MFG 512 Mechanics of Solids

Instructor	Adnan Kefal *(adnankefal@sabanciuniv.edu)*
Course	Sabanci University – 2021-22 Fall Semester
Attributes	Doctorate/Masters Level
	3 SU Credit / 10 ECTS / 42 Teaching Hours
Course	Mon 13:40 - 15:30 FASS 1096
Schedule	Tue 09:40 - 10:30 FENS G035
	Online lectures: https://sabanciuniv.zoom.us/j/3923709046

Course Relevance

Fundamentals of solid mechanics will be explained throughout this course. At the first stage, overview of basic structural mechanics will be shown. Then, vector calculus for engineering and vector & tensor properties and rules will be explained to establish a mathematical background for the students to earn advanced level mechanics problem solution capabilities. Later, small and/or large deformation theory in its general form will be explained and necessary equations for solid mechanics modeling like; conservation of energy, conservation of momentum will be discussed in detail. Afterwards, linear elastic material models and relations for isotropic, transversely isotropic, orthotropic, and anisotropic materials will be shown within the course. After that, variational principles and virtual work and energy principles will be explained and analytical solutions to simple boundary and initial value problems will be demonstrated. In addition, numerical solutions of continuum problems with finite element methods will be illustrated and examples of 1D-2D finite element analysis will be performed. Lastly, introductory level of plate theories, which covers the basic relationships for kinematic relations of deforming thin/thick 2D structures and composite-ply mechanics, will be explained within the course.

Objectives

This course is primarily designed for graduate students to gain understanding in the fields of mechanics of solids. Course introduces concepts of continuum mechanics, thermodynamic laws, and governing physics and equations for deformation of solids based on small and large deformation theories. The finite element concepts will be explained at introductory level and the students will be asked to solve practical solid mechanics problems using both analytical methods and numerical methods utilizing commercially available finite element software.

Learning Outcomes

At the conclusion of this course, students should be able to:

(i) Vector calculus and mathematical background for solid mechanics problems
(ii) Understanding of small/large deformation theories
(iii) Ability to develop continuum elastic models for solid mechanics problems
(iv) Understanding of analytical solution methods for boundary value problems
(v) Finite element skills with applications of 1D-2D problems
(vi) Ability to solve basic engineering problems using commercially available software
(vii) Introductory level understanding of plate and composite-ply mechanics

Course Syllabus

Week	Topic
Lecture 1	**Review of Structural Mechanics** Static equilibrium equations, Hooke's Law, tension, compression, shear, torsion, bending, combined loading, stress transformations, beam deflections and buckling, failure theories, etc.
Lectures 2-3	**Introduction to Vector/Tensor Calculus** Scalars, vector and tensor definition, index (Summation) notation, vector/tensor operations, cross product, dyadic product, inner product, double contractions, transpose, Kronecker delta and Levi-Civita operators, high-order tensors, Eulerian/Lagrangian description, spatial derivatives including gradient, divergence, curl.
Lectures 4-5	**Deformation and Shape Changes in Solids** Reference/deformed configurations, displacement and velocity fields, displacement and deformation gradient tensors, Jacobian of the deformation gradient, Lagrange strain tensor, infinitesimal strain tensor, engineering shear and normal strains, infinitesimal rotation tensor, principal values and directions of the infinitesimal strain tensor, Cauchy-Green deformation tensors.
Lecture 6	**Internal Forces in Solids** Surface tractions, internal body force, traction acting on planes, Cauchy stress tensor, stress conjugates, Kirchhoff, nominal, and material stress tensors, hydrostatic, deviatoric, von Mises effective stresses, $1^{st}/2^{nd}$ Piola-Kirchhoff Stress Tensors, boundary conditions on stresses.
Lecture 7	**Constitutive Equations** Symmetry property of elasticity tensor, isotropic elasticity tensor bulk, shear and Lame constants, Young's modulus, Poisson's ratio, thermal expansion coefficients, orthotropic elasticity tensor, transversely isotropic materials, anisotropic elasticity tensor, reduced stress-strain equations for plane deformation of isotropic solids, strain energy derivation of elasticity.
Lectures 8-9 **(Midterm)**	**Thermodynamic Laws and Equilibrium Equations** Thermodynamic states and restrictions, equation of motion for deformable bodies, linear momentum balance in terms of Cauchy stress, angular momentum balance in terms of Cauchy stress.
Lecture 10	**Variational Methods and Principal of Virtual Work and Energy** Work done by Cauchy stresses, rate of mechanical work in terms of stress measures and infinitesimal deformations, virtual work equations in terms of stress measures and infinitesimal deformations, Rayleigh-Ritz method, Reissner's variational theorem, weighted residual methods, D'Alambert principle.
Lecture 11 **(Project assignment)**	**Solutions for Linear Elastic Solids and Boundary Value Problems** Summary of governing equations: boundary and initial boundary value equations, superposition and linearity of solutions, uniqueness and existence of solutions, Saint-Venant's principle, Airy function solution to plane stress and strain static linear elastic solids, variational derivations of beam equations.

Lectures 12-13	**Finite Element Method and Computational Applications** Finite element mesh, nodes and elements, element connectivity, element types, material behavior, boundary conditions, initial conditions, constraints, solution procedures and time increments, post-processing, 1D/2D applications of finite element method: mesh and material inputs, processor, assembly of equations, solution procedures, visualization of results.
Lectures 14	**Introduction to Plate Theories and Laminated Composites** Kirchhoff-Love plate theory, Mindlin–Reissner plate theory, macro mechanical analysis of laminates: classical lamination theory.
Exam Week **(Project deadline)**	**Final Exam**

Books and References

1. Bower, A.F., 2009. Applied mechanics of solids. CRC press.
2. Tadmor, E.B., Miller, R.E. and Elliott, R.S., 2012. Continuum mechanics and thermodynamics: from fundamental concepts to governing equations. Cambridge University Press.
3. Logan, D.L., 2016. A first course in the finite element method. Cengage Learning.
4. Zienkiewicz, O.C., Taylor, R.L., Taylor, R.L. and Taylor, R.L., 2000. The finite element method: solid mechanics (Vol. 2). Butterworth-heinemann.
5. Reddy, J.N., 2003. Mechanics of laminated composite plates and shells: theory and analysis. CRC press.

Assessment Criteria

Group Project (20%), Midterm Exam (30%), Final Exam (50%)

- *There will be a semester-project and groups of four will be formed to work on the projects.*

Course Material

The outline of lecture notes, project guidelines, and other course-related material will be posted at the SUCourse site *(https://sucourse.sabanciuniv.edu/)*.