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Introduction to Solid Mechanics
(Third Edition)

固体力学引论（第3版）

Irving H. Shames & James M. Pitarresi

清华大学出版社

内容简介

本书把固体力学的基本概念、基本原理和常用公式提取出来，采用物理概念加简明数学推导的讲授方法，不追求理论的完整性和系统性，不要求学生掌握用解析方法求解固体力学二维、三维问题的能力，而把重点放在正确理解概念和合理应用基本原理及常用公式去解决工程问题。

本书像一本拓展了的材料力学教材，按基础课的要求把固体力学和材料力学两者融为一体、选其精华，是一本颇有特色的教材，目前已经是第3版。作者有丰富的教学经验，曾写过不少优秀教材，本书对我国工程专业力学系列课程的教学改革具有参考意义。

本书可以作为我国材料力学、工程力学和弹性力学课程的英文教材或教学参考书。

本书特色

- 按基础课的要求把固体力学和材料力学两者融为一体、选其精华。
- 采用物理概念加简明数学推导的讲授方法，理论、分析与应用相辅相成，反映了作者丰富的教学经验。
- 把重点放在正确理解概念和合理应用基本原理及常用公式去解决工程问题。不追求理论的完整性，不要求掌握解析求解固体力学问题的能力。
- 每章包括大量例题和习题，全部习题均有答案。

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THIRD EDITION

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Introduction to Solid Mechanics (Third Edition)

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影 印 版 序

随着计算机的迅速发展、有限元分析软件的广泛应用，对工程师们力学基础的要求也越来越高，然而教学学时却在不断压缩。如何改造材料力学和固体力学的教学体系和教学大纲是当今国内外都在研究的重要问题。本书在这方面进行了有益的探讨。

本书把固体力学中最基本的概念、原理和部分常用公式提取出来，尽量用概念加简明的数学推导进行讲述，不求理论上的完整性、系统性，也不要求学生掌握用解析方法求解固体力学二维、三维问题的能力，而把重点放在正确地理解概念和合理地应用基本原理及常用公式去解决工程问题。本书又包括了材料力学课程中最基本的教学内容，像是一本拓展了的材料力学教材，在学习本课程以前不必先修材料力学课程，是一本颇有特色的教材。

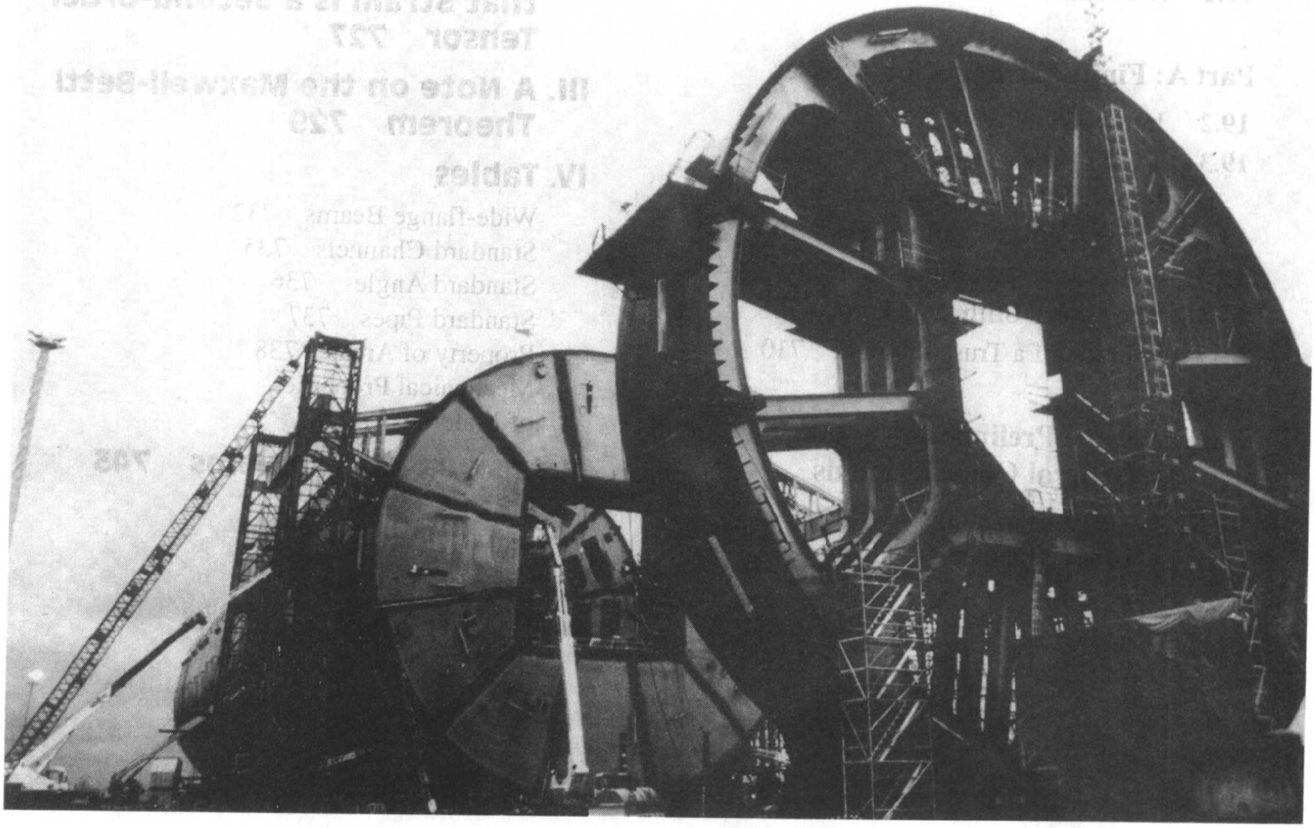
作者有丰富的教学经验，曾写过工程力学、固体力学、流体力学、力学中的变分方法、有限元方法等领域中的 10 本教材，其中有些已被国外大学所采用，并被翻译成其他语言版本。

