普通高等教育“十一五”国家级规划教材

Structural Mechanics

Bao Shihua Gong Yaoqing

Wuhan University of Technology Press

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Bao Shihua
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Henan Polytechnic University

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内容简介

本书是根据中国高等学校土木工程专业的教学计划、结构力学课程的教学大纲和课程基本要求，为中国高等学校土木工程专业结构力学课程“双语教学”编写的英文结构力学教材。全书共分14章，包括：绪论，结构的几何组成分析，静定梁，静定刚架，三铰拱，静定桁架和组合结构，静定结构总论，影响线，虚功原理和结构的位移，力法，位移法，渐进法和超静定结构的影响线，矩阵位移法和超静定结构总论。除第一章外，每章均有提要、小结、思考题和习题，书后附有答案。

本书与第一作者主编的中文结构力学(参考文献1)在章节次序和内容上基本上是对应的，便于中文与英文教学中交互使用。

本书可作为土木工程专业，即“大土木”的房建、路桥、水利等各类专门化方向的“双语”教材及参考用书，也可供工程技术人员学习专业外语之用。

Brief Introduction of the Book

The textbook, written in terms of the national education program, syllabus and requirement of the course—Structural Mechanics—for the undergraduates majoring in civil engineering in China, is intend to be a sort of bilingually teaching material. It includes 14 chapters, which are: introduction, geometric construction analysis of structures, statically determinate beams, plane statically determinate rigid frames, three-hinged arches, plane statically determinate trusses and composite structures, general remarks on statically determinate structures, influence lines, principle of virtual work and displacement of structures, force method, displacement method, method of successive approximations and influence lines for indeterminate structures, matrix displacement method, and general remarks on statically indeterminate structures. All chapters except for chapter 1 are arranged by abstract, text, summary, problems for reflecting, and problems for solution; the answers to selected problems are attached to the back as well.

It should be pointed out that the arrangement of the content and the order of the chapters for the book is almost the same as its Chinese counterpart (bibliography 1), so as to give an alternant usage for Chinese readers and teachers.

The book can be not only used as a textbook and/or reference book for the students majoring in civil engineering structures, but also employed as a specialized English book for the engineer and technicians interested in civil engineering and English.

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出版教材和专著25本。教材有《高层建筑结构设计》、《结构力学》、《结构力学教程》等，分别于1987年获建设部优秀教材二等奖，1988年、1992年获国家教委国家优秀教材奖，1988年度获教育部科学技术进步奖一等奖，1999年度获国家科学技术进步奖二等奖，2002年获全国普通高等学校优秀教材一等奖。专著有《薄壁杆件结构力学》、《高层建筑结构计算》、《新编高层建筑结构》、《高层建筑结构设计和计算》等。

在国内外发表学术论文110多篇。其中，壳体研究成果被收入国家行业标准《钢筋混凝土薄壳结构设计规程》。提出和创建高层建筑结构解析和半解析常微分方程求解器法系列。科研成果：1993年获北京市科委技术成果奖，1986年、1992年、1994年分别获国家教委科学技术进步奖一、二、三等奖。

龚耀清 1999年清华大学土木工程系毕业并获结构工程专业工学博士学位，师从我国著名土木工程专家龙驭球院士和我国著名高层建筑专家包世华教授。现为河南理工大学特聘教授，研究生导师；国家一级学会中国力学学会主办的中文核心期刊《工程力学》编委会委员；国家自然科学基金委员会工程与材料科学部项目评审专家。1994年被中国力学学会评为优秀力学教师。长期从事"结构力学"的教学工作，近年来主要从事超高层建筑结构与大型桥跨结构的分析与研究，发表学术论文30多篇，其中部分已被EI收录；出版了首部用半解析方法分析超高层建筑结构的专著——《弹性地基上高层建筑结构及半解析法研究》；先后参加和主持国家级、省部级科研基金项目9项，研究成果已得到国内外同行的认可和关注。目前正在英国爱丁堡大学(Edinburgh University)做高级研究者。

About the Authors

BAO SHIHUA, professor in Civil Engineering Department of Tsinghua University, is one of consulting editors of *Engineering Mechanics*, an academic periodical superintended by the China Science Association (CSA) and the Chinese Society of Theoretical and Applied Mechanics (CSTAM); one of commissioners in the Tall Building Committee of the Chinese Society of Architecture. He was a visiting scholar in Civil Engineering Department of University of Illinois during 1985-1986, research fellow in Civil Engineering and Structure Department of Hong Kong Polytechnic University during 1991-1993. He is engaged in the education and academic research for the fields of tall building structures, structural mechanics, elastic theory, energy theorem and finite element method, plate and shell structures, thin walled member structures and so on.

