Modeling and Computation in Vibration Problems, Volume 1

Numerical and semi-analytical methods

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Preface

The primary objective of this two-volume book is to bring together leading researchers of vibrations who are involved in the development of new computational and analytical/semi-analytical techniques. Vibration problems are commonly encountered in various systems of applied mathematics, physics, aeronautical, civil, architectural, marine, mechanical, nuclear, biological and other areas of science and technology. These systems need to be analyzed by easy, fast and efficient computational approaches. Different mathematical theories of vibration, numerical simulation, machine intelligence techniques, physical experiments with computational investigations and their various engineering and science applications are included in these two volumes. Accordingly, these volumes will provide an outstanding opportunity to learn from the contributions of well-known researchers of their ideas, experiences, and advances.

Volume 1 of this book contains numerical and semi-analytical methods including analytical methods in solving various vibration problems. A total of 14 chapters are included in this volume. Chapters 1–3 contain theoretical and modelling investigations of different vibration problems. Studies on nano-structural members are incorporated into chapters 4–9. Finally, chapters 10–14 address various applications of structural vibrations. More details of each chapter are outlined next.

Chapter 1 is contributed by Tornabene, Viscoti, and Dimitri. They have investigated an interesting problem of 'Higher-order theory for the modal analysis of doubly-curved shells with lattice layers and honeycomb cores.' They proposed an innovative method based on Higher Order Shear Deformation Theories (HSDTs) to study the free vibration response of composite lattice structures, with a single or double curvature. A general method for the homogenization of lattice layers made of honeycomb cells and grid patterns is presented, which predicts accurately the anisotropic equivalent elastic constants for a wide range of cell configurations with different heights, wall thicknesses, and geometric layups. The reliability of the strategy is successfully verified against solutions from finite element analyses, both in terms of frequencies and mode shapes, with a very good agreement.

The second chapter is contributed by Ahmad, Gupta, Sujata, and Poomani, titled, 'Particle impact damping technology: modelling and applications.' In this chapter a modelling technique is introduced to capture the interactions between the dynamics of the damping particles and the dynamics of the host structure with a particular focus on the discrete element method (DEM). Hertz's dissipative contact model for normal contact forces and Coulomb's friction model for tangential force are used to derive the governing equation. The vibration attenuation trend has been studied for the location of particle dampers, size of particles, fill fraction, and excitation energy.

Transverse vibration of thick functionally graded (FG) skew plates with various skew angles has been investigated by Pradhan and Chakraverty in chapter 3. Material properties of FG constituents may vary spatially along thickness direction in power-law form. A shear deformation plate theory is considered here to define the constitutive relation, and the generalized eigenvalue problem is obtained by means of the Ritz method. The obtained results for natural frequencies are validated with those from the existing literature.

Chapter 4 is authored by Tornabene, Dimitri, and Brischetto, where mechanical modelling of functionally graded carbon nanotubes-reinforced composite materials and structures is studied. Variation of the material properties, such as thermal resistance, thermal conductivity and coefficient of thermal expansion, is included. Several higher-order shear deformation theories are used to investigate the problems of the vibration response, the dynamic stability, and the critical speed evaluation of thin and moderately thick structures with high values for the in-plane and transverse anisotropy; the governing equations are solved numerically by means of the Generalized Differential Quadrature (GDQ) method.

In chapter 5, contributed by Saxena and Sarkar, vibration of micro/nano structural members is investigated by discrete energy-based formulation. The authors focused on deriving a molecular-dynamics like discrete framework for different local and non-local continuum models such as beams and plates so that the models can simulate discontinuities. A major aspect of the formulation is that it unifies different local and non-local theories.

Chapter 6 includes the problem of 'Effect of thermal environment on nonlinear flutter of laminated composite plates reinforced with graphene nanoplates,' authored by Guo, Yang, Żur, Reddy, and Ferreira. The authors employed the element-free IMLS-Ritz method to obtain the flutter behavior of matrix cracked functionally graded multilayer graphene nanoplatelets (GPLs) reinforced composites (GPLRCs).

