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ScienceDirect

Structural Safety 29 (2007) 167–182

STRUCTURAL SAFETY

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Benchmark study on reliability estimation in higher dimensions of structural systems – An overview

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Available online 7 September 2006

Abstract

This work is concerned with a Benchmark study on reliability estimation of structural systems. The Benchmark study attempts to assess various recently proposed alternative procedures for reliability estimation with respect to their accuracy and computational efficiency. The emphasis of this study is on systems which include a large number of random variables. For this purpose three sample problems have been selected which cover a wide range of cases of interest in the engineering practice and involve linear and nonlinear systems with uncertainties in the material properties and/or the loading conditions. Here an overview of the Benchmark study is provided.

Keywords: Structural reliability; Structural systems; High dimensions; Benchmark study

1. Introduction

1.1. Background

The need for the assessment of uncertainty propagation of structural responses is widely accepted since many parameters used in the analysis are usually not known in a deterministic sense. In this context, the random variables and vectors, stochastic processes and fields with various probabilistic characteristics have been used to model the different sources of uncertainty.

While the modeling assumptions have become more elaborate and accurate over the years, the reliability analysis of stochastic structural systems still remains a challenging problem. Despite the prodigious development in computer technology, direct Monte Carlo simulation, which is the most generally applicable procedure, is inefficient or infeasible in engineering practice, due to, for example:

- The complexity in the behavior of structural systems of practical interest. This often requires the numerical solution of nonlinear equations with multiple unknowns, which imposes a heavy computational burden even in deterministic setting.

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0167-4730/$ - see front matter
doi:10.1016/j.strusafe.2006.07.010

- The high number of random parameters that must be incorporated in order to accurately account for the uncertainties observed.
- The complexity in the probabilistic characteristics of certain random parameters (i.e. non-stationarity, non-Gaussianity, etc.).

Several reliability estimation methods, procedures and algorithms with various capabilities, accuracy and efficiency have been suggested in the past. A quantitative comparison of these approaches is considered to be most instrumental and useful for the engineering community. Significant progress in structural reliability evaluation has been achieved since the last Benchmark in the year 1997 on nonlinear stochastic structural dynamics [15,16]. Moreover, a more recent partially qualitative comparison of methods was reported in [14].

This new Benchmark study, initiated in 2004 [15], attempts to assess various recently proposed alternatives for reliability estimation with respect to their accuracy and computational efficiency. The emphasis of this current study is now on systems which include a large number of random variables. For this purpose three sample problems have been chosen, which cover a wide range of cases of interest in engineering practice and involve linear as well as nonlinear systems with uncertainties in the material properties and/or the loading conditions.

Results obtained in this new Benchmark study are reported in this Special Issue of *Structural Safety*. The present work provides an overview of the Benchmark study and of the methods compared, as well as the current status of the results obtained.

1.2. Motivation

Engineering practice expects to have structural reliability procedures available which are applicable to problems of practical relevance. Naturally this implies procedures capable of solving high dimensional systems.

Since the presentation of the first Benchmark study in 1997 significant developments both in the hardware and software sectors, respectively, have taken place. Hence procedures for treating higher dimensional problems came into the realm of feasibility. It is the purpose of this Benchmark study to evaluate and compare these procedures in view of their generality, accuracy, efficiency and practical applicability. Based on these results the directions for future developments might be derived.

1.3. Posed Benchmark problems

The selection of the Benchmark problems aimed at retaining salient features which are encountered in realistic problems but at the same time remove unnecessary intricacies which would only complicate matters without significant benefit to the purposes of the Benchmark study. It should be stressed, though, that the posed sample problems are selected so that anticipated and expected requirements in reliability evaluation are addressed. All selected reliability problems are rather difficult, and no solution, besides direct MCS, could have been offered one decade ago. More specifically, the three Benchmark problems considered are:

1. the reliability of an earth dam with stochastic soil properties under static deterministic loading,
2. the excursion probability of a ten-degree-of-freedom (linear and nonlinear) Duffing-type oscillator subjected to random excitation and
3. the excursion probability of a hysteretic nonlinear five-degree-of-freedom system with uncertain structural properties and excitation.

The posed example problems are summarized in Appendix A. In brief, the number of random variables are 2160 for the first (dam) example, 4000–4030 for the second (Duffing), and 225 for the third (hysteretic) example. The stochastic excitation is represented in Problem 2 (Duffing MDOF-system) by filtered modulated white noise, leading to a colored non-stationary ground acceleration. Three different configurations are studied for this problem. The first case is a deterministic nonlinear system with a stiffening nonlinearity. The second case is a linear system with uncertain (random) structural properties. The third case combines the nonlinearity of case 1 and the random structural properties of case 2. In all three cases, failure with respect to the first and last