The University of Lille and the Centrale Lille Institute

Module handbook for Semester 3

9 ELECTIVE MODULES		
1	Extended Methods for Finite Element Modeling	5 ECTS
2	Goematerials and Porous Media	5 ECTS
3	Advanced Composite Materials	5 ECTS
4	Advanced Experimental and Numerical Dialogue	5 ECTS
5	Rubbing contact: Coupling and Multi-scale Effects	5 ECTS
6	Fatigue of Materials and Structures	5 ECTS
7	Limit Analysis and Shakedown	5 ECTS
8	Damage Mechanics	5 ECTS
9	Biomechanics	5 ECTS

The student has to choose 6 modules among the 9 elective modules listed above.

<table>
<tr><td>Module #1</td><td colspan="4">EXTENDED METHODS FOR FE MODELING</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 modules</td><td><u>Offered :</u>
3rd semester</td></tr>
<tr><td>Institution in charge</td><td colspan="4">Université de Lille - Ecole Centrale de Lille</td></tr>
<tr><td>Instructors</td><td colspan="4">J.-B. Colliat, J.-F. Shao</td></tr>
<tr><td>Contents</td><td colspan="4">This course aims at presenting the most up-to-date methods dealing with kinematics enhancements within the classical FE method.

- Recall of the standard Finite Element Method for linear and nonlinear structural problems (2h)
- Enhancement of FEM through « weak » discontinuities and application to heterogeneous materials (2h)
- Enhancement of FEM through « strong» discontinuities and application to fracture mechanics (2h)
- The Hu–Washizu variational theorem (4h)
- Local FE enhancements: the static condensation procedure and the E-FEM method (2h)
- The partition of unity (2h)
- Global FE enhancements: the X-FEM method (2h)

A large part of the examples shall be devoted to the use and the analysis of some FE codes, and the implementation (in Fortran or Matlab) of the local and global methods of enhancements.</td></tr>
<tr><td>Examination</td><td colspan="4">Written exam of 2 hours</td></tr>
<tr><td>Requirement for examination</td><td colspan="4">No specific requirement</td></tr>
<tr><td>Learning outcomes</td><td colspan="4">Proficiency with theoretical backgound and computing techniques</td></tr>
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Module #2	GEOMATERIALS AND POROUS MEDIA			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective modules	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	J.-F. Shao, N. Burlion			
Contents	• General presentation geomaterials: microstructures, mineralogical compositions • Basic mechanical and physical properties of geomaterials • Geomaterials as porous geomaterials • Deformation of porous materials • Stress and momentum balance in porous media • Thermodynamics of porous media • Thermo-poroelastic behavior of porous media • Basic solution methods for thermo-hydromechanical problems			
Examination	Written exam of 2 hours			
Requirement for examination	No specific requirement			
Learning outcomes	Proficiency with theoretical background and skill for engineering applications			

Module #3	ADVANCED COMPOSITES MATERIALS			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	M. Brieu, G. de Saxcé, P. Lecomte			
Contents	The aim of this course is to focus on the behavior of composites materials focusing on the anisotropic linear elastic behaviors. **Part I : Constitution and elaboration of uni directionnal and multi layered composites** Definition of uni-directionnal and multi-layered composites, processing techniques **Part II : Behavior of uni directionnal and multi layered composites** Introduction of the anisotropic behavior and tensor, homogenization of multi layered composites **Part III : Identification of anisotropy and gap to a class of anisotropy**			
Examination	Written final exam			
Requirement for examination	No specific requirement			
Learning outcomes	On successful completion of the course, students will be able to: • know the basic definitions of composite materials, their nature and the orders of magnitude of their properties, the different architectures as well as the manufacture processes; • model the linear elasticity behaviour of anisotropic materials; • calculate the properties of the equivalent homogeneous ply from the properties of the constituents; • model the average behaviour of laminated composites by the Classical Laminate Theory from the mechanical properties of the elementary ply; • know the fields of validity of the assumptions of these different models; • identify the mechanical properties of anisotropic material and to know the class of anisotropy of the material behaviour; • choose the most suitable material and architecture for a given application.			

