COMPUTATIONAL MECHANICS FOR THE TWENTY-FIRST CENTURY

Saxe-Coburg Publications on Computational Engineering

Computational Modelling of Masonry, Brickwork and Blockwork Structures
Edited by: J.W. Bull

Innovative Computational Methods for Structural Mechanics
Edited by: M. Papadrakakis and B.H.V. Topping

Parallel and Distributed Processing for Computational Mechanics: Systems and Tools
Edited by:B.H.V. Topping

High Performance Computing for Computational Mechanics
Edited by: B.H.V. Topping and L. Lämmer

Derivational Analogy Based Structural Design
B. Kumar and B. Raphael

Parallel Finite Element Computations
B.H.V. Topping and A.I. Khan

COMPUTATIONAL MECHANICS FOR THE TWENTY-FIRST CENTURY

Edited by
B.H.V. Topping

SAXE-COBURG PUBLICATIONS
EDINBURGH

published 2000 by
Saxe-Coburg Publications
10 Saxe-Coburg Place
Edinburgh, EH3 5BR, UK

Saxe-Coburg Publications is an imprint of Civil-Comp Ltd

ISBN 1-874672-13-X

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Cover Image: Rapid (real-time) modelling using special gloves and virtual reality facility to generate the model of a nanospacecraft.
Courtesy of Derek Wilson of the University of Virginia
Center for Advanced Computational Technology.

Printed in Great Britain by Bell & Bain Ltd., Glasgow

Contents

Preface

The start of a new century provides not only the opportunity for celebration but also time for reflection. Regardless of whether you believe that the new millenium commences at the start or the end of 2000, this year is an opportunity for assessment of past progress and future possibilities. This volume of lectures presented at The Fifth International Conference on Computational Structures Technology and The Second International Conference on Engineering Computational Technology held in Leuven, Belgium between 6 and 8 September 2000 does just that with respect to the field of Computational Mechanics.

Computational Mechanics is a broad field based on a bed-rock of mathematics and computer science which leads to applications in all branches of engineering including aeronautical, chemical, civil, mechanical, geotechnical and structural disciplines. The lectures in this book include both review chapters and descriptions of a body of work from well established researchers in the field. There are contributions from engineers, mathematicians and computer scientists. The chapters deal with important established techniques as well as new and emerging areas of interest.

In the first Chapter, the use of simulation and modelling for the design and development of high-tech products is discussed. The importance of simulation in the training and education fields is also covered with special reference to virtual environments. The full effect of these technologies on all application areas has yet to be fully realised by the engineering community at large.

Chapter 2 is the first of a number of chapters which look at various aspects of the finite element method. This chapter reviews the key areas of development of finite element methods including incompressible solids, plate and shell structures, fully coupled fluid flow-structure interaction problems and error estimation. Also contained in Chapter 2 is some new work on the development of an effective meshless solution technique to avoid the computational expense of the meshing process. The chapter concludes with some illustrative examples using the leading finite element code *ADINA*.

In the late 1970s researchers and practitioners were concerned about the *"garbage in – garbage out"* facility with which most computers could easily be used to produce either inappropriate or in some cases ridiculous results. This message is of course still relevant today where the requirement to ensure software standards and appropriate modelling is of great interest. In Chapter 3, the question of quality assurance in finite element based simulation is addressed in the context of both modelling and of numerical solution. As described in this chapter, there is much still to be accomplished in the area of adaptive procedures and error estimation.

The next four chapters review various aspects of the finite element method. In Chapter 4 recent advances in the use of finite element templates and preliminary benchmark tests are reported. In Chapter 5, the quest for reliable shell finite elements is outlined and in Chapter 6 the development of special hybrid stress finite elements with traction-free segments is introduced. Chapter 7 is concerned with the inverse problem of non-steady metal forming where derivative calculations and shape optimisation using a finite element model are key elements of the simulation process. This process also requires mesh optimisation. In Chapter 8, the development of micromechanics models for composites and foam materials for use in finite element analysis is reviewed. These models permit functionally oriented materials design.

Chapters 9 and 10 discuss the use of optimization techniques for smart structures and active control devices. Chapter 9 presents refined finite element models based on higher order displacement fields applied to the optimal design of laminated composite plate structures. Optimization techniques are used to find appropriate locations for piezoelectric actuators embedded within the composite plates. In Chapter 10, random uncertainty models are applied to the active control and optimal design of structures.