全书共分 19 章，5 个附录。第 1 章介绍基本概念和符号；第 2 章讲述应力基本概念和平衡微分方程；第 3 章讲述应变基本概念、应变-位移公式和协调方程；第 4 章是固体力学性质引论，包括弹性、塑性、时间相关性、疲劳、应力集中、热应力等方面；第 5 章讨论材料力学的一维拉压问题，包括静定、静不定问题和残余应力问题；第 6 章讲述广义虎克定律、应变能和卡氏第一定律，最后总结了弹性力学基本方程；第 7 章、第 8 章讲述平面应力和平面应变情况，包括两类问题的特点、坐标转换关系、主应力、主应变和莫尔圆，而不涉及弹性力学中导出和求解平面问题基本方程的内容；第 9 章讲述失效准则，包括最大正应力、最大正应变、最大剪应力、最大剪应变、最大畸变（歪形）能 5 个准则；第 10 章到第 12 章讲述材料力学的经典内容，包括梁的内力和内力矩、梁的应力和挠度；第 13 章用奇函数求解梁的挠度，属于选讲内容；第 14 章讲述圆轴和薄壁杆件的扭转问题；第 15 章和第 16 章介绍弹性力学的三维应力和应变理论，包括应力和应变性质、斜面应力公式、坐标转换关系、主应力、主应变、张量的不变量等；第 17 章介绍弹性稳定性问题，包括临界载荷、压杆的屈曲、纵横弯曲、偏心和初曲率的影响、非弹性情况等；第 18 章讲解能量法，包括位移法（虚功原理，势能原理和卡氏第一定律）和力法（余虚功原理，余能原理和卡氏第二定律），属于选讲内容；第 19 章介绍有限元法，

先以杆系为对象讲述有限元法的基本思想，然后做一般性的推广，也属于选讲内容。每章都包含大量例题和习题。附录 I 是各向同性材料的变形；附录 II 用张量符号证明应变是二阶张量；附录 III 是关于麦克斯威尔-贝蒂定理的注释；附录 IV 是一组常用表格；附录 V 是全部习题的答案。

目前我国没有与本书相适应的课程：作为材料力学教材，本书内容偏多，学时不够；作为弹性力学教材，本书的要求偏低。本书是按基础课的要求把两者融为一体、选其精华的教材，对我国工程专业力学系列课程的教学改革具有参考意义。目前可以作为我国材料力学、工程力学和弹性力学课程的英文教材或教学参考书。

清华大学工程力学系
陆明万



A deep-draft caisson vessel to be used for off-shore oil drilling.
Photo by Wilfred Kruger / Black Star / Courtesy Exxon Corporation.

