Preface

Structural dynamics is a subject that traditionally figures in the curriculum of engineering schools. An introductory course in structural dynamics is often available as an elective in engineering programs, followed by a more advanced course during graduate work at the master's or doctoral level. The new standards and building codes promote the use of dynamic computation to determine the distribution of seismic forces when designing large or irregularly shaped buildings or, in some cases, as the method of choice for determining the effects of seismic forces. As a result, the importance of an introductory course in structural dynamics should be obvious. This book is intended for engineering students and practising engineers dealing with problems related to structural vibration and seismic design.

This volume has two parts. The first deals with single-DOF systems, which include complex systems that can be reduced to single-DOF systems. The second part looks at systems with multiple DOF that are solved using the finite-element method. This division could be viewed as the separation between an introductory course on structural dynamics for undergraduates and an advanced course for graduate students. That would not be a very profitable approach, since it would not include modal analysis, which is discussed in the second part of this book. The goal is to introduce modal analysis as part of an introductory course on structural dynamics analysis. Understanding the book's contents requires no more knowledge of mathematics and structural analysis than any engineering student would have. The book breaks down as follows.

Chapter 1 provides an introduction to structural dynamics. The first part of the book deals with single-degree-of-freedom (SDOF) systems. Chapter 2 provides the equations of motion for single-DOF systems. Chapter 3 develops conventional solutions for single-DOF systems, i.e. under the initial conditions imposed without dynamic loading. System response to harmonic loading is discussed in Chapter 4, which leads to damping and its experimental measurement, dealt with in Chapter 5. The Fourier decomposition of periodic loading is considered in Chapter 6, which shows that the response is the superimposition of a set of harmonic loadings. Chapter 7 shows how to calculate the response of a single-DOF system subjected to any kind of loading using Duhamel's integral. Chapter 8 introduces applying frequency-domain analysis to dynamics problems and calculating the response to any kind of loading using the Fourier transform. Chapter 9 provides an introduction to the direct numerical integration of equations of motion. The topics treated include an exact method for piecewise linear loading functions, the central difference method, and conventional Newmark methods. Chapter 10 considers computation of the response of nonlinear single-DOF systems using direct numerical integration combined with Newton's iterative method for error reduction. Chapter 11 focuses on systems that can be reduced to a single DOF using Rayleigh's method. The book's first part ends with an examination of single-DOF systems under earthquake action (Chapter 12).

Part 2 is devoted to discrete systems with multiple DOF. Chapter 13 establishes the equations of motion for multiple-degree-of-freedom (MDOF) systems and defines mass, damping and stiffness matrices based on a basic knowledge of structural matrix computations. Chapter 14 provides an introduction to the finite-element method so that the mass and rigidity matrices can be established more formally. The free response of conservative multiple-DOF systems is seen in Chapter 15, which provides for defining and computing the natural frequencies and associated mode shapes. Chapter 16 deals with the free vibration of discrete dissipative systems. Chapter 17 shows how to use modal superposition to compute the response of discrete systems for any load, whereas Chapter 18 deals with seismic loading. Chapter 19 looks at several properties of eigenvalues and eigenvectors required for a more in-depth study of their numerical determination. Chapter 20 presents several coordinate reduction methods, which are of prime importance in structural dynamics, and introduces Ritz analysis. Chapter 21 presents several classic methods for computing eigenvalues and the associated eigenvectors. Direct numerical integration methods to solve equations of motion for discrete multiple-DOF systems receive in-depth treatment in Chapter 22, including error and stability analysis of the different methods. Application of direct numerical integration methods to solve nonlinear problems is seen in Chapter 23.

The appendix provides some mathematical notions needed to understand the text. This book contains 88 examples illustrating application of the theories and methods discussed herein as well as 181 problems.

The contents can be used to develop a number of courses, including:

1) Introduction to Structural Dynamics: an introductory course for engineering students would cover Chapters 1 to 7, 9, 11 and part of 12, 13, 15 to 18.

