COMPUTATIONAL MODELLING OF MASONRY, BRICKWORK AND BLOCKWORK STRUCTURES

Also available from Saxe-Coburg Publications

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

3D Modeling with ACIS
J. Corney and T. Lim

Strength of Materials: An Undergraduate Text
G.M. Seed

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

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

COMPUTATIONAL MODELLING OF MASONRY, BRICKWORK AND BLOCKWORK STRUCTURES

Edited by
J.W. Bull

SAXE-COBURG
PUBLICATIONS

published 2001 by
Saxe-Coburg Publications
Dun Eaglais, Station Brae, Kippen
Stirling, FK8 3DY, UK

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

ISBN 1-874672-04-0

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

Printed in Great Britain by Bell & Bain Ltd, Glasgow

Contents

Preface

This book is aimed at: design engineers who need to know the latest advances in masonry, brickwork and blockwork; architects wanting to develop building shape still further; engineering consultants who must ensure designs are safe; academics who research into masonry and postgraduates approaching masonry for research purposes.

The use of masonry, brickwork and blockwork for building and civil engineering structures has a long history going back to ancient times. For many hundreds of years, the main masonry material has been stone, with clay becoming the main brickwork material. With the introduction of other materials including concrete, the term blockwork is now also used.

As masonry and brickwork structures have a long history, design standards have generally accepted the empirical design requirements that place 'natural' height restrictions on masonry and brickwork structures. Further, brickwork and blockwork are often still seen as just infill material for steel framed or reinforced concrete buildings.

With the advent of reinforcing or post tensioning brickwork, increasingly complex structures became a possibility. Further there is an increasing requirement to assess the strength of existing masonry structures and to determine the most suitable means of improving masonry performance.

Designers, engineers and research workers want to exploit masonry to its full potential. To determine how masonry reacts to extreme conditions, there is a need for the computational modelling of a whole range of masonry, brickwork and blockwork materials and structures, including the composite action of the brick/joint interface.

Although much of the information on masonry structures is available from publications in journals and at conferences, masonry research is widely scattered throughout the world. In recognition of this fact, the expert chapter authors in this book have been drawn together from around the world. Their up-to-date knowledge and expertise in masonry structures is drawn upon to determine the present state of the computational modelling of masonry, brickwork and blockwork structures and to point to future developments.

This book brings together a wide range of masonry, brickwork and blockwork disciplines and shows where computational modelling has been used successfully. The ten chapters have been divided into five topic areas: damage and failure models; vibration and earthquake effects; settlement; fire; and historic buildings. Each topic area can be described briefly as follows:

Damage and failure models

Chapter one reviews the literature regarding the homogeneous and heterogeneous constitutive laws for masonry and describes two models based on damage mechanics. In the first model, masonry is considered as a homogeneous, orthotropic material, but in the second model the overall mechanical properties of masonry are determined based on the properties of the components. The numerical results from the two models are in good agreement with experimental data.

Chapter two considers the formulation of an elastic-plastic joint element to determine the structural behaviour and characteristics of masonry structures. The chapter then goes on to investigate the effectiveness of the joint element.

Earthquake and vibration effects

Chapter three refers to the computational modelling of masonry structures subject to earthquake and vibration effects. After a general survey covering the effect of earthquake and vibration loads on civil engineering structures, the chapter then focuses on the modelling of the structure, the material and load simulation. Two case studies are included.

Chapter four studies the dynamic behaviour of masonry bell towers. Measurements of the transient response during full-circle ringing of a single heavy bell gave the natural frequency, mode shape, damping, and peak response for each tower. Finite element analyses of the towers for frequency, mode shape and transient response correlated well with the observed behaviour. Very large factors of safety were found in the bell towers.

Settlement

Chapter five describes the development and use of a complex three-dimensional finite element model to study the effect of constructing a tunnel beneath an existing masonry building. Results are presented for simple arrangements of masonry facades as well as more complex buildings for which field data are available.

Fire

Chapter six provides insight into factors affecting the thermo-structural behaviour of masonry firewalls. The elevated temperature material properties of some masonry materials are discussed. This has facilitated a greater understanding of the structural response of masonry in high temperature environments. A computational model has been used to successfully simulate the experimental data from fire testing of masonry walls.

Historic buildings

Chapter seven applies discontinuous deformation analysis, within the context of the computational modelling, to the assessment of masonry arch bridges. The method was tested on a series of benchmark problems related to the stability of a masonry arch under its own weight. The analysis predictions were compared with nonlinear finite element analysis and discrete element analysis predictions. Satisfactory comparisons of failure mode and formation of hinges were obtained.

Chapter eight reviews the basic problems associated with the computational modelling of masonry arches. The chapter discusses the basic characteristics of masonry materials and describes the development of a 'rigid block' mechanism method of analysis, which allows estimates of the ultimate load carrying capacity of arches to be obtained. As not all constituent blocks in a masonry arch are rigid, issues relevant to the non-linear elastic methods of analysis are also discussed.

Chapter nine looks at the conservation and rehabilitation of historic masonry structures and uses computational modelling to study the safety and stability of structural elements in old "difficult" masonry. The results show that masonry structures can reach unpredictable limit states. Furthermore, every technological and structural detail must be taken into account, and with computational modelling the results of a variety of different assumed structural models and analysis methods have to be compared with each other.

Chapter ten considers computational techniques for structural assessment of historic masonry structures and focuses on establishing feasible states of equilibrium that encourage interaction between the engineer and the computer. The computational models are based on finite element concepts developed with characteristics relating to equilibrium elements. The techniques involve the determination of thrust lines for skeletal structures using spreadsheets, the optimization of general thrust lines by limit analyses and the use of finite element models that can simulate cracking. The techniques are illustrated by case studies using historic structures.

My thanks go to my family for their support, to the chapter authors for their contributions and to Saxe-Coburg Publications for their help and guidance especially Barry Topping, Jelle Muylle, and Rosemary Brodie.

John W. Bull