**Chalmers University of Technology** **2020-11-23**
**Department of Industrial and Materials Science**

# TME250 Finite Element Method - Solids

**7.5 credit points,**
**Quarter 2, fall semester 2020**

**Instructors**
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## General purpose and contents

The aim is to provide the student with further understanding of the nature of the Finite Element Method (FEM), in particular its approximate character, and to provide extended skill in applying FEM to engineering problems related to solid mechanics. Hence, the course builds on knowledge acquired in continuum mechanics (mechanics of solid bodies), material modeling and the application of FEM to basic problems. These topics are covered in the courses Mechanics of Solids TME235, Material Mechanics MHA042 and TME245 Finite Element Method – Structures. Computer assignments play a key role as the means of implementing and assessing models and algorithms.

Approximately 18 lectures will comprise the following topics:
- Linear elasticity: Some fundamentals
- Linear elasticity: Mixed methods, in particular for the incompressible limit
- Nonlinear elasticity: Finite deformation theory
- Contact mechanics
- Multifield/coupled problems: thermomechanics
- Linear elasticity: Error analysis and adaptive methods

## Course web page

All course information, including handed out material and the updated schedule will be available on the course webpage on CANVAS. Add a bookmark!

## Organization of lectures and lab classes

The course comprises lectures in accordance with the schedule available on the course web page. In addition, 4 hours per week are schedule for computer classes. Each of the four computer assignment will be introduced in the computer classes according to the schedule.

Due to the Covid-19 pandemic, the course will this year be offered online. The lectures will be held on zoom and the exercises will be held in Microsoft TEAMS. All information on how to access the classes will be available on CANVAS.

**Course work and examination**

The main course work consists of four computer assignments (CA1-CA4) involving FE-computation using Matlab (CALFEM) and a final written exam.

The Calfem package can be downloaded from
*http://sourceforge.net/projects/calfem/*

The topics of the CA's are as follows:

- CA1: Incompressible elasticity (2 credit points)
- CA2: Contact mechanics (2 credit points)
- CA3: Finite elasticity (3 credit points)
- CA4: Error-control and adaptivity for linear elasticity (2 credit points)

An informal written report for each assignment must be submitted before the deadline given in the schedule. The assignments are graded and will then give maximum credit points as indicated above. Altogether, **9 credit points** can thus be obtained towards the final grade, see below. These points will remain valid until the course is given next time.

The final written exam comprises questions/problems of theoretical character. Altogether, **9 points** can thus be obtained towards the final grade, see below. Study questions accompanying the lectures will outline the possible topics for exam questions.

Grades are awarded as follows:

| Collected credit points | Chalmers grade |
|---|---|
| 0-9 | U |
| 10-12 | 3 |
| 13-15 | 4 |
| 16-18 | 5 |

To complete the course, it is thus **necessary to participate in computer assignments and complete the final exam**.

**Changes from last year's edition of the course**

Due to the Covid-19 pandemic, the course will be offered online, both lectures and computer classes. Depending on the situation in January, the final exam may be held online or on-site in Chalmers facilities. However, the format of the exam will not be affected.

Starting this year, the exam will be open-book (i.e. all aids permitted), as opposed to last year, when the written exam was a closed-book exam.

Other than that, only minor changes in the lectures and modification of the computer assignments are applied to the course this year.

**Course evaluation**

A continuous evaluation will be held during and after the course consisting of three meetings: one introductory meeting during the first week, a mid-course meeting in the fourth week and a final evaluation after the course. A group of students will be chosen during the first lectures to represent the class at the meetings. The goal of the mid-course meeting is to assess the current status of the course while the final meeting aims at developing the course for next year. **We greatly appreciate your feedback!** In-between the written exam and the final evaluation meeting, a questionnaire will be sent out to all course participants.

With the online teaching adopted this year, which is new to all of us, we are particularly interested in obtaining your feedback on what is working and what can be improved during the course. In addition to contacting us teacher directly, comments are gratefully accepted on the discussion group set up in CANVAS.

## Literature

[1] M. Ekh, R. Jänicke, F. Larsson and K. Runesson, The Finite Element Method – Solid Mechanics. Department of Industrial and Materials Science, Chalmers University of Technology, 2018. (in preparation). **Selected chapters**.[1]
[2] N.S. Ottosen and H. Peterson. *Introduction to the finite element method.* Prentice –Hall, New York 1992.
[3] Fredrik Larsson. *Nonlinear finite element analysis – A short introduction*. Dept. of Applied Mechanics, Chalmers, 2010. [1]
[4] P-E. Austrell, O. Dahlblom, J. Lindemann, A. Olsson, K-G. Olsson, K. Persson, H. Petersson, M. Ristinmaa, G. Sandberg and P-A. Wernberg, *CALFEM, A Finite element toolbox to MATLAB, Version 3.4.* Dept. of Structural Mechanics and Solid Mechanics, Lund 2004. [2]
[5] Kenneth Runesson, Paul Steinmann, Magnus Ekh and Andreas Menzel , Tensor Calculus Toolbox, Excerpt from Constitutive Modeling of Engineering Materials –Theory and Computation, Chalmers University of Technology, 2011.[1]

[1] The pertinent chapters will be available on the course homepage (CANVAS) for individiual downloading. Hence there is no cost other than printing paper.
[2] Available for downloading in electronic format at
`http://www.solid.lth.se/fileadmin/hallfasthetslara/utbildning/kurser/FHL064_FEM/calfem34.pdf`