Module #4	ADVANCED EXPERIMENTAL AND NUMERICAL DIALOGUE			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	A. El Bartali (Centrale Lille), P. Lecomte (Centrale Lille), V. Magnier (U.Lille), J.F. Witz (CNRS)			
Contents	The aim of this course is focused on the non-conventional experimental mechanical tests based on particular using Digital image (2D, DIC) and Volume (3D, DVC) correlation coupled to Finite Elements calculations to characterize mechanical properties under complex loadings. We will rely on the inverse methods to identify heterogeneous properties in heterogeneous materials. The steps of this course are the following: **Part I**: reminder of the DIC and introduction of the DVC **Part II**: Introduction to inverse methods **Part III**: Experimental practice **Part IV**: Characterization of heterogeneous material using experiment-numerical dialog			
Examination	Projects			
Requirement for examination	No specific requirement			
Learning outcomes	On successful completion of the course, students will be able to: • characterize the mechanical behaviour of various materials; • identify the constitutive laws; • build a physical model based on experiments.			

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<tr><td>Module #5</td><td colspan="4">RUBBING CONTACT: COUPLING AND MULTISCALE EFFECTS</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">Université de Lille - Ecole Centrale de Lille</td></tr>
<tr><td>Instructors</td><td colspan="4">J.-F. Brunel, A. Dufrénoy, V. Magnier (U. Lille), A.-L. Cristol, Y. Desplanques (Centrale Lille)</td></tr>
<tr><td>Contents</td><td colspan="4">This course deals with multi-scale and multi-physic couplings involved in rubbing systems. Tribological, thermal, thermomechanical and dynamical aspects are considered, from micro- and meso- scales of friction materials and wear mechanisms at the friction interface to macro scales involved by components and systems.

Part I – Phenomena induced by friction
Physical coupling at the friction interface, contact fatigue, thermal contact, thermomechanics and thermal localisation, noise and vibration.

Part II – Advance friction experiment
Tribosystem analysis and multi-physic couplings, similitude rules, scale shift from full-scale to laboratory test, rubbing-surface infrared thermography, multi-scale characterisation of rubbed surfaces, identification of couplings and friction-wear mechanisms.

Part III – Experimental and numerical practice
Numerical analysis of thermal – mechanical coupling involved in rubbing systems;
Numerical analysis of contact structure dynamical interaction;
Experimental case study of friction-induced vibrations;
Experimental case study of friction with high energy dissipation and thermal localisations.</td></tr>
<tr><td>Examination</td><td colspan="4">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">At the end of this module, students will be able to dimension and design complete brake systems by integrating multi-physical aspects. They will also have a broad vision of tribological problems.</td></tr>
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Module #6	FATIGUE OF MATERIALS AND STRUCTURES			
Information	Credit Points : 5 ECTS	Workload : 50h	Mode : Elective module	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	A. El Bartali, N. Limodin, Ph. Quaegebeur			
Contents	The aim of this course is focused on the progressive damage of materials and structures under cyclic loading that leads to the initiation and propagation of cracks. The objective of this course is to introduce the important concepts in mechanical fatigue of materials and structures to enable students to implement calculation and design approaches in this area. - Phenomenological description of fatigue - Damage mechanisms in metallic materials - Structural designing against high cycle fatigue - Structural designing against low cycle fatigue - Crack initiation and propagation by fatigue - Consideration of defects			
Examination	Written final exam			
Requirement for examination	No specific requirement			
Learning outcomes	On successful completion of the course students will be able to: • Identify the basic fatigue mechanisms from failure analysis; • Develop an understanding of the influent parameters and basic mechanisms in the different fatigue regimes (Low Cycle fatigue, High Cycle fatigue); • Correctly predict fatigue crack growth and fatigue lifetimes; • Design components to avoid fatigue failure during service loading.			

