The National Technical University of Athens

Module handbook for Semester 3

7 ELECTIVE MODULES		
1	Advanced Plastic Analysis of Frames	5 ECTS
2	Applied Structural Analysis of Frames and Shell Structures	5 ECTS
3	Advanced Structural Dynamics	5 ECTS
4	Fracture Mechanics	5 ECTS
5	Geotechnical Engineering in Design of Structures	5 ECTS
6	Mechanics of Composite Materials	5 ECTS
7	Contact Mechanics	5 ECTS

The student has to choose 6 modules among the 7 elective modules listed above.

Module #1	**ADVANCED PLASTIC ANALYSIS OF FRAMES**			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 3rd semester
Institution in charge	National Technical University of Athens			
Instructors	K. Spiliopoulos			
Contents	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	**APPLIED STRUCTURAL ANALYSIS OF FRAMED AND SHELL STRUCTURES**			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 3rd semester
Institution in charge	National Technical University of Athens			
Instructors	E. Sapountzakis			
Contents	The Displacement Vector and Strain Components of a Particle of a Body. Implication of the Assumptions of Small Deformation. Traction and Components of Stress Acting on a Plane of a Particle of a Body. Strain and Stress Tensors. Components of Displacement for a General Rigid Body Motion of a Particle. The Compatibility Equations. The Requirements for Equilibrium of The Particles of a Body. Constitutive Relations. Boundary Value Problems for Computing the Displacement and Stress Fields of Solid Bodies on the Basis of the Assumption of Small Deformation. Prismatic Body under Axial Loading. Prismatic Body under Bending Loading. Fundamental Assumptions of the Theories of Mechanics of Materials for Line Members. Internal Actions Acting on a Cross Section of Line Members. Action Equations of Equilibrium for Line Members. The Classical Theory of Beams. The Timoshenko Beam Theory. Computation of Shear Center Position. Uniform Shear Beam Theory. Computation of Shear Stresses. Computation of Shear Deformation Coefficients (required for Timoshenko Beam Theory). Nonuniform Shear of Beams. Displacements, Strains, Stresses. Stress Resultants, Global Equilibrium Equations, Boundary Conditions. Shear Warping Function, Local Equations of Equilibrium. Nonuniform Torsion of Bars, Displacements, Strains, Stresses. Stress Resultants, Equilibrium Equation, Boundary Conditions. Generalized Warping beam theory. Shear and torsion Warping Functions, Local Equations of Equilibrium. Distortion beam theory. Displacements, Strains, Stresses. Stress Resultants, Global Equilibrium Equations, Boundary Conditions. Shear and torsional Warping and Distortional Functions, Local Equations of Equilibrium. Axial warping. Buckling of beams.			
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: • apply theory of elasticity for the study of boundary value problems (e.g. Axial Loading, Prismatic Body under Bending Loading); • extract equation of equilibrium of a Line Member subjected to Axial Centroidal Forces, of Classical Beam Theory and of Timoshenko Beam Theory; • understand Nonuniform Shear, Nonuniform Torsion, Generalized Warping, Axial Warping, Distortion Beam Theories, Buckling of Beams.			

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<tr><td>Module #3</td><td colspan="4">ADVANCED STRUCTURAL DYNAMICS</td></tr>
<tr><td>Informations</td><td><u>Credit Points :</u>
5 ECTS</td><td><u>Workload :</u>
50h</td><td><u>Mode :</u>
Elective module</td><td><u>Offered :</u>
3rd semester</td></tr>
<tr><td>Institution in charge</td><td colspan="4">National Technical University of Athens</td></tr>
<tr><td>Instructors</td><td colspan="4">J. Katsikadelis</td></tr>
<tr><td>Contents</td><td colspan="4">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, Langrage 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. The finite element method for skeletal structures (plane and space trusses and frames). Rigid bodies in elastic structures. Axial constraints. 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 (ABSSUM, CQC, SRSS). Nonlinear response of structures. Numerical solution of the equations of motion in time domain. Dynamic analysis of multi-story buildings. Base isolation.</td></tr>
<tr><td>Examination</td><td colspan="4">Written final exam. Final grade: 50% written examination, 30% exercises, 20% project.</td></tr>
<tr><td>Requirement for examination</td><td colspan="4">Solution of the exercises, completion of the project</td></tr>
<tr><td>Learning outcomes</td><td colspan="4">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.</td></tr>
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<tr><td>Module #4</td><td colspan="4">FRACTURE MECHANICS</td></tr>
<tr><td>Information</td><td><u>Credit Points :</u>
5 ECTS</td><td><u>Workload :</u>
50h</td><td><u>Mode :</u>
Elective module</td><td><u>Offered :</u>
3rd semester</td></tr>
<tr><td>Institution in charge</td><td colspan="4">National Technical University of Athens</td></tr>
<tr><td>Instructors</td><td colspan="4">G. Exadactylos, A. Giannakopoulos</td></tr>
<tr><td>Contents</td><td colspan="4">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. Mixed-mode Fracture Mechanics. Fatigue crack growth. Calculation of kinetic energy and crack velocity. Dynamic values of K and G. Crack branching and arrest.</td></tr>
<tr><td>Examination</td><td colspan="4">Written final exam. Final grade: 70% examination and 30% exercises & project</td></tr>
<tr><td>Requirement for examination</td><td colspan="4">No specific requirement</td></tr>
<tr><td>Learning outcomes</td><td colspan="4">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</td></tr>
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Module #5	GEOTECHNICAL ENGINEERING IN DESIGN OF STRUCTURES			
Information	Credit Points: 5 ECTS	Workload: 50h	Mode: Elective module	Offered: 3rd semester
Institution in charge	National Technical University of Athens			
Instructors	V. Georgiannou, G. Gazetas			
Contents	The geotechnical applications (i.e. settlement of structures, embedded retaining walls, reinforced soil retaining walls and/or steepened embankments; seismic loading of retaining walls, bridge abutments, piles and pile groups) are related to engineering practice and to current research work. The topics of seepage, compression and consolidation are examined briefly and 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 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 multi-propped deep excavations in urban areas are examined. 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 response of piles and pile groups to seismic loading is also examined; the benefits of Unconventional Seismic Foundation Design in changing the established philosophy in seismic foundation design are assessed. In situ measurements of stress, deformation and pore pressures as well as instrumentation for monitoring structures are briefly described. As part of the course case studies are analyzed and the Codes of practice are applied, using bespoke and commercial software.			
Examination	50% written final examination and 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. Finally, the students will collaborate in the review and analyses of case studies that illustrate how the concepts covered in the course are used in typical geotechnical applications in the design of structures such as foundations and retaining walls.			

