Modern Problems in Mechanics

Course Contents:

The class presents acquaintance with modern problems in mechanics, the actual development directions of solid and fluid mechanics. During the course the representation about position of mechanics in modern science and its interdisciplinary communications with other areas of natural sciences is given. Finally numerical methods applied in solid mechanics are presented. The course covers all disciplines in the field of modern mechanics (solid mechanics, fluid mechanics, fracture mechanics) including their applications to technology, material sciences, engineering, environmental sciences, Maths and Physics.

Subjects covered by the lectures are:

Section 1. General and Applied Mechanics

Topic 1.1. The Analytical Mechanics and Stability of Motion

Stability and accidents in mechanical systems.

Topic 1.2. Control and Optimization in Mechanical Systems

Theory of controlled systems. The estimation and navigation theory. Applied theory of motion control. The problem of maximum deviation, absolute stability and robust stabilization. Oscillations of mechanical systems. Celestial Mechanics. Mechanics of machines and robots. Mechatron and robot systems. Dynamic simulation of controlled movements. Mobile robots.

Section 2. Fluid Mechanics

Topic 2.1. General and Applied Hydrodynamics

Motion of viscous fluid. Oil and gas hydrodynamics in porous mediums. Mathematical models of multiphase immiscible liquids filtering in porous mediums. The boundary layer theory. Motion of mediums with complex rheology. Hydrogas dynamics of multiphase mediums. The theory of multiphase mediums motion. Hydrodynamic instability and turbulence.

Topic 2.2. General and Applied Gas Dynamics

Transsonic currents of gas. Aerodynamics of subsonic and supersonic streams. Aerogas dynamics of permeable mediums. The parachute theory. Physical and chemical hydrogas dynamics.

Section 3. Solid Mechanics

Topic 3.1. The Elasticity and Viscoelasticity Theory

Main questions of the elasticity theory. Problems’ definition and settling. Mechanics of the nonuniform bodies and composites. Problems of the applied elasticity theory. Essential principles of viscoelasticity.

Topic 3.2. The Plasticity and Creep Theory

Basic principles of the plasticity theory. Experimental investigation. Theory of small elasto-plastic deformations. The general theory of elastoplastic processes. Boundary-value problems of the plasticity and creep theory. Applied problems of the plasticity theory. Investigation of material dynamic properties and high-speed processes modeling.

Topic 3.3. Mechanics of Fracture and Damage

Topic 3.3.1. Models, criteria, testing, engineering methods.

Topic 3.3.2. Multiaxial/mixed mode fatigue and fracture. Multiaxial/mixed mode fracture. In-plane and out-of-plane constraint effects. Multiaxial fatigue and fracture. Notch fracture mechanics.

Topic 3.3.3. Dynamic fracture. Dynamic fracture; damage and fracture under dynamic loading. Dynamic deformations and fracture of composite structures. Dynamic strength and fracture.

Topic 3.3.4. Multicyclic loading and multiscale fracture. Multicyclic loading. Multiscale material structures. Multi-scale modeling of material fracture. Modeling of multiscale fracture of materials.

Topic 3.3.5. Fatigue of materials, components and structures. Fatigue of materials, components and structures. Fatigue and fracture under variable amplitude loading.

Topic 3.3.6. Fracture processes under the action of physical fields and chemically active media. Fracture processes under the action of physical fields. Fracture processes under the action of chemically active media. Fracture processes under the combined action of physical fields and chemically active media. Hydrogen effects on structural integrity of material.

Topic 3.3.7. Structural integrity. Methods of residual lifetime evaluation and prediction. Structural integrity assessment. New equipment and technologies for monitoring the technical state of potentially dangerous structures. Diagnostics of structural materials ageing. Inverse problems of defects and cracks identification. Structural integrity of welded joints. Methods for prediction of material properties and structural integrity assessment.

Topic 3.3.8. New methods and equipment for fracture testing. New methods and equipment for fracture resistance testing. Experimental testing and photoelasticity.

Topic 3.3.9. Fracture mechanics applications. Aircraft, marine transport, railway transport, nuclear, gas and oil industry, energetics. Durability, safety and reliability of complex technical systems. Nondestructive testing and evaluation of structural components. Fracture mechanics in design of fracture resistant materials and components. Fracture in technology.

Topic 3.3.10. Computational fracture mechanics. Methods of computational fracture mechanics and benchmark problems. Numerical modeling of fracture of materials and structures. Virtual fracture analysis and testing.

Topic 3.3.11. Geomechanics and geomaterials. Laboratory and field measurements of fracture characteristics of geomaterials and natural objects. Models of fracture in geomechanics and geoengineering. Fracture mechanics and earthquake prediction. Fracture mechanics in geotechnologies.

