Computational Mechanics

(*English Course*)

Yongliang Wang

School of Mechanics and Civil Engineering

China University of Mining and Technology (Beijing)

Friday, May 5, 2023

Teachers

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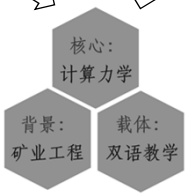
Course arrangements and requirements

力学、土木、矿业工程
本研基础课程:

材料力学
结构力学
弹性力学
采动损伤断裂力学
张量分析
数学物理方法
数值分析
专业外语
编程语言程序设计
… …

• 全英文
(2023，80学时，6学分)



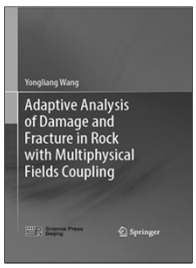
• 矿业特色的计算力学
双语教学模式
(2017，48学时，3学分)

力学、土木、矿业工程
本研高阶课程:

ANSYS、ABAQUS应用
COMSOL计算软件应用
结构分析与SAP2000应用
岩土工程数值分析方法
岩体力学与数值分析方法
有限单元基础(研)
计算固体力学
计算流体力学
岩石破坏理论与数值方法
… …

Course arrangements and requirements

■ **Books**



- Yongliang Wang. Basic Theory of Finite Element Method. Science Press, 2023.
- Yongliang Wang. Adaptive Analysis of Damage and Fracture in Rock with Multiphysical Fields Coupling. Springer Press & Science Press, 2021.

Course arrangements and requirements

■ **Books**

- O. C. Zienkiewicz, R. L. Taylor, J. Z. Zhu. The Finite Element Method: Its Basis & Fundamentals (7th edition). Elsevier Pte Ltd, 2015.
  —O.C. Zienkiewicz, J.Z. Zhu (Swansea University, UK), R.L.Taylor (University of California, Berkeley, US)
- O. C. Zienkiewicz, R. L. Taylor著, 曾攀译. 有限元方法: 基本原理(第5卷). 清华大学出版社, 2008.

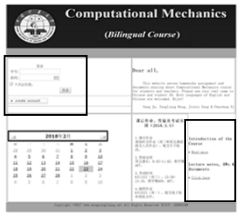
Course arrangements and requirements

Plato is dear to me,
but dearer still is truth !

尽信《书》，
则不如无《书》！

Course arrangements and requirements

- **Homeworks (English): Submit before next Monday** (7&8)
- **Questions time: Friday 17:00-18:00**
- **Online documentations**
  http://www.wangyongliang.net/computmech.aspx
- **Programming: Static computation program of FEM**
- **Final examination: Week 19**



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Course arrangements and requirements

- **Website**

- **Score**

Total score: Homeworks(20%) and in-class quizzes(20%, 4times, 15mins/time), programming homework(20%, week14) and close-book exam(40%)

各项成绩比例：课后作业(20%)和随堂测验(20%，共4次，15mins/次)，编程大作业(20%，17周开始)，闭卷考试(40%)。

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Course arrangements and requirements

- **Static computation program of FEM**

- **Computation function:**
  Standard FEM
  Displacement, Stress, and strain solutions
- **Test examples: one-, two-, and three-dimensional programs of finite element method**
- **Code: Fortran, or Matlab/C++…**
- **Time: 2 weeks, submit in week 19**

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Course arrangements and requirements

- **Requirements**

- **选一位课代表；**
- **请按时交作业（周一课前提交上次作业），晚交不予批改；**
- **作业请独立、认真完成；**
- **随堂测验独立完成；**
- **请按时上课，不迟到、不早退；**
- **请保持课堂的安静(手机静音)；**
- **请遵守网上作业系统的要求（严禁上载课程无关文件）。**

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Course arrangements and requirements

- **WeChat group for CM course**

- **微信群用于课程讨论、发送即时通知；**
- **请遵守课程要求（严禁发表课程无关讨论）。**

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1 Introduction of Finite Element Method

