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Engineering Mechanics

SECOND EDITION

BASUDEB BHATTACHARYYA

Engineering Mechanics

SECOND EDITION

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Dedicated
to the sweet memories of
my grandfather
(Late) Shibendra Bhusan Bhattacharyya
and
my grandmother-in-law
(Late) Susangini Devi

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Foreword

A thorough understanding of engineering mechanics is a prerequisite for successfully pursuing professional courses in various engineering disciplines such as civil, mechanical, aerospace, chemical, and materials engineering. Therefore, the availability of a good textbook on engineering mechanics is equally important for both students and teachers of almost all engineering disciplines. This authoritative text, painstakingly written by Professor Basudeb Bhattacharyya, goes a long way in fulfilling this requirement.

Mechanics is generally taught as a part of a course in physics, where the emphasis is on the basic principles. However, to apply these principles to solve real-life engineering problems, a strong foundation in modelling, especially of the supports at the foundation or frame and the connections between the various elements idealized as extended rigid or deformable bodies, is essential. Special attention given to this aspect in the text under consideration makes it unique amongst a large number of existing texts on engineering mechanics.

A balanced treatment has been provided to the three sub-areas of mechanics, namely statics, kinematics, and dynamics. While dynamics of particles and rigid bodies have been discussed in detail covering several chapters, a brief introduction to vibration, that is, dynamics of deformable bodies, has also been included. A large number of problems have been worked out in sufficient detail. This makes the book very suitable for self-study by any interested student. Another outstanding feature of the book is the excellent collection of review and multiple-choice questions and numerical problems in every chapter, which can be used by students for practice and testing his/her understanding of the concepts covered. I also appreciate another unusual feature, that is, inclusion of a brief historical perspective of every topic, which is generally not found in other texts. This will help both teachers and students to familiarize themselves with the gradual development of engineering mechanics for almost two centuries.

I am confident that the community of students and teachers will appreciate the great effort made by Prof. Bhattacharyya to produce this outstanding text on a very fundamental and useful subject.

A.K. Mallik
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Foreword

Preface to the Second Edition

Engineering Mechanics is the practical application of mechanics concerned with the behaviour of bodies or a system of bodies subjected to external forces or displacements. The main objective of this course is to help students develop a thorough understanding of the theories and principles and thereby acquire the analytical capability required for solving real-life problems. It is one of the foundation courses that form the basis of many of the traditional branches of engineering, such as aerospace, civil, and mechanical engineering. This textbook has been developed to provide a comprehensive and consistent coverage of the fundamentals of statics and dynamics.

About the Book

This edition provides an in-depth coverage of the basic concepts of mechanics. The text is divided into two parts—statics and dynamics. In *statics,* the concept of force systems and equilibrium is followed by the applications of statics. *Dynamics* deals with the motion of particles and rigid bodies under the application of forces. A large number of solved examples (some solved using the vector approach) with step-by-step explanation and numerous illustrations have been included to aid in the understanding of theoretical concepts.

The book has been revised and updated by incorporating necessary additions and alterations, so as to cover the syllabi of almost all the standard technical universities in India. Although this book primarily targets the undergraduate students of engineering and technology in the first and/or sophomore year, it can also be used to prepare for various competitive examinations at graduate level such as IAS, IES, WBCS, and WBAS.

New to the Second Edition

- A chapter on simple lifting machines
- Additional topics such as parabolic and catenary cables, product and principal moment of area, stability of equilibrium, equations of motion with variable acceleration, angular impulse, and angular momentum
- Numerous illustrations, solved problems, review questions, and numerical problems
- Two new appendices—Appendix A on the timeline of important discoveries and inventions in classical mechanics and Appendix H on shear force and bending moment

Extended Chapter Material

Chapter 1 Basic concepts such as different types of vectors and vector algebra have been moved to Appendix D from this chapter. New sections on force fields; different approaches to find the resultant of coplanar, concurrent force systems

(triangular/parallelogram/polygon law of forces); resolution of a force into components; resultant of coplanar, non-concurrent force systems; resultant of non-coplanar, concurrent force systems; and resultant of non-coplanar, non-concurrent force systems have been included.

Chapter 2 New sections on parallel shifting of forces, active and reactive forces, and different types of support have been added to this chapter.

Chapter 3 This chapter now includes different types of trusses, elements of suspension cables, and catenary and parabolic cables. New figures have been added to show the different types of trusses.

Chapter 4 As a result of reorganization, the sections on screwjack and differential screwjack have been moved to Chapter 7. A number of new examples have been included.

Chapter 5 This chapter has been expanded by including topics such as definition and formulation of product moment of area, rotation of axes and principal axes, principal moments of area, and maximum and minimum values of moments of area.

Chapter 6 New sections on virtual displacement, virtual rotation, and stability of equilibrium and necessary conditions have been added to this chapter.

Chapter 7 This is a new chapter which discusses different types of simple lifting machines.

Chapter 8 This chapter now includes derivation of kinematic parameters in angular motion, equations of motion with variable acceleration, and analysis of projectile motion along an inclined plane.

Chapter 12 A new section on angular impulse and momentum has been included. The section on conservation of momentum has been expanded.

Appendix H A new appendix on different types of beams and shear force and bending moment diagrams has been included.

Content and Structure

The book has been structured into two parts and has 13 chapters.

Part I: Statics

Chapter 1 provides an introduction to statics and discusses the concepts of idealization of matter, force, principle of superposition, resultant of different types of force systems, and moment of a force and a couple. **Chapter 2** discusses the static equilibrium (both force and moment) of rigid bodies and free-body diagrams. **Chapter 3** covers the analysis of trusses, frames, and suspension cables with point and uniformly distributed loading.