Preface

With the publication of the third edition, this book enters the third decade of its existence—this time with a co-author who used the book, first as an undergraduate student and then later for many years as a professor. The main thrust has not changed from that of its predecessors. We have strived to make this treatment careful and thorough without short changing or sneeking around important but challenging fundamentals. We have presented the theory in a mature manner that we have found for many years and for varied classes to be within the reach of sophomores.* The goal has been to get to a point wherein students know the theory well enough so as to solve problems from first principles. That is, we have tried to avoid presenting in a weak matrix of discussion, lists of procedures for solving various classes of problems and for which strings of examples are presented in a way to encourage the mapping of homework problems from the examples. In short, we have tried to avoid a "black box" approach whose main thrust is on methodology. We have found over the years that students will retain the material much better when learning stems from fundamentals to applications directly with a minimum of rote learning of recipes accompanied by excessive problem mapping. What is worse, we believe that students that "plug and chug," relying on the recipes while cramming for exams, do not mature analytically in mechanics as they should. Furthermore, we believe that well grounded theory in solids will give the student a more meaningful experience and grasp in later mechanics-based courses such as fluids, structures, machine design etc.

The steps we have taken in this edition to help foster problem solving from first principles and to increase retention of basics are as follows:

1. At appropriate places, we have inserted "A Look Back" section that reviews the material covered in Statics, Dynamics, and Physics for purposes of continuity and to make for greater ease in dealing with new material that depends on these earlier studies. These sections are short and to the point.

*Later, more will be said about sophomore coverage as well as possible use of this book.

2. There are a number of starred sections entitled "A Look Ahead" which open-end the text toward future work that may interest the student. We found that the more serious students will look at this material and at a later in more advanced courses will come back to these sections for valuable linkups with the solids courses. At the least, they will see that the theory they are studying with some depth does continue on in later courses.
3. At the end of each chapter, there is a "Closure" that reminds the Student of the contents of the chapter and sets the stage for the next chapter which with an "Introduction" section picks up the subject thread.

Thus, with these three items, we are attempting to provide continuity first between courses in the curriculum and also continuity between chapters in the course. This is important since mechanics in a vertical subject and solids is but one part of a very extensive discipline. That is another reason for emphasizing the theory since it is the glue that binds the various aspects of the subject. There is yet one more new item that we have included.

4. At the end of each chapter, there is a "Highlights" section. Here, we go over the essence of the chapter without mathematical and developmental details to give a physically meaningful discussion of key items. This reading comes after the student has read relevant parts of the chapter for his/her course, done the assigned homework, participated in classroom work, and heard and participated in discussions in and out of the classroom. This possibility of an uncluttered but informed overview we find to be very valuable for the learning process.

We wish to emphasize that the developments and the examples are firmly built around what we call the three pillars of solid mechanics, namely **equilibrium, constitutive laws,** and **compatibility**.* Compatibility is carefully defined early in the book in terms of requiring the strain fields to be properly related to single-valued and continuous displacement fields. We do not use the second-order partial differential equations to satisfy compatibility but instead use geometry and trigonometry to accomplish this goal. As an example, for a truss we make sure at a joint that, when the pin is associated with one of the members, its movement is compatible with the movement of this pin when it is associated with any other member at the joint. That is, the pin must end up at the same position, independent of which member it might be associated with. Thus, in this way using geometry and trigonometry we insure a single valued, continuous deformation of the truss. Those readers that get into the energy formulations will see that compatibility plays an analogous and an equally important role as equilibrium. In energy formulations we can use the vital strain-displacement relations developed early in the book to form compatible strain fields. The three pillars are identified as they occur in the energy material and are thus highlighted throughout the entire book.

*Notice from the cover that even the publisher is supporting **"SOLID MECHANICS"** with three pillars—presumably the three mentioned above.

As is well known, there are two conventions in use for shear forces, bending moments, etc. One is highly favored by civil engineers (called the structural convention) and the other (called the stress convention) is used by a significant number of mechanical and aerospace engineers as well as by some applied mechanicians. We have introduced both conventions. However, at the request of users of the earlier editions, we have gone over to the structural convention in this text. Also, we have used the more standard notation, v, for the deflection of the neutral surface.

