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Editors

Topology Optimization in Structural and Continuum Mechanics

Springer

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PREFACE

Structural Topology Optimization (STO) is a relatively new, but rapidly expanding and extremely popular field of structural mechanics. Various theoretical aspects, as well as a great variety of numerical methods and applications are discussed extensively in international journals and at conferences. The high level of interest in this field is due to the substantial savings that can be achieved by topology optimization in industrial applications. Moreover, STO has interesting theoretical implications in mathematics, mechanics, multi-physics and computer science.

This is the third CISM Advanced Course on Structural Topology Optimization. The two previous ones were organized by the first author of this Preface, the current one – by both authors.

The aim of the present course is to cover new developments in this field since the previous CISM meeting on STO in 1997. The topics reviewed by various lecturers of this course are summarized briefly below.

In his first lecture, George I. N. Rozvany reviews the basic features and limitations of Michell's (1904) truss theory, and its extension to a broader class of support conditions.

In the second lecture, George Rozvany and Erika Pinter give an overview of generalizations of truss topology optimization, via the Prager-Rozvany (1977) optimal layout theory, to multiple load conditions, probabilistic design and optimization with pre-existing members, also briefly reviewing optimal grillage theory and cognitive processes in deriving exact optimal topologies.

George Rozvany's third lecture discusses fundamental properties of exact optimal structural topologies, including (non)uniqueness, symmetry, skew-symmetry, domain augmentation and reduction, and the effect of non-zero support cost.

In a joint lecture with Tomasz Sokół, the verification of various numerical methods by exact analytical benchmarks is explained, and conversely, the confirmation of exact analytical solutions by Sokół's numerical method is discussed. The latter can currently handle ground structures with several billion potential members. In his final lecture, George Rozvany gives a concise historical overview of structural topol-

ogy optimization, and critically reviews various numerical methods in this field.

The lecture by Tomasz Lewiński and Tomasz Sokół is focused on one aspect of the lectures by George Rozvany, namely on the Michell continua. This theory is constructed for volume minimization of trusses which finally reduces to a locking material problem.

The Michell problem belongs to the class of optimization of statically determinate structures whose behavior is governed only by the equilibrium conditions and constraints bounding the stress level. More complex problems arise if one optimizes the shape of elastic bodies, even those being homogeneous and isotropic. In general, the layout problems in linear elasticity are ill-posed, which is the central question of the lecture by François Jouve. This author discusses the above problem and clears up the remedies: either to extend the design space and to relax the problem, or to reduce the design space by introducing new regularity constraints. The relaxation by homogenization method is outlined in Sec. 2 of this lecture, along with numerical techniques. The method is efficient due to fundamental results concerning optimal bounds on the energy. Although this exact and explicit result is restricted to the compliance minimization for a single load condition, it has served as the basis for various researchers to develop other homogenization-based methods, such as the one by Grégoire Allaire, Eric Bonnetier, Gilles Francfort and François Jouve in 1997. In his lecture François Jouve discusses also the methods of partial relaxation of selected problems for which the exact relaxations are not at our disposal, or they assume a non-explicit form. The last chapter of the lecture concerns the level set method proposed in the early 2000's, which gives very promising results, even in an industrial context, with complex state equations, objective functions and constraints. This author shows how this method can be combined with shape derivatives and by the topology derivatives of selected functionals.

The lecture by Grzegorz Dzierżanowski and Tomasz Lewiński delivers a complete derivation of the crucial result mentioned: the optimal bounds on the energy. The derivation is based on the translation method for the case of two isotropic constituents and then reduced to the case if one constituent is a void.

Structural topology optimization comprises also the design of material characteristics without linking them with the density of mass.

This optimization field is called the Free Material Design (FMD). The classical FMD problem is aimed at finding the optimum values of all components of the Hooke tensor from the criterion of compliance minimization, under the isoperimetric condition of boundedness of the integral of the trace of the Hooke tensor. The lecture by Sławomir Czarnecki and Tomasz Lewiński shows that the FMD problem can be reduced to a locking material problem, even in the multi-load case.

The six lectures by Niels Olhoff, Jianbin Du and Bin Niu concern the optimization of structures subjected to dynamic loads. These authors explain how to design a structure such that the structural eigenfrequencies of vibration are as far away as possible from a prescribed external excitation frequency - or band of excitation frequencies - to avoid resonance phenomena with high vibration and noise levels. This objective may be achieved by

- *maximizing the fundamental eigenfrequency of the structure,*
- *maximizing the distance (gap) between two consecutive eigenfrequencies,*
- *maximizing the dynamic stiffness of the structure subject to forced vibration,*
- *minimizing the sound power flow radiated from the structural surface into an acoustic medium.*

A special lecture by Niels Olhoff and Bin Niu discusses how maximization of the gap between two consecutive eigenfrequencies generates significant design periodicity, and the final (sixth) lecture presents the application of a novel topology based method of simultaneous optimization of fiber angles, stacking sequence, and selection of materials, for vibrating laminate composite plates with minimum sound radiation.

In the first three of his five lectures, Kurt Maute discusses applications of the density method to diffusive and convective transport processes, as well as to multi-physics problems. The complexity of selecting appropriate objectives and constraints are emphasized in the chapter on diffusive transport optimization problems. The extension of the porosity model to fluid problems is presented for flow topology optimization problems, characterized by the Darcy-Stokes and Navier-Stokes equations at steady state conditions. The fundamental differences in solving multi-physics problems that are either coupled via constitutive laws or via surface interactions are discussed and illustrated with applications to piezo-electric coupling and fluid-structure *interaction problems. The fourth lecture introduces an alternative to topology optimization approaches that employ density or Ersatz material approaches to represent the material layout in the mechanical model. The integration of the eXtended Finite Element Method (XFEM) into a level-set topology optimization method is discussed and illustrated with applications to flow topology optimization. The last lecture by Kurt Maute is devoted to topology optimization methods that account for uncertainty in material parameters, geometry, and operating conditions. Here, the aim is to arrive at reliable and robust designs. This lecture introduces basic techniques in reliability based design optimization (RBDO) and robust design optimization (RDO), and discusses their application to topology optimization.*

G.I.N. Rozvany and T. Lewiński

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