FEM for Engineering Applications SE1025 Autumn 2019

1. General information, intended learning objectives & prerequisites

The course gives an introduction to energy principles in solid mechanics and to approximate methods for numerical analysis of engineering problems with the finite element method (FEM). This method is now routinely used to analyse complex engineering systems and also common in scientific computations. Specifically, linear elasto-static solid mechanics problems and heat conduction problems will be treated in detail. FEM equations will be derived from energy and variational principles, which will be introduced at the beginning of the course.

Intended learning outcomes in sequential order — after the course the student should be able to:

- Determine the elastic energy stored in deformed solids such as truss structures and planar frames, and analyse such structures by use of energy principles.
- Identify the degrees of freedom in a discrete linear elastic system, formulate equilibrium equations on matrix form, and solve for the displacements of the system.
- Formulate finite element equations (FEM) for physical phenomena described by ordinary or partial differential equations and define boundary conditions appropriate for the system to be analysed.
- Apply FEM to analyse linear elastic quasi-static problems in solid mechanics described by truss-, beam- or two-dimensional continuum elements.
- Apply FEM to analyse one- and two-dimensional steady state problems in heat conduction.
- Evaluate the results from a FEM analysis and to reconstruct the solution at level of elements.
- Perform FEM analysis of problems in solid mechanics and heat conduction with a commercial program.

Prerequisites: the student should have a good knowledge in strength of materials, mechanics and mathematics. The student should be well acquainted with matrix/linear algebra and methods for solving linear systems of equations. A central part of the course is based on matrix formulated methods. The homework assignments will be easier to solve if the student also have some experience in using mathematical programs such as Matlab, Maple or Mathematica.

2 . Teachers and home page

Lecturer: Erik Olsson (erolsson@kth.se)
Tutorials: Chiara Ceccato (ceccato@kth.se)
Workshops (computer labs): Hossein Shariati (hsha@kth.se)
Examiner: Jonas Neumeister (jonasn@kth.se)
Course home page: **https://kth.instructure.com/courses/11290**

3. Literature

- G. R. Liu & S.S. Quek (2003) The finite element method—A practical course. Butterworth-Heinmann, Oxford, UK. (referred to as LQ in the syllabus). Available as an electronic text book at the KTH library. Instructions on how to download a pdf is available on the course home page.
- Jonas Faleskog (2013) FEM for Engineering Applications—Exercises with Solutions. Dept. of

Solid Mechanics, KTH. Included in a "course package", sold at the student office at Dept. of Solid Mechanics, prize 100 SEK. (referred to as EX in the syllabus).

- Some material on energy principles and strong/weak form of differential equations will be handed out during lectures.

Reference books of interest: J.N. Reddy (2005) *An Introduction to the Finite Element Method*. Syllabus: FEM for engineering applications (SE1025), 6 hp, Sep-Oct, 2014

4. Schedule

Time and place for the lectures and tutorials can be found and downloaded at KTH webpage here. In total 18 lectures (**L**), 8 tutorials (**T**) and 2 computer workshops (**W**) are given during the course. Each lecture and tutorial corresponds to 2 x 45 minutes. The two workshops, each 4 hours (2 time slots/lab), will be held in the Solid Mechanics Track room at Teknikringen 8D.

5. Examination

Homework assignments, HEM1 (1.5 hp)

HEM1 is a compulsory part of the course. The recommended way to pass HEM 1 is to solve the three homework assignments (HW). HEM1 is automatically passed if the written exam is passed. The following applies:

- Should be solved in groups of two or three students and should be presented in a written report, where the problem statement, the solution steps and the results should be clearly stated. Please note that, printouts from various mathematical programs can be added to the report, but only as an appendix. Reports consisting solely on such printouts will not be graded!

- The homework solutions should be handed to one of the teachers or put in the box outside the student office at the latest 6pm the day of the deadline (the department door closes at 6pm).

- To pass HEM1, a total of 12 points out of 25 points available on HW1, HW2, HW3, is required. Also note that, if the written exam is passed, HEM1 is automatically passed.

- Points earned in the homework assignments, renders extra bonus points at the written exam. The bonus points, *p*bonus, are determined based on the sum of the points earned in the homework assignments according to: *p*bonus = 1 (≥ 6 points); 2 (≥ 10 points); 3 (≥ 14 points); 4 (≥ 18 points); 5(≥ 22 points). The bonus points can be used on future exams until August next year and will expire thereafter. In some of the problems the solutions can be checked by solving the corresponding problem using simple FEM-based Matlab program, which can be down loaded from the home page.

Deadlines for the homework (HW):

HW1: Tuesday 10 September, 18:00
HW2: Friday 4 October, 18:00
HW3: Monday 14 October, 18:00

Computer workshops, LAB1 (0 hp)

The purpose of the two compulsory computer workshops is to obtain some experience on how to solve elasto-static and heat conduction problems with commercial finite element software. In this course the multi-physics FEM program ANSYS is used. Of special interest is how an engineering problem is set up for analysis by FEM, i.e. *pre-processing*, and the interpretation of results, i.e. *post-processing*. Lists to sign up for the workshops will be available at the lectures.

