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An efficient methodology for robustness evaluation by advanced interval analysis using updated second-order Taylor series expansion

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ABSTRACT

An enhanced and efficient methodology for interval analysis is proposed to evaluate the robustness of an uncertain structure. While a basic assumption of "*inclusion monotonic*" is introduced in some of the interval analyses, the possibility is taken into account of occurrence of the extreme value of the objective function in an inner domain of interval parameters. It is shown that the critical combination of interval parameters can be derived explicitly so as to maximize the objective function by second-order Taylor series expansion. Two different approaches, called the FRP (Fixed Reference-Point) method and the URP (Updated Reference-Point) method, are proposed to obtain such a critical combination of interval parameters. The method is applied to building structures with passive dampers sustained by flexible supports. The objective function is given by the sum of the mean squares of interstorey drifts under random input. The damper capacity, its supporting member stiffness and building storey stiffness are taken as interval parameters. In order to investigate the validity of the proposed methods, numerical analyses are conducted for 2- and 20-storey building models including passive dampers. By comparing the results with the reference solution and those by other conventional methods, it is demonstrated that the URP method can provide the most accurate response bounds without hard computational effort.

1. Introduction

In the usual structural design procedure, the maximum dynamic responses have to be evaluated in a structure subjected to wind or earthquake excitation in order to quantify its structural safety. It is well known that there exist a lot of uncertainties in structural parameters caused by various sources, e.g. material-property variability, initial manufacturing errors, and aging deterioration of performance. These uncertainties may lead to various unexpected situations where the structural responses such as deformation and stress may exceed the performance limit. For this reason, it is needed to evaluate more accurately and efficiently the uncertainty of the structural response for the sake of the robust and reliable design under various uncertainties of structural parameters.

A number of studies on uncertainties of structural parameters have been accumulated so far [1–3]. The interval analysis is well known as a representative of the reliable analysis methods. The concept of interval analysis was introduced in [4]. Alefeld and Herzberger [5] have then done the pioneering work. They treated linear interval equations, nonlinear interval equations and interval eigenvalue analysis by developing interval arithmetic. The interval arithmetic is a mathematical rule for the sets of intervals which appeared in 1924. Since their innovative achievements, the interval arithmetic algorithm has been used. Qiu et al. [6] have applied the interval arithmetic algorithm to obtain the bounds of static structural response by using a convergent series expansion of the uncertain structural response. Qiu and Elishakoff [7] have proposed an application of the interval arithmetic algorithm by using a Neumann series expansion of the inverse stiffness matrix. Mullen and Muhanna [8] have shown the bounds of the static structural response for all possible loading combinations using the interval arithmetic. Similar works of interval analysis for the static response or eigenvalue have been developed by many researchers [9–18]. An overview of the recent state of the art for the interval analysis has been provided by Moens and Hanss [19].

More recently, the interval analysis using Taylor series expansion has been proposed in [20–22]. In the early stage of the interval analysis using Taylor series expansion, first-order Taylor series expansion was investigated for the problems of static response and eigenvalue. Chen et al. [22] developed the matrix perturbation method using second-order Taylor series expansion and obtained an approximation of the bounds of the objective function without interval arithmetic. They pointed out that the computational effort can be reduced from the number of calculations 2^N (N: number of interval parameters) to $2N$ by neglecting the non-diagonal elements of the Hessian matrix of the objective function with respect to interval parameters. Although neglecting the non-diagonal elements makes the algorithm efficient, the deterioration

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