The 2018 World Congress on
Advances in Civil, Environmental, & Materials Research (ACEM18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Keynote Paper

Coupled mechanics-probability multiscale approach to computations, testing and uncertainty propagation for massive composite structures safety

* Adnan Ibrahimbegovic[1)],
A. Boujelben[1,2)], X.N. Do[1,2)], S. Dobrilla[1,2)], E. Hadzalic[1,2)], I. Imamovic[1,2)], S. Grbcic[1,2)], E. Karavelic[1,2)], P. Moreno-Navarro[1,2)], I. Rukavina[1,2)], T. Rukavina[1,2)] and A. Stanic[1,2)]

[1)] *Mechanical Engineering, UTC-Sorbonne Universites, France*
[1)] *adnan.ibrahimbegovic@utc.fr*

ABSTRACT

In this work we address the challenge pertinent to guaranties of safety for massive engineering structures, both in terms of integrity to failure under extreme conditions and durability within their environment. Of particular interest are industrial domains of excellence in France, such as energy-production (nuclear power plants, large offshore turbines) and air- or land- transportation (large airplanes, high speed trains, cargo ships). The main obstacle to overcome pertains to our inability to certify the structural safety by performing with real-size and real-time experiments, either due to excessive structure size, to excessive cost due to irreplaceable structure component or due to inability to reproduce with high fidelity the extreme conditions to which the structure is exposed.
We seek to propose the state-of-the-art advances in computational methods that can be brought to bear upon this class of problems, providing the full understanding of the potential failure modes of the given system, along with the very detailed simulation of extreme conditions brought by man-made and natural hazards (explosion, fire, stormy wind, earthquake, tsunami …). We also seek further developments in recently proposed approach to coupled mechanics-probability computations that can be successfully used to provide a detailed interpretation of structure tests under heterogeneous stress field and to identify both model parameters and their probability distribution. Finally, we propose to use such a combined approach with probability computations for uncertainty propagation, which can offer a clear explanation of the size effect influence on dominant failure modes of massive composite structures.

[1)] Professor, Chair for Computational Mechanics UTC, IUF Senior Member
[2)] collaborations: D. Brancherie (UTC), E. Lefrancois (UTC), S. Dolarevic (Univ. Sarajevo), G. Jelenic (Univ. Rijeka), A. Kurtovic (Univ. Sarajevo), Z. Nikolic (Univ. Split), J.L. Perez-Aparicio (Univ. Politècnica Valencia), I. Kozar (Univ. Rijeka), B. Brank (Univ. Ljubljana), H.G. Matthies (TU Braunschweig)

Keywords: massive structures safety; multiscale computations; coupled mechanics-probability approach; size effect quantification;

1. INTRODUCTION

This paper deals with important challenge on quantifying durability and lifetime integrity to guarantee the safety against failure of massive composite structures under extreme conditions. The illustrative examples (see Figure 1) come from the application domains in energy production systems, with both currently dominant nuclear or renewable energy sources (nuclear power plant, offshore wind-turbines or hydro-turbines), as well as in air- and land-transportation (large airplanes, high speed trains or cargo ships). Special attention is given to costly massive structures with ‘irreplaceable’ components, which are characterized by a number of different failure modes that require the most detailed description and interaction across the scales. We would like to significantly improve the currently dominant experimental approach, and thus accelerate innovations in this domain.

a) *b)* *c)*

Fig. 1 Durability of (costly) massive composite structures: a) nuclear power plant both existing PWR and new EPR systems - stringent requirement on waterproof containment structure of CBFR composites; b) (European answer to) Boeing 787 Dreamliner, the most fuel-efficient aircraft built of CFRP composites - requirement on no-return-to-hub for crack reparation; c) large offshore wind-turbine with CFRP composites blades and deep-sea CBRF composites support – requirement of operation capabilities for extreme weather conditions

2. MAIN OBJECTIVES

The main objective is development of novel Mesh-in-Element (MIEL) Multiscale Method capable of representing strain field heterogeneities induced by evolution (and interaction) of localized failure mechanisms in massive structure, pertaining to micro scale (FPZ-fracture process zone), macro scale including softening (macro cracks) and non-local macro scale (bond-slip for long fiber reinforcement). The objective of MIEL Multiscale Method is also to provide capabilities for quantifying the risk of premature localized failure through probability description of initial defects (microstructure heterogeneity) and uncertainty propagation through scales. The novel scientific concept to be explored pertains to multiscale formulation and solution of coupled nonlinear mechanics-probability problem replacing the standard homogenization approach that can only provide average (deterministic) properties of heterogeneous composites. This concept is of interdisciplinary nature with Mechanics (defining probability distribution) and Applied Mathematics (providing uncertainty propagation) combined in order to capture the influence of heterogeneities and fine scale defects on premature failure.

