Preface

Theories and methods for analysis of solids and structures have developed over several centuries. The academic curricula in most engineering programs cover those ideas through multiple courses starting from the basic course on statics to the very advanced courses on nonlinear solid mechanics and dynamics of structures. Integration of all these ideas, in the form of computer-aided matrix method analysis of multi-degree-of-freedom systems, has evolved into the finite element method – which is an indispensable part of current engineering practice for design and analysis of solids and structures. Many books have been produced over the past half century with a great deal of reference information on analytical formulations and relevant numerical implementation details. These reference books definitely serve as good references for the developers of finite element software packages. The theory manuals of actual software implementations tend to mimic similar analytical details of the reference textbooks. Other software-related documents, namely the users' manuals and example manuals, tend to focus on the computer graphics-based techniques for efficient model preparation and post-processing of results. The successful use of finite element simulation technology, in actual engineering problem solutions, requires the mastery of all relevant subjects and tools – starting from the basic understanding of solids mechanics principles to the computer user skills for post-processing the right response results as obtained from finite element simulation models. The large swath of published materials, available in the form of textbooks and software manuals, and the easy availability of computing equipment and software products have made the learning of finite element subjects accessible and difficult at the same time. Aspiring stress analysts in today's world face the difficult challenge of taking a long suit of academic and non-academic courses to build the bridge between theory and software-oriented engineering practice. It is quite normal that graduates in the structural analysis field appear with disconnected knowledge bins, often with good understanding of the mechanics field without the knowledge of how to approach a practical analysis problem; and occasionally with good user skills of specific software features without the knowledge of what goes inside those tools.

From the synthesis of 30+ years of hands-on work in research, programming, teaching, and practical use of the finite element simulation method, the author has developed this book as an introductory reference to the key ideas of the technique. The attempt is by no means a substitute for existing books and reference materials. It is rather a complimentary guidebook for navigating through the complex learning path of finite element subject, for both academic students and self-learning practicing engineers. Comprehensive theory-to-practice coverage of the essential subject matters also makes the book an excellent reference for use in corporate training programs for engineering graduates who lack the formal rigor of academic preparation in stress analysis domain. The analytical formulations have been presented by using matrix and vector notations, unlike the tensor notation as often used in many other reference books and software manuals. This is intended to make an explicit link between theory and actual analysis projects that obviously involve input and output

of data in matrix and vector forms. The analytical and numerical implementation details of finite element methods have been discussed side-by-side with user options available in commercial software packages. The example demonstration of software user features has been discussed with specific references to the analysis capabilities of the ABAQUS package. The discussions on software-aided model preparation and quality checks have been presented with example references to the HyperMesh software package. These software-specific feature descriptions will need to be adapted if different software products are used to solve the practice problems.

This book is structured to progressively build the basic expertise in finite element analysis methods – following the same sequence that the author has used in teaching of one-semester graduate courses over the past many years. Chapters 1 and 2 present the theory of elasticity topics that form the foundation of linear elastic finite element methods. Practice problems are presented, with pre-built analysis model files, to test the basic stress–strain analysis theories by using finite element analysis software as a virtual experimentation tool. Chapter 3 introduces the basics of finite element formulations, including the numerical details as implemented in software tools, for analysis of solids that can be represented by 2D stress fields. Practice problems are presented to use software analysis tools with manual preparation of finite element model input files. The objective is to achieve clear knowledge of the input data structure required for an error-free analysis model preparation. This is an essential skill to debug model errors that often appear while preparing more complex analysis models by using computer-graphics-based model preparation tools. Chapter 4 focuses on how to produce good quality finite element models of two-dimensional solids by using general-purpose model pre-processing software. Although specific references are made to HyperMesh software features for model build operations, and to ABAQUS software for actual FEA solutions, the discussions on key aspects of quality model preparation are equally applicable to other software products for model preparation and validation of results. Three-dimensional elasticity problems, having an axis of symmetry, are discussed in Chapter 5, followed by the introduction of 3D finite element formulations that are required for analysis of general 3D solids. Chapter 6 is dedicated to the elastic deflection and stress–strain analysis of beams for bending, transverse shear and torsional load effects. The size of this chapter, with comprehensive coverage of both theoretical and finite element implementation aspects, is understandably large for a single class learning session. A reduced presentation can be formulated by focusing on finite element implementation methods, with selected references to the analytical methods, if desired. Chapter 7 presents the plate and shell element formulations for the analysis of 3D thin-walled structures. Analysis problems, discussed in Chapters 1–7, represent components that can be modeled with single finite element types. Chapter 8 introduces special numerical techniques that are required to simulate the behavior of joints and interface contacts in multi-component model assemblies. The basic purpose of finite element simulation, i.e. the interpretation of stress analysis results for engineering decisions, is discussed in Chapter 9, with special focus on strength, durability, and integrity assessment of solid products. Chapter 10 presents a comprehensive review of the analytical and numerical methods for vibration frequency analysis which is an important topic in design and analysis of structures for cyclic load effects. Chapter 11 is dedicated to the analysis of structural

response for noncyclic dynamic load events. The use of finite element simulation models to predict design response spectra, frequency response function, and time-domain response histories of structures is specifically discussed in this chapter. Finally, Chapter 12 presents a review of key analysis techniques relevant for predicting the nonlinear response of structures. At the end of each chapter, practice problems have been presented for solving with finite element analysis models, and for verification of the results by using simplified analytical prediction models. These studies are intended to reinforce the importance of conducting minimum quality checks of the finite element simulation results. For comprehensive learning experience, some practice problems will require the use of electronic data files that can be downloaded from the site: https://www.routledge.com/Finite-Element-Analysis-of-Solids-and-Structures/Bhattacharjee/p/book/ 9780367437053. PowerPoint slides of the materials covered in this book, and the solution manual of practice problems, are available upon request from academic instructors.