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Bayesian Model of Accidental Actions for Steel Structures

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Working language: English/French

Student profile: Civil Engineering/Architectural Engineering

Prerequisites/special skills: A good knowledge of structural analysis and finite elements is required, along with a taste for programming.

Summary

The design of buildings according to the Eurocodes requires the modeling of all actions (dead load, wind, earthquakes, etc.) [1]. Following their frequency and variability with time, they are separated in permanent, variable, and accidental actions. While the first two categories are generally well known and modeled by the designers, the modeling of accidental events (e.g. impact, explosion) is still too simplistic, and often neglects their random nature, despite the general philosophy prescribed in the Eurocodes. In this context, the works by Vrouwenvelder [2] have already allowed for stochastic approaches for the impact of trucks or boats on bridge piles. However, advanced theories based on *Bayesian statistics* are becoming more and more popular to describe such events.

Therefore, the aim of this research is to:

- draw a state-of-the-art review of the modeling of accidental actions, and in parallel of Bayesian theory for reliability-based design;
- propose a Bayesian model for accidental impact of trucks on steel columns of buildings. For this part, a numerical implementation will be performed to validate the proposed methodology;
- from the results obtained on rigid frame steel structures, propose guidelines helping designers to select a suitable design method according to accidental actions.

References

[1] H. Gulvanessian, J.-A. Calgaro, M. Holický, Designers' Guide to EN 1990 – Eurocode: Basis of structural design, Thomas Telford, London, UK (2008).

[2] T. Vrouwenvelder, Stochastic modelling of extreme action events in structural engineering, Probabilistic Engineering Mechanics 15, 109-117 (2000).

Anti-Optimization of 3D Frame Structures under Uncertainty

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Student profile: Civil Engineering/Architectural Engineering

Prerequisites/special skills: A good knowledge of structural analysis and finite elements is required, along with a taste for programming.

Summary

In order to build structural designs minimizing the environmental impact for instance, optimization methodologies are mandatory. They consist in coupling an optimization algorithm with a structural analysis simulation (typically, the finite element method), in order to iteratively converge to an optimal solution. However, uncertainties appear everywhere in the modeling, namely in the material properties, the actions, and the geometry of the structural elements [1]. To combine optimization with uncertainty quantification, a novel approach called *anti-optimization* has been recently proposed by Elishakoff and Ohsaki [2]: it consists in combining standard optimization with an improved worst-case scenario, allowing for a compromise between optimization and safety.

Therefore, the aim of the research is to investigate how efficient anti-optimization strategies can be for the structural optimization of 3D rigid frame structures (buildings). Basically, a state-of-the-art of anti-optimization and worst-case methods will be performed by the candidate, followed by a numerical implementation of an anti-optimization algorithm specifically dedicated to structures made of beam elements. Original and critical conclusions are expected to be drawn by the candidate about the possible benefits of anti-optimization in an industrial context.

References

[1] E. Nikolaidis, D.M. Ghiocel, S. Singhal (eds.), *Engineering Design Reliability*, CRC Press, New York, 2005.

[2] I. Elishakoff, M. Ohsaki, *Optimization and Anti-Optimization of Structures under Uncertainty*, Imperial College Press, London, 2010.

Geometrical constraints in the preliminary shape design of skeletal shell structures

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Prerequisites/special skills Computational Geometry, Structural Form Finding

Summary

Inspired by the development of physical hanging models, the 1920s saw the advent of a new structural typology, namely the thin-shell structures. Thanks to the form finding principles [1], their equilibrium shape is the corner stone for covering wide spans with a limited amount of material. Originally built in reinforced concrete, the today's actual trend promotes the use of discrete elements to support glass panels. As such, the early stage of the design process has to be reconsidered to face new challenges related to construction geometrical constraints: regular mesh pattern, planarity constraints, structural members of the same length, specific boundary conditions. This problem is made difficult because of the simultaneous treatment of geometry and equilibrium considerations.

Over years, some interesting context-oriented approaches have been proposed to overcome these issues. To mention a few, Giles and Berk [2] focus on the geometrical problem by generating planar quadrilateral mesh based on principle curvatures of a given surface. Alternatively, Adriaenssens *et al.* [3] employ the dynamic relaxation method to generate an equilibrium shape while enforcing planarity constraints using optimization methods. Nevertheless, a general and versatile strategy is still missing.

Therefore, the goal of the research project is twofold:

- identify geometrical constraints usually encountered in practical design of skeletal shells and classify them according to their nature,
- develop a relevant strategy to resolve the problem using either programming methods or existing CAD and FEA software.

