Andreas Öchsner · Marco Öchsner

# The Finite Element Analysis Program MSC Marc/Mentat

## A First Introduction

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Andreas Öchsner
Griffith School of Engineering
Griffith University
Southport, QLD
Australia

Marco Öchsner
Griffith School of Medical Sciences
Griffith University
Southport, QLD
Australia

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*Nichtstun ist eine der größten und verhältnismäßig leicht zu beseitigenden Dummheiten*

Franz Kafka (1883–1924)

# Preface

This book is a short introduction to the general-purpose finite element program MSC Marc, which is distributed by MSC Software Corporation. It is a specialized program for nonlinear problems (implicit solver) which is common in academia and industry. The primary goal of this book is to provide a quick introduction to the software, based on simple examples. The documentation of all finite element programs nowadays contains a variety of step-by-step examples of different complexities. In addition, all software companies offer professional workshops on different topics. The intention of this book is not to compete with these professional offers and opportunities. We would rather like to focus on simple examples, often single-element problems, which can easily be related to the theory which is provided in finite element lectures. In that sense, it is rather a companion book to a classical introductory course in the finite element method.

Chapter 1 starts with some historical comments on the development of finite element software. Then, a short introduction into the steps of a finite element analysis as well as the graphical interface Mentat is provided. Chapter 2 introduces the simplest one-dimensional element, i.e., a rod which can only deform along its principal axis. The spatial arrangement is then treated to cover more practical problems. Chapter 3 covers simple beam elements which can deform perpendicular to their primary axis. These elements are then arranged as plane frame structures under the consideration of a generalized beam element which can elongate and deflect. Chapter 4 presents a higher order beam theory according to Timoshenko. This formulation considers the contribution of the shear force on the deflection. Chapter 5 extends the rod element to a two-dimensional plane elasticity problem. Chapter 6 introduces the two-dimensional equivalent of the simple beam, a classical plate. Chapter 7 covers three-dimensional elements in the form of hexahedrons. Chapter 8 introduces a nonlinear problem, i.e., the elasto-plastic deformation of rod elements. Chapter 9 summarizes a few advanced topics which are helpful for larger simulations or parametric studies.

The instructions provided in this book relate to the Marc/Mentat 2014.0.0 (64 bit) version. The graphical interface and the command structure might be slightly different for older versions and in such case the reader is advised to adjust some of the given instructions. The same must be expected for future versions.

We look forward to receiving some comments and suggestions for the next edition of this introductory work.

Southport, QLD, Australia
December 2015

Andreas Öchsner
Marco Öchsner

# Contents

# Symbols and Abbreviations

## Latin Symbols (Capital Letters)

| | |
|---|---|
| $A$ | Area, cross-sectional area, geometrical dimension |
| $B$ | Geometrical dimension |
| $A_s$ | Shear area |
| $E$ | YOUNG's modulus |
| $EI$ | Bending stiffness |
| $F$ | Force, yield condition |
| $G$ | Shear modulus |
| $GA$ | Shear stiffness |
| $GI_p$ | Torsional stiffness |
| $H$ | Kinematic hardening modulus |
| $I$ | Second moment of area, |
| $\boldsymbol{K}$ | Global stiffness matrix |
| $\boldsymbol{K}^e$ | Elemental stiffness matrix |
| $L$ | Element length |
| $M$ | Moment |
| $N$ | Normal force |
| $Q$ | Shear force |
| $X$ | Global Cartesian coordinate |
| $Y$ | Global Cartesian coordinate |
| $Z$ | Global Cartesian coordinate |

## Latin Symbols (Small Letters)

| | |
|---|---|
| $a$ | Geometrical dimension |
| $b$ | Geometrical dimension |
| $c$ | Geometrical dimension |
| $\boldsymbol{f}$ | Column matrix of loads |
| $h$ | Geometrical dimension |

| | |
|---|---|
| $k$ | Yield stress |
| $k_s$ | Shear correction factor |
| $q$ | Distributed load |
| $t$ | Geometrical dimension |
| $u$ | Displacement |
| $w$ | Specific work |
| $x$ | Local Cartesian coordinate |
| $y$ | Local Cartesian coordinate |
| $z$ | Local Cartesian coordinate |

## Greek Symbols (Capital Letters)

| | |
|---|---|
| $\Gamma$ | Boundary |
| $\Omega$ | Domain |

## Greek Symbols (Small Letters)

| | |
|---|---|
| $\alpha$ | Angle |
| $\beta$ | Angle |
| $\gamma$ | Shear strain |
| $\varepsilon$ | Strain |
| $\kappa$ | Curvature, isotropic hardening parameter |
| $\lambda$ | Consistency parameter |
| $\nu$ | POISSON's ratio |
| $\rho$ | Density |
| $\sigma$ | Stress |
| $\phi$ | Rotation |
| $\varphi$ | Rotation |