Module #6	MECHANICS OF COMPOSITE MATERIALS			
Information	Credit Points: 5 ECTS	Workload: 50h	Mode: Elective module	Offered: 3rd semester
Institution in charge	National Technical University of Athens			
Instructors	N. Tsouvalis, S. Triantafyllou			
Contents	**Part I**: General introduction to composite materials. Mechanical and physical characteristics and material properties. Structural configuration (layers, laminates, sandwich, terminology). Manufacturing methods. Applications. Calculation and measurement of material properties (theoretical formulae, testing procedures). Classical lamination theory. Laminate stiffness calculations. Layers strains and stress calculations. Failure modes. Layer failure criteria. Laminate strength. Structural design principles and guidelines. Bending and buckling of hat-type stiffeners and laminated plates. Design of joints. **Part II**: Advanced Composites. Graphene and CNT Reinforced Polymers, Metamaterials. Atomistic models of Carbon-based nanomaterials. Fundamentals of micromechanics: RVE, Hill condition, boundary conditions, mean field theories, scale separation. Computational homogenization theories, first and second order homogenization, RVE, method of cells and its variants. Nonlinear homogenization, modeling of interfaces, extraction of phenomenological nonlinear constitutive models, Continuum/discrete damage modelling. RVE and SVE representations, concurrent FE2 multiscale modeling. The need of surrogate models.			
Examination	Written final examination Final grade: 60% examination, 25% laboratory exercise, 15% theoretical exercises			
Requirement for examination	Participation and passing grade to: • **Theoretical exercises**: Two or three theoretical exercises (projects) requiring use of specialized software for analyzing the mechanical behavior of composite materials. • **Laboratory exercise**: One laboratory exercise for manufacturing and testing composite materials, requiring the submission of a technical report. • **Theoretical exercises**: Multiscale analysis of CNT Reinforced Composites in the MSolve open-source software.			

Learning outcomes	The course addresses composite materials with respect to both macro and micro level. On successful completion, students will be able to: • understand the mechanical behavior of composite materials; • being able to identify the differences from the conventional isotropic structural materials; • being able to familiarize themselves with the experimental testing methods of composite materials; • calculate stresses and strains on a laminated plate; • 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; • 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.

Module #7	**CONTACT MECHANICS**			
Information	Credit Points: 5 ECTS	Workload: 50h	Mode: Elective module	Offered: 3rd semester
Institution in charge	National Technical University of Athens			
Instructors	Th. Zisis, P. Gourgiotis			
Contents	Kinematics of contact. Fundamental solutions in contact mechanics, 3D and 2D problems. Flamant, Boussinesq and Cerruti problems. Hertzian contact. Contact between two elastic bodies. Elliptic contact. Adhesive contact. Sticky contact. JKR theory. Friction laws. Coulomb friction. Bowden and Tabor theory. Tangential contact. Tangential loading. Sliding contact. No-slip contact. Partial slip. Rolling contact. Sliding and sticking. Asymptotic solutions in contact mechanics. Thermo-elastic contact. Micromechanical contact models – Generalized continua.			
Examination	Written final exam Final grade: 70% examination and 30% exercises & project			
Requirement for examination	No specific requirement			
Learning outcomes	**Subject-specific Knowledge:** On successful completion, students will be able to have an understanding of the fundamental concepts of contact analysis and the critical ability to select an appropriate numerical tool to tackle a specific contact problem. **Subject-specific Skills:** An awareness of current technology, analysis methods and practices along with the ability to apply those methods in novel situations. To use effectively specialized, advanced analytical/computational tools for the analysis of problems in contact mechanics. An in-depth knowledge and understanding of specialized and advanced technical and professional skills, an ability to perform critical assessment and review and an ability to communicate the results of their own work effectively. **Key Skills:** Capacity for independent self-learning within the bounds of professional practice. Highly specialized numerical/analytical skills appropriate to an engineer. Mathematics relevant to the application of contact mechanics concepts.			