Malikan and Eremeyev have studied forced vibrations of piezo-flexomagnetic nano-actuator beams in chapter 7. The effect of excitation frequency on the piezomagnetic Euler–Bernoulli nanobeam taking the flexomagnetic material phenomenon is addressed here. The attained linear differential equation is transferred into an algebraic equation by using the Galerkin method. Then, the resulting linear algebraic equation is solved to determine the numerical values of dynamic deflections.

Nano-electromechanical systems have made significant advances in various sciences such as mechanics, medicine, and chemistry, due to their unique features and properties, especially in the fields of sensors and actuators. As such, vibration of size-dependent carbon nanotube-based biosensors in liquid is investigated by Sheikhmamoo, Mohammad-Sedighi, and Shishesaz in chapter 8. The equations and boundary conditions are derived using the Hamiltonian principle. The electrostatic and Casimir forces are the source of the nonlinearity in this problem. In this work, an analytical modified Adomian decomposition method is used to investigate the static response of the system. In the static section, the instability of the system and the pull-in voltage under the influence of surface tension effect and size effect are investigated.

Chapter 9, authored by Brischetto, Tornabene, and Dimitri, incorporates continuum 3D and 2D shell models for free vibration analysis of single-walled and double-walled carbon nanotubes. 3D shell solutions based on the exponential matrix methodology for the study of the free vibration response of simply supported

Single- and Double-Walled Carbon NanoTubes (SWCNTs and DWCNTs) are presented. A continuum approach based on the three-dimensional theory of elasticity is employed to represent discrete elements such as SWCNTs and DWCNTs. Proposed analytical 3D shell models are compared with some classical and refined 2D models based on the Generalized Differential Quadrature Method (GDQM) in the case of free vibration study of SWCNTs and DWCNTs with different lengths, diameters and equivalent elastic properties. Moreover, comparisons with well-known continuum beam models from the literature are proposed to analyze the differences between 3D, 2D and 1D approaches, depending on the carbon nanotube length and on the thickness of its walls.

Crack and interface interaction under quasi-static and dynamic loading is addressed by Pranavi, Reddy, Rajagopal, and Reddy in chapter 10. A thermodynamically consistent phase-field formulation for modelling the interactions between interfacial damage and bulk fracture in heterogeneous materials having matrix and inclusion phases with a matrix-inclusion interface is presented. A regularization scheme is considered for both the interface and the crack phase field. A coupled exponential cohesive zone law is adopted to model the interface which has the contributions of both normal and tangential displacement jump components. A novel nonlocal approach is devised to evaluate the smoothed values of jump at the regularized interface using element specific geometric information. The effects of stiff and soft interface on the mechanical response and the crack propagation is studied.

Industrial robotic systems have two essential functional sub-systems namely, gripper and wrist, that are prone to vibration-induced characteristics. This vibration is randomized in real-time and can be *in situ* and/or external impulse-based. Compliant Robotic Gripper (CRG) belongs to a selected niche of the first sub-system and these grippers are modular, semi-flexible and often small-enveloped with multi-task enabled ability. Accordingly, chapter 11 authored by Roy addresses vibration of compliant robotic grippers and wrists. The chapter includes modelling of vibration of CRG & CRW *ab initio*, for both *in situ* as well as external excitation. The author also discusses the local effects of vibration in this section, which are in the form of vibration accumulation at CRW and the consequences of external forcing on the robotic manipulator. Case-studies supported by test results are reported for a table-top small-sized semi-flexible robotic system, augmented with a tailor-made CRG.

Reinforced concrete (RC) beams are one of the critical structural elements in buildings. These elements suffer from distress and primarily cracks due to many reasons resulting into degradation of stiffness and strength. The mode shape-based approaches are very efficient techniques in damage identification in structural elements. As such, in chapter 12, authored by Panigrahi, Chourasia, and Bisht, a study of mode shape based approaches for health monitoring of reinforced concrete beams under transverse loading is presented. An analytical approach has been developed for identification of damage on a beam model considering damage in the beam. The mode shapes and modal curvatures have been computed both for an undamaged and damaged beam structure for damage identification. For validation of the approach, simply-supported RC beams were subjected to an incrementally increasing static two-point loading in steps till ultimate failure. After each load step, vibration measurements were performed using sensors mounted at critical locations. The mode shapes and modal curvature graphs have been drawn to find out the location of developed crack pattern on the beam.

