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Peter Howell , Gregory Kozyreff , John Ockendon
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APPLIED SOLID MECHANICS

Much of the world around us, both natural and man-made, is built from and held together by solid materials. Understanding how they behave is the task of solid mechanics, which can in turn be applied to a wide range of areas from earthquake mechanics and the construction industry to biomechanics. The variety of materials (such as metals, rocks, glasses, sand, flesh and bone) and their properties (such as porosity, viscosity, elasticity, plasticity) are reflected by the concepts and techniques needed to understand them, which are a rich mixture of mathematics, physics, experiment and intuition. These are all brought to bear in this distinctive book, which is based on years of experience in research and teaching. Theory is related to practical applications, where surprising phenomena occur and where innovative mathematical methods are needed to understand features such as fracture. Starting from the very simplest situations, based on elementary observations in engineering and physics, models of increasing sophistication are derived and applied. The emphasis is on problem solving and on building an intuitive understanding, rather than on a technical presentation of theoretical topics. The text is complemented by over 100 carefully chosen exercises, and the minimal prerequisites make it an ideal companion for mathematics students taking advanced courses, for those undertaking research in the area or for those working in other disciplines in which solid mechanics plays a crucial role.

Cambridge Texts in Applied Mathematics

APPLIED SOLID MECHANICS

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Prologue

Although solid mechanics is a vitally important branch of applied mechanics, it is often less popular, at least among students, than its close relative, fluid mechanics. Several reasons can be advanced for this disparity, such as the prevalence of tensors in models for solids or the especial difficulty of handling nonlinearity. Perhaps the most daunting prospect for the student is the multitude of different behaviours that can occur and cause elementary theories of elasticity to become irrelevant in practice. Examples include fracture, buckling and plasticity, and these pose intellectual challenges in solid mechanics that are every bit as fascinating as concepts like flight, shock waves and turbulence in fluid dynamics. Our principal objective in this book is to demonstrate this fact to undergraduate and beginning graduate students.

We aim to give the subject as wide an accessibility as possible to mathematically-minded students and to emphasise the interesting mathematical issues that it raises. We do this by relating the theory to practical applications where surprising phenomena occur and where innovative mathematical methods are needed.

Our layout is essentially pragmatic. Although more advanced texts in solid mechanics often begin with quite general theories founded on basic mechanical and thermodynamic principles, we start from the very simplest models, based on elementary observations in engineering and physics, and build our way towards models that are the basis for current applied research in solid mechanics. Hence, we begin by deriving the basic Navier equations of linear elasticity, before illustrating the mathematical techniques that allow these equations to be solved in many different practically relevant situations, both static and dynamic. We then proceed to describe some approximate theories for the elastic deformation of thin solids, namely bars, strings, beams, rods, plates and shells. We soon discover that many everyday phenomena, such as the buckling of a beam under a compressive load, cannot be fully described using linear theories. We therefore give a brief exposition of the general theory of nonlinear elasticity, and then show how formal asymptotic methods allow simplified linear and weakly nonlinear models to be systematically deduced. Although we regard such asymptotic techniques as invaluable to any applied mathematician, these last two topics may both be omitted on a first reading without loss of continuity. We go on to present simple models for fracture and contact, comparing and contrasting these apparently similar phenomena. Next, we show how plasticity theory can be used to describe situations where a solid yields under a sufficiently high stress. Finally, we show how elasticity theory may be generalised to include further physical effects, such as thermal stresses, viscoelasticity and porosity. These “combined fields” of solid mechanics are increasingly finding applications in industrial and medical processes, and pose ever more elaborate modelling questions.

Despite the breadth of the models and relevant techniques that will emerge in this book, we will usually try to present the theoretical developments *ab initio*. Nonetheless, the book is very far from being self-contained. Any student who aspires to becoming a solid mechanics specialist will have to delve further into the literature, and we will provide references to help with this.

We assume only that the reader has a reasonable familiarity with the calculus of several variables. Fluency with the more advanced techniques required for Chapters 6 and 7, in particular, will readily be acquired by a student who works through the exercises in the early Chapters, especially those cited in the text. Indeed, we firmly believe that solid mechanics provides a wonderful arena in which to build an understanding of such important mathematical areas as linear algebra, partial differential equations, complex variable theory, differential geometry and the calculus of variations. Our hope is that, having read this book, a student should be able to confront any practical problem that may be encountered in everyday solid mechanics with at least some idea of the basic mathematical modelling that will be required.

During the writing of this book, we received a great deal of help and inspiration as a result of discussions with David Allwright, Jon Chapman, Sam Howison, L. Mahadevan, Roman Novokshanov and Domingo Salazar, as well as many other colleagues and students too numerous to thank individually. We would like to express our particular gratitude to Gareth Jones, Hilary Ockendon and Tom Witelski who gave invaluable advice on draft Chapters. We are also indebted to David Tranah and his colleagues at Cambridge University Press for helping to make this book a reality.