土建类专业双语教学教材

# 初等钢筋混凝土结构

（第2版）

# Elementary Reinforced Concrete Design

李著璟 著

清华大学出版社

## 内容简介

本书是土建类专业双语教学系列教材之一。鉴于不同国家的“钢筋混凝土结构”课程教学及工程实践经验有所不同，国外的教材往往并不适合于国内的教学，因此，编写符合中国国情的英文教材就成了必要之举。

第一版已于1992年出版并受到广泛好评。本书是在第一版的基础上，根据建设部最新修订颁布的《混凝土结构设计规范GB 50010—2002》修编而成的。本书的编写着眼于结构设计实践，结合结构设计规范讲解钢筋混凝土结构设计的基本原理和方法。

本书可作为国内高等院校“钢筋混凝土”课程的英文教材和钢筋混凝土结构工程设计人员的参考书，还可作为海外土木工程师了解我国现行设计规范的参考书。



**图书在版编目（CIP）数据**

初等钢筋混凝土结构/李著璟著. —2版. —北京：清华大学出版社，2005.1
（土建类专业双语教学教材）
ISBN 7-302-09452-7

Ⅰ. 初…　Ⅱ. 李…　Ⅲ. 钢筋混凝土结构-高等学校-教材-英文　Ⅳ. TU375

中国版本图书馆CIP数据核字（2004）第091436号

**出 版 者**：清华大学出版社　　**地　　址**：北京清华大学学研大厦
http://www.tup.com.cn　　**邮　　编**：100084
**社 总 机**：010-62770175　　**客户服务**：010-62776969
**组稿编辑**：徐晓飞
**文稿编辑**：梁广平
**版式设计**：刘祎淼
**印 装 者**：三河市春园印刷有限公司
**发 行 者**：新华书店总店北京发行所
**开　　本**：203×253　**印张**：22.5　**字数**：517千字
**版　　次**：2005年1月第2版　2005年1月第1次印刷
**书　　号**：ISBN 7-302-09452-7/TU・230
**印　　数**：1~3000
**定　　价**：35.00元

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To

My Students

# PREFACE 1

## TO THE FIRST EDITION

This book is written on the request of the Civil Engineering Department of Tsinghua University. It is the policy of the Civil Engineering Department of Tsinghua University to create for their students a condition so that they may maintain a constant contact with the English language during their academic years in school. Besides giving them the regular language course, it is suggested that the best means to achieve this is to use English textbooks or reference books in some technical courses. This book is the outcome of this policy.

For theoretical courses, such as Theory of Structures, any books published in the United States or Great Britain will serve the purpose. But for a design course, such as Reinforced Concrete Structures, due to the difference of practice in different countries, a foreign textbook will not do. A textbook based on Chinese practice must be written in English. Thus this book is an attempt to answer that purpose; it replaces no other textbooks.

In the writing of a book on the subject of practical design, there is always the problem of to what extent the book is to follow the prevailing design code. As the provisions in a design code are often the results of compromise of different opinions and subject to alterations from time to time, while the principles, on which the design practice are based, are more generally accepted and less subject to changes, the emphasis of this book is placed decidedly on the basic principles involved, and refer to code GBJ 10—89 provisions only when necessary. It is hoped that in this way, the subject discussed in the text will be valid for a longer period of time.

Thus this book is written with the purpose of to be used as a reinforced concrete textbook for Chinese colleges using English language in their lectures. It may also serve as a useful reference book for practicing engineers and designers. For overseas engineers, this book may be used as a reference to the current Chinese design code.

As this book is written in a relatively short time, and not in the writer's mother language, some errors may have slipped the writer's notice. The writer should be much obliged if he is notified by the reader when any error, whether in language or in content, is detected.

Computer programs for the design and calculation of reinforced concrete member sections are compiled at the end of this book. Although these programs have been tested and verified, it is left to the user's discretion to decide whether they are valid for the problem on hand. Neither the writer nor the publisher shall accept liability for any consequence due to the usage of these programs.

