Preface

This book contains a selection of research works first presented at the 2nd International Conference on Multiscale Computational Methods for Solids and Fluids, which was held in Sarajevo, June 10–12, 2015. Among them are the contributions from several experts from France and Germany (A. Ibrahimbegovic, A. Ouahsine, H. Matthies, N. Limnios, and P. Villon) who jointly taught the conference short course entitled "Current Research on Solids & Fluids: Computations, FE Code Coupling, Model Reduction, Probability," on dates preceding the conference, June 8 and 9, 2015. With the complementary contributions from the short-course instructors and a number of other conference participants, we seek to provide a comprehensive review of the state of the art in this currently active research domain. The presented contributions pertain to more than one of these aspects: (i) multiscale computations for solids and fluids, (ii) probability aspects, and (iii) model reduction. Given that each contribution touched upon more than one of these aspects, it is deemed the most appropriate to present them in a random-like order of the first authors' names.

The main ideas in each chapter are briefly outlined and commented upon for the benefits of readers.

Beckers Benoit has presented his work on "Multiscale Analysis as a Central Component of Urban Physics Modeling." The original aspects of presented point of view on urban physics are in placing it in between the scales of environmental physics and building physics. Being able to simulate at this scale is principally needed for energy exchange. Namely, the urban environment with its rapid worldwide growth has become a complex dynamic interface for either top-down problem with generation of an urban microclimate or bottom-up one with influence of an urban morphology on the final consumption of the entire city, jointly used to define properly the role of cities in global warming. The main benefits pertain to energy balance, urban planning, and participation to global climate models.

Brank Boštjan et al. have presented their work on "A Path-Following Method Based on Plastic Dissipation Control." The proposed method is a multiscale solution strategy, the most suitable for dealing with softening phenomena, which allows for path-following response computations. Here, the fine-scale representation is only controlled by the total inelastic dissipation passing to coarse scale. Detailed validation is presented for elasto-plastic model. An important model ingredient concerns the discrete approximation, which relies upon the embedded discontinuity finite element method that uses rigid-plastic cohesive laws with softening to model material failure process. Illustrative developments are presented for 2D solid and frame finite elements with embedded discontinuities that describe cohesive stresses and stress resultants by rigid plasticity with softening.

Cai Shang-Gui et al. have presented their work on "Improved Implicit Immersed Boundary Method via Operator Splitting." The main challenge tackled herein is in providing an efficient approach to fluid-flow simulation over moving solid with complex shape. The efficiency of the implicit immersed boundary method is achieved via symmetry of tangent arrays and operator splitting technique. An additional moving force equation imposes the interface velocity condition exactly on the immersed surface and the rotational incremental projection method ensures that the numerical boundary layers are generated towards the velocity and pressure during the calculation. Cai Shang-Gui et al. have also presented their work on "Modelling Wave Energy Conversion of a Semi-submerged Heaving Cylinder." The proposed model, based upon full 3D viscous Navier–Stokes equations, aims at simulating the ocean wave energy conversion of a semi-submerged heaving cylinder.

Dumont Serge et al. have presented their work on "Multiscale Modeling of Imperfect Interfaces and Applications." A systematic development of multiscale approach for an interface model can be developed by using asymptotic techniques where the thickness of the interface is considered as a small parameter. At the microscale, the model can account for imperfect interface models by taking into account microcracks. The homogenization techniques of matched asymptotic for media with microcracks is used then both in 3D and 2D cases, which leads to a cracked orthotropic material. It is shown that the Kachanov-type theory leads to soft interface models, while the approach by Goidescu leads to stiff interface models. A fully nonlinear variant of the model is also proposed, derived from the St. Venant–Kirchhoff constitutive equations. Among broad set of applications, the masonry structures are chosen to illustrate the model performance.

Jehel Pierre has presented his work on "A Stochastic Multi-scale Approach for Numerical Modeling of Complex Materials—Application to Uniaxial Cyclic Response of Concrete." Accounting for inelastic behavior of heterogeneous materials, such as concrete, calls for development of multi-scale techniques that looks for sources on nonlinearity at the relevant scale, combined with stochastic methods accounting for uncertainties. The chosen model represents the mechanical response of a representative volume of concrete in uniaxial cyclic loading. The heterogeneities are represented at mesoscale and inelastic nonlinear local response is modeled in the framework of thermodynamics with internal variables. Spatial variability of the local response is represented by correlated random vector fields generated with the spectral representation method. Macroscale response is recovered through standard homogenization procedure from representative volume element and shows salient features of the uniaxial cyclic response of concrete that are not explicitly modeled at mesoscale.