Chapter 13, authored by Gupta, Ahmad, Aditya, and Poomani, addresses the analysis and testing of honeycomb sandwich structures for spacecraft. Sandwich panels generally consist of three significant components, two thin face sheets and a thick core. The adhesive films are placed between face sheets and core to bond them. The honeycomb sandwich structure is widely used as a primary cylinder, payload mounting panels, shear webs and other support structures in a spacecraft. The experimental setup used in this work is described and then responses obtained through experiments and finite element computations are compared.

Finally, in chapter 14, numerical analysis of Qutb Minar (New Delhi, India) using non-linear plastic-damage macro model for constituent masonry is investigated by Chourasia and Panigrahi. A plastic–damage macro model, originally proposed to model plasticity in concrete, has been adapted to simulate the behavior of masonry present in Qutb Minar. The natural frequencies obtained from an idealized finite element model show better correlation with experimental values from previous studies. The material model implemented is characterized by a bi-dissipative and isotropic degradation of material during cyclic loading. A seismic simulation has been carried out for comparison between response in two cases—elastic and non-elastic material models for constituent masonry. The need to take account of the dynamic parameters and material non-linearity for a realistic seismic response prevision has also been established.

The Editors are certain that the contents of this book will be useful for academic researchers as well as engineers in industry. In academics, this book will be useful for graduate students and researchers of vibration problems of different fields. The Editors believe the integrated and holistic analytical, new theories, computationally efficient approaches presented in various chapters will certainly benefit readers for their future studies and research. The editors thank all the chapter contributors for their effort and support in preparing and submitting on time. Finally, the editors also thank the IOP team for their help and support throughout this project.

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Editor biographies

S Chakraverty

Professor S Chakraverty has 30 years of experience as a researcher and teacher. Presently he is working in the Department of Mathematics (Applied Mathematics Group), National Institute of Technology Rourkela, Odisha as a Senior (Higher Administrative Grade) Professor. Prior to this, he was with CSIR-Central Building Research Institute, Roorkee, India. After completing Graduation from St. Columba's College (Ranchi University), his career started from the University of Roorkee (now, Indian Institute of Technology Roorkee) and did MSc (Mathematics) and MPhil (Computer Applications) from there securing the first positions in the university. Dr Chakraverty received his PhD from IIT Roorkee in 1993. Thereafter he did his post-doctoral research at the Institute of Sound and Vibration Research (ISVR), University of Southampton, UK and at the Faculty of Engineering and Computer Science, Concordia University, Canada. He was also a visiting professor at Concordia and McGill universities, Canada, during 1997–1999 and visiting professor of University of Johannesburg, South Africa during 2011–2014. He has authored/edited 24 books, published 392 research papers (till date) in journals and conferences and two books are ongoing. He is in the Editorial Boards of various International Journals, Book Series and Conferences. Professor Chakraverty is the Chief Editor of *International Journal of Fuzzy Computation and Modelling* (IJFCM), Inderscience Publisher, Switzerland (http://www.inderscience.com/ijfcm), Associate Editor of *Computational Methods in Structural Engineering, Frontiers in Built Environment* and happens to be the Editorial Board member of Springer Nature Applied Sciences, IGI Research Insights Books, Springer Book Series of Modeling and Optimization in Science and Technologies, *Coupled Systems Mechanics* (Techno Press), *Curved and Layered Structures* (De Gruyter), *Journal of Composites Science* (MDPI), *Engineering Research Express* (IOP) and *Applications and Applied Mathematics: An International Journal*. He is also the reviewer of around 50 national and international Journals of repute and he was the President of the Section of Mathematical Sciences (including Statistics) of Indian Science Congress (2015–2016) and was the Vice President Orissa Mathematical Society (2011–2013). Professor Chakraverty is a recipient of prestigious awards viz. Indian National Science Academy (INSA) nomination under International Collaboration/Bilateral Exchange Program (with the Czech Republic), Platinum Jubilee ISCA Lecture Award (2014), CSIR Young Scientist Award (1997), BOYSCAST Fellow. (DST), UCOST Young Scientist Award (2007, 2008), Golden Jubilee Director's (CBRI) Award (2001), INSA International Bilateral Exchange Award ([2010–11 (selected but could not undertake), 2015 (selected)], Roorkee University Gold Medals (1987, 1988) for first positions in MSc and MPhil (Comp. Appl.) etc.