Module #7	**LIMIT ANALYSIS AND SHAKEDOWN**			
Information	Credit Points : 5 ECTS	Workload : 45h	Mode : Elective module	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	G. de Saxcé, J.-B. Tritsch, A. Oueslati			
Contents	The course allows to acquire a thorough knowledge of the calculus of the collapse plastic load under proportional loadings (limit analysis) and repeated variable loadings (shakedown analysis), as opposed to the incremental methods. The application concerns the structures as well as the materials. • Limit analysis theory : proportional loadings, collapse by mechanism, statical and kinematical bound theorems, applications to plates and shells. Numerical methods. • Shakedown analysis: repeated variable loadings, collapse by ratchet and accommodation, criticism of the incremental methods, Melan's statical theorem, Koiter's kinematical theorem, extension of the classical forms, applications. Numerical methods. • Technics of limit and shakedown analysis in mechanics of materials: obtaining macroscopic criteria of plasticity and fatigue by homogenization.			
Examination	Written final exam			
Requirement for examination	No specific requirement			
Learning outcomes	On successful completion of the course students will be able to: • Demonstrate an understanding of bound theorems for proportional and repeated variable loadings; • Demonstrate an ability to apply these theorems to various kind of structures in order to assess their collapse load; • Demonstrate a knowledge of the corresponding numerical technics; • Demonstrate a knowledge of analytical tools used in mechanical of materials.			

Module #8	DAMAGE MECHANICS			
Information	Credit Points : 5 ECTS	Workload : 46h	Mode : Elective module	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	A. El Bartali, P. Lecomte-Grosbras			
Contents	This course consists in an introduction on failure and damage of materials. The objective is to start from the phenomenological description of these damage mechanisms to define micromechanical models and macroscopic approaches. This course will focus primarily on metallic materials. At the end of the course, the student will be able to design structures subjected to loadings leading to these various damages and failures. Some industrial problems will be used in order to justify and illustrate the different parts of the course: - Phenomenological description of main failure types and damage mechanisms of metallic materials : cases of ductile, brittle failure - Different modes of failure - Toughness tests and Irwin Criteria - Stress concentration factor and Stress Intensity Factor - Description and consideration of notch, defects, cracks… - Applications and illustrations on case study and structures			
Examination	Written final exam			
Requirement for examination	No specific requirement			
Learning outcomes	On successful completion of the course students will be able to: • Identify the failure types and damage mechanisms; • Apply linear elastic fracture mechanics theory; • Model Crack growth; • Design components to avoid damage and fracture during service loading.			

Module #9	**BIOMECHANICS**			
Information	Credit Points : 5 ECTS	Workload : 46h	Mode : Elective module	Offered : 3rd semester
Institution in charge	Université de Lille - Ecole Centrale de Lille			
Instructors	P. Lecomte, O. Mayeur			
Contents	This course is an introduction to the biomechanics of biological tissues. It will address the notions of mechanical behaviour of biological tissues in relation to their composition. Students will experiment with methods for characterizing mechanical behaviour taking into account the difficulties associated with the manipulation of biological tissues. They will apply the notions of modelling mechanical behaviour in relation to experimental methods and in continuity with the notions introduced in continuum mechanics and the other courses of the Master STRAIN in order to choose the behaviour model, identify its parameters and validate it.			
Examination	Evaluations will be conducted during the sessions of the biomechanics course and a work of bibliography will be carried out.			
Requirement for examination	No specific requirement			
Learning outcomes	At the end of the module the student will be able to: • Choose, identify and validate a behaviour law of biological tissue • Analyse experimental data • From image build a numerical model of biological system • Perform numerical simulation of biological system • Adopt a global vision and grasp the problem in all its complexity • Take into account the uncertainty generated by complexity • Analyze the acceptability of a solution (assumptions, orders of magnitude, ...)			