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Interval importance sampling method for finite element-based structural reliability assessment under parameter uncertainties

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Abstract

Parameters of a probabilistic model often cannot be determined precisely on the basis of limited data. In this case the unknown parameters can be introduced as intervals, and the imprecise probability can be modeled using a probability bounding approach. Common methods for bounding imprecise probability involve interval analysis to compute bounds of the limit state probability. A large number of interval finite element (FE) analyses have to be performed if the structural response defined as the limit state is determined implicitly through FE analysis. A new interval importance sampling method is developed in this paper which applies importance sampling technique to the imprecise probability. The proposed methodology has a desirable feature that expensive interval analyses are not required. Point samples are generated according to the importance sampling function. The limit states are computed using deterministic FE analyses. The bounds of the imprecise probability density function are introduced in the formulation at a later stage to incorporate the effects of the imprecision in the probability functions on the reliability results. Examples are given to illustrate the accuracy and efficiency of the interval importance sampling method. The second example also compares the proposed method with the conventional Bayesian approach.

Highlights

► The new method calculates the bounds of structural failure probability. ► The unknown statistical parameters are modeled as intervals. ► The method does not involve expensive interval FE analysis. ► Two examples demonstrated the accuracy and efficiency of the present method. ► The present method is compared with the Bayesian approach.

Keywords

Finite element method; Importance sampling; Imprecise probability; Interval analysis; Interval uncertainty; Probability box; Simulation; Structural reliability; Statistical uncertainty

Figures and tables from this article:

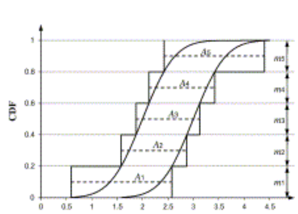

Fig. 1. Discretization of a continuous p-box (n = 5).

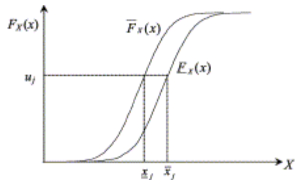

Fig. 2. Generation of random intervals from a continuous *p*-box.

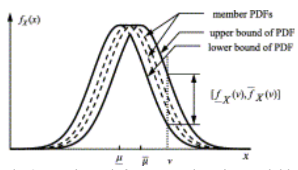

Fig. 3. PDF bounds for a normal random variable with interval mean $[\underline{\mu}, \bar{\mu}]$.

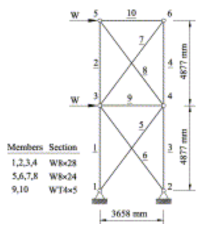

Fig. 4. One-bay, two-story plane truss (redrawn from Ref. [20]).

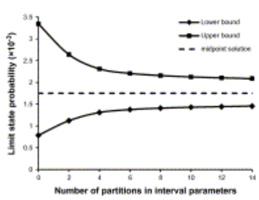

Fig. 5. Reliability bounds for the truss of Fig. 4.

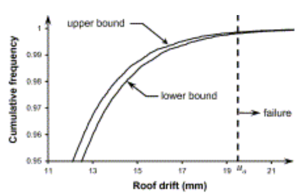

Fig. 6. Bounds for the empirical cumulative frequency distribution (upper tail) of the roof drift (truss in Fig. 4).

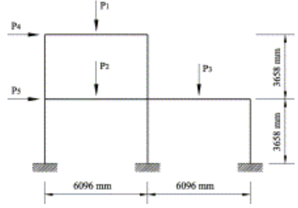

Fig. 7. Asymmetric frame (after [38]).

Figure options

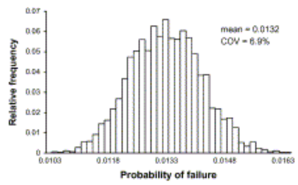

Fig. 8. Relative frequency histogram for P_f obtained from the Bayesian approach (frame in Fig. 7).

Figure options

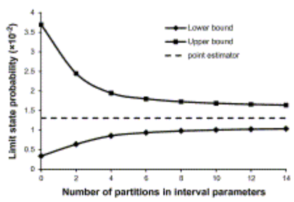

Fig. 9. Reliability bounds for the frame in Fig. 7 (confidence level for the means = 95%).

Figure options

Table 1. Random variables for the planar truss.

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Table 2. Interval estimates for P_f (truss in Fig. 4).

IIS = interval importance sampling.IMC = direct interval Monte Carlo.

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Table 3. Random variables for the asymmetric frame.

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Table 4. Interval estimates for P_f obtained from interval importance sampling method (frame in Fig. 7).

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Table 5. Bounds of limit state probability P_f for example 2 ($\times 10^{-2}$).

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