An Overview of Basic Concepts of Finite Element Analysis and Its Applications in Orthodontics

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Abstract: *Purpose:* The aim of this article is to acquaint the readers with the aims and goals of the finite element method and how to use it in dentistry and especially in orthodontics.

Methods: The finite element method (FEM) has shown to be a beneficial research tool that has assisted scientists in various analyses such as stress-strain, heat transfer, dynamic, collision, and deformation analyses. The FEM is responsible for predicting the behavior of objects under different working conditions. It is a computational procedure to measure the stress in an element, which performs a model solution to solve a problem; the FEM subdivides a large system into smaller, simpler parts called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object. The technique of FEA lies in the development of a suitable mesh arrangement.

Conclusions: The FEM can be effective in understanding the behavior of teeth, both jaws, craniofacial structures, and other hard tissue structures of humans under various working conditions, as the technique allows for evaluating tooth movement and the stress distribution within the surrounding alveolar bone, the periodontal ligament (PDL). This technique is exceptionally valuable for evaluating mechanical aspects of biomaterials and human tissues that can hardly be measured in vivo. This review article presents the FEM, its methodology, and its application in the orthodontic domain.

Keywords: Finite element analysis, Finite element method, Orthodontics.

INTRODUCTION

Experimental, analytical, and numerical methods are well-known techniques used to solve problems [1]. Each method has some advantages and disadvantages making them practical or impractical in different problems. For instance, although experimental technique can lead to trustable outcomes, it has some drawbacks such as being time consuming, can be influenced from human error, being high-cost technique, all variables cannot be controlled, and its result can be applied to only one situation [2]. Furthermore, employing analytical methods would be really challenging and, in some cases, inapplicable for complex problems (like alveolar structures). Therefore, the numerical method can be a good choice in terms of time, cost, eliminating human error, managing the variables, repeating the analyses, and solving complex problems. The Finite Element Method (FEM) is regarded as a numerical method that can be employed to model physical or physiological phenomena. Computers using the FEM, simulate different physical and geometrical characteristics of any structures. This method can assist in the prediction of behavior of any object under differing situations, and can help with the design and manufacturing process [3].

Finite element analysis (FEA) evaluates physical phenomena using a numerical technique, the FEM. It is a powerful computerized method that can analyze the behavior of complex geometry with heterogeneous material properties. FEA is employed in orthodontics by evaluating the interactions between the teeth and the surrounding tissues. The method allows orthodontists to understand better the physiological reactions that are likely to occur within the dento-alveolar complex, resulting from thermal stress created by hot and cold drinks [4].

FEA was first developed by R. Courant [5] in 1943 using the Ritz method in numerical analysis. A few years later, in 1956, Turner MJ et al. [6] published a paper focusing on the "stiffness and deflection of

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Finite Element Method And Its Applications

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Finite Element Method And Its Applications:

The Finite Element Method and Its Applications Masatake Mori,1986 **The Finite Element Method: Its Basis and Fundamentals** O. C. Zienkiewicz,R. L. Taylor,2013-08-31 The Finite Element Method Its Basis and Fundamentals offers a complete introduction to the basis of the finite element method covering fundamental theory and worked examples in the detail required for readers to apply the knowledge to their own engineering problems and understand more advanced applications This edition sees a significant rearrangement of the book s content to enable clearer development of the finite element method with major new chapters and sections added to cover Weak forms Variational forms Multi dimensional field problems Automatic mesh generation Plate bending and shells Developments in meshless techniques Focusing on the core knowledge mathematical and analytical tools needed for successful application The Finite Element Method Its Basis and Fundamentals is the authoritative resource of choice for graduate level students researchers and professional engineers involved in finite element based engineering analysis A proven keystone reference in the library of any engineer needing to understand and apply the finite element method in design and development Founded by an influential pioneer in the field and updated in this seventh edition by an author team incorporating academic authority and industrial simulation experience Features reworked and reordered contents for clearer development of the theory plus new chapters and sections on mesh generation plate bending shells weak forms and variational forms *Finite Element Methods and Their Applications* Zhangxin Chen,2005-06-23 Introduce every concept in the simplest setting and to maintain a level of treatment that is as rigorous as possible without being unnecessarily abstract Contains unique recent developments of various finite elements such as nonconforming mixed discontinuous characteristic and adaptive finite elements along with their applications Describes unique recent applications of finite element methods to important fields such as multiphase flows in porous media and semiconductor modelling Treats the three major types of partial differential equations i e elliptic parabolic and hyperbolic equations *Finite Element Method and Its Applications* Kaitai Li,Aixiang Huang,Qinghuai Huang,2015 Finite element method and its applications discusses the methods in a general frame and the performance on the computer the variational formulations for elliptic boundary value problems the error estimates and convergence for finite element approximate solutions and nonstandard finite element In particular presentations of the subject include the applications of finite element method to various scientific and engineering problems for example three dimensional elastic beam elastic mechanics three dimensional neutron diffusion problems magnetohydrodynamics three dimensional turbomachinery flows Navier Stokes equations and bifurcation phenomena for nonlinear problem etc Most applications results were established by the authors in the past three decades *The Finite Element Method Set* O. C. Zienkiewicz,R. L. Taylor,2005-11-25 The sixth editions of these seminal books deliver the most up to date and comprehensive reference yet on the finite element method for all engineers and mathematicians Renowned for their scope range and authority the new editions have been significantly