Course Schedule

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|---|---|---|---|---|---|---|
| W1 | | | | | | |
| Mon, 2/11 | $10^{00}$-$11^{45}$ | Zoom | Lecture 1 | Course Intro. Elasticity | FL, RJ | [1], Ch3 |
| Wed,4/11 | $10^{00}$-$11^{45}$ | Zoom | Lecture 2 | Linear elasticity | FL | [1], Ch3 |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 3 | Linear elasticity | FL | [1], Ch3 |
| | $15^{15}$-$17^{00}$ | TEAMS | Exercise | *Hand-out CA1* | FE | |
| W2 | | | | | | |
| Mon, 9/11 | $08^{00}$-$09^{45}$ | Zoom | Lecture 4 | Linear elasticity | FL | [1], Ch3 |
| | $10^{00}$-$11^{45}$ | TEAMS | Exercise | | FE | |
| Wed, 11/11 | $10^{00}$-$11^{45}$ | Zoom | Lecture 5 | Linear elasticity | FL | [1], Ch3 |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 6 | Non-linear elasticity | FL | [1], Ch4 |
| | $15^{15}$-$17^{00}$ | TEAMS | Exercise | | FE | |
| W3 | | | | | | |
| Mon, 16/11 | $08^{00}$-$09^{45}$ | TEAMS | Exercise | | FE | |
| | $10^{00}$-$11^{45}$ | Zoom | Lecture 7 | Contact problems | RJ | [2] |
| Wed, 18/11 | $10^{00}$-$11^{45}$ | Zoom | Lecture 8 | Contact problems | RJ | [2] |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 9 | Contact problems | RJ | [2] |
| | $15^{15}$-$17^{00}$ | TEAMS | Exercise | *Hand-out CA2* | FE | |
| **Fri, 20/11** | **$17^{00}$** | | | **Hand-in CA1** | | |
| W4 | | | | | | |
| Mon, 23/11 | $08^{00}$-$09^{45}$ | Zoom | Lecture 10 | Non-linear elasticity, finite deformations | FL | [1], Ch5 |
| | $10^{00}$-$11^{45}$ | TEAMS | Exercise | | FE | |
| Wed, 25/11 | $10^{00}$-$11^{45}$ | Zoom | Lecture 11 | Non-linear elasticity, finite deformations | FL | [1], Ch5 |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 12 | Non-linear elasticity, finite deformations | FL | [1], Ch5 |
| | $15^{15}$-$17^{00}$ | TEAMS | Exercise | | FE | |
| W5 | | | | | | |
| Mon, 30/11 | $08^{00}$-$09^{45}$ | Zoom | Lecture 13 | Non-linear elasticity, finite deformations | FL | [1], Ch5 |
| | $10^{00}$-$11^{45}$ | TEAMS | Exercise | *Hand-out CA3* | FE | |
| Wed, 2/12 | $10^{00}$-$11^{45}$ | Zoom | Lecture 14 | Coupled problems:Thermoelasticity | RJ | [1], Ch12 |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 15 | Error analysis | FL | [1], Ch15 |
| | $15^{15}$-$17^{00}$ | TEAMS | Exercise | | FE | |
| **Fri, 4/12** | **$17^{00}$** | | | **Hand-in CA2** | | |
| W6 | | | | | | |
| Mon 7/12 | $08^{00}$-$09^{45}$ | Zoom | Lecture 16 | Error analysis | FL | [1], Ch15 |
| | $10^{00}$-$11^{45}$ | TEAMS | Exercise | | FE | |
| Tue, 8/12 | $13^{15}$-$15^{00}$ | TEAMS | Exercise | *Hand-out CA4* | FE | |
| Wed, 9/12 | $10^{00}$-$11^{45}$ | Zoom | Lecture 17 | Error analysis | FL | [1], Ch15 |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 18 | Error analysis | FL | [1], Ch15 |
| **Fri, 11/12** | **$17^{00}$** | | | **Hand-in CA3** | | |
| Week 7 | | | | | | |
| Mon, 14/12 | $08^{00}$-$09^{45}$ | Zoom | Lecture 19 | Error analysis | FL | [1], Ch15 |
| | $10^{00}$-$11^{45}$ | TEAMS | Exercise | | FE | |
| Wed, 16/12 | $11^{00}$-$11^{45}$ | Zoom | Lecture 20 | Course summary - Course review | FL, RJ | |
| | $13^{15}$-$15^{00}$ | Zoom | Lecture 21 | Course summary - Old exam + Q&A | FL, RJ | |
| | $15^{15}$-$17^{00}$ | TEAMS | Exercise | | FE | |
| | | | | | | |
| **Fri, 8/1 (2021)** | **$17^{00}$** | | | **Hand-in CA4** | | |
| | | | | | | |
| **Sat, 16/1 (2021)** | **$14^{00}$-$18^{00}$** | | | **Written exam** | | |
| | | | | | | |
| **Fri, 9/4 (2021)** | **$14^{00}$-$18^{00}$** | | | **Re-sit exam** | | |
| **Wed, 18/8 (2021)** | **$14^{00}$-$18^{00}$** | | | **Re-sit exam** | | |

**Literature**

[1] M Ekh, R. Jänicke, F. Larsson and K. Runesson, The Finite Element Method – Solid Mechanics.
Dept. of Industrial and Materials Science, Chalmers, 2018.
[2] Separate notes handed out during the course

**Teachers**

RJ = Ralf Jänicke
FL = Fredrik Larsson
FE = Fredrik Ekre