

## PROGRAM

### Monday

- Variational formulation in linear solid mechanics (RLT)**  
Strong, weak and variational forms of BVP in linear elasticity  
FEM technology for 1D problems
- Fem technology in 1d problems (RLT)**  
Axisymmetric 1-d elasticity  
Euler-Bernoulli and Timoshenko beam models  
Locking numerical evidences
- Fem technology in solids problems (MB)**  
Isoparametric elements and numerical integration  
Incompressibility / near incompressibility  
Hybrid and mixed FE  
Enhanced strain FE
- Structural finite elements (MB)**  
Dimensional reduction  
Plate and shell models  
Finite elements for thin-walled structures
- Introduction to feap and problem solution (TUTORIAL)**  
Tutorial on FEAP command language  
Tutorial on programming in FEAP environment

### Tuesday

- Enhancing structural fem performance (MB)**  
Shell theory and finite elements  
Assumed strain and enhanced strain FE  
Reduced integration plus stabilization
- Theoretical foundation of mixed interpolation methods (FB)**  
Locking phenomena  
Inf-sup condition
- Inelastic constitutive behavior at small strains (FA)**  
Inelasticity and plasticity models  
Solution schemes (return map)  
Integration of evolution equations  
Operator split method and consistent tangent modulus
- Advanced inelastic constitutive behavior at small strains (FA)**  
Generalized plasticity  
Nonlinear kinematic hardening  
Shape-memory alloys  
Extension to capture soil/concrete behaviors
- Locking problems in plasticity (TUTORIAL)**  
Choice of element type  
Tutorial on FEAP Command language  
Tutorial on programming user-models in FEAP environment

### Wednesday

- Nonlinear solid mechanics problems at large displacements (FA)**  
Kinematics and strain measure at large displacement  
First and second Piola-Kirchhoff, Kirchhoff and Cauchy stress tensors  
Finite element interpolations; consistent linearization
- Nonlinear constitutive models for large displacements (FA)**  
Finite elasticity (stored energy function forms)  
Plasticity at large deformations  
Formulations in reference and current configurations
- Nonlinear structural mechanics and stability analysis (MB)**  
Nonlinear structural models

Solution methods, path following techniques  
Identification of critical points, buckling and snap-through phenomena  
Prebuckling analysis and nonlinear stability analysis

- Solution techniques for nonlinear dynamical problems (RLT)**  
Nonlinear problem solution techniques  
Explicit vs. implicit integration schemes  
Generalized alpha-scheme and schemes for stiff equations  
Solution techniques with computer code FEAP
- Tutorial on nonlinear problems (TUTORIAL)**  
Example on instability issues using a symbolic approach  
Finite-strain problem solution in FEAP environment  
Programming finite-strain user-models in FEAP environment

### Thursday

- Isogeometric modeling and analysis (AR)**  
Introduction to splines and NURBS  
Simple investigations
- Isogeometric modeling and analysis (GS)**  
Definition of locally refinable splines (T-splines, LR-splines, hierarchical splines) and basic properties  
Some approximation results  
T-splines based IGA: elliptic and mixed problems
- Isogeometric modeling and analysis (RLT)**  
Computational technologies  
Implementation details for displacement and mixed forms  
Example applications for elastic and inelastic materials
- Contact problems (RLT)**  
Formulation of contact problems (penalty, augmented Lagrangian)  
Implementation of nodal and surface methods  
Impact dynamics and contact
- Tutorial on isogeometric analysis (TUTORIAL)**  
Some simple in-house Matlab codes  
Isogeometric problem solution in FEAP environment