The writer wishes to thank the Civil Engineering Department of Tsinghua University for the opportunity of writing this book, which is a pleasure in itself. The writer wishes also to thank the many students he has taught over the past thirty years, for they afforded him the experience of teaching which he hopes he has incorporated in the text. To them this book is sincerely dedicated.

Li Zhujing

Nov. 1990, Beijing

# PREFACE 2

## TO THE PRESENT EDITION

The first edition of this text was published by the Seismological Press of Beijing in 1992. It has since been used to good purpose and well received. But now, after 10 years, in 2002, a new design code, the GB 50010—2002, was passed and put to practice in China. Thus a revision of the text is called for to conform to the stipulations in the new code. The writer regretted to observe that, in his opinion, this new code was unwarrantably over-elaborated. So he has no alternative but to stick to the principle followed in the original edition, i.e. to place the emphasis on the basic principles involved, and refers to the current code only when necessary.

All the examples of course must be rewritten and the computer programs attached at the end of the text were reedited to conform to the new code requirements.

Errors detected in the original edition were corrected, and it is hoped that were all. However, the writer will appreciate if he is informed of any further errors detected in this edition.

The writer wishes to express his indebtedness to the Tsinghua University Press who undertakes the task of publishing this edition.

Li Zhujing

Aug. 2003

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# CHAPTER 1

# INTRODUCTION

## 1.1 Reinforced Concrete Structures

By the definition adopted by the American Concrete Institute in 1923, **concrete** is 'a compound of gravel, broken rock, or other **aggregate**, bound together by means of hydraulic cement, coal tar, asphaltum, or other **cementing materials**. Generally when a qualifying term is not used, **portland cement concrete** is understood.' It is generally known that concrete is weak in tension, with a tensile strength averages only about 1/10 of the compressive strength. Therefore steel reinforcing bars are embedded in concrete structures where tensile stress may occur to take up the tension after the concrete has cracked. Without this reinforcement, the good compressive strength of concrete cannot be fully put into action.

Generally speaking, reinforced concrete structures possess the following features:

(1) Large dead mass

The density of reinforced concrete may reach 2500 kg/m$^3$. Compared with structures of other materials, the reinforced concrete structure generally has a larger dead mass. However, this may not always be a disadvantage, particularly for those structures that rely on dead weight to maintain their stability, such as gravity dam and other retaining structures. The development of **lightweight concrete** by using **lightweight aggregate** has to some extent made concrete structure less massive.

(2) High stiffness

Most of the reinforced concrete structures have members with rather large cross sections. As concrete has a very high modulus of elasticity, reinforced concrete structures are usually stiffer than structures of other materials, and thus are less prone to large deformations. However, this property also makes reinforced concrete less adaptable to structures that require certain flexibility, such as high-rise buildings under seismic action, and particular provisions should be made if reinforced concrete is used in them.

(3) Durability

With the reinforcing steel protected by the concrete, reinforced concrete is perhaps the most durable of all the materials of construction. It will neither rot nor rust, nor vulnerable to efflorescence. It is fire resistant. It requires little maintenance. But at the same time, reinforced concrete structures are the most difficult to demolish or remodel.

(4) Long curing period

It normally takes 28 days curing period under specified conditions for concrete to acquire its full nominal strength. This makes the erection of reinforced concrete structures subject to seasonal climate changes. The development of factory **prefabricated concrete** members alleviates this disadvantage. The standardization of prefabricated members and investment in steel forms in the factory also reduce the consumption of form work materials.

(5) Easily cracked

Concrete is weak in tension, and is thus easily cracked. Reinforcing bars are provided not to prevent the concrete from cracking, but to take up the tension after the concrete has cracked. So most of the reinforced concrete structures in service work in a cracked state. This is an inherent weakness of reinforced concrete structures. **Prestressed concrete** structures subject the concrete to compression before service load is applied, so the pre-compressed concrete can take up some tension without cracking.