Topic 3.3.12. Fracture processes in forming and contact interaction.

Topic 3.3.13. Physical mesomechanics of fracture. Physical Mesomechanics of fracture. Nano-structured materials. Fracture mechanics of biomaterials.

Topic 3.3.14. Micromechanisms of fracture and fatigue.

Topic 3.3.15. Acoustic and other forms of energy emissions from fracture phenomena.

Topic 3.3.16. Advanced crack models. Recent advances in cohesive modeling. Damage based fracture models. Ductile Failure.

Topic 3.4. Nonclassical Models of Solid Mechanics

The general theory of defining ratios of continuous medium mechanics. Nonclassical models of mediums.

Topic 3.5. Inverse Problems in Solid Mechanics

Coefficient inverse problems in mechanics of deformable solid body. About identification of the linear dynamic systems. Identification of polymeric materials by the differential form of определяющих equations. Inverse problems for the elastic rod. Inverse problem for the wave equation. Inverse seismicity problem. Inverse Lamb problem. Integrated equations in inverse elastic theory problems. Inverse problems of an untied thermoelasticity (thermoelasticity factor definition). Problems of electroelasticity.

Inverse boundary problems of elasticity theory. Statement of inverse boundary problems in elasticity theory and methods of their research. Boundary inverse problems for finite bodies. Inverse boundary problems for a band. Inverse boundary problems for plates. A conditional correctness of inverse boundary problems of the elasticity theory.

Geometrical inverse problems in acoustics and in the elasticity theory. Geometrical inverse problems in acoustics in diffractional statement. Shape definition of a near-surface crack in ultrasonic medium. Determination of the vacuity shape in an elastic semiplane. Determination of a crack configuration in aeolotropic medium. Identification of flat cracks in the elastic medium. The asymptotic approach to the solution of problems of crack identification. Identification of small cracks in elastic bodies. Short-wave methods in inverse geometrical problems. Definition of spherical elastic insert or spherical vacuity by means of invariant integrals of fracture mechanics.

Section 4. Different Fields of Mechanics

Topic 4.1. Biomechanics.

Topic 4.2. Problems of mechanics of natural processes. Seismodynamics. Fundamental ecology.

Section 5. Computing Mechanics

Topic 5.1. Packets of character mathematics and their use in mechanical problems: functional capabilities, examples. ANSYS, ABACUS.

Topic 5.2. Computer technologies in the applied mechanics of liquid and gas. Special packets of three-dimensional hydrodynamic modeling of oil and gas deposits.

Topic 5.3. Decomposition of computing algorithms in mechanical problems. Algorithms, examples and tasks.

Topic 5.4. Computational methods of fracture mechanics. Calculation of invariant integrals in fracture mechanics.

Learning Outcomes of the Course:

Through a deep understanding of the theory and the realization of a project, the student will be able to study a wide class of mechanical problems. In particular:

- He will have a deep understanding of modern mechanics theories and will be able to summary, compare and explain them.
- He will be able to apply the computing methods to a wide class of problems.
- He will be able to analyse and to evaluate (justify and criticise) these methods.
- He will be able to analyse new problems.

Topics for Reports and Term Papers:

1. Displacement-rotation equations of elastodynamics and coupled thermoelasticity [12].
2. The first axially-symmetric problem. Elastostatics and thermoelastostatics [12].
3. The second axially-symmetric problem. Elastodynamics [12].
4. The first problem of plane strain state. Elastodynamics [12].
5. The second problem of plane strain state. Elastodynamics [12].
6. Vector equations. Elastodynamics. The vector of Galerkin-Cauchy type [12].
7. One-dimensional problems of elastostatics and thermoelastostatics [12].
8. Shakedown theory [13].
9. A minimum theorem for cyclic load in excess of shakedown, with application to the evaluation of a ratchet limit [13].
10. Assessment of autonomous phase unwrapping of isochromatic phase maps in digital photoelasticity [14].
11. A numerical two-scale homogenization scheme: the FE2-method [15].
12. Variational modeling of microstructures in plasticity [15].
13. Micromorphic approach to crystal plasticity and phase transformation [15].
14. Formation of deformation substructures observed in ductile materials [15].
15. On scale-dependent crystal plasticity models [15].
16. Construction of statistically similar representative volume elements [15].
17. A variational approach to fracture and other inelastic phenomena. Brittle fracture [16].
18. A variational approach to fracture and other inelastic phenomena. Regularization [16].
19. A variational approach to fracture and other inelastic phenomena. Microstructures [16].
20. A variational approach to fracture and other inelastic phenomena. Irreversibility [16].