In Chapter 11, the features of modelling engineering processes are shown to be a major challenge in computational mechanics. The development of a multiphysics approach exploiting parallel computational procedures is discussed. In Chapter 12, the parallel theme continues but in the area of aerospace simulations. Here the issues of generating large meshes of nearly 100 million elements, partitioning the meshes and load balancing their parallel solution are addressed. The aerospace theme is continued, in Chapter 13, by reviewing finite element based methods for solution of problems involving the scattering of waves by perfectly conducting obstacles. The large computational problems require the generation of large unstructured meshes and grids as prevously described in Chapter 12.

In Chapter 14, the fluid-structure interaction problem, addressed in Chapter 2, is considered in more detail. In Chapter 15, important developments in computational stochastic structural mechanics are reviewed. This review includes: Monte Carlo simulation techniques; nonlinear stochastic dynamics; random eigen-value problems; and stochastic finite elements.

In Chapter 16, a review of life-cycle reliability-based technology for design of structural systems is presented. In Chapter 17, the use of health monitoring techniques for civil engineering structures is discussed in relation to a box bridge. This is an example of how computational mechanics research is being used in the monitoring and assessment of many existing structures. Chapter 18 describes the use of the finite element method in the analysis of the structural stability of concrete armour units using the *ADINA* program mentioned in Chapter 2.

In Chapter 19, the Rational Krylov Algorithm for nonlinear eigenvalue problems is presented. The algorithm is applied to the free vibration analysis of damped mechanical systems with the damping effects modelled using a visco-elastic constitutive relationship.

Chapters 20 and 21 review aspects of optimization methods applied to engineering structures. In Chapter 20, evolutionary structural optimization procedures for topology and shape optimization are described. These procedures minimize maximum stress and maximize stiffness. This multicriteria design problem, which has many applications in engineering practice, is illustrated in the chapter with a number of interesting examples. Chapter 21 reviews the use of evolution strategies to solve large scale structural optimization problems under seismic loading.

Chapters 22 and 23 describe the use of metaphors from nature applied to computational mechanics problems. In the first of these chapters, neural networks, classifier systems (involving the use of genetic algorithms) and cellular automata for multidisciplinary synthesis are considered. In the second of the chapters the use and future development of neural networks in structural mechanics is reviewed.

Computational Mechanics is a truly interdisciplinary activity that only became possible with the development of the digital computer after World War II. Key to the development of the discipline was the finite element method which has its roots in the 1950s. After almost fifty years of development one might expect the field of Computational Mechanics to be mature. While some would consider the finite element method a mature research topic, the range of new applications and problems continues to develop. In particular, multiphysics problems are in an area receiving much current attention. The size and complexity of most engineering problems continues to increase – ever matching or exceeding the capabilities of the available computer hardware. Today, the performance of current computers permits the implementation of some long abandoned algorithms as a possible route to the solution of previously intractable problems. Like a genetic algorithm, the development of Computational Mechanics appears to have a 'mutating' life cycle with 'cross-overs' to many other disciplines, which continues to find many 'local maxima'. The search for the 'global maximum' will, of course, continue for the forseeable future.

Barry H.V. Topping
Department of Mechanical and Chemical Engineering
Heriot-Watt University, Edinburgh, United Kingdom

Acknowledgements

The Fifth International Conference on Computational Structures Technology and The Second International Conference on Engineering Computational Technology, were held in Leuven, Belgium from 6-8 September 2000. I should like to thank all the authors of the lectures included in this volume. The time available to prepare this book was very short and the response of the authors is greatly appreciated.

These Conferences could not have been organised without the contribution of many people who helped in their planning, organisation and execution. Professor G. De Roeck was a valuable source of help locally in Leuven and in many aspects of the organisation of the conferences. Professor K.J. Bathe and Professor A.K. Noor were a constant source of encouragement and their continued support for these Conference series is gratefully acknowledged.

The kind help of Professor A.K. Noor and D. Wilson of the University of Virginia Center for Advanced Computational Technology in providing the splendid image shown on the cover of this book is greatly appreciated.

My thanks are also due to all at Saxe-Coburg Publications: Civil-Comp Ltd for their help and perseverance in the realisation of these conferences, particularly Mrs Rosemary Brodie. The assistance of members of the Structural Engineering Computational Technology Research Group at Heriot-Watt University, Edinburgh is gratefully acknowledged especially from Roman Putanowicz, Janos Nezö and Péter Iványi.

The delights of Leuven were first drawn to my attention by Jelle Muylle, a former student of Professor G. De Roeck. Jelle's tireless and enthusiastic assistance in bringing these Conferences to fruition is gratefully acknowledged.

Barry H.V. Topping
Department of Mechanical and Chemical Engineering
Heriot-Watt University, Edinburgh, United Kingdom