## 1.2 Design of Structures

The design process of a structure can be divided into two distinctive stages: the **preliminary design** stage and the **technical design** stage.

The preliminary design stage is also termed the **schematic design** stage. In this stage, the following decisions are generally to be made.

(1) The structure system.

(2) The material of the structure.

(3) The method of erection.

(4) Some control dimensions of the structure.

For instance, in the design of a mill building structure, the structure system may be rigid frame, post and lintel, arch, or truss and columns. The material may be of steel, reinforced concrete, timber, or any combinations of these materials. For a steel truss, the method of assembly may be welding or bolt connections. For reinforced concrete frame, the method of erection may be cast-in-place or assembly of prefabricated parts. The clear span and clear height of the structure must of course be decided.

Clearly, the above decisions cannot be made separately and independently of each other. They must be taken together to form a unified structure entity that answers the purpose and conforms to the conditions at hand.

The technical design stage involves the following works.

(1) The collection of loads that are going to act on the structure. Here the word 'load' is used in the most general sense of the word: any element, which may cause mechanical responses such as displacement, deformation, stress, acceleration, vibration, etc. in the structure, is a load. Thus besides actual weight acting on the structure, temperature change, uneven settlement of foundations, shrinkage of material, wind pressure, etc. are all 'loads'. It is important to find out all the loads that may probably happen to a structure. Then after careful evaluations, some of the less important loads may be left out in the subsequent considerations.

(2) The evaluation of the internal forces, such as moment, shear, torque, normal forces, in every part of the structure.

(3) Based on these internal forces, and taking account of the properties of the materials, check the dimensions of different parts of the structure for adequacy of safety and serviceability.

(4) Taking into consideration of construction requirements, make a detailed design of the structure.

Of these two design stages, clearly the schematic design stage is the decisive and strategic stage. The technical design only confirms the feasibility of the scheme and fills in some necessary details. If the structural scheme is defective, no technical design can cure it. Regrettably it is not possible to give the training of schematic design in school except in a most indirect sense. An adequate schematic design comes from intuition based on the designer's experience, knowledge, and mastery of the information concerning the job on hand and the local conditions. It needs inspiration and so actually belongs to the realm of art. The technical design, on the other hand, belongs to the realm of science. Courses are offered in the curriculum of colleges to give the students a sound training in almost every aspect of the technical design process. Together with Engineering Mechanics, Mechanics of Materials, Theory of Structures, Material of Construction, etc. this course of Reinforced Concrete Design serves that purpose.

## 1.3 A Brief Historical Sketch

Although the use of natural cement as a material of construction may be dated back to the age of the Romans or even earlier, the use of steel reinforced concrete for construction purpose is a much later event. The beginning of reinforced concrete is generally attributed to the Frenchman, Lambot, who in 1850 made a small boat with this material. In England, W. B. Wilkinson registered a patent for reinforced concrete floor slab in 1854. In 1861, the Frenchman Francois Coignet published a statement on the principle of this new construction. In the same year, a gardener in Paris, Joseph Monier, used metal frames as reinforcement to make concrete pots and tubs. Before 1870, Monier had taken a series of patents to make reinforced concrete pipes, slabs, and arches. But Monier had no knowledge of the working principle of this new material and placed the metal reinforcement at the mid-depth of the thickness of his wares. In the meantime, little construction was done in reinforced concrete. It was not until 1887, when the German engineers Wayss and Bauschinger investigated and reported on the Monier system, and proposed to place the reinforcement where the concrete was in tension, that the use of reinforced concrete as a material of construction began to spread rapidly.

Before the early twenties of last century, reinforced concrete went through the initial stage of its development. Various structural elements, such as beams, slabs, columns, frames, arches, footings, etc. were developed with this material. However, the strength of concrete used was still very low. The elements were designed along the principle of allowable stresses, which was an extension of the principles in mechanics of materials. By the late twenties, with the appearance of pre-fabricated members, the prestressed concrete, and thin shells, reinforced concrete entered a new stage of development. Reinforced concrete, because of its low cost and easy availability, has become the staple material of construction all over the world. The quality of concrete was greatly improved. The range of it utility was greatly expanded. The design approach was renovated to fit the new role it was playing in the field of construction.