The most important challenge concerns the ability to provide the sound, probability-based explanation of size effect, with different failure modes observed for different size specimens and real structure built of the same composite materials (see Figure 2).

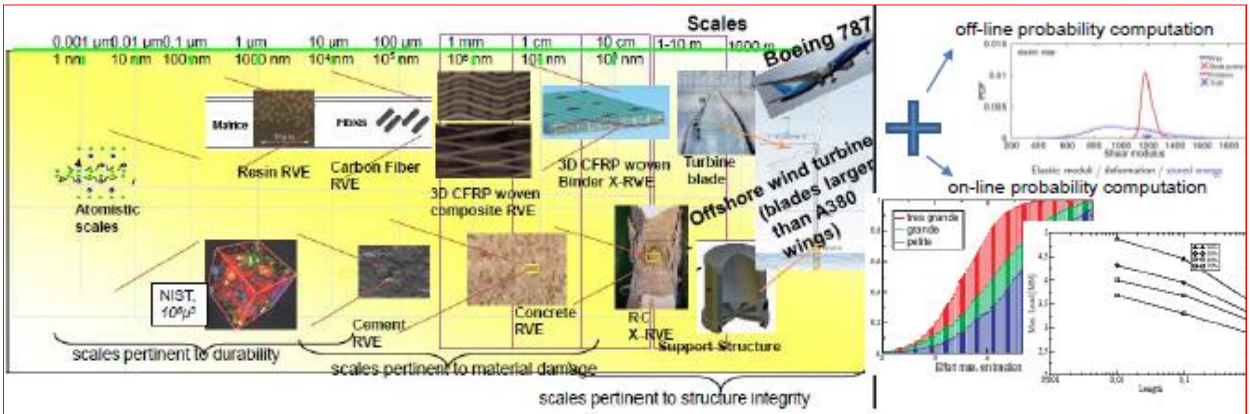

Fig. 2 Mesh-In-Element (MIEL) multiscale method – validation of structural integrity of giant offshore wind-turbines with carbo-epoxy blades and reinforced concrete support: i) left-top row: scales for 3D carbon-epoxy woven composite with fine scale for resin constituents, meso-scale warp and weft stuffers and non-local scales for binder; left-bottom row: scale for cement, concrete and reinforced concrete; ii) right top: off-line probability computation for identification by Bayesian updates; right-bottom: on-line probability computation for probability-based interpretation of size effect.

3. CONCLUDING REMARKS ON CURRENT AND FUTURE RESEARCH

The biggest potential gain concerns changing the validation procedures for massive structures that are beyond the size suitable for testing at present. The scientific gains concern providing the Mesh-in-Element (MIEL) Multiscale Method that connects computations with design studies (optimization), testing (identification) and safety verification (monitoring) of massive composite structures. The scientific gains also concern further placing the proposed method within multiphysics framework, along with the original use of goal oriented error estimates to provide sufficiently reliable interpretation of extreme conditions (e.g. fluid or heat flow) and the code-coupling software implementation to quickly integrate existing simulation codes within such a framework.

The main technological gain is in development of the open source computational tools that can speed-up testing, innovation and decision-making in complex composite systems. Of special interest is the strategy that allows to integrate the existing legacy software products that are used to verify and validate safety of particular components assembled within such complex systems. There are multiple challenges in solving any such problem pertaining to: theoretical formulation, discrete approximation, algorithmic stability and robustness, and finally informatics developments capable of integrating existing legacy codes. Two model problems of composites with great application potentials will be examined. First pertains to cement-based fiber reinforced (CBFR) composites, which will allow for validation of our method against recently completed experimental program in French excellence project ECOBA. Second model of carbon fiber reinforced polymers (CFRP) that is validated in collaboration with experimentalists at Université de Technologie de Compiègne.

Further details on point of departure in the current research and developments to follow are given in our recent works (Ibrahimbegovic et al. 2003a, 2003b, 2003c, 2003d, 2004, 2005, 2007, 2008, 2009a, 2009b, 2009c, 2010a, 2010b, 2011, 2012, 2014, 2015, 2016, 2017, 2018).

ACKNOWLEDGEMENTS

The research described in this paper is financially supported by the Region Hauts-de-France, Europe (FEDER), ANR and DFG, Ministry of Research and Ministry of Foreign Affairs.