He has been written totally 25 books involving textbooks and monographs. His textbooks written in Chinese are: *Design of Tall Building Structures*, *Structural Mechanics* and so on, which were born off the palms of second-class prize awarded by China Construction Ministry in 1987, advanced textbook prize awarded by China Education Committee in 1988 and 1992, first-class prize of technology advancement awarded by China Education Ministry in 1988, second-class prize of national technology advancement awarded by China Science and Technology Ministry in 1999, and first-class advanced textbook awarded by China Education Ministry in 2002, respectively. His monographs written in Chinese are: *Structural Mechanics for Thin Walled Member Structures*, *Analysis of Tall Building Structures*, *Newly Edited Tall Building Structures Desing and Analysis of Tall Building Structures* Design and Analysis of Tall Building structures and so forth.

His published papers both in his mother language and foreign language exceed 110 pieces, of which papers pertinent to shell structures are adopted by national profession code—*Design Code of Reinforced Concrete Thin Shell Structures*. His pioneering work is analytical and semi-analytical methods by Ordinary Differential Equation Solver used for analyzing tall building structures. His research findings were brought down the persimmon, and awarded for technology advancement prize by Beijing government in 1993, for technology advancement fist-class prize, second-class prize and third-class prize by China Education Committee in 1986, 1992 and 1994, respectively.

GONG YAOQING, graduated and obtained doctor's degree of structural engineering in Civil Engineering Department of Tsinghua University, is a student of Academician Long Yuqiu (a well-known expert in civil engineering) and Professor Bao Shihua (a famous expert in tall building structures), a specially engaged professor and supervisor of postgraduate students in Henan Polytechnic University, one of editors of ***Engineering Mechanics***, an academic periodical superintended by the China Science Association (CSA) and the Chinese Society of Theoretical and Applied Mechanics (CSTAM), one of experts examining and commenting proposal projects in Department of Engineering & Materials Science of National Natural Science Foundation of China. He got an honor of excellent teacher from Chinese Society of Theoretical and Applied Mechanics in 1994.

He has been engaged in the education and academic research for structural mechanics, super tall building and very long-span bridge structures for many years. His published papers have been more than 30 pieces, some of which are accepted by EI Index. In 2003, he published a monograph—*Tall Building Structures on Elastic Subgrade and Research of Semi-Analytical Method* (in Chinese), which is a first monograph pertinent to the semi-analytical analysis about tall and super tall building structures. He has finished 9 researching projects involving with those helped by National Natural Science Foundation of China and local government. His research findings have been paid attention to and interested in by pertinent fellows. He has been doing some research work in Edinburgh University of United Kingdom.

Preface

BACKGROUNG

When time reaches to the 21st century, strong pressures developed from many ranks to write a textbook of *Structural Mechanics* in English for Chinese undergraduates majoring in civil engineering specialty. The naissance of the book is the balance of the pressures and the request of WUTP, Wuhan University of Technology Press, a press in China.

In recent years, the manner of teaching technical courses in English or partially in English is strongly promoted by Chinese Ministry of Education. In the circumstance, the course of *Structural Mechanics* has been taught in English or partially in English in Civil Engineering Department of Tsinghua University since middle 1980s. Here, "taught in English" means that English language is employed in all teaching procedure, such as in class, textbooks and the like; whereas "taught partially in English" indicates that only Chinese language is used in class and English language is adopted in other teaching process, such as textbook, students' homework and so on. The two teaching ways are strongly dependent on the English oral level of the teachers. Nowadays, undergraduates learning *Structural Mechanics* in Civil Engineering Department of Tsinghua University are grouped into two classes, an English class and a Chinese class. In the English class, class language is English, that is, the teacher must use English to prelect and the students must read English textbooks and use English to do their homeworks; while in the Chinese class, class language is Chinese. The two teaching ways have been normalized into teaching plan of Tsinghua University.