He is in the list of 2% world scientists recently (2020) in Artificial Intelligence & Image Processing category based on an independent study done by Stanford University scientists. His world rank is 1862 out of 215114 researchers throughout the globe.

IOP Publishing Top Cited Paper Award for one of the most cited articles from India, published across the entire IOP Publishing journal portfolio within the past three years (2018 to 2020). It also features in the top 1% of most cited papers in the Materials subject category. This data is from the citations recorded in Web of Science.

He has already guided nineteen (19) PhD students and twelve are ongoing. Professor Chakraverty has undertaken around 16 research projects as Principle Investigator funded by international and national agencies totaling about Rs.1.5 crores. He has hoisted around 8 international students with different international/national fellowships to work in his group as PDF, PhD, visiting researchers for different periods. A good number of international and national Conferences, Workshops, and Training programs have also been organised by him. His present research areas include differential equations (ordinary, partial and fractional), numerical analysis and computational methods, structural dynamics (FGM, Nano) and fluid dynamics, mathematical and uncertainty modeling, soft computing and machine intelligence (artificial neural network, fuzzy, interval and affine computations).

Following are his Google, Scopus, other related and Vidwan (Institute) links:

Google Scholar : https://scholar.google.co.in/citations?user=4EeFYt4AAAAJ&hl=en

Scopus ID: http://www.scopus.com/authid/detail.url?origin=resultslist&authorId=7005011457&zone=

ORCID ID: https://orcid.org/0000-0003-4857-644X

Publons: https://publons.com/researcher/685949/snehashish-chakraverty/

Researchgate: https://www.researchgate.net/profile/S_Chakraverty

Vidwan (Institute) Link: http://nitrkl.irins.org/profile/62073

My VIDEO Lectures: https://www.youtube.com/channel/UCEsAtWBMIvDTnrPH7Yn82wA/videos?view_as=subscriber

F Tornabene

Francesco Tornabene is an Assistant Professor and Lecturer at the School of Engineering, Department of Innovation Engineering, University of Salento. He was born on 13 January 1978 in Bologna, where he received the high school degree at Liceo Classico *San Luigi*, in 1997. In 2001 he achieved a National Patent Bologna (Italy) for the Industrial Invention: *Friction Clutch for High Performance Vehicles* Question BO2001A00442. He received from the University of Bologna - Alma Mater Studiorum, an MSc degree in *Mechanical Engineering* (Curriculum in *Structural Mechanics*), on 23 July 2003, discussing a thesis entitled: *Dynamic Behavior of Cylindrical Shells: Formulation and Solution*. In December 2003, he was admitted to the PhD course in *Structural Mechanics*, at the University of Bologna, reaching the first position in the competitive admission. In 2004, he received from the University of Bologna a Thesis prize in memory of *Carlo Felice Jodi*; in 2007 he received the PhD degree in *Structural Mechanics* at the University of Bologna, discussing the Thesis entitled *Modeling and Solution of Shell Structures Made of Anisotropic Materials*. From 2007 to 2009 he received a research fellowship by the University of Bologna, working on the *Unified Formulation of Shell Structures Made of Anisotropic Materials. Numerical Analysis Using the Generalized Differential Quadrature Method and the Finite Element Method*. From 2011 to 2012 he became a junior researcher within the research program entitled *Advanced Numerical Schemes for Anisotropic Materials*; from 2012 to 2018 he was an Assistant Professor and Lecturer at the Alma Mater Studiorum - University of Bologna; from 2018 up to date he has been an Assistant Professor in Structural Mechanics and Lecturer at the University of Salento, Department of Innovation Engineering (Lecce). For a long time his scientific interests have included structural mechanics, solid mechanics, innovative and smart materials, computational mechanics and numerical techniques, damage and fracture mechanics. He is author of more than 260 scientific publications, and collaborates with many national or international researchers and professors all over the world, as visible from his scientific production. He is author of 11 books, see e.g. *Meccanica delle Strutture a Guscio in Materiale Composito. Il metodo Generalizzato di Quadratura Differenziale* (2012); *Mechanics of Laminated Composite Doubly-Curved Shell Structures. The Generalized Differential Quadrature Method and the Strong Formulation Finite Element Method* (2014); *Laminated Composite Doubly-Curved Shell Structures I. Differential Geometry. Higher-Order Structural Theories* (2016); *Laminated Composite Doubly-Curved Shell Structures II. Differential and Integral Quadrature. Strong Formulation Finite Element Method* (2016), *Anisotropic Doubly-Curved Shells. Higher-Order Strong and Weak Formulations for Arbitrarily Shaped Shell Structures* (2018), among many. He is member of the Editorial Board for 42 international journals (see, e.g. *Journal of Engineering*, *International Journal of Engineering & Applied Sciences*, *Composite Structures*, *Technologies*, *Journal of Applied and Computational Mechanics*, *Journal of Composites Science*, *Advanced Materials and Technologies*, *Heliyon, International Scholarly Research Notices, Mathematical Problems in Engineering, ISRN Mechanical Engineering, Journal of Computational Engineering, Advances in Aircraft and Spacecraft Science*, among others). He is also Editor-in-Chief for two international journals: *Curved and Layered Structures and Journal of Composites Science*; from 2019 he has been Associate Editor for the international journal *Mechanics Based Design of Structures and Machines*. In recent years he received different important awards, see e.g. *Highly Cited Researcher by Clarivate Analytics* (years 2018, 2019, 2020), *Ambassador of Bologna Award* for the organization of 21st International Conference on Composite Structures ICCS21, 4–7 September 2018, Bologna, Italy (2019), Member of the European Academy of Sciences (since 2018). He collaborates as a reviewer with more than 240 prestigious international journals in the structural mechanics field. From 2012, his teaching activities have included: dynamics of structures; computational mechanics; plates and shells; theory of structures; structural mechanics or mechanics of solids and structures. He is habilitated as Associate Professor and Full Professor in the area 08/B2 (Mechanics of Solids and Structures) and as Associate