Kozar Ivica has presented his work on "Relating Structure and Model," seeking to gain an additional insight into large structure modeling. The presented approach deviates from usual model building procedures that leads us to transfer of parameters between the model and the real structure. Here, the problem is addressed in a more general manner, where both modeling and discretization are formulated, subsequently seeking relationship between relevant parameters of the real structure and its model. The corresponding procedure provides how to determine the scaling matrices in parameter and measurement spaces.

Lebon Jérémy et al. have presented their work on "Fat Latin Hypercube Sampling and efficient Sparse Polynomial Chaos Expansion for Uncertainty Propagation on Finite Precision Models: Application to 2D Deep Drawing Process." The main motivation stems from uncertainty propagation in model parameters, with the variation range of random variables that may be many orders of magnitude smaller than their nominal values. This is typical of the nonlinear finite element method computations involving contact/friction and material nonlinearity. A particular attention was given to the definition of adapted design of experiment, taking into account the model sensitivity with respect to infinitesimal numerical perturbations. The samples are chosen using an adaptation of the Latin hypercube sampling, requiring them to be sufficiently spaced away to filter the discretization and the other numerical errors limiting the number of possible numerical experiments, which leave the challenge to building an acceptable polynomial chaos expansion with such sparse data.

Marenic Eduard and Adnan Ibrahimbegovic have presented their work on "Multiscale Atomistic-to-Continuum Reduced Models for Micromechanical Systems." The main focus is upon the development of multiscale-reduced models and computational strategy for micromechanical systems, with currently interesting applications to graphene. The fine scale concerns the atomistic model and is formulated and solved along with the corresponding coarse-scale model obtained by homogenization. Two mainstream multiscale methods, the quasi-continuum and bridging domain, are compared and brought to bear upon the optimal model reduction strategy. Consequently, these two methods are further advanced from their standard formulation to a unified coupling and implementation strategy. The method can also deal with a defect-damaged graphene sheet granting an excellent performance of the proposed multiscale solution strategy.

Matthies Hermann et al. have presented their work on "Inverse Problems in a Bayesian Setting." The work reveals the strong connection between the inverse problems of the parameter identification and the forward computations of uncertainty quantification with parameter uncertainty propagating through response computations. The connection of this kind is naturally placed in the Bayesian setting, where the Bayesian updates, or filters, are derived from the variational problem associated with conditional expectation. Among various constructions of filters, the most efficient seem to be the linear or nonlinear Bayesian updates based on functional or spectral approximation constructed with polynomials, which grant much higher computational efficiency in forward uncertainty quantification than the time-consuming and slowly convergent Monte Carlo sampling.

Niekamp Rainer et al. have presented their work on "Heterogeneous Materials Models, Coupled Mechanics-Probability Problems and Energetically Optimal Model Reduction." It is shown that the sound theoretical formulation of a multiscale model of damage behavior of heterogeneous materials can be cast as coupled mechanics-probability problem. In particular, such the fine-scale interpretation of damage mechanisms can provide the most meaningful probability density distribution of material parameters governing the failure phenomena, which can be described in terms of random fields. The second challenge tackled here pertains to providing an efficient solution procedure to this coupled mechanics–probability problem, formulated by the spectral stochastic finite element method. Here, the curse of dimension, with the coupled mechanics–probability problem dimension growing with a number of random fields, is handled through low-rank approach and solution space reductions. In particular, a rank-one update scheme is devised as the optimal low-rank representation with respect to the minimal energy at the given rank.

Nikolic Mijo et al. have presented the work on "Modelling of Internal Fluid Flow in Cracks with Embedded Strong Discontinuities." The proposed multiscale model can handle fluid–structure interaction problem typical of localized failure of heterogeneous rock material under internal fluid flow. Of special interest are the methods where the fine-scale mechanics failure phenomena are presented only at the coarse-scale parameter in terms of fracture energy needed to achieve the full crack creation. The crack propagation induced steep displacement gradients are accounted for by using the concept of embedded discontinuity FEM. The computational efficiency is granted by the rock mass representation by Voronoi cells, kept together by cohesive links. The latter is chosen in terms of the Timoshenko beams capable of providing the crack-induced discontinuity propagation between the rock grains both in mode I and mode II. The model can account for rock material heterogeneities with pre-existing cracks represented by weak links placed in agreement with given probability distribution.

