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A MULTI-OBJECTIVE APPROACH FOR RELIABILITY-BASED DESIGN OPTIMIZATION

Dimos C. Charmpis

Department of Civil and Environmental Engineering, University of Cyprus,
75 Kallipoleos Str., P.O. Box 20537, 1678 Nicosia, Cyprus
Email: charmpis@ucy.ac.cy

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ABSTRACT

Structural design optimization aims in detecting the optimum design by minimizing the weight or cost of a structure subject to certain behavioral constraints, mainly on stresses and displacements, as imposed by design codes. Although such optimization applications are usually treated within a deterministic setting ignoring uncertainties in material properties, geometric parameters, loads etc., non-deterministic concepts are increasingly being taken into account in the design optimization process. Reliability-Based Design Optimization (RBDO) and Robust Design Optimization (RDO) are the two most common approaches applied to structural design optimization problems under uncertainty. RBDO is a single-objective optimization procedure with an incorporated structural reliability constraint: the objective is to minimize the weight or cost of the structure, while reliability is addressed by pre-specifying the maximum allowable failure probability of the structure for the final design. RDO, on the other hand, is a multi-objective optimization approach, which focuses at minimizing both the weight/cost of the structure and the influence of uncertain input parameters on the final design and the associated structural response. Thus, RBDO optimizes the structure taking into account extreme uncertain events, while RDO considers the sensitivity/variability introduced in the final design due to the uncertainties of the structural problem at hand.

Typically, RDO monitors output variability by calculating corresponding second moment statistical information (variance or coefficient of variation). Although minimizing such output “sensitivity” measures is certainly useful in managing the effects of input uncertainties, gaining control over output tail probabilities is usually more important in structural engineering applications, because such tails are directly associated with structural failure events and their probability to happen. In that sense, the explicit consideration of structural reliability offers RBDO an advantage over RDO. However, RDO treats output uncertainties within one or more optimization objectives, providing this way the design engineer with explicit means to minimize output variability and not just restrict an output probability measure below some pre-specified level (which is the case in RBDO).

In an effort to enhance the typical single-objective RBDO procedure and enrich the

optimal design options provided by the optimization process, RBDO is treated in the present work as a bi-objective problem considering weight/cost and probability of failure criteria. In other words, in the new multi-objective RBDO formulation presented, which is designated as MO-RBDO, structural reliability is upgraded from being imposed through a constraint to being pursued as an optimization objective. MO-RBDO is implemented in the framework of a multi-objective evolutionary algorithm, which yields results in the form of Pareto-optimal solutions. This MO-RBDO implementation is capable of producing several trade-off optimal structural designs with a single run, as opposed to the single structural design located by classical RBDO. Thus, MO-RBDO is a formulation for structural design optimization under uncertainty, which combines the multi-objective nature of RDO with the explicit treatment of structural reliability.

However, richer output information comes at a cost: MO-RBDO needs to perform a substantially larger number of optimization cycles (and therefore requires the assessment of significantly more candidate optimum designs throughout the optimization process) compared to standard RBDO. This associates MO-RBDO with considerably more computational labour than RBDO, since the assessment of each additional candidate optimum design is not a trivial task, even if customized computationally efficient methods are invoked to accelerate the structural analysis and reliability evaluation processes for each design. Therefore, special attention is given to minimizing the number of optimization cycles executed by MO-RBDO. This is achieved through appropriate search procedures to effectively and economically explore the design space for Pareto-optimal solutions. Moreover, MO-RBDO output information is restricted to the part of the Pareto front, which is essential for the particular problem at hand. Thus, significant computational time is saved by not exploring parts of the Pareto front, which are not of interest anyway.

The numerical results reported in the form of Pareto-optimal solutions for a number of test cases demonstrate the effectiveness of the proposed design optimization process and justify the upgrade of structural reliability to an optimization objective. MO-RBDO proves to be an effective tool providing the design engineer with the flexibility of detecting several trade-off optimal structural designs and then choose the most appropriate among these based on his/her preference system and attitude towards cost and reliability.