1.1 Development process of finite element method

1.2 Computation procedure of finite element method

1.3 Main contents of the book

1.4 Exercises

1.1 Development process of finite element method

- **Keywords**

- **Computational mechanics 计算力学**
- **Numerical method 数值方法**
- **Numerical algorithm 数值算法**
- **Numerical model 数值模型**
- **Continuous system 连续系统**
- **Discrete system 离散系统**
- **Finite element method (FEM) 有限元法**
- **Finite element analysis (FEA) 有限元分析**
- **Element 单元 Mesh 网格**

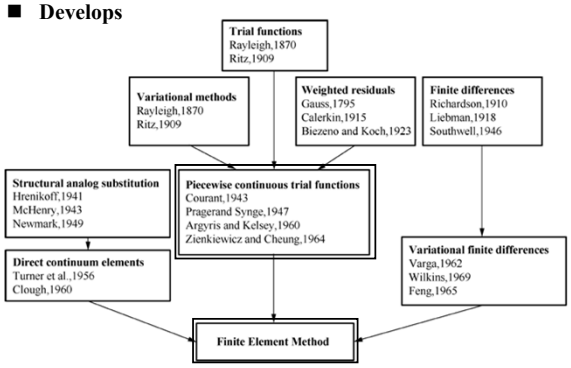
1.1 Development process of finite element method

- **The treatment of "standard discrete problems".**

1. The continuum is divided into a finite number of elements whose behaviour is specified by a finite number of parameters.
2. As an assembly of its elements, the solution for the complete system precisely follows the same rules as those applied to standard discrete problems.

1.1 Development process of finite element method

- **Develops**



- **History of approximate methods**

1.1 Development process of finite element method

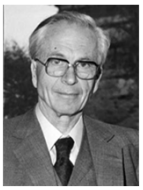
- **Develops**

有限元的发源－科学的发展与工业界需求相关

Ray W. Clough， 毕业于MIT
1949，Berkeley土木工程学院任教
1952，Boeing(波音)项目研究机翼振动分析，采用传统梁理论和数学计算，机翼结构挠度计算结果与试验数据相差甚远，工作失败。
1953，计算小三角形板的刚度性能，将一片片汇合成机翼，形成Direct Stiffness Method（直接刚度法），机翼结构挠度计算结果与试验数据吻合，成为有限元法的雏形。

John H. Argyris
1955，发展矩形单元。
1956，第一篇有限元法学术论文发表(Turner, Clough, Martin, Topp)。

- **Prof. Ray W. Clough**



- **Prof. John H. Argyris**

1.1 Development process of finite element method

- **Develops**

• 通过波音研究组的工作和Turner、Clough、Martin和Topp（1956）的著名文章，使线性有限元分析得以闻名，不久后，在许多大学和研究所里，工程师们开始将方法扩展至非线性、小位移的静态问题。他们非常清楚有限元方法的前途，它提供了处理复杂形状真实问题的可能性。

1.1 Development process of finite element method

- **Develops**

Prof. Kang FENG（冯康）, Member of Chinese Academy of Sciences, Professor and Honorary Director of the Computing Center of the Chinese Academy of Sciences, famous mathematician and physicist, founder and pioneer of Chinese computational mathematics.

- **Prof. Kang FENG**

In the later 50s and early 60s, based on the computations of dam constructions, Professor Feng proposed a systematic numerical method for solving partial differential equations. The method was called "***Finite Difference Method based on variation principle***". This method was also independently invented in the west, calling "***Finite Element Method***". Now it is regarded that the invention of finite element method is a milestone of computational mathematics.

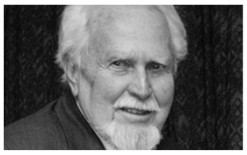
Feng Kang Prize of Scientific Computing

http://lsec.cc.ac.cn/fengkangprize/index.html

1.1 Development process of finite element method

- Books

Zienkiewicz&Taylor(1967): Finite Element Method
（庄茁、曾攀、符松等译，有限元方法：I基本原理，II固体力学，III流体力学，清华大学出版社，2002）
Oden(1972): Finite elements of nonlinear continua



- Prof. Olek Zienkiewicz

- Prof. J. Tinsley Oden

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1.1 Development process of finite element method