Professor in Area 09/A1 (Aeronautical and Aerospace Engineering and Naval Architecture).

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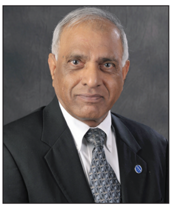

Dr Reddy, the *O'Donnell Foundation Chair IV Professor* in J. Mike Walker '66 Department of Mechanical Engineering at Texas A &M University, is a highly-cited researcher, author of a large number of journal papers and 24 books (several with second, third, and fourth editions) on energy principles, variational methods, plates and shells, composite materials, mechanics of solids, and the finite element method (linear and nonlinear) and its applications. Dr Reddy has delivered over 180 plenary, keynote, and invited lectures at international conferences; and taught 116 short courses; he advised 50 postdoctoral fellows and research visitors, and guided and co-guided 120 graduate students (74 PhD and 46 MS students).

In research, Dr Reddy is known worldwide for his significant contributions to the field of applied mechanics through the authorship of widely used textbooks on the linear and nonlinear finite element analysis, variational methods, and composite materials and structures. His pioneering works on the development of shear deformation theories (that bear his name in the literature as the *Reddy third-order plate theory and the Reddy layerwise theory*) have had a major impact and have led to new research developments and applications. Some of the ideas on shear deformation theories and penalty finite element models of fluid flows have been implemented into commercial finite element computer programs like ABAQUS, NISA, and HyperXtrude.

Dr Reddy is the recipient of numerous professional awards from various professional organizations and societies. Recent significant national and international awards include: member of the US National Academy of Engineering, and foreign member of the Indian National Academy of Engineering, Canadian Academy of Engineering, Brazilian National Academy of Engineering, the Royal Academy of Engineering of Spain, the Chinese Academy of Engineering, a member of the European Academy of Sciences and Arts, Honorary Member of the European Association of Sciences, and the Academia Scientiarum et Artium Europaea (the European Academy of Sciences and Arts). He also received the *John von Neumann Medal* from the US Association of Computational Mechanics, the *Theodore von Karman Medal* from the American Society of Civil Engineers, and the *Stephan P. Timoshenko Medal* from American Society of Mechanical Engineers.

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