2001. He was appointed the H. T. Person Professor of Engineering in 2002. He is currently a member of Building Code Subcommittee 318-F of the American Concrete Institute. He has served as chair of the ACI Technical Activities Committee, of ACI Committee 358 on Transit Guideways, and ACI-ASCE Committee 423 on Prestressed Concrete. In private design practice for nearly 20 years, he was the project engineer on the Walt Disney World Monorail, the Detroit Downtown Peoplemover guideway, and the Dallas-Fort Worth Airport transit system guideway. He received the ASCE T. Y. Lin Award in 1973 for outstanding contributions to the field of prestressed concrete. A Fellow in ACI and the Prestressed Concrete Institute (PCI), he is an internationally recognized leader in the development of fiber reinforced polymers for concrete reinforcement. He is a registered professional engineer and a consultant in the design 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.

Preface

The thirteenth edition of Design of Concrete Structures has the same dual objectives as the previous work: first to establish a firm understanding of the behavior of structural concrete, then to develop proficiency in the methods used in current design practice. The text has been updated in accordance with the provisions of the 2002 American Concrete Institute (ACI) Building Code.

It is generally recognized that mere training in special design skills and codified procedures is inadequate for successful professional practice. As new research becomes available and new design methods are continually 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 basic performance of concrete and steel as structural materials, and in the behavior of reinforced concrete members and structures. On the other hand, 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 not only presents the basic mechanics of structural concrete and methods for the design of individual members for bending, shear, torsion, and axial forces, but also provides much detail pertaining to applications in the various types of structural systems, including an extensive presentation of slabs, footings, foundations, and retaining walls. The important topic of joint design is included. Coverage of seismic design is updated, and an introduction to prestressed concrete is included, as in previous editions.

There have been major changes in the ACI Building Code, which governs design practice in most of the United States, and serves as a model code in many other countries as well. Load factors and strength reduction factors have been entirely revised to agree with the recommendations of the American Society of Civil Engineers (ASCE). The strain-based "unified method" of design for flexure for reinforced and prestressed concrete members, presented as an alternative in an appendix in the 1999 ACI Code, has been incorporated in the main body of the 2002 Code. These changes required rewriting significant sections of the thirteenth edition text and revision of the design examples and problems. The "alternative design method," also known as "allowable stress design," has been removed from the Code and from the text.

A feature of the text is a comprehensive presentation of all aspects of slab design. The two chapters of the previous edition dealing with two-way edge-supported and column-supported slabs have been combined into one, deleting the coefficient method, which is now seldom used in practice. The text continues to include methods of slab analysis and design based on the theory of plasticity: the yield line method for analysis and the strip method for design of slabs, both particularly useful for innovative structures.

The strut-and-tie method, originally developed in Europe, has been introduced into American practice and into an appendix of the 2002 ACI Code. It offers a rational approach to both the detailing of joints and connections and the design of special types of members, such as deep beams. Accordingly, an entirely new chapter giving details of this design approach has been introduced.

The chapter on analysis has been expanded to include load combinations for use in design, a description of envelope curves for moment and shear, and by adding guidelines for proportioning members under both gravity and lateral loads, strengthening the section on preliminary design.

Most present-day design is carried out using computer programs, either generalpurpose commercially available software or individual programs written for special needs. Step-by-step procedures are given throughout the book to guide the student and engineer through the increasingly complex methodology of current design, with the emphasis on understanding the design process. Once mastered, these procedures are easily converted into flow charts to aid in programming. References are given, where appropriate, to the more widely used commercial programs.

The text will be found 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 and 2 respectively; the material on flexure, shear, and anchorage in Chapters 3, 4, and 5; Chapter 6 on serviceability; Chapter 8 on short columns; and the introduction to two-way slabs found in the first five sections of Chapter 12. Time may or may not permit classroom coverage of frame analysis or building systems, Chapters 12 and 18, 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 first year of graduate study. The second course should include the increasingly important topics of torsion, Chapter 7; slender columns, Chapter 9; the strut-and-tie method of Chapter 10; and the design and detailing of joints, Chapter 11. It should also offer an opportunity for a much-expanded study of slabs, including the remaining sections of Chapter 13, plus the methods for slab analysis and design based on plasticity theory found in Chapters 14 and 15, yield line analysis and the strip method of design. Other topics appropriate to a second course include foundations and retaining walls, Chapters 16 and 17, and the introduction to seismic design in Chapter 20. Prestressed concrete is sufficiently important to justify a separate course. If time constraints do not permit this, Chapter 19 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 solutions manual is available online at www. mhhe. com/nilson.