2) Advanced Structural Dynamics: this course for graduate students who have taken the introductory course in structural dynamics would comprise Chapters 1, 8, 12 to 18, and 20 to 23, in part.

3) Computational Structural Dynamics: this advanced course would be reserved for graduate students who have already taken the advanced structural dynamics course, in which Chapters 1, 8 and 14 to 23 would be seen.

This text was used in delivering the structural dynamics course to senior students at the University of Sherbrooke. I take this opportunity to thank all my former students who, through attending lectures and their enthusiasm for solving weekly problems with CALWin, LAS and MATLAB, led me to write this book. Professor Jacky Mazars played an essential role in the process leading to this book, first by inviting me to give a course on structural dynamics at the École Normale Supérieure in Cachan to students at the DEA-MAISE and Laboratoire de Mécanique et Technologie for a number of years, and then by inviting me to publish it in the civil-engineering collection at ISTE and John Wiley & Sons. This text provided the foundation for an introductory course in structural dynamics given to Master's students in civil engineering and infrastructure at the Grenoble IUP as well as for an advanced computational structural dynamics course given to students at the doctoral school of Joseph Fourier University in Grenoble at the invitation of Professor Laurent Daudeville. Lastly, part of the book was presented in English to doctoral students attending ALERT sessions in Aussois, France.

I entered the text, performed the layout, and designed the artwork. Professor Najib Bouaanani read some of the chapters of the French version and made suggestions that, without a doubt, have improved the presentation and made the text clearer. In the final phase of writing the French version of the book, Dr. Benedikt Weber and Dr. Thien-Phu Le read all the chapters. Dr. Benedikt Weber played an essential role suggesting clarifications and developing solutions for several problems using MATLAB, whereas Éric Lapointe and myself developed all solutions with LAS. Olivier Gauron, Research Assistant at the University of Sherbrooke proofread the translation of the French version of the book into English, checked the solutions of the problems and coordinated the production of the artwork in English. His role was not limited to these tasks as he made valuable suggestions that helped clarify part of the book. The author is grateful to Sébastien Mousseau, Najib Bouaanani, Cédric Adagbe, Adamou Saidou Sanda, Danusa Tavares and Gustavo Siqueira for their dedication in meticulously and expertly preparing the drawings.

I am particularly grateful to my former Professor René Tinawi for initially piquing my interest in the subject. For a number of years, I taught a course on structural dynamics in parallel with a course taught by Professor Pierre Léger, first at McGill University and now at École Polytechnique in Montréal. I have fond memories of many discussions with Professor Léger about teaching approaches and the development of software for teaching structural dynamics. The same is true for Professor Jean Proulx who also wrote the first version of the CALWin program which is the ancestor of LAS. I wish to thank Éric Lapointe, Master's student at the University of Sherbrooke for the development of the LAS[1] program that runs under Windows. The LAS program is based on an earlier non-graphical basic version developed by Dr. Charles Carbonneau. Éric Lapointe's enthusiasm, technical knowledge, refined programming skills that allows him to put algorithms into code at a record speed led to completion of a project that was dear to me for a number of years. The program is available as freeware to anyone interested. LAS is a powerful program that can be used to quickly learn structural matrix computation methods, the finite-element method, structural dynamics and matrix computations. LAS software can be downloaded from http://www.civil.usherbrooke.ca/ppaultre/. Lastly, I would like to thank Professor Jean Proulx who was a great help in the translation of the book from French to English.

This book was typeset with LaTeX2ε. Donald Knuth cannot be thanked enough for TeX.

Patrick Paultre, Sherbrooke 2010

"Let no one say that I have said nothing new; the arrangement of the subject is new."

Blaise Pascal, Pensées 22-696

1. LAS is an acronym for **L**anguage for the **A**nalysis of **S**tructures which in French is **L**anguage pour l'**A**nalyse des **S**tructures.