European Master in Advanced Solid Mechanics

ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ

The National Technical University of Athens

Module handbook for Semester 2

8 ELECTIVE MODULES		
1	Non-linear finite element analysis of structures	5 ECTS
2	Load carrying behaviour of structural systems	5 ECTS
3	Boundary elements	5 ECTS
4	Stochastic finite elements	5 ECTS
5	Structural optimization	5 ECTS
6	Biomechanics of soft tissues	5 ECTS
7	Seismic design of surface and underground structures	5 ECTS
8	Engineering Materials	5 ECTS

The student has to choose 6 modules among the 8 elective modules listed above.

Module #1	**NON-LINEAR FINITE ELEMENT ANALYSIS OF STRUCTURES**			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	K. Spiliopoulos, V. Papadopoulos, M. Papadrakakis			
Contents	Issues of continuum mechanics and basic tensor analysis. Introduction to nonlinear analysis. Incremental equations of motion, Green Lagrange strain tensor. Cauchy stress tensor, Piola Kirchhoff stresses, Incremental total and updated Lagrangian formulations. Principle of Virtual work in a non-linear setting. Linearization of non-linear equations of motion and incremental - iterative solution methods. Newton-Raphson algorithm. Path following techniques. Arc-Length. Geometric Non linearity. Finite element method for geometric non – linear problems: Truss and Cable elements, Plane Strain and plane stress elements, Three-dimensional solid elements, Structural elements: beam and general shell elements. Material nonlinearity. Problem statement. Elastoplastic problem in one dimension. Isotropic and Kinematic Hardening. J2 Plasticity. Deviatoric stress. Deviatoric strain. Yield surface. Von Mises & Tresca Yield criteria. Drucker's postulate. Maximum dissipation principle. Associated and non-associated flow rules. Perfect plasticity. Radial return algorithm. Algorithms for isotropic, kinematic and combined hardening. Algorithmic tangent operator. Finite element method for materially nonlinear problems. Implementation using MSOLVE and Commercial Software.			
Examination	Written final exam. Final grade: 70% examination and 30% exercises & project.			
Requirement for examination	No specific requirement			
Learning outcomes	The knowledge of safeguarding against any kind of failure is very important, as structures nowadays, for better efficiency, are being pushed to be able to operate under extreme loading conditions. On successful completion, graduates will be able to: • have a good understanding of the of inelastic behavior of the continuum structures; • have a good understanding of the geometric nonlinear effects on the structures; • know the numerical treatment of the geometric and material nonlinearity within the framework of the finite element method.			

Module #2	LOAD CARRYING BEHAVIOR OF STRUCTURAL SYSTEMS			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	L. Stavridis			
Contents	The influence of creep on the behavior of concrete structural systems. The use of prestressing and its influence on the load carrying capacity of concrete structures. The concept of pressure line and its application to frame and arch roofing structures. Behavior of multistory frames under lateral static loading. Stability and the influence of II-order effects on laterally loaded beams and frames under axial compression. Arch structures. Cables and cable roof structures. Suspension, prestress-ribbon and cable-stayed systems. Load carrying behavior of flat plates using also prestressing. Thin shell structural systems. Torsional behavior of thin walled beams subjected to warping with undeformable profile. Torsional behavior of rectilinear and curved single-cell box girders with deformable profile. Response of spatial systems of buildings under lateral and temperature loading.			
Examination	Written final exam. Final grade: 70% examination and 30% exercises			
Requirement for examination	No specific requirement			
Learning outcomes	The course addresses both the master degree student and the practicing engineer. On successful completion, students will be able to: • have a clear understanding of the load carrying behavior of the various structural systems; • perform a successful conceptual design for wide span roofing structures and bridges; • check and validate the structural analysis results gained by computer programs used in the design practice; • make critical assessment and possible adjustments in the application of pertinent Codes of Practice.			

