

MODULE HANDBOOK

SEMESTER 3	
Track 1: Mechanics of Structures	
Advanced Plastic Analysis of Frames	5 ECTS
Load-carrying behavior of structural systems	5 ECTS
Modelling of structural concrete	5 ECTS
Advanced Structural Dynamics	5 ECTS
Geotechnical Engineering in Design of Structures	5 ECTS
Fracture Mechanics	5 ECTS
Fluid-Structure Interaction with Application to Wind Turbines	5 ECTS
Mechanics of Composite Materials	5 ECTS

Students must choose 6 courses out of the 8 available.

Module #1	ADVANCED PLASTIC ANALYSIS OF FRAMES		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Elective
Instructor(s)	K. Spiliopoulos		
Content	Introduction to the plastic design of structures. Redistribution of forces. Ductility. Relation with the Codes of Practice. Step-by-step 1st order elastoplastic analysis of frames. Principle of virtual work. Lower and upper bound theorems of plastic collapse. Safe moment distribution. Collapse mechanisms. Holonomic and non-holonomic behavior. Mathematical programming. Kuhn-Tucker conditions. Linear programming. Simplex method. Mesh and nodal description. Static-kinematic duality. Flow rule. Stable materials. Rigid plastic behavior. Alternative linear programs of limit analysis. Uniqueness of limit load. Automatic limit load evaluation. Optimal plastic design. Automatic optimal plastic design using linear programming. Variable loading. Alternating plasticity. Incremental collapse. Shakedown. Residual stress. Melan's theorem. Mesh-unsafe shakedown linear program and automatic shakedown load evaluation. Relation between limit and shakedown load. Inelastic dynamic analysis of MDOF systems. Seismic response of buildings. Ductility ratios. Pounding of buildings. Reference to approximate static methods (pushover, etc.). Practice with well-known software packages (SAP, Abaqus, etc.). Elastoplastic analysis with 2nd order effects. Large displacements. Geometric non-linear elastoplastic stiffness matrix. Arc-length method. Comparison of limit loads with and without 2nd order effects. Merchant-Rankine formula.		
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 inelastic behavior of framed structures; • know the mathematical framework and the computational techniques of plastic analysis; • critically assess the pertinent Codes' requirements, since plasticity is the basis of all today's Codes of Practice.		

Module #2	LOAD-CARRYING BEHAVIOUR OF STRUCTURAL SYSTEMS		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Elective
Instructor(s)	L. Stavridis		
Content	Simply supported beams. Continuous beams. 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.		
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	MODELLING OF STRUCTURAL CONCRETE		
Information	Credit points: 5 ECTS	Workload: 50h	Mode: Elective
Instructor(s)	E. Vougioukas, M.D. Kotsovos		
Content	<u>Concrete behavior</u>: Strength, stress-strain behavior under short-term loading, cracking, failure mechanism. (1 course) <u>Behavior of structural concrete elements</u>: Modes of failure, causes of failure, physical model of element behavior. (3 courses) <u>Design of concrete structures</u>: Compressive force path method, earthquake-resistant design, application of the method for the design of beams, columns, structural walls, slabs, frames, etc. (8 courses) <u>Numerical analysis of concrete structures</u>: constitutive modelling, nonlinear strategy, numerical predictions of structural elements under short-term loading ranging from static to dynamic. (2 courses)		
Examination	Written final exam. Final grade: 70% examination and 30% exercises.		
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 structural concrete behavior; • design concrete structures from first principles so as to fulfil the code requirements for structural performance. • predict load-carrying capacity and causes and locations of possible failure of existing concrete structures.		

Module #4	ADVANCED STRUCTURAL DYNAMICS		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Elective
Instructor(s)	N. Babouskos, S. Triantafyllou		
Content	Dynamic loads and dynamic models of structures. Methods of derivation of equations of motions for structural systems (Equilibrium of forces, principle of virtual displacements, Hamilton's, principle, Lagrange equations). Free and forced vibrations of SDOF systems. Numerical solution of the SDOF equation of motion (linear and nonlinear). Damping (viscous, Coulomb, structural, fractional). Discretization of continuous systems. Continuous systems exact and approximate methods. Generalized SDOF systems. Analysis in the frequency domain. Discretization of continuous systems. Free vibrations of MDOF systems. Modal damping, proportional damping. Numerical evaluation of eigenfrequencies and mode shapes. Partially restrained structures. Forced vibrations of MDOF systems. The method of modal superposition. Modal participation, static correction method. Reduction of degrees of freedom (kinematic constraints, Ritz vectors). Support excitation. Response spectrum analysis (CQC, SRSS). Nonlinear response of structures. Numerical solution of the equations of motion in time domain. Dynamic analysis of multi-story buildings. Base isolation.		
Examination	Written final exam. Final grade: 50% written examination, 50% exercises		
Requirement for examination	Solution of the exercises		
Learning outcomes	The course addresses both the researcher and the practicing engineer. On successful completion, students will be able to: • To formulate the dynamic model of a given structure • To derive the equations governing its motion • To solve the equations of motion using numerical methods. • To establish the stress resultants due to the prescribed dynamic loading as well as their extreme values • To check the results obtained by available professional codes		