developed in terms of both contents and scope Each book is now complete in its own right and provides self contained reference used together they provide a formidable resource covering the theory and the application of the universally used FEM Written by the leading professors in their fields the three books cover the basis of the method its application to solid mechanics and to fluid dynamics This is THE classic finite element method set by two the subject s leading authors FEM is a constantly developing subject and any professional or student of engineering involved in understanding the computational modelling of physical systems will inevitably use the techniques in these books Fully up to date ideal for teaching and reference **The Virtual Element Method and its Applications** Paola F. Antonietti,Lourenço Beirão da Veiga,Gianmarco Manzini,2022-10-08 The purpose of this book is to present the current state of the art of the Virtual Element Method VEM by collecting contributions from many of the most active researchers in this field and covering a broad range of topics from the mathematical foundation to real life computational applications The book is naturally divided into three parts The first part of the book presents recent advances in theoretical and computational aspects of VEMs discussing the generality of the meshes suitable to the VEM the implementation of the VEM for linear and nonlinear PDEs and the construction of discrete hessian complexes The second part of the volume discusses Virtual Element discretization of paradigmatic linear and non linear partial differential problems from computational mechanics fluid dynamics and wave propagation phenomena Finally the third part contains challenging applications such as the modeling of materials with fractures magneto hydrodynamics phenomena and contact solid mechanics The book is intended for graduate students and researchers in mathematics and engineering fields interested in learning novel numerical techniques for the solution of partial differential equations It may as well serve as useful reference material for numerical analysts practitioners of the field Finite Element Method with Applications in Engineering Y. M. Desai,2011 The book explains the finite element method with various engineering applications to help students teachers engineers and researchers It explains mathematical modeling of engineering problems and approximate methods of analysis and different approaches *Finite Element Method and Its Applications* Swee Eng Khor,2003 **The Finite Element Method** Zhangxin Chen,2011 A fundamental and practical introduction to the finite element method its variants and their applications in engineering **The Mathematics of Finite Elements and Applications** J. R. Whiteman,2014-05-10 The Mathematics of Finite Elements and Applications provides information pertinent to the mathematics of finite elements applications algorithms and computational techniques This book discusses the developments in the mathematics of finite elements Organized into 32 chapters this book begins with an overview of the basis of the finite element process as a general approximation tool This text then examines the methods for obtaining bounds on the errors in finite element solutions to two dimensional elliptic boundary value problems defined on simply connected polygonal regions Other chapters consider the practical implementation of the Galerkin and the Rayleigh Ritz methods to equations of importance to physics and engineering This book discusses as well a fundamental investigation into the problem