Module #3	BOUNDARY ELEMENTS			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	J. Katsikadelis			
Contents	Introduction. Boundary versus domain methods. Preliminary Mathematical Knowledge. The Gauss-Green Theorem. The Divergence Theorem of Gauss. Green's Second Identity. The Adjoint Operator. The Dirac Delta Function. Elements of Calculus of Variations. Euler-Lagrange Equation. The BEM for Potential Problems in Two Dimensions. Fundamental Solution. The Direct BEM for the Laplace Equation and the Poisson Equation. The BEM for Potential Problems in Anisotropic Bodies. Numerical Implementation of the BEM. Evaluation of Line and Domain Integrals. The Program LABECON for Solving the Laplace and Poisson Equation. Domains with Multiple Boundaries. The Program LABECONMU for Domains with Multiple Boundaries. The Method of Subdomains. Boundary Element Technology. Linear Elements. Higher Order Elements. Near-Singular Integrals. Application to the Torsion of Noncircular Bars, Deflection of Elastic Membranes, Bending of Simply Supported Plates, Heat Transfer Problems, Fluid Flow Problems. The BEM for Two-Dimensional Elastostatic Problems. The Dual Reciprocity Method. The Analog Equation Method. Solution of the General Second Order Elliptic Partial Differential Equation. The BEM for Coupled Second Order Partial Differential Equations. The BEM for Time Dependent Problems. The BEM for the General Second Order Parabolic and Hyperbolic Partial Differential Equation. Applications. The BEM for Nonlinear Problems. The Nonlinear Potential Equation. Coupled Nonlinear Equations. Applications.			
Examination	Written final exam. Final grade: 50% written examination, 30% exercises, 30% project.			
Requirement for examination	Delivery of the solved exercises, completion of the project			
Learning outcomes	The course addresses both the researcher and the practicing engineer. On successful completion, students will be able to: • learn the BEM as a computational method; • solve potential problems described by the Laplace and Poisson equation using the BEM; • solve linear and nonlinear problems, both static and dynamic, described by second order partial differential equations using the BEM.			

Module #4	**STOCHASTIC FINITE ELEMENTS**			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	V. Papadopoulos			
Contents	**Stochastic process theory**. Review of random variables, cumulative distribution function, probability density function, statistical moments. Introduction to stochastic processes and fields. Mean, autocorrelation and spectral density functions. Analysis in the frequency domain. Definition of simple Gaussian and non-Gaussian processes. **Uncertainty quantification**. Representation/discretization of stochastic processes and fields: Point discretization methods, Local Average discretization methods, series representation methods. Simulation of stationary Gaussian stochastic processes and fields: Spectral representation method and Karhunen-Loeve expansion. Formulation and solution of the stochastic finite element method (SFEM): Stochastic virtual work approach. **Available analytic solutions**. Variability Response Function approximations. Approximate non- intrusive Monte Carlo SFEM methods: Derivation of stochastic stiffness matrices for a class of finite elements. SFEM formulation in the context of non- intrusive Monte Carlo methods. Introduction to Spectral Stochastic Finite element method. Basic Reliability Analysis. Monte Carlo, FORM and SORM and Response Surface methods. Variance reduction techniques. Computer applications on real structures.			
Examination	Written final exam. Final grade: 70% examination and 30% exercises & project.			
Requirement for examination	No specific requirement			
Learning outcomes	The course addresses both the researcher and the practicing engineer. On successful completion, students will be able to: • have an in-depth understanding of the stochastic process theory and simulation methods; • know the mathematical framework and the computational techniques of uncertainty quantification using finite elements; • critically assess the pertinent Codes’ requirements, from the point of view of stochastic and reliability analysis of structures.			

Module #5	STRUCTURAL OPTIMIZATION			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	N. Lagaros			
Contents	Introduction to structural optimization. Definitions formulations and simple examples of structural optimization problems. Optimality criteria – problems with no constraints (unimodal and multimodal functions). Optimality criteria – problems with constraints (Introduction to Lagrange multipliers, KKT conditions). Linear Programming (Introduction, Duality, Simplex Algorithm, examples). Linear Programming (Engineering problems, plastic design of minimum weight). Non-Linear Programming (Gradient methods). Non-Linear Programming (Condition number, diagonal solving, Newton's method). Metaheuristics / Derivative free algorithms. Laboratory class PC (at the PC lab). Formulations of structural optimization problems (Sizing, Shape & Topology optimization). Multi-objective optimization problems & Generic Algorithms. Sizing structural optimization problems. Shape & Topology structural optimization problems.			
Examination	Written final exam. Final grade: 70% examination and 30% exercises & project.			
Requirement for examination	No specific requirement			
Learning outcomes	The course addresses both the researcher and the practicing engineer. On successful completion, students will be able to: • have an in-depth understanding of the problem formulations of the three types of structural optimization problems; • know the mathematical background and the computational implementation of the search algorithms used for solving this type of problems; • critically assess problem formulations obtained from the industry.			