REFERENCES

Ibrahimbegovic A., D. Markovic (2003a), Strong coupling methods in multi-phase and multi-scale., *Comp. Meth. Appl. Mech. Eng.*, **192**, 3089-3107

Ibrahimbegovic A., D. Brancherie (2003b), Combined hardening and softening constitutive model for plasticity: precursor to localized failure, *Comp. Mech*., **31**, 88-100

Ibrahimbegovic A., A. Delaplace (2003c), Microscale and mesoscale discrete models for dynamic fracture of structures, *Comp. Struc*., **81**, 1255-1265

Ibrahimbegovic A., D. Markovic, F. Gatuingt (2003d), Constitutive Model of Coupled Damage-Plasticity and Its Numerical Implementation, *Revue euro. élém. finis*, **12**, 381-405

Ibrahimbegovic A., C. Knopf-Lenoir, A. Kucerova, P. Villon (2004), Optimal design and optimal control of structures undergoing finite rotations, *Int. J. Num. Meth. Eng*., **61**, 2428-2460

Ibrahimbegovic A., I. Gresovnik, D. Markovic, S. Melnyk, T. Rodic (2005), Shape optimization of two-phase material with microstructure, *Eng. Comp*., **22**, 605-645

Ibrahimbegovic A., S. Melnyk (2007), Embedded discontinuity finite element method for modeling of localized failure in heterogeneous materials with structured mesh: an alternative to extended finite element method, *Comp. Mech.*, **40**, 149-155.

Ibrahimbegovic A., P. Jehel, L. Davenne (2008), Coupled damage-plasticity model and direct stress interpolation, *Comp. Mech.*, **42**, 1-11

Ibrahimbegovic A., G. Herve, P. Villon (2009a), Nonlinear impact dynamics and field transfer suitable for parametric design studes, *Eng. Comput*., **26**, 185-204

Ibrahimbegovic A., A. Kucerova (2009b), 'CE structures: multiscale damage representation, identification..', in 'Damage assessment and quick reconstruction after wars and natural desasters', Springer, 1-28

Ibrahimbegovic A. (2009c). *Nonlinear Solid Mechanics: Theoretical Formulations and Finite Element Solution Methods*, Springer, (ISBN 978-90-481-2330-8, E-book 978-1-4020-9793-5), pp. 1-571

Ibrahimbegovic A., A. Boulkertous, L. Davenne, D. Brancherie (2010a), Modeling of reinforced-concrete structures providing crack-spacing based on XFEM, ED-FEM and novel operator split solution procedure., *Int. J. Num. Meth. Eng.*, **83**, 452-481

Ibrahimbegovic A., A. Boulkertous, L. Davenne, M. Muhasilovic, A. Pokrklic (2010b), 'On modeling of fire resistance tests on concrete and reinforced-concrete structures', Computers and Concrete, vol **7**. No. 4, 285-301

Ibrahimbegovic A., J.B. Colliat, M. Hautefeuille, D. Brancherie, S. Melnyk, (2011), Probability based size effect representation for failure of civil engineering structures built of heterogeneous materials, in (eds. M. Papadrakakis, M. Fragiadakis, G. Stefanou), '*Computational Methods in Stochastic Dynamics*', Springer, Berlin, 289-311

Ibrahimbegovic A., H.G. Matthies (2012), Probabilistic Multiscale Analysis of Inelastic Localized Failure in Solid Mechanics, *Comp. Assis. Meth. Eng. Sci.*, **19**, 277–304

Ibrahimbegovic A., R. Niekamp, C. Kassiotis, D. Markovic, H. Matthies (2014), Code-coupling strategy for efficient development of computer software in multiscale and multiphysics nonlinear evolution problems in computational mechanics, *Advances Eng. Software*, **72**, 8-17

Ibrahimbegovic A., J-M. Ghidaglia, A. Serdarevic, E. Ilic, M. Hrasnica, S. Dolarevic, N. Ademovic (2015), 'ECCOMAS MSF 2015 – Multiscale Computational Methods for Solids and Fluids', Univ. Sarajevo, (ISBN 978-9958-638-23-7), pp. 1-269

Ibrahimbegovic A. (2016), 'Computational Methods for Solids and Fluids: Multiscale Analysis, Probability Aspects and Model Reduction', Springer, (ISBN 978-3-319-27994-7), pp. 1-493

Ibrahimbegovic A., B. Brank, I. Kozar (2017), 'ECCOMAS MSF 2017 – Multiscale Computational Methods for Solids and Fluids', (ISBN 978-961-6884-49-5), Univ. Ljubljana, pp. 1-279

Ibrahimbegovic A., A. Boujelben (2018), Long-term simulation of wind turbine structure for distributed loading describing long-term wind loads for preliminary design, *Int. J. Coupled Systems Mechanics,* 7, 233-254, (2018)