Next, we have presented the second Castigliano theorem carefully via the interesting Maxwell-Betti reciprocal theorem fairly early in the text and it is used for trusses at its introduction. Later, it is used in the beam and torsion chapters. In presenting this very useful theorem, we point out that it is the third derived principle in the **energy force methods** and that there is an analogous set of principles called the **energy displacement methods**. The interested student is invited to examine these beautiful and powerful systems of principles in chapter 18. Advanced work in solid mechanics will require a thorough understanding of this material. We have found that this chapter, although rigorous, is within the reach of competent sophomores should the instructor desire to use it for extra credit or honors work.

To discourage excessive mapping, the homework problems are placed at the end of the chapters. Two-thirds of the problems indicate in brackets the latest section of the chapter for which knowledge is needed for a solution; the last third is in random order. The instructors manual will give the instructor the information as to what last section is needed for a solution of these random problems. Also, the manual includes a three-level rating system of the degree of difficulty to be expected for each problem. Finally, examples are not adjusted to fit each on a single page nor are they delineated as a series of steps. Instead generous explanations are made to elaborate how the theory and the modeling have been applied without such artificial constraints of space and form. In short, the examples are meant more to be read and studied and less to be mapped.

It is the feeling of the authors that the student should be familiar with the use of modern engineering computer-based tools. These include (but are by no means limited to) such general purpose codes as *Mathematica*, MathCAD, and Maple. Such computer programs allow for both symbolic and numeric manipulations of expressions. This can be very helpful for both the derivation of equations as well as their solution. But perhaps most importantly, codes such as these permit the students to conveniently maintain certain key parameters as variables within the solution equations. By subsequently plotting the relationship between the variables, insight into the nature of the solution is gained. In this way, the students can accelerate their development of "engineering feel." These problems are double-starred and are at the very ends of the chapters. We have presented a series of problems throughout the text using this philosophy. We have made the problems independent of any particular software package. The focus is on the nature of the solution and the interaction of the variables. We want to encourage the student to try these problems—they are often challenging and fun! To help foster and maintain computer programming skills, a number of problems and/or projects are also presented whereby the student is asked to write a program using high level computer language such as FORTRAN or C.

Design is blended in throughout the text. We have not presented specialized formulas for this phase of the text. A number of regular problems and particularly computer-based problems and projects are design oriented.

We continue to include a treatment of singularities. We do not use the "disappearing brackets" approach. Instead, we use the step function, the delta function and the doublet function. This approach takes more time to learn, but once learned it can be used in important numerical methods such as the boundary element method, not to speak of heat transfer, electromagnetic theory, and many forms of continuum mechanics. Finally, we wish to point out that our singularities stem from a legitimate area of mathematics called *distribution theory*. We normally do not cover this material in our first course except to explain the gains to be realized from its use. To our delight, we have found that there are some students each year who learn the method on their own in order to spare themselves of the excessive amount of arithmetic for solving the deflection of beams problems.

Now a word about the chapter (19) on the introduction of finite elements. Our reviewers approved of its inclusion. However, our primary reason for including it stems from the following experience. Many of our seniors do design projects and use finite element codes for computing stresses. When queried, we found they were working without the slightest understanding of the finite element method and spending much time as a "black box" participant. We believe it is not wise to have students working blindly with computer software and so we continue to urge these students to study with our help the introductory chapter on finite elements when they use software for finite elements.

A quick inspection of the text will indicate that there is a fair amount of what is considered "advanced" material for sophomores and that there is more material than can be comfortably covered in a three-credit or even a four-credit course. This is deliberate on the part of the authors and we make no apologies for this. We have found that students in our curricula come back to this text in their later studies for linking up new material in solid mechanics with expositions that are extrapolations of their earlier familiar work. As examples, we have included treatments of three-dimensional stress and three-dimensional strain, the six principles of energy methods, singularity functions, a gentle introduction to second-order tensors, viscoelasticity and creep, composite materials, and a direct way to determine the sign of shear stress in thin-walled open members. Furthermore, we have endeavored to write this text to be flexible in its possible uses. Thus, for a number of years an earlier edition of this book was used as a second course at Binghamton when engineering was an upper division program there and the students were transfers from community colleges where they received the usual first course in solid mechanics. Also, by deleting starred material; by carefully choosing topics in the text: and by using problems in the lower levels of difficulty as specified in the instructors manual, the instructor can still present an excellent, rigorous course of modest proportions should that be called for. The authors employ about 65 percent of the book in their respective schools in a first 3 credit hour course.

