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Fuzzy-based robust structural optimization

Giuseppe Carlo Marano [a,*], Giuseppe Quaranta [b]

[a] Department of Environmental Engineering and Sustainable Development, Technical University of Bari, Viale del Turismo 10, 74100 Taranto, Italy
[b] Department of Structural Engineering and Geotechnics, University of Rome "La Sapienza", via A. Gramsci 53, 00197 Roma, Italy

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Abstract

Robust optimization is conventionally defined as the collection of the possible problem solutions that can ensure acceptable performances and sufficient immunity against the effects of uncertain parameter variability. Methods proposed until now use a probabilistic way to model uncertainty and to quantify the final sensitivity. In this work, a fuzzy uncertainty modellization is adopted for structural engineering. In particular, to define solution performance scattering, the fuzzy entropy is used as a global measure of variable dispersion. The final formulation of the problem deals with two antithetical objective functions, the fuzzy expected value of structural performance and its fuzzy entropy. This fuzzy-based approach in robust design is able to give a set of Pareto optimal solutions in terms of structural efficiency and sensitivities regarding uncertainty, and represents a suitable tool in supporting the decision maker. Finally, different applications have been developed to demonstrate the applicability of the proposed method.

Keywords: Robust design; Fuzzy variable; Expected value; Fuzzy entropy

1. Introduction

Uncertainty treatment is still an open problem in many technical and scientific fields, such as in structural engineering in which the importance of overcoming the intrinsic limits of the deterministic approach has produce many scientific works in last few decades. Different theories have been proposed on dissimilar mathematical grounds in dealing with uncertainty. The probabilistic technique is more commonly used due to the confidence that researches have in this approach. Nevertheless, there are other different approaches that have been proposed and applied, such as the fuzzy and interval analysis, just to name a few of them. The main characteristic of the field of structural optimization is that no correct definitions exist in the mathematical modelling of uncertainty.

The probabilistic approach is assumed to be a more qualified method, given that its information is sufficiently detailed in comparison to other approaches. Nevertheless, the selection of a specific probability

* Corresponding author. Tel.: +39 080 5963875.
E-mail address: g.marano@poliba.it (G.C. Marano).

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density function is a complicated problem that has no unique solution even if a great number of experimental data are available.

In many cases the existing set of data isn't satisfactory for a consistent statistical analysis and sometimes literature or expert opinions are the only basis for uncertainty treatment. In these circumstances, alternative approaches may be used to surmount these restrictions. The theoretical background, in all methods employed in undeterministic data treatment, deals with the evidence that uncertainties associated to a physical phenomena are derived from several and different sources. In the common language, something is uncertain when it assumes random meanings or behaviours (randomness), or when it is not clearly established or described (vagueness), or when it may have more than one possible meaning or status (ambiguity) or, finally, when it is described on the basis of a very limited amount of information (imprecision) (Biondini et al., 2004). More precisely, randomness, vagueness, ambiguity and imprecision denote uncertainties with different and specific characteristics: for randomness, the source of uncertainty is due to intrinsic factors related to the physics of the phenomena which determine the events under investigation. In other cases, the uncertainty source arises from the limited capacity of formal language in describing engineering problems to be solved (ambiguity) or from incorrect and/or ill-posed definitions of quantities which convey some informative content (vagueness), or finally from some lack of knowledge (imprecision). The last three aspects have a subjective nature and are usually included in the wider concept of fuzziness which, in this sense, results in a juxtaposition with the objective concept of randomness.

In view of the unavoidable presence of uncertainties, the concept of "robustness" has been introduced in structural design optimization to reduce the detrimental effects due to the uncertainty variable fluctuations around the best available estimation. In fact, standard optimal solutions can be very sensitive to small parameters variations also because they deal only with the best structural performances, by minimizing a deterministic objective function (OF) without taking into account the parameters of uncertainty. Conventional Robust Design Optimization (RDO) approaches have been developed due to the extreme importance of this aspect. They consist in the search of design solutions that are able to maximize absolute structural performances and, contemporarily, to minimize their variability due to related uncertainties. The final solutions obtained are less efficient, if evaluated only in terms of performance sense, but also less sensitive, thus rendering such solutions more stable in real applications. RDO applications deal with the randomness-type source of uncertainties (Beyer and Sendhoff, 2007) but the presence of non-probabilistic variables is not negligible from a practical point of view. It should be observed that in many realistic circumstances only few data about a single or more models and structural parameters are accessible. Commonly, experimental investigations about mechanical and geometrical system properties as well as load conditions are economically inconvenient or practically impossible. A further but not negligible theme is the significance of the "expert opinion" given in some phases of the design process. Such opinion does not offer numerical data and raises the necessity to define a reasonable tool with the purpose of evaluating a specific technical point of view.

In the presence of fuzzy modelling data, this paper proposes a fuzzy-based way to obtain robust solutions in structural optimization. The search of robust solutions is formulated as a multiobjective optimization problem (MOOP) in the framework of the credibility theory. Once the output fuzzy variable is estimated for an assigned deterministic model with fuzzy input variables, the OFs are taken to be its expected value and entropy. Finally, the proposed method, that produces a Pareto optimal set instead of a single optimal solution, is applied to different structural problems.

2. Robust design optimization

Many methods and codes have been developed for a wide range of engineering problems in support of designer decisions and in order to achieve the best solutions for each specific case.

Unfortunately, these solutions often show a greater sensitivity in comparison to the natural variability of data. Instead of aiming to find a single "best" solution in robust-based strategy, this work aims to produce a set of "good" compromises between performance and sensitivity allowing the decision maker to make a choice (Beyer and Sendhoff, 2007). For instance, if each uncertain variable is assumed to be random, the second-order perturbation methods can be used (Doltsinis and Kang, 2004) to achieve the