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Chaotic conjugate stability transformation method for structural reliability analysis

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Highlights

- A robust approach is proposed using chaotic conjugate discrete map for reliability analysis.
- A chaotic control factor is developed using results of reliability problems and Logistic map.
- The proposed method guarantees numerical stability in comparison with other FORM algorithms.
- Proposed chaotic approach improves the efficiency and robustness of FORM iterative formula.

Abstract

The efficiency and robustness are two important issues in First Order Reliability Method (FORM). The Hasofer and Lind–Rackwitz and Fiessler (HL–RF) algorithm is widely used in FORM, but it produces unstable results as periodic and chaotic solutions for highly nonlinear problems. Hence, the stability transformation method (STM) with chaos feedback control was proposed to overcome the numerical instabilities of FORM, but it is inefficient for both concave and convex reliability problems. In this paper, a stability transformation method with chaotic conjugate search direction is proposed to improve both the robustness and efficiency of FORM formula, where a chaos control factor is proposed based on Logistic map, and a transformation matrix is adaptively defined based on the reliability index and the Logistic map at each iteration. Eight nonlinear mathematical and structural/mechanical examples are selected to demonstrate the efficiency and robustness of the proposed chaotic conjugate stability transformation method (CCSTM). Results illustrate that the CCSTM is more robust than the HL–RF and more efficient than other existing reliability methods.

Keywords: Reliability analysis; First order reliability method; Stability transformation method; Chaotic conjugate stability transformation method

1. Introduction

Various uncertainties, such as the mechanical properties, geometric dimension and external loads, are encountered in the design and implementation phases of engineering structures. Structural reliability analysis is a useful

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Nomenclature

a	Control parameter of Logistic map
$\boldsymbol{C}$	Involutory matrix
CCSTM	Chaotic conjugate stability transformation method
FORM	First-order reliability method
FSL	Finite-step length method
$\boldsymbol{H}$	Transformation matrix
HL–RF	Hasofer and Lind–Rackwitz and Fiessler method
LSF	Limit state function
MCS	Monte Carlo simulation
RHL–RF	Relaxed HL–RF
SORM	Second-order reliability method
STM	Stability transformation method
$\boldsymbol{d}_k$	Conjugate search direction vector
$g()$	Limit state function
$g() \leq 0$	Failure region
$f_C(\boldsymbol{U}_k^{CG})$	Discrete conjugate dynamical map
f_X	Joint probability density function
P_f	Failure probability
$\boldsymbol{X}$	Basic random variables
$\boldsymbol{U}^{CCSTM}$	Point-based chaotic conjugate stability transformation method
$\boldsymbol{U}^*, \boldsymbol{X}^*$	Most probable point (MPP) in U-space, X-space
$\boldsymbol{\alpha}_k^C$	Normalized conjugate search direction
$\boldsymbol{\alpha}_k$	Normalized search direction
β	Reliability index
ε	Stopping criterion
μ, σ	Mean, standard deviation
λ^C	Chaotic control factor
λ	Control factor
$\rho(\boldsymbol{J})$	Jacobian matrix
$\rho(z)$	Chebyshev distribution
Φ	Standard normal cumulative distribution function
$\nabla g(\boldsymbol{U}_k)$	Gradient vector of the LSF

methodology to consider these uncertainties based on probabilistic models [1,2]. The first-order reliability method (FORM) [2–5], second-order reliability method (SORM) [6], and Monte Carlo simulation (MCS) [2] are used for the reliability analysis of engineering problems under uncertainties. Generally, the MCS is more computationally inefficient for complex engineering problems [1,4]. The FORM is widely used to estimate the failure probability due to the good balance between accuracy and efficiency for the reliability analysis by searching the most probable point (MPP) on the failure surface [7–9].

Hasofer and Lind [8] proposed an iterative method for computing the reliability index. Later, Rackwitz and Fiessler [10] extended the Hasofer and Lind method by including distribution information (HL–RF method). The HL–RF method is widely implemented for estimating the reliability index (β) in FORM. The HL–RF scheme could produce unstable results as periodic and chaotic solutions [4] or could be slowly converged for highly concave limit state function (LSF) [2]. The stability transformation method (STM) using chaos feedback control was proposed to improve the robustness of FORM, but the STM has a slower convergence rate when the control factor is selected as a smaller value to achieve the stabilization [9]. Consequently, the computational cost could increase to obtain stabilization in the reliability analysis. Therefore, the main challenges of reliability analysis-based MPP search are the computational demand (i.e. efficiency) and stable convergence (robustness).