Chapter IV

Optimal Reliability-Based Design Using Support Vector Machines and Artificial Life Algorithms

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Abstract

Reliability-based optimization is considered by many authors as the most rigorous approach to structural design, because the search for the optimal solution is performed with consideration of the uncertainties present in the structural and load variables. The practical application of this idea, however, is hindered by the computational difficulties associated to the minimisation of cost functions with probabilistic constraints involving the computation of very small probabilities computed over implicit threshold functions, that is, those given by numerical models such as finite elements. In this chapter, a procedure intended to perform this task with a minimal amount of calls of the finite element code is proposed. It is based on the combination of a computational learning method (the support vector machines) and an artificial life technique (particle swarm optimisation). The former is selected because of its information encoding properties as well as for its elitist procedures that complement...
those of the a-life optimisation method. The later has been chosen due to its advantages over classical genetic algorithms. The practical application of the procedure is demonstrated with earthquake engineering examples.

Introduction

Since its initial developments in the middle of the last century, earthquake engineering incorporated the modelling of uncertainties in its procedures. This was due to the fact that, much more than gravity loads, earthquake loads are rather unpredictable. In addition, account must be taken of the randomness of shaking duration, ground amplification and structural parameters to have an adequate picture of the probabilistic behaviour of structures subject to strong earthquakes. The introduction of performance-based design represents an improvement over classical design procedures which use equivalent static forces and reduction factors that take into account nonlinear energy dissipation. In practical analysis, performance-based design consists in doing a nonlinear static analysis of a predesigned structure with increasing lateral loads in order to determine a unique load-displacement curve (the so-called capacity spectrum) and comparing it to the plot of spectral acceleration vs. spectral displacement (the so-called composite spectrum) (Reinhorn, 1997). However, the question about the seismic safety of the structure remains unsolved while uncertainties are not incorporated into this kind of design process.

Despite the developments of probabilistic modelling, specifically those of random vibration analysis and structural reliability, practical seismic design as prescribed in design codes has incorporated the uncertainties only in load modelling. In fact, codes declare that the design is performed for a maximum acceleration with a certain probability of exceeding a given threshold, but nothing is required about the probability of structural failure, i.e., the probability of surpassing one or more undesirable performance limits. This is defined as:

$$P_f = P[g(x) \leq 0] = \int_{F=\{g(x)\leq 0\}} p_X(x)dx$$

(1)

where $X$ is the vector of random variables whose deterministic realisation is represented by $x$, $F$ is the failure region determined by mapping the surpassing a dangerous threshold (such as a critical floor acceleration or drift) onto the $x$-space, $P_X(x)$ is the joint probability density function of the random vector and $g(x)$ is a function describing the performance of the structure with respect to the critical threshold, such that the contour $g(x) = 0$ divides the $x$-space into two subdomains: safe and failure. The former is defined as $S=\{x: g(x)>0\}$ and the latter as indicated in equation (1). The reliability is defined as the complementary probability $R = 1 - P_f$.

The difficulty to accomplish a full probabilistic analysis incorporating all uncertainties explains why only the maximum acceleration uncertainty is included in code procedures. In fact, to assess the failure probability of a certain structure under earthquake loads in an accurate manner it is necessary to perform a Monte Carlo simulation, implying the genera-
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