The first author of the book, Professor Bao Shihua, has been teaching *Structural Mechanics* partially in English in Tsinghua University since middle 1980s. The second author of the book, Professor Gong Yaoqing, one of Ph D students of the first author, has been teaching *Structural Mechanics* partially in English in Ningxia University and Henan Polytechnic University for many years. The first draft of the book has also been used in Henan Polytechnic University. Apparently, the didactical experience has provided a bed for the appearance of the book.

In China, every specialty in a university has its own teaching plan and every course has its own teaching program and demand depending on different specialties, so does *Structural Mechanics*. The course has formed its own teaching system after nearly 50 years' didactical experience. Nowadays, the teaching system is quite different from that of America or the Great British because the content and system of the textbooks of *Structural Mechanics* coming from the two countries do not have unified syllabus and requirement. So it is hard for the original English textbook of *Structural Mechanics* to meet Chinese syllabus and

requirement. In addition, in the universities of China the teaching plan and program of *Structural Mechanics* must be unchangeable no matter how the course is taught, in English or in Chinese. The tenet has been obeyed for many years by the teachers who teach *Structural Mechanics* in Tsinghua University. Based on the tenet, the book is written by means of teaching plan and program of *Structural Mechanics* used in civil engineering specialty of Chinese universities. In other words, the content and system of the *Structural Mechanics* written in English are identical to those of the *Structural Mechanics* written in Chinese. The original intention of the consistence is to facilitate Chinese readers and teachers.

ORGANIZATION AND APPROACH

Since there are too many contents pertinent to *Structural Mechanics*, the contents are divided, by Chinese teaching program and demand, into two portions, fundamental portion that will be a required course for the common students majoring in civil engineering and advanced portion that is planned to be a selected course for the undergraduates or graduate students who have some advanced requirement for structural analysis. The contents of the fundamental portion are organized by the book, named *Structural Mechanics* including the analysis of statically determinate and indeterminate structures, matrix structural analysis and so on; whereas the contents of the advanced portion are composed by another book, known as *Advanced Topics of Structural Mechanics* or *Advanced Structural Mechanics* comprising the structural dynamics, stabilities of structures, plastic analysis and the like. It is actually the sister book of *Structural Mechanics*.

The compiling outline, content and requirement are designed by the first author, Professor Bao Shihua of Tsinghua University. The initial draft of the book including English composition, figure design and so on is completed by the second author, Professor Gong Yaoqing of Henan Polytechnic University. The final manuscript of the book is also revised and checked by the first author.

Each chapter of the book begins with an abstract introducing its objective, proceeds with text presenting its contents, ends with a summary outlining its salient features, and provides with problems for both reflecting and solution.

The nature of the book is consistent with that of the book written in Chinese.

CONTENTS

This book consists of 14 chapters. Chapter 1 provides a brief introduction of the various types of structural forms and loads. The structurology (or geometric construction) of framed structures is discussed in chapter 2. The analysis of statically determinate structures is covered in the next 5 chapters. Chapter 3 through 6 discuss the analysis of statically determinate beams, rigid frames, three-hinged arches and plane trusses and composite structures, respectively. Chapter 7 presents general remarks on statically determinate structures so as to enhance and deepen the comprehension about the types of structures and their analytical

methods. In chapter 8, influence lines for beams, girders and trusses are discussed by static and mechanical methods, respectively. Chapter 9 covers the principle of virtual work and evaluation of the displacements of statically determinate structures.

In chapter 10 through 12, the analysis of statically indeterminate structures is discussed by the force method (chapter 10), displacement method (chapter 11) and successive approximation method (chapter 12), respectively.

Chapter 13 presents an analytical method by computer program, matrix displacement method. In the chapter, a computer program for the analysis of plane framed structures is also attached.

Chapter 14 makes a general discussion about the analytical methods, behavioral characteristics and computing models of statically indeterminate structures.