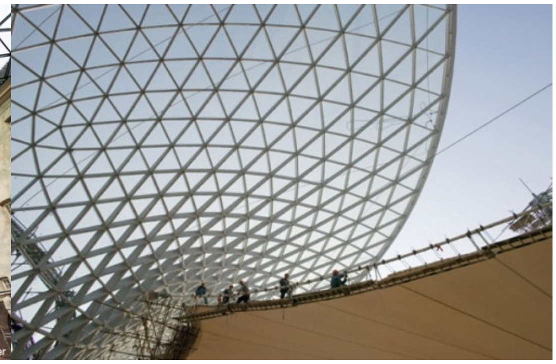

Fig. 1: Dutch Maritime Museum (Ney & Partners) *Fig. 2: Shanghai Expo 2010 (SBA architects)*

References

[1] R. M. O. Pauletti, P M. Pimenta, "The natural force density method for the shape finding of taut structures", *Computer Methods in Applied Mechanics and Engineering*, vol. 197, pp.4419-4428 (2008).

[2] H. Giles, A. Berk, "Complex Surface Reconstruction using Planar Quadrilateral Meshing". *In*: *Proceedings of the International Associations for Shell and Spatial Structures.* London, UK, (2011).

[3] S. Adriaenssens, L. Ney, E. Bodarwé, C. Williams, "Dutch Maritime Museum: Form-finding of an irregular faceted skeletal shell". *In*: *Proceedings of the International Associations for Shell and Spatial Structures.* Valencia, Spain, pp. 41-49 (2009).

Structural optimization applied to real-world construction design projects

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Prerequisites/special skills Strong Programming Skills (Matlab or Python), Finite Element Analysis

Summary

The structural design process is traditionally based on engineer's experience. A model is created, tested and updated in a series of structural analyses in order to optimize it. This time-consuming, empirical process might become cumbersome, especially for large-scale design problems. As a remedy, researchers have continuously developed over decades numerical tools for structural optimization. After CAD and FEA revolutions, numerical optimization methods stand themselves as the next change. Although they succeed in aeronautics and automotive industry in many respects, such methods meet difficulties in becoming the promised revolution in the construction industry.

Several factors have been forwarded by practitioners like the uniqueness of each construction project, or the fact that the number of stakeholders makes any change of habits very slow [1]. From a theoretical point of view, the problem remains a challenging task because of the huge number of design variables and constraints, the mixed nature (discrete and continuous) of these variables, and the multiple objectives to be simultaneously optimized. Although some authors [2,3] develop strategies for addressing real-world design problems, this way should be clearly pursued again.

Therefore, the goal of the research project is twofold:

- identify the barriers that hinder the use of numerical optimization in construction practice,
- based on a real-world project (to be defined in agreement with the student and a structural engineering office), develop a relevant strategy to address a complex construction design problem that involves a large number of variables, of constraints and several objectives.

References

[1] C. Luebkeman, K. Shea, “Computational Design + Optimization in practice”, *The Arup Journal*, vol. 3, pp.17-21 (2005).

[2] R. Meske, J. Sauter, E. Scnack, “Nonparametric gradient-less shape optimization for real world applications”, *Structural and Multidisciplinary Optimization*, vol. 30, pp.201-218 (2005).

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Approximation by polynomial chaos for global sensitivity analysis in engineering design

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Prerequisites/special skills: An interest for numerical methods and programming is required.

Summary

This subject will be performed in collaboration with Cenaero (http://www.cenaero.be), a research center dedicated to numerical methods in aeronautics, automotive engineering, etc.

In engineering, each product is controlled through design parameters, whose fine tuning allows for finding optimal solutions with respect to given criteria (e.g. finding the lightest structure, increasing the safety, reducing the environmental impact). In this context, the ANOVA (Analysis of Variance) techniques are popular methods to have a deeper understanding of the impact of one parameter modification on the quantities of interest (mass, stresses, displacements, efficiency). However, they require a huge number of simulations (for instance finite element analyses), which is often unaffordable for industrial applications.

Therefore, the aim of this research consists in investigating an alternative approach called *polynomial chais expansion* to reduce the computational cost while keeping a reasonable accuracy. The applications will focus on aerodynamic problems, although the generality of the method allows for considering structural examples.

References

[1] R.G. Ghanem, P.D. Spanos, *Stochastic Finite Elements: A Spectral Approach*, Springer-Verlag, New York, 1991.

[2] D.A. Freedman. *Statistical Models: Theory and Practice*, Cambridge University Press, Cambridge, 2005.