A word must be said about units. In the United States, regrettably, the transition from our customary units to the metric system has proceeded very slowly, and in many quarters not at all. This is in part because of the expense to the construction industry of the conversion, but perhaps also because of perceived shortcomings in the SI metric system (use of derived units such as the pascal, elimination of the convenient centimeter, etc.) compared with the traditional European metric system. Although probably most basic science courses are taught using SI units, in most upper class and graduate design courses, inch-pound units are customarily used, reflecting conditions of practice here. Accordingly, inch-pound units are used throughout the text, although 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 thirteenth 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 80 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. George Winter, also of Cornell, collaborated with Urquhart in preparing the fifth and sixth editions. Winter and the present senior author 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 Arthur Nilson subsequent to George Winter's passing in 1982.

In preparing the present thirteenth edition, Arthur Nilson was joined by David Darwin, of the University of Kansas, and Charles Dolan, of the University of Wyoming. Both have been deeply involved in research and teaching of reinforced and prestressed concrete, as well as professional code-writing committees, and have spent significant time in professional practice as well, invaluable in developing the perspective and structural judgment that sets this book apart.

Special thanks are due to reviewers and former students for their many helpful comments and suggestions for this and previous editions. In particular, the authors would like to thank the following reviewers: Dan Branson, University of Iowa; Hany Farran, California State University, Pomona; Kenneth Fridley, University of Alabama; Kurt Gerstle, University of Colorado; Louis Geschwidner, Pennsylvania State University; Wayne Klaiber, Iowa State University; William Saul, Michigan State University; Shan Somayaji, California Polytechnic State University, San Luis Obispo; Michael Stallings, Auburn University; John Stanton, University of Washington; James Wight, University of Michigan; and Nur Yazdani, Florida State University.

Special mention is due to B. J. Clark, who was Executive Editor for Engineering at McGraw-Hill, and who worked with the senior author in the production of five editions of the text, as well as the present McGraw-Hill project team, notably Kate Scheinman, Developmental Editor, and Sheila Frank, Project Manager.

We gladly acknowledge our indebtedness to the original authors. Although it is safe to say that neither Urquhart nor O'Rourke would recognize very much of the detail, 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. We acknowledge with particular gratitude the influence of George Winter in developing a point of view that has shaped all of the work in the chapters that follow.

Arthur H. Nilson
David Darwin
Charles W. Dolan

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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 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 mix, on the thoroughness with which the various constituents are intermixed, and on the conditions of humidity and temperature in which the mix 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 B.C. 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 are evident advantages. 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 small compared with its compressive strength. This prevents its economical use 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.

In more recent times, it has been found 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 would not only be unsightly but that could significantly reduce the durability of the structure. This limits the useful yield strength of high-strength reinforcing steel to 80 ksi* according to many codes and specifications; 60 ksi steel is most commonly used.

A special way has been found, however, to use steels and concretes of very high strength in combination. This type of construction is known as prestressed concrete. 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.

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* Abbreviation for kips per square inch. or thousands of pounds per square inch.

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 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.

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

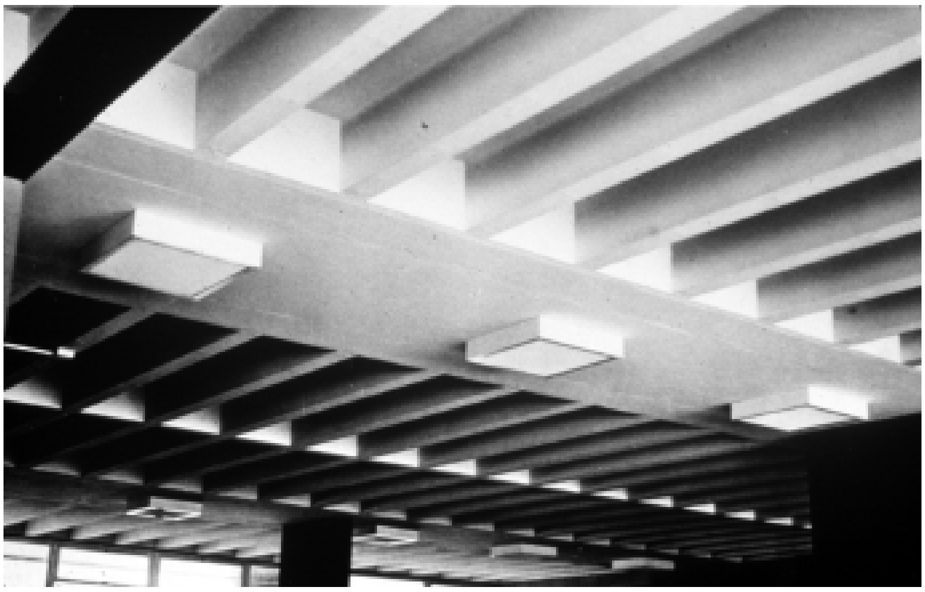

FIGURE 1.2 One-way joist floor system, with closely spaced ribs supported by monolithic concrete beams; transverse ribs provide for lateral distribution of localized loads. (Portland Cement Association.)

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

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.