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Masterarbeit - *Master thesis*

für

Vorname Nachname

Matrikel-Nr.: XXXXXXXX

Ausgabe der Arbeit: XX.XX.20XX	Bearbeitungsumfang: 150 h (5 LP)
Abgabe der Arbeit: XX.XX.20XX	Bearbeitungsdauer: 6 Monate
Prüfer/in: Prof. Dr.-Ing. U. Nackenhorst	Betreuer/in: Zhibao Zheng

Stochastic finite element method based structural reliability analysis

As a powerful tool to quantify uncertainty in practical engineering problems, reliability analysis nowadays has become an indispensable cornerstone for analyzing complex stochastic problems in many fields, such as structural design, optimization and decision management. Although significant effort has been made, the estimation of the failure probability in reliability analysis is still challenging. On one hand, since the multidimensional integral encountered in reliability analysis for calculating the failure probability often lies in high-dimensional stochastic spaces (hundreds to more), expensive computational costs for the purpose are usually prohibitive. On the other hand, the limit state surface is rarely known explicitly and only can be evaluated by numerical solutions because the failure region is generally complicated and irregular. Existing methods are still unsatisfactory in terms of accuracy and efficiency in dealing with complex problems, such as the small failure-probability three-dimensional problems with highly irregular limit state surfaces and high-dimensional random inputs. The stochastic finite element method (SFEM) is an attractive way to overcome the above difficulties. Several SFEM based reliability analysis methods can be found in [1,2,3,4]. However, existing SFEMs may not be able to achieve a general-purpose computational framework for reliability analysis. For instance, Polynomial Chaos based methods suffer from the curse of dimensionality and thus cannot be applied to high-dimensional stochastic problems. Sampling based methods such as Monte Carlo simulation need to solve a large number of deterministic equations to achieve accurate failure probabilities, which is computationally very expensive.

The main goal of this thesis is to estimate failure probabilities using a weakly intrusive SFEM [5]. The weakly intrusive SFEM is adopted to accurately solve stochastic solutions, and the limit state functions can then be easily evaluated. Thus, the failure probabilities are calculated accurately and efficiently. Numerical benchmark problems will be tested to illustrate performance of the proposed method.

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