- Books

Owen&Hinton(1980): Finite Elements in Plasticity: Theory and Practice
Hughes(1987): Finite Element Method: Linear Static and Dynamic Analysis
Belytschko&Hughes(1983), Malkus&Plesha(1989), Kleiber(1989), Cook&Crisfield(1991), Zhong ZH(1993), Bathe(1996), Bonet&Wood(1997)

- Prof. D. Roger J. Owen

- Prof. T. J. R. Hughes

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1.1 Development process of finite element method

- Books

Belytschko, Liu, Moran: Nonlinear Finite Elements for Continua and Structures
（庄茁等译，连续体与结构的非线性有限元，清华大学出版社，2002）

- Prof. Ted Belytschko

龙驭球，有限元法概论，人民教育出版社, 1978
朱伯芳，有限单元法原理及应用，北京，水利电力出版社，1979
王勖成，有限单元法，北京，清华大学出版社，1987、1995、2003

- Prof. Yuqiu LONG

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1.1 Development process of finite element method

- Develops

在这个信息时代，像许多其它方面的进步一样，在有限元分析中，**应用程序和软件**往往比书籍、文献更好地代表了最新的进展。

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1.1 Development process of finite element method

在20世纪60年代，由于Ed Wilson发布了他的第一个程序，这种激情终于被点燃了。这些程序的第一代没有名字。在遍布世界的许多实验室里，通过改进和扩展这些早期在Berkeley开发的软件，工程师们扩展了新的用途，带来了对工程分析的巨大冲击和有限元软件的随之发展。

SAP：在Berkeley开发的第二代线性程序称之为SAP(Structural Analysis Program)，之后发展的第一个非线性程序是NONSAP，它具有隐式积分进行平衡求解和瞬时问题求解的功能。北京大学Prof. Mingwu YUAN引入中国并进行开发、使用。

- Prof. Mingwu YUAN

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1.1 Development process of finite element method

MARC：1969年，在Brown大学任教的Pedro Marcal，为了第一个非线性商业有限元程序进入市场，于建立了一个公司；程序命名为MARC，目前它仍然是主要软件，1999年被MSC公司兼并，MSC/MARC。

ANSYS：大约在同期，John Swanson为了核能应用在Westinghouse发展了一个非线性有限元程序。为了使ANSYS程序进入市场，他于1969年离开Westinghouse。ANSYS尽管主要是关注非线性材料而非求解完全的非线性问题，它多年来仍垄断了商业非线性有限元软件的舞台。

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1.1 Development process of finite element method

ABAQUS：David Hibbitt，他与Pedro Marcal合作到了1972，1978建立了HKS公司，使ABAQUS商用软件进入市场。因为该程序是能够引导研究人员增加用户单元和材料模型，对软件行业带来了实质性的冲击。

UEL: User subroutine to define an ELement.

UMAT: User subroutine to define an element with access to Abaqus Materials.

清华大学Prof. Zhuo ZHUANG引入中国并进行开发、使用、推广。

- Prof. Zhuo ZHUANG

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1.1 Development process of finite element method

NASTRAN：大型通用有限元软件。The MacHeal-Schwendler Corporation (MSC)，1963年创立，主要得到美国航空界赞助，如NASA和FAA，为飞行器验证软件。前处理为PATRAN。

ADINA：Jürgen Bathe是在Ed Wilson的指导下在Berkeley获得博士学位的，不久之后开始在MIT任教，这期间他便发布了他的程序。这是NONSAP软件的派生产品，称为ADINA。

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1.1 Development process of finite element method

DYNA：显式有限元程序发展的里程碑来自于Lawrence Livermore实验室的John Hallquist的工作。1975年，John开始他的工作，1976年，他首先发布DYNA程序。他慧眼吸取了前面许多人的成果，并且与Berkeley的研究人员紧密交流合作，包括Jerry Goudreau，Bob Taylor，Tom Hughes和Juan Simo。他之所以成功的部分关键因素是与Dave Benson合作发展了接触－冲击相互作用，和他的令人敬畏的编程效率，以及计算程序DYNA-2D和DYNA-3D的广泛传播。

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1.1 Development process of finite element method

■ Open source programs

- OPENSEES: http://opensees.berkeley.edu/
- FEAP: http://www.ce.berkeley.edu/projects/feap/
- ……
- …

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The End