### Friday

- Particle methods / sph / meshless schemes (AR)**  
An introduction to meshless methods  
Smoothed particle hydrodynamics and other approaches  
Some recent developments
- Fluids (MB)**  
Basic assumptions/equations, Newtonian Fluids, Euler/Navier Stokes  
Incompressible vs. compressible, laminar vs. turbulent flow, stationary vs. transient solutions  
Finite elements for fluids
- Solution methods for coupled and interaction problems (MB)**  
Introductory remarks on coupled problems, monolithic vs. partitioned modeling, simultaneous vs. staggered solution  
Solving problems of fluid-structure interaction using finite element discretization,  
Arbitrary Lagrangian Eulerian Formulation (ALE)
- Multi-scale problems (RLT)**  
Homogenization methods  
Scale bridging using representative volume elements (FE2)  
Parallel implementation details  
Example applications
- Mimetic finite differences in computational mechanics (FB)**

## SECRETARIAT

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## REGISTRATION

Participants should communicate by e-mail a statement of participation to the Secretariat and, after the payment, a scan copy of the bank transfer receipt.

Course fees are established as follows:

<b>Participants from industry:</b>	<b>1300€ (early)</b>	<b>1500 €</b>
<b>Faculty members:</b>	<b>800€ (early)</b>	<b>1000 €</b>
<b>PhD students &amp; Post-Docs:</b>	<b>650€ (early)</b>	<b>850 €</b>

The method of payment is by bank transfer to:

**FONDAZIONE EUCENTRE**  
**Banca Popolare Commercio e Industria - Strada Nuova 61/C - 27100 Pavia**  
**IBAN: IT36S050481130200000042461**  
**SWIFTCODE/ BIC: POCIITM1XXX**  
indicating as **purpose of payment: "NL12" and the attendee's name.**

Early registration is kindly recommended. Registration is transferable to another member of the same organization. For the **early registration**, payment should be sent **before 31.01.2012**.

To get the reduced rate PhD students and post-docs should send a proof of status.

**The fee comprises fixed-menu lunches, coffee breaks and course material.**

For cancellations communicated prior to March 1<sup>st</sup> 2012, 70% of the registration fee will be refunded. No refund will be made for cancellation after that date.

## ORGANIZING COMMITTEE

Prof. Ferdinando Auricchio auricchio@unipv.it  
Dr. Alessandro Reali alessandro.reali@unipv.it  
Mrs. Elisa Reali elisa.reali@unipv.it

## COURSE SCHEDULE

9.00-10.00	Lecture 1	14.00-15.00	Lecture 4
10.00-10.15	Coffee break	15.00-15.15	Coffee break
10.15-11.15	Lecture 2	15.15-16.30	Tutorial
11.15-12.15	Lecture 3	16.30-17.00	Open discussion
12.15-14.00	Lunch		

## COURSE LOCATION

The course will be held at the **conference room of IMATI – CNR** (Institute of Applied Mathematics and Information Technologies) in **via Ferrata 1, 27100 Pavia, Italy.**

## ACCOMMODATION

Participants have to proceed with **personal reservations**. Please refer to the course website for a list of possible hotels in Pavia.

## COURSE OBJECTIVES

The main objective of this course is to provide engineers who use computer codes, graduate students, and researchers with an **extensive review of advanced numerical techniques and solution algorithms for nonlinear mechanics**. It presents the current state-of-the-art in finite element modeling of nonlinear problems in solid and structural mechanics and illustrates difficulties (and possible solutions) which appear in a number of applications.

Different sources of nonlinear behavior are presented in a systematic manner. Special attention is paid to **nonlinear constitutive behavior of materials, large deformations and rotations of structures, contact and instability problems** with either material (localization) or geometric (buckling) nonlinearities, which are needed to fully grasp weaknesses of structural design.

The course will also provide insight both on advanced mathematical aspects as well as into the practical aspects of several computational techniques, such as the finite element method, **isogeometric analysis, meshless techniques, mimetic differences**.

The objective is thus to provide the participants with a solid basis for using computational tools and software in trying to achieve the optimal design, and/or to carry out a refined analysis of nonlinear behavior of structures.

