Damage Detection Method by Topology Optimization Based on Eigenvalue Analysis

Takafumi Nishizu (1); Akihiro Takezawa (2); Mitsuru Kitamura (2)
(1) Graduate School of Engineering, Department of Transportation and Environmental Systems, Hiroshima University
(2) Faculty of Engineering, Division of Mechanical Systems and Applied Mechanics, Hiroshima University
Higashihiroshima City, Hiroshima Prefecture, Japan

ABSTRACT

The non-destructive testing is significant in the long life operation of large structure such as ships. In the non-destructive testing, the variation in structural characteristics from the original one to the damaged one is used to identify the damage. In this paper, a damage identification method in non-destructive testing is proposed using difference of eigenvalue between the original structure and the damaged one. Damage is specified by topology optimization that minimizes this difference. An optimization algorithm is constructed based on the topology optimization and MMA. The validity and the usefulness of the proposed method are confirmed by several numerical examples.

KEY WORDS: topology optimization; SIMP; finite element method; eigenvalue analysis; non-destructive inspection; MMA; sensitivity analysis

INTRODUCTION

Non-destructive inspection is important for lifetime improvement of large offshore structure. As kinds of non-destructive inspection method, there are methods by ultrasonic waves, eddy current, and so on (Mix. PE, 2005). In non-destructive inspection, damage is detected by difference between response of normal structure and damaged structure. A process to specify damage is done by engineer typically. Thus, accuracy of damage detection depends on skill of engineer. For establishment of identification method that does not depend on skill of laboratory technician, method that use database of many damage structures is proposed. However this method is usable only for limited structure.

In contrast, method that takes up inspection result analytically and specifies damage is proposed. This method derives structure gotten by inspection, using numeric calculation based on dynamical model and optimization algorithm. Based on the result, this method specifies damage of structure. On the other hand, topology optimization attracts attention as one of structural optimization method (Bendsoe. MP, 2003). Topology optimization is highest flexibility among structural optimization method. Some application examples have been reported in the field of ship and ocean (Rais-Rohani. M, 2007). These relevant researches use topology optimization regarding the design problem of structure. But topology optimization is also able to apply damage identification algorithm. Namely, topology optimization can result in a highly flexible method of damage detection. As damage detection method based on topology optimization, methods using frequency response analysis are proposed (Lee. JS, 2007) (Niemann. H, 2010) so far. In non-destructive inspection, there are methods using vibration characteristic of structure. These researches also focus on vibration characteristic of structure. A trait of these researches is damage detection method using frequency response characteristic among vibration characteristic. Methods of these researches derive parallel structure by topology optimization based on result of frequency response analysis of damage structure. Therefore, approximate position and shape of damage is specified. However, researches that applied topology optimization to damage detection method like these are only these two examples. The research using eigenvalue that is the most basic dynamic characteristic of structure is not yet conducted.

Based on the above, this research constructs damage detection method using eigenvalue and topology optimization. Namely this research method assigns eigenvalue of damage structure, and automatically derives structure that has this eigenvalue using topology optimization. Result structure of optimization corresponds with damage structure.

FORMULATION

Eigenvalue analysis by finite element method

This research use finite element analysis for eigenvalue analysis of structure. At first, free vibration problem of structure is discretized by finite element method. Following discretized vibration equation is gotten by presuming that solution is periodic displacement $u(t)$. $u(t) = 0$

$$\begin{align*}
(K - \omega_n^2 M)\mathbf{u} &= 0
\end{align*}$$

$K$ is stiffness matrix. $M$ is mass matrix. $\omega_n$ is natural angular frequencies. $\mathbf{u}$ is amplitude vector. $\mathbf{u}$ to correspond to natural angular frequencies is gotten by solving above equation as eigenvalue problem. Thus, it is eigenmode $\Phi_i$.

Topology optimization

Foundation of topology optimization is introduction of design domain and characteristic function $x_{bi}$. That is to say, optimization problem is