## Mathematical Symbols

| | |
|---|---|
| $\times$ | Multiplication sign (used where essential) |
| $[\ldots]$ | Matrix |
| $[\ldots]^{\mathrm{T}}$ | Transpose |
| $\mathrm{sgn}(\ldots)$ | Signum (sign) function |

## Indices, Superscripted

| | |
|---|---|
| $\ldots^{\mathrm{e}}$ | Element |
| $\ldots^{\mathrm{el}}$ | Elastic |
| $\ldots^{\mathrm{elpl}}$ | Elasto-plastic |

| | |
|---|---|
| $\ldots^{init}$ | Initial |
| $\ldots^{pl}$ | Plastic |

## Indices, Subscripted

| | |
|---|---|
| $\ldots_{c}$ | Compression |
| $\ldots_{eff}$ | Effective |
| $\ldots_{max}$ | Maximum |
| $\ldots_{nom}$ | Nominal |
| $\ldots_{R}$ | Reaction |
| $\ldots_{s}$ | Shear |
| $\ldots_{t}$ | Tensile |

## Abbreviations

| | |
|---|---|
| 1D | One-dimensional |
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| BC | Boundary condition |
| FEM | Finite element method |
| SI | International system of units |

# Chapter 1
# Introduction to Marc/Mentat

## 1.1 Historical Comments on the Program Development

The development of finite element software goes back to the early 60s when Richard MacNeal and Bob Schwendler in 1963 founded the MacNeal-Schwendler Corporation (MSC). In 1965 MSC was awarded the original contract from NASA to commercialize the finite element analysis software known as Nastran (NASA Structural Analysis) [8]. Nastran is still today the workhorse for large *linear* simulations.

Marc was the first commercial *non-linear* general-purpose finite element program. The development of the Marc software is significantly connected with two scientists, namely i.e., Pedro V. Marcal and David Hibbitt. From the development of the Marc software, a competitive product called Abaqus emerged and Table 1.1 illustrates the common roots of both packages. Both packages have a similar core and are popular in research because the user can write user-subroutines in the programming language Fortran, which is the language of all classical finite element packages. This subroutine feature allows the user to replace certain modules of the core code and to implement new features such as constitutive laws or new elements.

## 1.2 General Comments on Finite Element Analyses

A finite elements analysis involves different steps and program modules. A user normally defines the computational model to be solved in a graphical interface, called the pre-processor. The geometry can either be created in the pre-processor or imported from external computer-aided design programs (CAD), see Table 1.2.

Most of the commercial finite element pre-processors have specific import filters open to third-party CAD files, e.g. a prt-file in the case of Pro/ENGINEER (Pro Creo). If there is no import filter available for a specific CAD package, the importing of a geometry file is still possible via a neutral file format such as ACIS, IGES, STL or STEP. It should be noted here that the generation of complex geometries is in



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**Table 1.1** Some historical steps in relation to the development of MSC Marc

| Year | Comment | Ref. |
|---|---|---|
| 1964 | Pedro V. Marcal received a Ph.D. in Applied Mechanics from the Imperial College of Science and Technology, University of London | [13] |
| ... | Pedro V. Marcal worked as Lecturer at the Imperial College of Science and Technology, University of London | [6] |
| ~1965 | A group of researchers at Brown University in Providence, Rhode Island started the development of finite element software | [20] |
| 1967–1974 | Pedro V. Marcal taught as Professor in the Division of Engineering, Brown University in Providence, Rhode Island | [6] |
| 1971 | Pedro V. Marcal founded the MARC Analysis Research Corporation in Palo Alto, California | [20] |
| 1972 | The first version of MARC was introduced | [20] |
| 1972 | David Hibbitt received a Ph.D., related to computational mechanics using the finite element method, from Brown University | [20] |
| 1972–1977 | David Hibbitt worked for the MARC Analysis Research Corporation, responsible for the development of the MARC program | [4] |
| 1976 | Dr. Bengt Karlsson who worked for the Control Data Corporation (CDC) in Sweden joined MARC | [20] |
| 1977 | Paul Sorensen received a Ph.D. from Brown University and joined General Motors. He worked previously briefly for MARC | [1, 20] |
| 1978 | David Hibbitt founded Hibbitt, Karlsson & Sorensen, Inc. (later known as ABAQUS Inc.) and began the design and development of the ABAQUS program | [4] |
| 1999 | The MacNeal-Schwendler Corporation (now MSC Software Corporation) acquired the MARC Analysis Research Corporation for about $36 million | [15] |
| 2005 | Dassault Systèmes acquired ABAQUS Inc. for about $413 million | [20] |

**Table 1.2** Some common CAD packages

| Name | Company | Web page |
|---|---|---|
| AutoCAD | Autodesk | http://www.autodesk.com/ |
| CATIA | Dassault Systèmes | http://www.3ds.com/ |
| Pro/ENGINEER (PTC Creo) | Parametric Technology Corporation | http://www.ptc.com |
| Solid Edge | Siemens PLM | http://www.plm.automation.siemens.com |
| SolidWorks | Dassault Systèmes | http://www.3ds.com/ |