The course finally provides a basis to account for multi-physics and multi-scale effects, which are likely to achieve a significant breakthrough in a number of industrial applications.

Each lecture day is concluded and completed by **tutorial interactive sessions**, where the lecturers will present simple problems, or introduce the attendees to numerical codes (mainly FEAP) to solve advanced problems, with the possibility also to discuss the solution of specific problems, or to interact with the lecturers on the material presented during other lectures.

The **course material** will consist of copies of transparencies from the lectures and survey papers. Copies of Finite Element Analysis Program (FEAP) computer codes, written by Prof. Robert L. Taylor at UC Berkeley, and the complete volume of notes will be made available to all attendees.

## LECTURERS

**Franco Brezzi (FB)**. Full Professor of Analysis since 1977, he is Director of CeSNA IUSS-center and Director of IMATI CNR-Institute. Awarded as ISI Highly cited researcher in Mathematics, his scientific contribution counts more than 150 papers in international journals, 5 books and many book chapters. His scientific interests are mainly concentrated in the field of Numerical Methods for Partial Differential Equations. In particular, from the point of view of methodological tools, he works mainly on Finite Element Methods (of various kinds). From the applicative point of view, he is mostly interested in problems arising from various Engineering fields, such as Structural Mechanics, Fluid Mechanics, and Electromagnetics.

**Robert L. Taylor (RLT)**. Professor in the Graduate School, Department of Civil & Environmental Engineering, University of California, Berkeley, he is also member of US National Academy of Engineers since 1992, and has received a number of distinctions (including the von Neumann Medal of IACM) and honorary doctorates, (e.g., from University of Wales at Swansea, UK and University of Hannover, Germany). His scientific contribution counts more than 200 papers in scientific journals, co-authorship with Prof. Olek Zienkiewicz of the most well-known books on finite element method, as well as the finite element computer program FEAP.

**Manfred Bischoff (MB)**. Since 2006 he is Full Professor and head of the Institute of Structural Mechanics at the University of Stuttgart. In 2000 he won the EUROMECH European Young Scientist Award and in 2008 the IACM Young Investigator Award. Since 2008 he is elected member of the executive council of the German Association of Computational Mechanics (GACM). His main research topics span over nonlinear computational structural mechanics, modeling and analysis of shells with finite elements, finite element technology, structural optimization, multifield and multiscale problems, contact problems and computational material modeling.

**Ferdinando Auricchio (FA)**. Full Professor of Mechanics of Solids at the University of Pavia, Italy since 1998. He is Research Associate at IMATI CNR-institute, member of IUSS-CeSNA scientific committee (directed by Brezzi) and Professor at "European School for Advanced Studies on Seismic Risk Reduction". His main research topics span over constitutive modeling of innovative materials, biomechanics and finite element methods. He has published more than 90 papers in international refereed journals and has been invited to give about 50 seminars at international and national institutions.

**Giancarlo Sangalli (GS)**. Associate Professor at the Mathematics Department of the University of Pavia, Italy since 2005. His main research interests are isogeometric analysis, numerical methods for the domain decomposition, multiscale numerical methods, analysis of the linear diffusion-convection-reaction operator and of its discretizations. He has published more than 35 papers in international refereed journals.

**Alessandro Reali (AR)**. Currently Assistant Professor of Mechanics of Solids at the Structural Mechanics Department of the University of Pavia. His main research interests are isogeometric analysis, advanced material constitutive modeling, mixed finite elements, and particle methods. He authored more than 30 papers on international journals with more than 30 invited lectures and 20 plenary/keynote lectures at international conferences. He is the recipient of the 2010 ERC Starting Grant "ISOBIO – Isogeometric Methods for Biomechanics"

## NL12 COURSE



## NONLINEAR COMPUTATIONAL SOLID & STRUCTURAL MECHANICS

Theoretical formulations,  
technologies and computations

Pavia  
April 16-20, 2012

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