Module #5	GEOTECHNICAL ENGINEERING IN DESIGN OF STRUCTURES		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Elective
Instructor(s)	V. Georgiannou, A. Zervos		
Content	The topics of seepage, compression, and consolidation are briefly examined and related to both engineering practice and current analytical research. By using an extended case study of the Tower of Pisa as a theme, the concepts can be applied to different soils and the long-term settlement of soil can be assessed. The major challenges facing designers of multi-propped deep excavations, particularly in crowded urban areas are examined. Embedded retaining walls such as secant bored pile walls and diaphragm walls used in the construction of deep sections of retained cuttings and cut-and-cover tunnels in road schemes and excavations in urban cities are studied with emphasis on the stress transfer and deformation mechanisms around diaphragm walls. The study of retaining systems is extended to include reinforced soil retaining walls and/or steepened embankments, as a relatively new cost-effective method of construction which reduces embankment width and land-take and is environmentally acceptable. The classic preliminary design methods, including Eurocode 7, are presented both for retaining walls and reinforced soil. By using case studies (e.g. Egnatia Motorway) the Codes of practice are applied using bespoke and commercial software. Groundwater flow around an embedded retaining wall in a deep excavation is analyzed, while the response to earthquake loading is assessed for conventional retaining walls, reinforced-soil walls, and bridge abutments. Finally, in situ measurements of stress, deformation, and pore-water pressure, together with instrumentation for structural monitoring, are briefly described.		
Examination	50% written final examination 50% four projects based on case studies		
Requirement for examination	No specific requirement		
Learning outcomes	Students will develop skills on how to quantify and use fundamental parameters that control the one-dimensional flow of water through soils and its implications to geotechnical analyses. Likewise, they will learn how to rigorously assess the stability of retaining structures and foundations under static and seismic loading. These skills are critical to successful design and analysis in soil-structure systems and to critical assessment of the Codes' requirements.		

Module #6	FRACTURE MECHANICS		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Elective
Instructor(s)	G. Exadactylos		
Content	Brittle vs. ductile fracture. Historical remarks. Philosophy and purpose. Size scales involved in Fracture Mechanics. Crack surface displacement modes. The energy release rate G. Specific surface energy and crack growth resistance. Compliance of linear elastic cracked solids. The J-integral and other conservation integrals. Complex potentials. Stresses and displacements around cracks (Westergaard's method). Boundary conditions and the complex Stress Intensity Factor (SIF). Dimensional considerations. Correlation of Stress Intensity Factors (Modes KI, KII, KIII) with Stress Concentration Factor. Equivalence of Stress Intensity Factor and Energy Release Rate approaches. Examples of crack tip solutions using the Westergaard's Stress Function. Muskhelishvili's method for the determination of SIF's. Boundary collocation. Weight function techniques. Finite element methods. Boundary element methods – Displacement Discontinuity Technique. The influence of load boundaries other than crack surfaces – Compounding methods. Experimental determination of SIFs. Cracks in anisotropic materials. Three dimensional problems. Irwin's Plastic Zone Model. Dugdale's Strip-Yield Model. Plastic zone shapes. Comparison of plate tests with strip yield predictions. Small scale yielding solutions for Mode I. Failure criteria with moderate plasticity. Crack tip opening displacement (COD). Plane stress vs. plane strain. The concept of the crack resistance (R-curve). Plane strain fracture toughness testing. Crack instability with plasticity. <i>Mixed-mode Fracture Mechanics</i>. Fatigue crack growth. Calculation of kinetic energy and crack velocity. Dynamic values of K and G. Crack branching and arrest.		
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 (mainly) and the practicing engineer. On successful completion, students will be able to: • have an in-depth understanding of the fundamental mechanics of fracture; • know the mathematical framework, the experimental analysis and the computational techniques utilized in fracture analysis.		