Module #6	**BIOMECHANICS OF SOFT TISSUES**			
Information	Credit Points: 5 ECTS	Workload: 50h	Mode: Elective module	Offered: 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	D. Eftaxiopoulos			
Contents	I. **Biomechanical topics in soft tissues** (Macroscopic models of tissues, interstitium and membranes. Tissue engineering redirected to tumor tissue exploration. Mechanisms of injury of the knee. Water and solid constituents of soft tissues). II. **Solids and multi-species mixtures as open systems : a continuum mechanics perspective** (Elements of continuum mechanics. Multi-species mixtures as thermodynamically open systems. Anisotropic and cone wise elasticity. Hyperelasticity. Poroelasticity. Viscoelasticity. Thermoelasticity. Transfers of mass, momentum, and energy. Waves). III. **Electro – chemo - mechanical couplings in tissues with a fixed electrical charge** (Directional averaging for fiber-reinforced tissues. Electro – chemo - mechanical couplings. Chemo-mechanical couplings in articular cartilage. Passive transport in the interstitium and circulation. Coupled transports in tissues with a fixed electrical charge. Effects of the pH on transport and mechanics. Finite element analysis of couplings in the extracellular matrix. Cornea and annulus fibrosus). IV. **Growth of biological tissues** (Tissue Engineering. Growth of soft tissues. Elastic-growing solids. Elastic-growing mixtures. Solid tumors)			
Examination	Written final examination and optional exercise or little project submission (30% contribution to the final grade for the latter)			
Requirement for examination	No specific requirement			
Learning outcomes	On successful completion of the course the student will have learned: • how key continuum mechanics concepts are used in constitutive modeling, experimental setups and computational procedures, regarding the study of coupled fields in mixtures of solids and fluids; • techniques to simulate the mechanical response of several soft tissues (articular cartilage, cornea, annulus fibrosus).			

Module #7	SEISMIC DESIGN OF SURFACE & UNDERGROUND STRUCTURES			
Information	Credit Points: 5 ECTS	Workload: 50h	Mode: Elective module	Offered: 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	G. Bouckovalas, A. Papadimitriou			
Contents	Seismic response of visco-elastic and elasto-plastic structural systems under seismic base motion. Theory of wave propagation in continua and across interfaces, with emphasis on seismic (P, S, R and L) waves. Design of tunnels and high pressure buried oil and gas pipelines under transient and permanent seismic ground displacements. Seismic response of tall dams and embankments. Seismic earth pressures on gravity-type (rigid) walls with un-limited displacement. Seismic earth pressures on flexible retaining walls with limited displacement. Hydrodynamic pressures on quay walls and port facilities. Pseudo-static and performance-based design of geotechnical structures (dams, embankments, rigid & flexible retaining structures, quay walls).			
Examination	Written final exam. Final grade: 60% examination and 40% exercises & TEPM project			
Requirement for examination	No specific requirement			
Learning outcomes	The course addresses both the researcher and the practicing engineer. On successful completion, students will: • acquire insight to the peculiarities of seismic ground response, as well the resulting transient and permanent loading effects of Civil Engineering structures; • be able to perform the basic Geotechnical Earthquake Engineering studies, including seismic ground response and liquefaction analyses, as well as seismic design of geotechnical structures (pipelines & tunnels, high embankments and dams, earth retaining structures, quay walls, etc.); • be able to critically assess the range of application and the assumptions of pertinent Seismic Code (e.g. EC-8) provisions.			

Module #8	ENGINEERING MATERIALS			
Information	Credit Points: 5 ECTS	Workload: 50h	Mode: Elective module	Offered: 2nd semester
Institution in charge	National Technical University of Athens			
Instructors	Professor G. Fourlaris			
Contents	Classes of materials: Metals and alloys, ceramics, polymers and composite materials. Technological evolution and trends, properties and cost comparison, main applications. Structure-properties relationships: Nature of chemical bonding, crystal structure and imperfections, dislocations. Solidification of metals. Mechanical properties and their dependence on the microstructure. Hardness, tensile strength, ductility, toughness, strain hardening, recovery and recrystallization. Fracture mechanisms, elements of fractography. Impact strength, transition from ductile to brittle fracture. Other properties: Fatigue and fretting fatigue. Creep. Wear resistance. Study of some common alloys: Iron and steel, cast iron, aluminium and light alloys, copper alloys. Production and processing methods and their relation to mechanical properties: Construction steels: Plain carbon and low-alloy steels. High elastic limit steels, dual phase steels, controlled rolling and microalloyed steels. Stainless steels. Steels for low temperature applications. Reinforced concrete steels: Types and relevant mechanical properties. Resistance to high temperatures.			
Examination	Written final exam at the end of the semester. Final grade: 100% assessed via final closed book exam			
Requirement for examination	No specific requirement			
Learning outcomes	The course addresses both the researcher (mainly) and the practicing engineer.			