ACKNOWLEDGEMENTS

The development of this book was strongly influenced by the authors' colleagues, their students and numerous books published here and abroad. We would like to hereby acknowledge all of their valuable suggestions, comments, help and English composition. In particular we would like to thank the second author's students, Gong Yun and He Shufeng, who prepared the most of the figures on the book.

The authors will be greatly indebted to the readers who dig out the errors slipped the authors' notice in the book because the book is written in a relatively short time, and not in the authors' native language.

Bao Shihua

Gong Yaoqing

June, 2005

Contents

CHAPTER 1
INTRODUCTION

Abstract of the chapter

The chapter will introduce four questions such as the objective and learning method of structural mechanics, the analytical models of structures, the classification of framed structures and their loads. Among the four questions, the analytical models are the most significant since they will lay the foundations of the other chapters of the book.

1.1 Structures and Their Classification

In civil engineering project, the generic term *an engineering structure* or briefly named a structure is referred to as a frame or skeleton used to carry loads applied on it and composed by members of buildings or other constructions made of construction materials. The following figures show some photographs of engineering structures. Figure 1.1 is a tall building suspended structure, Fig. 1.2 is a bridge structure, Fig. 1.3 is the structure of a hydraulic power station, Fig. 1.4 is the structure of an industrial premises. Speaking in detail, the roof panel, the roof truss, the beams, the columns, the foundation and their combination of the one-storey workshop of a plant shown in Fig. 1.18 are all structures.

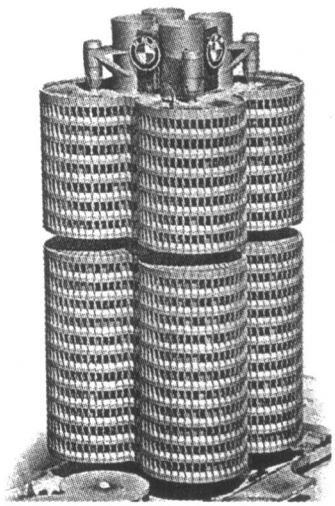


Fig. 1.1 Tall building suspended structure

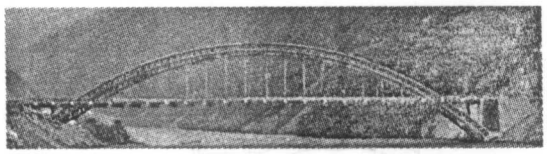


Fig. 1.2 Bridge structure

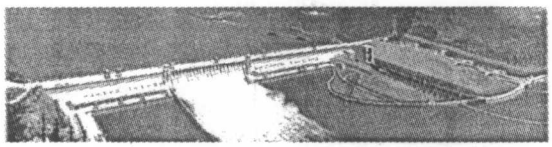


Fig. 1.3 Hydraulic power station

Fig. 1.4 Industrial premises

Structures can be classified into three categories by their geometric characteristics.

(1) Framed structure

A framed structure is comprised of members whose cross-sectional dimension (e. g. the width b and depth h of a rectangular cross section, the radius of a circular cross section, etc.) is much smaller than the length l as shown in Fig. 1. 5. The most commonly used types of structures in the structural engineering are framed structures which will be the main attention the book focuses on.

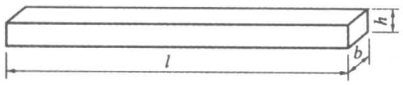


Fig. 1. 5 Bar

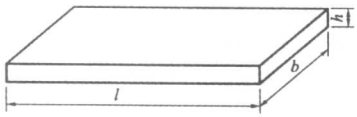
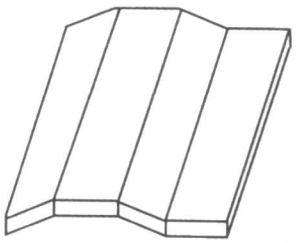


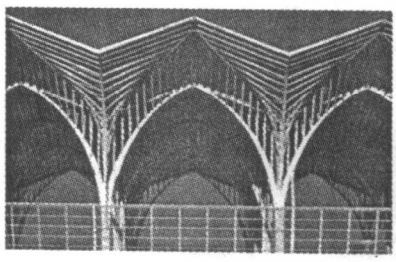
Fig. 1. 6 Plate

(2) Plate, slab and shell (or thin-walled structure)

