Wave Propagation in Material and Structures
Srinivasan Gopalakrishnan
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This text has an ambitious goal of capturing the multidisciplinary science of mechanical wave propagation covering both the basic and advanced features of wave propagation in a diverse set of materials. This book assumes the basic knowledge of graduate level engineering mathematics, material science, continuum mechanics and numerical analysis.

Chapter 1 introduces the basic structure of the book introducing the key difference between structural dynamics problems, where the designer is interested in the long-term effects of the dynamic load involving the first few normal modes, and wave propagation problems, where short term effects are of concern, involving many higher order modes. This text emphasizes the latter category of problems. The book also focuses on new methods of wave propagation analysis necessary for efficient nondestructive categorization of elastic media with nanostructures. Chapters 2–8 introduce fundamental aspects of wave propagation while Chapters 9–18 develop the advanced concepts.

Chapter 2 starts by covering the traditional local elasticity theory but quickly introduces the nonlocal theory of gradient elasticity necessary to understand the nanostructure wave guide models. Eringen's stress gradient theory (ESGT) and Laplacian stress gradient theory are covered in more detail. Chapter 3 discusses methods of developing constitutive models for fibrous, particulate and laminate composite materials. The chapter also introduces functionally graded materials (FGMs) where the percentage content of metal or ceramic is varied in a controlled way to achieve a desired property gradation in spatial direction, first conceived to increase adhesion and minimize the thermal stresses in metallic–ceramic composites. Chapter 4 summarizes the three important integral transforms, Fourier transforms, wavelet transforms, and Laplace transforms which are the pillars of modern spectral analysis.

Chapter 5 discusses the detailed procedures to compute critical parameters such as phase and group velocities and introduces basic concepts such as dispersive and nondispersive waves and critical definitions such transition and cut-off frequencies. Difficulties of accurate computation of wave numbers and group speeds in complex media and nanostructures are pointed out and possible solution methods are outlined. Chapters 2–5 complete the basic understanding of the concepts necessary to proceed to the remaining chapters. However, as pointed out before, this text only provides a summary of the concepts. To master the material, the study of other texts would be necessary.

Chapter 6 discusses the wave propagation in 1-dimension isotropic waveguides (rods, beams and frames) including tapered and rotating guides. The effects of additional constraints such as elastic constraints, elastic foundation and pretension on the wave propagation are treated. Chapter 7 discusses 2-D isotropic waveguides (membranes and plates) along with wave propagation in doubly bounded media. Special consideration is given to Rayleigh waves important in seismic engineering. The chapter points out the increasing difficulty (and thus the need for spectral methods) in obtaining numerically accurate solutions, as degrees of freedom increase. Chapter 8 studies the laminated composite waveguides where traditional Helmholtz decomposition used for isotropic solids is not applicable due to the coupling of longitudinal and transverse waves. Partial wave techniques are introduced as means of solution particularly considering effects of damping and cross-section ovaling. Chapter 9 discusses the wave propagation in sandwich structural waveguides that provides enormous increase in the stiffness for the same weight by merely increasing the depth of the core. The higher order analysis methods, e.g., Extended Higher Order Sandwich Plate Theory, that are necessary to account for multiple motions within the structure are addressed. Chapter 10 focuses on carbon nanotube structures employing the previously introduced theories of gradient elasticity while Chapter 11 concentrates on FGM structures.

Chapter 12 introduces new finite element formulations, namely, the super convergent finite element formulation and the time domain spectral element finite element formulation as well as new time integration schemes, namely, the Taylor–Galerkin scheme and energy momentum conserving time integrators. This chapter is supplemented by many numerical examples that illustrate the computational efficiency of these formulations. Chapter 13 discusses all three (Laplace, Fourier and wavelet) variants of spectral finite element formulation carefully illustrating with examples the suitability of a particular variant. The remaining chapters expand on these basic examples by focusing on special classes of problems particularly useful for the industry.

Chapter 14 discusses mechanical waveguides with embedded or surface-mounted smart patches where wave-scattering considerations are important. Examples of such materials are piezo ceramic material such as lead zirconate titanate (PZT) used in ultrasonic transducers and magnetorestrictive material such as Terfenol used in naval sonar systems. Chapter 15 discusses defective waveguides that include defects such as delamination and fiber breaks important for structural health monitoring. Chapter 16 extends the methods to study structures with periodic defects typical of many engineering structures. Chapter 17 introduces the readers to the emerging fields (e.g., lighter materials in aerospace industry) where the material properties show significant variation rendering traditional solutions intractable. Chapter 18 focuses on hyperelastic materials such as vulcanized rubbers. The various new finite element formulations are presented with suitable examples.

This book is essentially a compendium of the experience of the author and his graduate students working in the field of applying finite element methods to study advanced materials. The book provides a unifying theoretical perspective that is often overlooked as the students and researchers delve into the nitty-gritty of actual computations. Thus, this volume would be useful to students embarking on this field in search of new research projects as well as to the advisor trying to design courses on this subject. For researchers in other fields of wave propagation, this book will serve as a useful reference and may birth ideas that may successfully cross over to their chosen field of study. Each chapter can be studied independently and is supplemented with a comprehensive list of reference.

Arindam Ghosh
KBR, Houston, TX, USA
arindam.ghosh@kbr.com