The common strength of concrete at the beginning of the 20th century was about 15 N/mm$^2$ in compression. The concrete commonly used today has a compressive strength of 20~40 N/mm$^2$. For concrete used in prestressed concrete, the compressive strength may reach 60~80 N/mm$^2$. The development of high strength concrete makes it possible for reinforced concrete to be used in high-rise buildings, off-shore structures, pressure vessels, etc. In order to reduce the dead weight of concrete structures, various kinds of lightweight concrete have been developed with a density of 1.4~1.8 t/m$^3$ (the common concrete has a density of around 2.2 t/m$^3$). With a compressive strength reaching 50 N/mm$^2$, lightweight concrete may be used in load bearing structures. One of the best examples is the gymnasium of the University of Illinois, which has a span of 122 m, and is constructed of concrete with a density of 1.7 t/m$^3$. The Shell Plaza in Houston, built entirely in lightweight concrete, reached a height of 215 m.

The tallest reinforced concrete construction in the world today is the International Television Tower in Toronto, Canada, which reached a height of 549 m. The tallest reinforced concrete construction in China is the television tower in Shanghai, which reached a height of 415 m.

In the design method of reinforced concrete structures, limit state design principle has for the most part replaced the old allowable stress principle. Reliability analysis based on probability theory has been introduced to put the limit state design on a sound theoretical foundation. Elasto-plastic analysis of continuous beams was established and accepted in most of the design codes. Finite element analysis is extensively used in the design of massive reinforced concrete structures, and non-linear behavior of concrete is taken into consideration in the constitutive model of concrete elements. Recent earthquake disasters prompted the research in the design of seismic resistant reinforced concrete structures and significant results have been accumulated.

## 1.4 Special Features of this Course

In most of the curriculum of colleges, the course of Reinforced Concrete Design assumes as prerequisite courses Engineering Mechanics, Mechanics of Materials, and some, if not all of Theory of Structures. In all these courses, with the exception perhaps of Mechanic of Materials to some extent, a structure is treated in the abstract. For instance, in the theory of rigid frame analysis, all members have an abstract $EI / l$ value, regardless of what the actual value may be.

But the theory of reinforced concrete analysis is different. It deals with specific materials, concrete and steel. The values of most parameters must be determined by experiments and can no more be regarded as something abstract.

Although great progress has been made, the theory as it is standing today is yet empirical in nature instead of rational. Many formulas cannot be derived from a few propositions as in mechanics, and this may cause some difficulties for students having their first contact with empirical science in this course. Besides, most countries base their design practice on their own experience and experimental results. Consequently, what one learns in one country may not be valid in another country. Besides, the theory is still in a stage of very rapid development and is subject to revisions according to new findings in the laboratory or in the field. In China the design code undergoes major revision every 15 years or so with many minor revisions in between. In another word, the students must keep in mind that this course cannot give them some knowledge that is universally valid regardless of time and place, but some basic principles, on which the current design practice in this country is established.

The desk calculator has made calculation to a high degree of precision possible and easy. But students must not lose sight that concrete is a job-made material and a 10% consistency in quality is remarkably good. Reinforcing bars are rolled in factory, yet variation in strength may run as high as 5%. The position of bars in the formwork may deviate from their design positions. In fact, two-figure accuracy in calculation is adequate for almost all the cases. Rather than to carry calculations to meaningless precision, the time and effort of the designer are better spent to find out where tension may occur and to provide for it by placing reinforcement there.

However, in order to control the calculation, to make the checking easier, three-figure accuracy is generally required. And to ensure the accuracy of the third figure, it is recommended to carry calculations to the fourth figure. This is the practice this text will follow. With a desk calculator, this is not difficult.