When the thickness of the structure is very small in comparison with its other two dimensions (length and width), the structure is referred to as a thin-walled structure. The geometric characteristic of a thin-walled structure is that its thickness h is much smaller than its length l and width b. The plate shown in Fig. 1. 6 is one of instances of thin-walled structures. The combination of finite number of plates would develop a floded plate shown as in Fig. 1. 7 (a). Figure 1. 7 (b) shows a building with a roof structure composed of floded plates. If a structure has a curved middle surface, it is called a shell, as shown in Fig. 1. 8. In that context, a plate or a slab can be considered as a thin-walled structure with a plane middle surface.



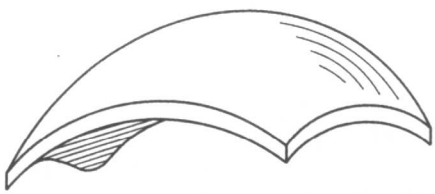
(a)



(b)

Fig. 1. 7 Floded plate structure

(a) floded plate; (b) floded plate roof



(a)

(b)

Fig. 1. 8 Shell structure

(a) shell; (b) shell roof

(3) Massive structure

The three dimensions (length l, width b and depth h) of a massive structure have the same order of magnitude. Consider, for example, the retaining wall shown in Fig. 1.9 and the dam shown in Fig. 1.10 are two of projects applying massive structures.

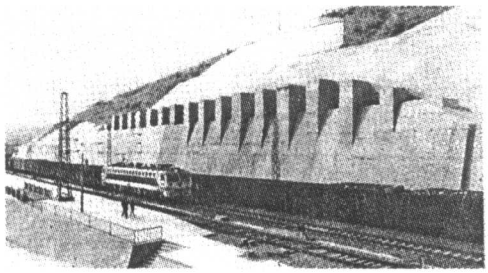


Fig. 1.9 Retaining wall

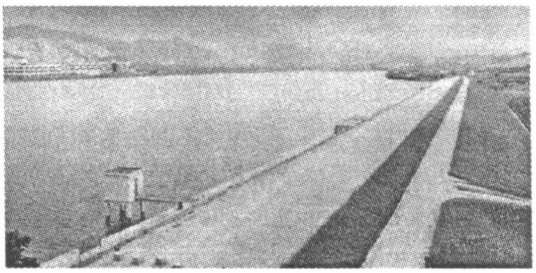


Fig. 1.10 Dam

1.2 Objective and Learning Method of Structural Mechanics

1.2.1 The relationship between Structural Mechanics and other curricula

In Structural Mechanics, the primary focus will be on the analysis of the structure. In this context, you can name the course as Mechanics of Framed Structure. For simplicity, Structural Mechanics is adopted.

Structural Mechanics belongs to one of technically fundamental courses, plays a very important role and is a connecting link between the preceding courses and the following (or subsequent) courses learned by the undergraduates majoring in the specialty pertinent to civil engineering.

Structural Mechanics is the following course of Theoretical Mechanics and Strength of Materials. The objective of Theoretical Mechanics is the investigation of essential rules and analysis of mechanical motion (including static state and equilibrium) of rigid bodies. The attention paid by Strength of Materials is the strength, stiffness and stability of a single member (or a bar). While the contents treated of in Structural Mechanics are the strength, stiffness and stability of framed structures, which are composed of many members. Therefore, Theoretical Mechanics and Strength of Materials would provide primary principles and basement of mechanical analysis for the studying of Structural Mechanics.

Structural Mechanics is meanwhile the preceding course of Theory of Elasticity (focusing on the strength, stiffness and stability of plate, shell and massive structures), Reinforced Concrete Design, Masonry Structure, Steel Structure and other specialized curricula associated with building construction, structural engineering, highway engineering, bridge engineering, water conservancy engineering and underground engineering. By this token, Structural Mechanics will provide basic mechanical knowledge for the studying of the subsequent courses and play a very important role in the specialty pertinent to civil engineering.