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A new three-phase algorithm for computation of reliability index and its application in structural mechanics

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Highlights

- An efficient 3-phase reliability algorithm for locating design point is proposed.
- Each phase uses a concept and a represented technique to approach design point.
- Candidate of the design point approaches real design point by three updating rules.
- Some concepts of importance sampling and optimization are used in the algorithm.
- The algorithm locates design point by generating a reasonable number of samples.

ABSTRACT

Computation of reliability index or probability of failure in practical problems is still a challenge. In this paper, an efficient three-phase non-gradient-based algorithm is proposed to be used in structural reliability analysis. Like approximation methods, the purpose in the proposed algorithm is to locate the position of design point. However, for this purpose, at the iterations of the phases random samples are generated based on a moving sampling density function, like what is done in adaptive importance sampling. At each phase, by representing an updating criterion, the position of the candidate of design point is updated to approach the real design point. Two criteria of the first and second phase are to reduce the initial relatively large distance between the candidate of design point and the real one. In the third phase, after introducing a new effective fitness function, the third updating criterion is represented to take the final smaller steps of approaching design point. Through various numerical examples, the accuracy and efficiency of three aforementioned phases have been shown.

Keywords: *Reliability index; Probability of failure; Design point; Fitness function; Adjusting constant.*

1. Introduction

In practical problems of structural analysis, there are different examples of uncertainty associated with material, external load and geometry of structures. Thus, for a more rational understanding of the behavior of a structure, inclusion of the uncertainty into the analysis is essential [1-3]. The structural reliability theory is a tool by which the effects of uncertainty can be considered in the analysis [4-6]. Evaluation of the probability of failure, P_f, is the main purpose of reliability analysis. The mathematical expression for P_f is

$$P_f = \int_{g(X)<0} f_X(X)dX \quad (1)$$

in which the vector $X=[X_1,X_2,\ldots,X_n]^T$ includes n random variables and $f_X(X)$ is the joint probability density function (JPDF) of vector X. The function $g(X)$ denotes limit state function (LSF) and $g(X)<0$ defines failure domain. However, from the computational viewpoint, the evaluation of the above multi-dimensional integral is a serious challenge. In this regard, more attention has been paid to other alternatives such as approximation methods [7-10] and simulation methods [11-14].

Approximation methods, such as first- or second-order reliability method (FORM or SORM), estimate LSF by Taylor expansion at design point or most probable point (MPP). As Hasofer and Lind [15] have defined, design point or MPP is on the limit state surface and has the minimum distance from the origin of standard normal coordinate system, and according to their definition this minimum distance is called reliability index, denoted by β. Standard normal coordinate system, which is also called U-space, is obtained by their introduced linear transformation. Using this transformation, the variable x_i in the original space (also called X-space) is transformed to the variable u_i in U-space. Limit state function which is denoted by $g(X)$ in the original X-space, will be denoted by $G(U)$ in U-space, hereafter. Generally speaking, approximation methods can appropriately work in some cases. However, the need to a differentiable explicit LSF has made these methods impractical for many cases. Besides, in highly nonlinear LSFs, they may result in divergence or slow convergence.

In simulation methods, such as Monte Carlo simulation (MCS), random samples are generated by means of a sampling density function (SDF) and LSF is evaluated for