Doctoral Dissertation

博士論文

A Study on Structural Analysis Method with Uncertainty by Stochastic Finite Element Method

不確定性を考慮した確率有限要素法による構造解析手法の研究

By

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ABSTRACT

In structural mechanics in the field of naval architecture and ocean engineering, currently, the structural analysis is very important such as linear static analysis and the eigenvalue analysis. In practical cases, the physical characteristics are not deterministic. There are a lot of uncertainties in load, material property, geometrical shape, corrosion and other characteristics in the structures. Such uncertainties may cause serious problems as reduction of strength or increase of stress which may reduce fatigue strength of the structure or reduction of buckling load because the influence of the uncertainties is usually unknown. So it can't be ignored in practice. Structural analysis when uncertainty exists in the structure is very important for safety risk assessment of ships and offshore structures.

This method which consider some uncertain input parameters to compute these uncertain results are usually referred to as uncertainty analysis. In the conventional uncertainty analysis, Monte Carlo Simulation methods (MCS) combined with finite element methods (FEM) is usually used when uncertainty is considered. However, MCS needs heavy and a large number of calculations, so that application of MCS to practical problems is sometimes very difficult to get reasonable results. Thus, it is very necessary that propose a new method of structural analysis to solve problems of response uncertainty when the case involves inherent uncertainty. In this study, we will discuss uncertainty problem from two aspects: linear static analysis (about studying of uncertainty in shape) and eigenvalue analysis.

In linear static analysis problem, in order to achieve effectively evaluate uncertainly of response (displacement, strain and stress), the Stochastic Finite Element Method (SFEM) based on response surface methodology is proposed for the solution of

problems of response uncertainty for the case that involves uncertainty in shape following the normal distribution or non-normal distribution. The proposed method makes use of an Hermite Polynomial Chaos Expansion (PCE) (response surface method) to represent the uncertainty of shapes and the response surface extending the deterministic finite element. And the proposed method ultimately achieved that the uncertainty of response of a displacement, strain and stress can be estimated by this method that solves the main stiffness equation only once. Some example problems are investigated by the method. The validity of the proposed method of structural analysis is discussed by comparing the results of the method with the MCS solution of the deterministic problems.

In eigenvalue analysis problem, in order to achieve effectively evaluate uncertainly of response (a natural frequency and natural mode in vibrations analysis or a buckling load and buckling mode in buckling analysis), we have been studied about solution of stochastic eigenvalue problems to discuss inherent uncertainty influences on the stochastic response eigenvalues and stochastic response eigenvectors. As solution of stochastic eigenvalue problem, in this study, we have proposed two methods. Firstly, the Improved Stochastic Inverse Power Method (I-SIPM) based on response surface methodology is proposed by which minimum eigenvalue and eigenvector of stochastic eigenvalue problems can be effectively evaluated. Secondly, the Sochastic Wielandt Deflation Method (SWDM) is proposed which can realize to evaluate $i^{\text{th}}(i>1)$ eigenvalues and eigenvectors of stochastic eigenvalue problems by using response surface method to extend the Widlandt deflation method. Finally, example problems are investigated to discuss the validity of the proposed new methods compared with a Monte-Carlo simulation, i.e. the vibration problem and the buckling problem when

consider uncertainty exists in the model.