21. A variational approach to fracture and other inelastic phenomena. Diffuse fracture: the local model [16].
22. A variational approach to fracture and other inelastic phenomena. Diffuse fracture: the non-local model [16].
23. Development of damage mechanics [17].
24. Survey of damage phenomena [17].
25. Survey of constitutive relations for damage [17].
26. Survey of kinetic equations for damaged materials [17].
27. Basis of isotropic damage mechanics [17].
28. Isotropic elasto-plastic damage mechanics [17].
29. Basis of anisotropic damage mechanics [17].
30. Brittle damage mechanics of rock mass [17].
31. Theory of visco-elasto-plastic damage mechanics [17].
32. Dynamic damage problems of damaged materials [17].
33. Transmission photoelasticity [18].
34. Reflection photoelasticity [18].
35. Colour image processing techniques [18].
36. Recent developments and future trends in photoelasticity [18].
37. Classification of fracture processes [19].
38. Basics of fracture mechanics [19].
39. Finite element method [1,2,19].
40. FE-techniques for crack analysis in linear-elastic structures [19].
41. Numerical calculation of generalized energy balance integrals [19].
42. FE-techniques for crack analysis in elastic-plastic structures [19].
43. Numerical simulation of crack propagation [19].
44. Basic equations of elasticity [20].
45. Point forces and systems of point forces in the three-dimensional space and half-space [20].
46. Three-dimensional crack problems for the isotropic or transversely isotropic infinite solid [20].
47. A crack in an infinite isotropic two-dimensional solid [20].
48. A crack in an infinite anisotropic two-dimensional solid [20].
49. Thermoeiasticity [20].
50. Contact problems [20].

Recommended or Required Readings:

1. Rao S. S. The Finite Element Method In Engineering. Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo: Elsevier, 2011. 727p.
2. Zienkiewicz O.C., Taylor R.L. The Finite Element Method for Solid and Structural Mechanics. Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo: Elsevier, 2005. 648p.
3. SIMULIA Abaqus/CAE User`s Manual
4. SIMULIA Abaqus Example Problems Manual

5. Segerlind L. J. Applied FiniteElement Analysis. Inc. New York/London/Sydney/Toronto: John Wiley and Sons, 1976. 393p.
6. Professor Suvranu De. Abaqus Handout. Rensselaer Polytechnic Institute. Department of Mechanical, Aerospace and Nuclear Engineering. 61 p.
7. Nushtaev D. V. Abaqus. The manual for beginners. The step by step instruction. TESIS, Moscow 2010, 78 p.
8. Abaqus. Complex application in engineering tasks. TESIS, Moscow, 2008. 99 p.
9. W.T. Koiter. General Theorems for Elastic-Plastic Solids. 1960. North-Holland publishing company. Amsterdam.79p.
10. H.G. Hahn. Elastizitätstheorie. Grundlagen der linearen Theorie und Anwendungen auf eindimensionale, ebene und räumliche Probleme. B.G. Teubner Stuttgart, 1985. 109b.
11. Kavhanov L.M. Bases of Fracture Mechanics. Science, 1974, 312 p.
12. Dyszlewicz J. Micropolar Theory of Elasticity. Springer
13. Ponter A.R.S., Chen H. A minimum theorem for cyclic load in excess of shakedown, with application to the evaluation of a ratchet limit. Eur. J. Mech. A/Solids, 2001, v. 20: 539-553
14. Ramji M., Nithila E., Devvrath K., Ramesh K. Assessment of autonomous phase unwrapping of isochromatic phase maps in digital photoelasticity. Sādhanā, 2008, v. 33 (1): 27-44
15. Schröder J., Hackl K. Plasticity and Beyond: Microstructures, Crystal-Plasticity and Phase Transitions. CISM, Udine 2014.
16. Piero G.D. A Variational Approach to Fracture and Other Inelastic Phenomena. Dordrecht, Heidelberg, New York, London: Springer, 2014.
17. Zhang W., Cai Y. Continuum Damage Mechanics and Numerical Applications. Dordrecht, Heidelberg, New York, London: Springer.
18. Ramesh K. Digital Photoelasticity. Advanced Techniques and Applications. Berlin, Heidelberg, New York, Barcelona, Hong Kong, London, Milan, Paris, Singapore, Tokyo
19. Kuna M. Finite Elements in Fracture Mechanics. Theory – Numerics – Applications. Solid Mechanics and Its Applications, 2013, v.201
20. Kachanov M., Shafiro B., Tsukrov I. Handbook of Elasticity Solutions. Springer-Science+Business Media, B.V., 2003, 329p.