Chapter 4 defines the phenomenon of friction and discusses its probable mechanism and the laws of friction. It also describes different types of friction, belt drives, and power transmission aspects. **Chapter 5** illustrates the physical properties of surfaces and solids which are very important for studying the mechanics of deformable bodies. **Chapter 6** deals with virtual work, which is another specialized approach to equilibrium analysis.

Chapter 7 elucidates different types of simple lifting machines. It also explains the different terms which are needed for analysis and problem-solving purposes. A number of figures have been included which show the schematic diagrams of these machines.

Part II: Dynamics

Chapter 8 introduces the kinematics of particles for both rectilinear and curvilinear motions in various reference coordinate systems, including the analysis of projectile motion. **Chapter 9** briefly describes the kinematics of rigid bodies. **Chapter 10** discusses the kinetics of particles and rigid bodies. D'Alembert's principle for linear as well as angular motion has also been presented.

Chapter 11 discusses the potential and kinetic energy of particles and rigid bodies. Mechanical efficiency and power aspects have been discussed at length. **Chapter 12** delves on impulse and momentum. Principle of conservation, different types of impact, and change of momentum are discussed in a comprehensive manner. **Chapter 13** presents the essential fundamentals of oscillation, free vibration, forced vibration, and pendulum.

Appendix A provides the timeline of the events that contributed to the development of the field of classical mechanics. **Appendices B–H** provide the dimensions and SI units of commonly used physical quantities, common trigonometric formulae, formulae for differentiation and integration, properties of geometrical figures, and homogeneous solids, vector algebra and a small discourse on gravitation and shear force and bending moment of beams, respectively.

Appendix I includes solutions to chapter-end multiple-choice questions and numerical problems.

Acknowledgements

During the revision process, I received immense help from senior professors Asok Kumar Mallik and Dipak Sengupta. I pay my most sincere gratitude to them. I am very much indebted to my once colleague and currently Associate Professor at Budge Budge Institute of Technology, Kolkata, Dr Suday Kumar Ghosh, who painstakingly solved all the numerical problems in the exercises.

In various stages of the revision work, I utilized the feedback received from several faculty development programmes organized by OUP, India. I am thankful to Mr Subir Pal of Books and Equipment Distributors for his promotional effort.

Last but not the least I would like to thank the editorial team at Oxford University Press India, who diligently and sincerely worked for the successful completion of this project.

It has been our utmost endeavour to publish the revised edition as an error-free one. Any suggestions and comments for the improvement of the book can be send to me at basubec@yahoo.com.

Basudeb Bhattacharyya

Preface to the First Edition

Engineering mechanics is a specialized and need-based extension of applied physics. The industrial revolution gave birth to two broad divisions: military engineering and non-military or civil engineering. Non-military engineering or the early civil engineering covered many topics which we now find as part of mechanical and electrical engineering. The thumb-rule techniques or experience-based methods of analysis were gradually found inadequate for construction, erection, or fabrication of different types of civil and military structures. Hence, there rose a need for methodical and logical idealization and corresponding procedures of analysis.

The rigid body idealization of prototype structures, in static condition or in motion, and corresponding generation of generalized forces became very important to produce an effective design. These requirements gradually laid the foundation for the formation of engineering mechanics as a subject and during the early decades of the 20th century, engineering mechanics was established as an essential subject for studying basic engineering. Initially, this subject was included in a disorganized manner in the engineering curriculum.

Stephen Prokofyevich Timoshenko (1878–1972) is believed to be the father of modern engineering mechanics, whose seminal contribution established this subject. Later, many researchers and scientists contributed to the development of the subject.

Engineering mechanics deals with the mechanics of rigid bodies—statics and dynamics—without taking the effect of their deformation into consideration. The basic essence of this subject revolves around the concept of static as well as dynamic equilibrium. Hence, the study of the subject initiates from the study of the fundamentals of the force system, computation of distribution of forces, properties of surface and material bodies, etc., and finally terminates at determination of various kinematic and kinetic parameters of rigid bodies.

Modern-day engineering mechanics idealizes the practical structures separately. Once idealizations are found correct it is easy to analyse properly. The startling growth of computational facilities also enhanced the purview of the subject by offering ample scope to analyse larger and typical structures. For this reason, the graphical techniques lost their importance. Therefore, to meet the present-day needs, the focus of teaching engineering mechanics turned to the knowledge of proper conceptualization and modelling, assuming that rest of the things will be carried out using standardized techniques, either manually or through programming.

About the Book

This book is specially designed for the undergraduate students of engineering. The text covers the syllabi requirements of almost all technical universities in India. Basic knowledge of the concepts of physics and mathematics is assumed. Starting from the fundamental concepts of forces and equilibrium along with the free-body

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diagrams, the book comprehensively covers the various analytical aspects of rigid body mechanics. The book is divided into two parts—Part I covers statics and Part II covers dynamics. In the text, simple topics and problems precede those that are more complex and advanced. A lucid pattern, both in terms of language and content, has been adopted throughout the text.

Each chapter starts with the key concepts and gradually builds up the advanced concepts through detailed explanations and illustrations. A large number of solved examples have been provided to elucidate the application of the theoretical part of each chapter. Review questions, multiple-choice questions, and numerical exercises add value to the rich content of the book.

Acknowledgements

I am immensely grateful to the senior teachers of my department for their encouragement and support. I also thank the editorial team of Oxford University Press for their sincere and diligent help in shaping this book. Finally, I would like to thank my wife Mou for her continuous support.

Every effort has been made to produce an error-free text, however, any suggestions, comments, and feedback for further improvement are welcome. The users of my book may also feel free to write to me at basubec@yahoo.com.

Basudeb Bhattacharyya

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