Module #7	FLUID-STRUCTURE INTERACTION WITH APPLICATION TO WIND TURBINES		
Information	Credit points: 5 ECTS	Workload 40 hours	Mode Elective
Instructor(s)	V. Riziotis, S. Voutsinas		
Content	The course lasts 13 weeks each having 3 didactic hours: 2 hours will correspond to lecturing while the 3rd will be given to the project. Lectures can be divided in two parts. Part I will present the theoretical background (both mathematical and physical of FSI), while Part II will present the application of the theory to wind turbines, which will also correspond to the project. The project will be carried out with hGAST, an in-house developed hydro-servo-aero-elastic simulation package for wind turbines. Outline of Lectures: • Structural modeling with application to 1D structures – full stiffness matrix approach for beams - FEM modeling background with application to beam theory. • Aerodynamic theory for airfoils and wings. Simulation procedures in aerodynamics covering from potential flow models to highly detailed CFD • Kinematics & Dynamics of Multi-body configurations dynamics • Introduction to FSI based on scaling. Identification of the relevant problems and review of solution methods. • Aeroelastic coupling and its modeling • Linear stability analysis and application to aeroelastic systems • Non-linear stability numerical approaches • Stability augmentation through control and/or tailoring • The certification aspect of FSI and its application to Wind turbines		
Examination	3 Intermediate quiz, a written final exam, a project report and its presentation to the class. Final grade: 15% examination, 30% final exam and 55% the project.		
Requirement for examination	Participation in the quiz, presentation of the project The report will be due with possible corrections at the end of the examination period.		

Learning outcomes	The course aims at providing sound theoretical background on FSI combined with hand-on training in connection to a software and the technology of Wind Turbines. On successful completion, students will be able to: • Have a good understanding of the mathematical and physical background of FSI in the context of Continuum Mechanics • Become familiar with simulation methods ranging from semi-empirical up to fully resolved ones • Formulate FSI problems related to external flows, • Identify the scaling laws that are connected to them and choose the appropriate modeling • Run simulations and collect the relevant engineering information from the output of the simulations • Review the numerical results and synthesize engineering answers to design questions
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Module #8	MECHANICS OF COMPOSITE MATERIALS		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Elective
Instructor(s)	I. Kalogeris, V. Papadopoulos, E. Bilalis		
Content	<u>Part I:</u> General introduction to composite materials. Mechanical/physical characteristics and material properties. Anisotropy/orthotropy. Structural configuration (layers, laminates, sandwich, terminology). Manufacturing methods and engineering applications of composite materials. Calculation and measurement of material properties (theoretical formulae, testing procedures). Analytical lamina property prediction. Rule of mixtures / inverse rule of mixtures. Halpin–Tsai-type estimates. Lamina constitutive modeling. Plane-stress orthotropic elasticity. Stress/strain transformations. Classical lamination theory (CLT). A–B–D matrices, coupling. Laminate stiffness and effective properties. Layer strain and stress calculations. Failure modes. Layer failure criteria (Maximum stress/strain, Tsai–Hill/Tsai–Wu, Hashin). First-ply failure vs laminate failure - laminate strength. Structural design principles and guidelines. Bending and buckling of hat-type stiffeners and laminated plates. Design of joints. <u>Part II:</u> Advanced composites. Graphene and CNT reinforced polymers and metamaterials. Atomistic models of carbon-based nanomaterials. Fundamentals of micromechanics: fibers/filaments, Hill–Mandel postulate, boundary conditions, scale separation. Mean-field theories (Voigt/Reuss bounds, Mori–Tanaka). Computational homogenization: first and second order homogenization, RVE, Method of Cells and variants. Nonlinear homogenization. Modeling of interfaces. Extraction of phenomenological nonlinear constitutive models. Continuum and discrete damage modeling. RVE and SVE representations. Concurrent FE² multiscale modeling. The need for surrogate models.		
Examination	Written final examination. Final grade: 60% final exam, 20% theoretical problem sets, 20% numerical programming exercise.		
Requirement for examination	Participation and passing grade in: • Theoretical exercises: Two or three analytical problem sets on composite lamina/laminate mechanics (lamina property prediction, CLT stiffness/stress recovery, failure criteria). • Numerical programming exercises: One computational project on multiscale modeling of composites (mean-field homogenization and/or RVE-based computational homogenization). Multiscale analysis of CNT-reinforced composites using the MSolve open-source software (or equivalent implementation).		

Learning outcomes	The course addresses composite materials at both macro (laminate/structure) and micro (micromechanics/RVE) scales. On successful completion, students will be able to: • understand the mechanical behavior of composite materials and identify key differences from conventional isotropic structural materials • estimate effective lamina properties from constituent data using analytical micromechanics approaches (rule of mixtures, Halpin–Tsai-type estimates) • apply Classical Lamination Theory (CLT) to compute laminate stiffness, stresses and strains in layered plates/laminates • identify whether a specific laminate fails under a certain loading condition and its failure mode • calculate the structural response of beams and plates made of composite materials • apply mean-field and computational homogenization methods (e.g., Mori–Tanaka and RVE-based FE homogenization) to obtain effective properties/constitutive response • understand the mechanical behavior of graphene and CNT reinforced polymers, and architected metamaterials • appreciate the merits and bottlenecks of multiscale simulation methods for composite structures • apply advanced multiscale damage modelling methods
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