of convergence in the finite element method The final chapter deals with an algorithm that is applicable to the analysis of arbitrary plane stress or plane strain configurations This book is a valuable resource for numerical analysts mathematical physicist applied mathematicians computer scientists and engineers **Finite Element Methods and Their Applications** Mahboub Baccouch,2021-11-17 This book provides several applications of the finite element method FEM for solving real world problems FEM is a widely used technique for numerical simulations in many areas of physics and engineering It has gained increased popularity over recent years for the solution of complex engineering and science problems FEM is now a powerful and popular numerical method for solving differential equations with flexibility in dealing with complex geometric domains and various boundary conditions The method has a wide range of applications in various branches of engineering such as mechanical engineering thermal and fluid flows electromagnetics business management and many others This book describes the development of FEM and discusses and illustrates its specific applications *The Finite Element Method* John Zhangxin Chen,2011 The Finite Element Method O. C. Zienkiewicz,R. L. Taylor,S. Govindjee,2024-11-21 The Finite Element Method Its Basis and Fundamentals Eighth Edition offers a complete introduction to the basis of the finite element method covering fundamental theory and worked examples in a kind of detail required for readers to apply the knowledge to their own engineering problems and understand more advanced applications This edition includes a significant addition of content addressing coupling problems including Finite element analysis formulations for coupled problems Details of algorithms for solving coupled problems Examples showing how algorithms can be used to solve for piezoelectricity and poroelasticity problems Focusing on the core knowledge mathematical and analytical tools needed for successful application this book is the authoritative resource of choice for graduate level students researchers and professional engineers involved in finite element based engineering analysis Includes fully worked exercises throughout the book Addresses the formulation and solution of coupled problems in detail Contains chapter summaries that help the reader keep up to speed Natural Boundary Integral Method and Its Applications De-hao Yu,2002-09-30 Boundary element methods are very important for solving boundary value problems in PDEs Many boundary value problems of partial differential equations can be reduced into boundary integral equations by the natural boundary reduction In this book the natural boundary integral method suggested and developed by Feng and Yu is introduced systematically It is quite different from popular boundary element methods and has many distinctive advantages The variational principle is conserved after the natural boundary reduction and some useful properties are also preserved faithfully Moreover it can be applied directly and naturally in the coupling method and the domain decomposition method of finite and boundary elements Most of the material in this book has only appeared in the author s previous papers Compared with its Chinese edition Science Press Beijing 1993 many new research results such as the domain decomposition methods based on the natural boundary reduction are added *Computational Electromagnetics and Its Applications* Thomas G. Campbell,Roy A. Nicolaides,Manuel D. Salas,2012-12-06 This volume contains the

proceedings of the first ICASE LaRC Work shop on Computational Electromagnetics and Its Applications conducted by the Institute for Computer Applications in Science and Engineering and NASA Langley Research Center We had several goals in mind when we decided jointly with the Elec tromagnetics Research Branch to organize this workshop on Computa tional Electromagnetics CEM Among our goals were a desire to obtain an overview of the current state of CEM covering both algorithms and ap plications and their effect on NASA s activities in this area In addition we wanted to provide an attractive setting for computational scientists with expertise in other fields especially computational fluid dynamics CFD to observe the algorithms and tools of CEM at work Our expectation was that scientists from both fields would discover mutually beneficial inter connections and relationships Another goal was to learn of progress in solution algorithms for electromagnetic optimization and design problems such problems make extensive use of field solvers and computational effi ciency is at a premium To achieve these goals we assembled the renowned group of speakers from academia and industry whose talks are contained in this volume The papers are printed in the same order in which the talks were pre sented at the meeting The first paper is an overview of work currently being performed in the Electromagnetic Research Branch at the Langley Research Center   *The Finite Element Method: Its Basis and Fundamentals* O. C. Zienkiewicz,R. L. Taylor,J.Z. Zhu,2005-05-26 The Sixth Edition of this influential best selling book delivers the most up to date and comprehensive text and reference yet on the basis of the finite element method FEM for all engineers and mathematicians Since the appearance of the first edition 38 years ago The Finite Element Method provides arguably the most authoritative introductory text to the method covering the latest developments and approaches in this dynamic subject and is amply supplemented by exercises worked solutions and computer algorithms The classic FEM text written by the subject s leading authors Enhancements include more worked examples and exercises With a new chapter on automatic mesh generation and added materials on shape function development and the use of higher order elements in solving elasticity and field problemsActive research has shaped The Finite Element Method into the pre eminent tool for the modelling of physical systems It maintains the comprehensive style of earlier editions while presenting the systematic development for the solution of problems modelled by linear differential equations Together with the second and third self contained volumes 0750663219 and 0750663227 The Finite Element Method Set 0750664312 provides a formidable resource covering the theory and the application of FEM including the basis of the method its application to advanced solid and structural mechanics and to computational fluid dynamics The classic introduction to the finite element method by two of the subject s leading authors Any professional or student of engineering involved in understanding the computational modelling of physical systems will inevitably use the techniques in this key text