We have set for ourselves the goal of continuing the development of a quality, time-tested text for sophomore or junior solids courses, and in addition to serve students for the remainder of his/her college work and even beyond.

The following professors were reviewers of this edition of the book:

1. Professor Joseph M. Bracci, Dept. of Civil Engineering, Texas A&M University
2. Professor Makola M. Abdullah, Dept. of Civil Engineering, Florida A&M University
3. Professor Eliot Fried, Dept. of Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign
4. Professor Michael D. Symans, Dept. of Civil and Environmental Engineering, Washington State University

We thank them for their efforts and their encouraging as well as useful comments. Professor Symans, in addition to an overall review mentioned above, gave us an in-depth line by line critique of the book including rewrites of selected short but important portions of examples and text. We thank him profusely. Professor Shahid Ahmad, a most esteemed colleague of coauthor Shames for many years, alternated teaching solid mechanics each semester with him to large sophomore classes at Buffalo using earlier editions of this book. His comments and ideas for using the book most effectively have found their way into this edition. Most importantly, his support and enthusiasm for the book is most gratefully received. Coauthor Pitarresi wishes to thank his former instructor Professor Toby Richards at Buffalo for permitting him to use a half-dozen of his excellent problems for this edition. And both coauthors wish to thank their other respective colleagues at Buffalo and at Binghamton for their continued support and approval of the contents and educational philosophy of the book. Finally, Professor Shames would like to take the liberty of extending his profound appreciation toward his new distinguished colleagues at The George Washington University for the welcome he has received from them. They have encouraged him to play a significant role in their academic program. And they have welcomed his continued writing efforts while at the same time they have insisted on using his existing books wherever possible.

About the Authors

Professor Shames spent 31 years at the State University at Buffalo where he attained the titles of Faculty Professor and Distinguished Teaching Professor. Since 1993 he has been teaching full time at The George Washington University as Visiting Distinguished Professor and as Professor. At the present time, he has written 10 books in mechanics including undergraduate and graduate texts. These books have been used world wide in English and in a half dozen translations. His books have had a number of important "firsts" that have become mainstays as to the way mechanics is now taught. Remarkably, virtually everything that Professor Shames has published during a period of over four decades is still in print. The following are his textbooks:

- *Engineering Mechanics—Statics,* Prentice-Hall, Inc.
- *Engineering Mechanics—Dynamics,* Prentice-Hall, Inc.
- *Engineering Mechanics—Statics and Dynamics,* Prentice-Hall, Inc.
- *Mechanics of Deformable Solids*, Krieger Publishing Co.
- *Introduction to Statics,* Prentice-Hall, Inc.
- *Introduction to Solid Mechanics*, Prentice-Hall, Inc.
- *Mechanics of Fluids*, McGraw-Hill, Inc.
- *Elastic and Inelastic Stress Analysis* (with F. Cozzarelli), Taylor & Francis
- *Solid Mechanics—A Variational Approach,* (with C.L. Dym), McGraw-Hill, Inc.
- *Energy and Finite Element Methods in Structural Mechanics,* (with C.L. Dym), Taylor & Francis

James M. Pitarresi is an Associate Professor in the Department of Mechanical Engineering at the State University of New York at Binghamton (Binghamton University). Dr. Pitarresi received his BS (1981), MS (1983) and PhD (1986) from the Department of Civil Engineering at the State University of New York at Buffalo. Throughout his career, he has been closely involved with the development and use of computers in solving complex engineering problems. He has worked as a stress analyst for the automotive and aerospace industry and as a post-doctoral research associate at the National Center for Earthquake Engineering Research. Dr. Pitarresi is a consultant to industry and government and is an active researcher having written over thirty-five technical papers. He is currently the director of the Opto-Mechanical Research Lab and co-director of the Vibration Research Lab at Binghamton University. In 1999, he was honored with the Chancellor's Award for Excellence in Teaching and the Peter A. Engel Memorial Teaching Award.

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