Papamichail Chrysanthi et al. have presented their work on "Reliability Calculus on Crack Propagation Problem with a Markov Renewal Process." The fatigue crack propagation is defined in terms of a stochastic differential system that describes the evolution of a degradation mechanism. A Markov or a semi-Markov process was considered as the perturbing process of the system that models the crack evolution. With the help of Markov renewal theory, the reliability of a structure is defined in terms of analytical solution. The method reduces the complexity of the reliability calculus compared with the previous resolution method, yet delivers good agreement with experimental data set, and Monte Carlo estimations.

Prieto Juan Luis has presented his work on "Multi-scale Simulation of Newtonian and Non-Newtonian Multi-phase Flows." The special attention is given to a level-set method to capture the fluid interface along with Brownian dynamics simulations to account for the viscoelastic effects of the fluid. The solution is obtained by using the second-order semi-Lagrangian scheme and evolving the level-set function along the characteristic curves of the flow. The proposed approach can also handle the free-surface flow taking into account viscous and surface tension effects, by using a semi-Lagrangian particle level-set method and by adding the marker particles to correct the shape of the free surface. The multiscale approach is used to solve stochastic, partial differential equations by using the finitely extensible nonlinear elastic kinetic model and a variance-reduced technique on a number of ensembles of dumbbells scattered over the domain.

Ravi Srivathsan and Andreas Zilian have presented their work on "Numerical Modeling of Flow-Driven Piezoelectric Energy Harvesting Devices." The devices of this kind provide a smart replacement of batteries with low power energy harvesting of flow-induced vibrations. The theoretical formulation leads to a coupled problem involving fluid, structure, piezo-ceramics, and electric circuit. The main difficulty pertains to problem nonlinearities and the need for reliable, robust, and efficient computations, which is here achieved by a monolithic approach involving surface-coupled fluid-structure interaction, volume-coupled piezoelectric–mechanics and a control of energy harvesting circuit. A space-time finite element approximation is used for the numerical solution of the governing equations, which allows for different types of structural elements (plate, shells) with varying cross sections and material constitutions and different types of harvesting circuits.

Rosic Bojana et al. have presented their work on "Comparison of Numerical Approaches to Bayesian Updating." The main challenge concerns Bayesian process of identifying unknown probability distribution of model parameters given prior information and a set of noisy measurement data. Two approaches are possible: one that uses the classical formula for measures and probability densities, and the other that leaves the underlying measure unchanged and updates the relevant random variable. The former is numerically tackled by a Markov chain Monte Carlo procedure based on the Metropolis–Hastings algorithm, whereas the latter is implemented via the ensemble/square root ensemble Kalman filters, as well as the functional approximation approaches in the form of the polynomial chaos based linear Bayesian filter and its corresponding square root algorithm. It was shown some of the principal differences between full and linear Bayesian updates when a direct or a transformed version of measurements are taken into consideration.

Ylinen Antti et al. have presented their work on "Two Models for Hydraulic Cylinders in Flexible Multibody Simulations." In modeling hydraulic cylinders, interaction between the structural response and the hydraulic system needs to be taken into account. In this work, two approaches for modeling flexible multibody systems are presented and compared: one with truss-element-like cylinder and bending flexible cylinder models, and other with bending flexible cylinder element chosen as a super element combining the geometrically exact Reissner beam element, the C1-continuous slide-spring element needed for the telescopic movement, and the hydraulic fluid field. Both models are embedded with a friction model based on a bristle approach and can be implemented within the standard finite element environment. In time the coupled stiff differential equation system is integrated using the L-stable Rosenbrock method.

The goal of gathering these contributions in a single book from Springer ECCOMAS series is to ensure more lasting value to the results first presented at the 2nd ECCOMAS Thematic Conference on Multiscale Computations on Solids and Fluids, providing the best starting point for further exploration in this currently very active research field. I would like to thank all the authors for contributing to this goal.

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