   Wavelet Numerical Method and Its Applications in Nonlinear Problems You-He Zhou,2021-03-09 This book summarizes the basic theory of wavelets and some related algorithms in an easy to understand language from the perspective of an engineer rather than a mathematician In this book the wavelet solution schemes are systematically

established and introduced for solving general linear and nonlinear initial boundary value problems in engineering including the technique of boundary extension in approximating interval bounded functions the calculation method for various connection coefficients the single point Gaussian integration method in calculating the coefficients of wavelet expansions and unique treatments on nonlinear terms in differential equations At the same time this book is supplemented by a large number of numerical examples to specifically explain procedures and characteristics of the method as well as detailed treatments for specific problems Different from most of the current monographs focusing on the basic theory of wavelets it focuses on the use of wavelet based numerical methods developed by the author over the years Even for the necessary basic theory of wavelet in engineering applications this book is based on the author s own understanding in plain language instead of a relatively difficult professional mathematical description This book is very suitable for students researchers and technical personnel who only want to need the minimal knowledge of wavelet method to solve specific problems in engineering   The Finite Element Method and Its Reliability Ivo Babuška,Theofanis Strouboulis,2001 The finite element method is a numerical method widely used in engineering Experience shows that unreliable computation can lead to very serious consequences Hence reliability questions stand more and more at the forefront of engineering and theoretical interests The present book presents the mathematical theory of the finite element method and focuses on the question of how reliable computed results really are It addresses among other topics the local behaviour errors caused by pollution superconvergence and optimal meshes Many computational examples illustrate the importance of the theoretical conclusions for practical computations Graduate students lecturers and researchers in mathematics engineering and scientific computation will benefit from the clear structure of the book and will find this a very useful reference   **Finite element theory and its application with open source codes** Anthony Pickett,2020-11-10 This book combines essential finite element FE theory with a set of fourteen tutorials using relatively easy to use open source CAD FE and other numerical analysis codes so a student can undertake practical analysis and self study The theory covers fundamentals of the finite element method Formulation of element stiffness for one dimensional bar and beam two dimensional and three dimensional continuum elements plate and shell elements are derived based on energy and variational methods Linear nonlinear and transient dynamic solution methods are covered for both mechanical and field analysis problems with a focus on heat transfer Other important theoretical topics covered include element integration element assembly loads boundary conditions contact and a chapter devoted to material laws on elasticity hyperelasticity and plasticity A brief introduction to Computational Fluid Dynamics CFD is also included The second half of this book presents a chapter on using tutorials containing information on code installation on Windows and getting started and general hints on meshing modelling and analysis This is then followed by tutorials and exercises that cover linear nonlinear and dynamic mechanical analysis steady state and transient heat analysis field analysis fatigue buckling and frequency analysis a hydraulic pipe network analysis and lastly two tutorials on CFD simulation In each case

theory is linked with application and exercises are included for further self study For these tutorials open source codes FreeCAD CalculiX FreeMAT and OpenFOAM are used CalculiX is a comprehensive FE package covering linear nonlinear and transient analysis One particular benefit is that its format and structure is based on Abaqus so knowledge gained is relevant to a leading commercial code FreeCAD is primarily a powerful CAD modelling code that includes good finite element meshing and modelling capabilities and is fully integrated with CalculiX FreeMAT is used in three tutorials for numerical analysis demonstrating algorithms for explicit finite element and CFD analysis And OpenFOAM is used for other CFD flow simulations The primary aim of this book is to provide a unified text covering theory and practice so a student can learn and experiment with these versatile and powerful analysis methods It should be of value to both finite element courses and for student self study   Current Trends in Mathematical Analysis and Its Interdisciplinary Applications Hemen Dutta,Ljubiša D. R. Kočinac,Hari M. Srivastava,2019-08-23 This book explores several important aspects of recent developments in the interdisciplinary applications of mathematical analysis MA and highlights how MA is now being employed in many areas of scientific research Each of the 23 carefully reviewed chapters was written by experienced expert s in respective field and will enrich readers understanding of the respective research problems providing them with sufficient background to understand the theories methods and applications discussed The book s main goal is to highlight the latest trends and advances equipping interested readers to pursue further research of their own Given its scope the book will especially benefit graduate and PhD students researchers in the applied sciences educators and engineers with an interest in recent developments in the interdisciplinary applications of mathematical analysis

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