Written examination 18/10 08:00-13:00 (TEN1; 4.5 hp)
A written 5-hours exam will cover the whole course. In order to participate in the exam, the student must register his/her participation at the latest two weeks prior to the date of the exam. This is done using the KTH web page "My pages". A second exam will take place in the middle of March. The written exam is Syllabus: FEM for engineering applications (SE1025), 6 hp, Sep-Oct, 2014 composed of about 5 problems, which if correctly solved gives 25 points. Counting the 5 points which can be earned by correctly solving the homework assignments, a total of 30 points can be obtained at the exam. The grading will be made according to ECTS as: ≤10 grade F (fail); 11 or 12 points gives grade FX; ≥13 grade E (pass); ≥15 grade D; ≥17 grade C; ≥20 grade B; ≥23 grade A. Students who obtain grade FX, will be offered to do a complementary exam 4-6 weeks after the ordinary exam.

6. Detailed program

Class	Time	Topic	Literature
L1	26/8 15-17	Introduction, Elastic energy	Notes
L2	27/8 10-12	Discrete systems, Castigliano's theorems	Notes
L3	28/8 08-10	Matrix formulated structural mechanics	Notes
L4	29/8 08-10	Direct matrix methods, spring/truss structures	Notes
T1	30/8 13-15	Problems on energy principles and matrix formulated structural mechanics	EX 1.6, 2.1, 2.2— direct method
L5	2/9 15-17	Principle of virtual work, Strong/weak forms, Approximate methods, Displacement interpolation and FEM-procedure, FEM-Eqs.	Notes
L6	3/9 10-12	FEM for trusses, 1D-example	LQ: chap. 1, 3, 4
L7	4/9 08-10	Accuracy, Higher order elements, FEM for truss structures, 2D-example	LQ: chap. 3, 4
T2	6/9 13-15	FEM –analysis of trusses (1D) and truss structures (2D), shape functions	EX 4.1, 3.3, 5.2
L8	9/9 15-17	FEM for beams, strong/weak forms, FEM-Eqs.	LQ: chap. 2, 5
L9	10/9 10-12	cont.' FEM for beams, 1D-example, features of FEM solutions	LQ: chap. 2, 5
L10	11/9 08-10	FEM for planar frames with beam elements	LQ: chap. 5, 6
T3	13/9 13-15	FEM – analysis of beams (1D) and planar frames (2D), shape functions	EX 4.6, 5.4, 5.6
L11	16/9 13-15	FEM for 2D & 3D solids in general, 2D analysis with CST-element	LQ: chap. 2, 7, 9
L12	17/9 10-12	cont.' 2D FEM analysis with CST-element	LQ: chap. 7,
T4	19/9 08-10	FEM-analysis of 2D elasto-static problem with CST-element	EX 6.14a,c
L13	23/9 15-17	Rectangular and isoparametric 4-node elements, coordinate transformation , Gauss integration	LQ: chap. 7
L14	24/9 10-12	Consistent nodal forces, Gauss integration	LQ: chap. 7
T5	25/9 08-10	cont.' 2D 4-node elements, Consistent nodal forces,	EX 6.8b, 6.9, 6.10

L15	26/9	08-10	3D FEM analysis, Modelling aspects, Convergence, Sub-structuring	LQ: chap. 9, 11
T6	27/9	13-15	Element technology, isoparametric elements	EX 6.2, 6.3, 6.4, 6.19
L16	30/9	15-17	FEM for heat conduction	LQ: chap. 12
L17	1/10	10-12	FEM for thermo-mechanical problems	LQ: chap. 12
T7	8/10	10-12	FEM-analysis of thermo-mechanical problems	EX 7.2, 7.3
L18	10/10	08-10	Extra time + repetition	
T8	11/10	13-15	Repetition, solving exam type of problems	Hand-out

7. Problems recommended for own exercise.

Problems in parenthesis are solved during lectures or tutorial sessions!

Energy principles
Castigliano's theorems: 1.1–1.3, 1.7 – 1.11 (1.6)

Matrix formulated structure & solid mechanics
Spring structures: 2.4, 2.3, 2.6–2.8, 2.11 (2.1, 2.2)
Strong/weak form in general: 3.1, 3.2 (3.3)
FEM for trusses & truss structures: 3.4, 3.5, 4.2, 4.3, 4.5 (5.1, 4.1, 4.4, 3.3, 5.2)
FEM for beams & planar frames: 3.6–3.8, 4.9, 5.5 (4.6–4.8, 5.3, 5.4, 5.6)
FEM for 2D/3D solids: 6.5, 6.6, 6.11, 6.15–6.18, 6.21 (6.2–6.4, 6.7–6.10, 6.12, 6.19)

FEM for heat conduction & thermo-elastic problems
3.9, 3.10, (7.1–7.3)

8. Note on the grading criteria (*nota bene*).

We pay particular attention on the ability to formulate the static equilibrium and to use the proper units in the submitted homework and exam. Please, be aware that incorrect units or equilibrium equations will give you no points in a considered task and undermine your effort in solving it.