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Sensitivity analysis for free vibration of rectangular plate

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ABSTRACT

This paper presents an effective sensitivity analysis algorithm for free vibration of a rectangular plate structure by using the finite element-transfer stiffness coefficient method (FE-TSCM). The basic concept of FE-TSCM combines both the modeling technique of the finite element method (FEM) and the transfer technique of the transfer stiffness coefficient method (TSCM) in order to benefit from the merits of both FEM and TSCM in the dynamic analysis of a structure. From the results computing the sensitivities of eigenvalues and eigenvectors for a simply supported rectangular plate structure by FE-TSCM and Fox's method, we can confirm that FE-TSCM has merits from the viewpoint of computational time and memory in sensitivity analysis for free vibration of the rectangular plate structure with a large number of degrees-of-freedom. In addition, when the design variables are the thicknesses of the plate elements, the results computing the sensitivities of the first eigenvalues for the rectangular plate structures with clamped edges are illustrated in detail by using the computation program introducing the concept of FE-TSCM.

1. Introduction

When designing mechanical or structural systems, it is important to understand the characteristics of the systems. The sensitivity analysis provides designers with reasonable and effective data for structural modification, optimization, and so on [1–2].

Since the 1960s, many studies for obtaining the dynamic sensitivity of systems have been carried out [3–5]. Most of the studies have focused on obtaining the derivatives of eigenvalues and eigenvectors with respect to design variables by using large matrices with total degrees-of-freedom of the discrete system; for example, the system stiffness and mass matrices of the finite element method (FEM) [6].

However, large matrices in dynamic analysis for a structure with a lot of degrees-of-freedom may result in many problems from the viewpoint of computational time and memory [7]. In order to overcome these problems, many researchers suggested a variety of methods [8–11] using the transfer matrix method [12]. As a result of studying computational algorithms to analyze effectively the free vibration of plate structures, the finite element-transfer stiffness coefficient method (FE-TSCM) was suggested by Choi [13]. The basic concept of FE-TSCM combines both the modeling technique of FEM and the transfer technique of the transfer stiffness coefficient method (TSCM) [14,15] in order to benefit from the merits of both FEM and TSCM in the free vibration analysis of the rectangular plate structure.

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The sensitivity analysis algorithm for free vibration of a straight-line beam structure by using the transfer stiffness coefficient method (TSCM) was suggested in a previous paper [16]. However, TSCM in the previous study was limited to the sensitivity analysis of a simple one-dimensional structure such as beam and shaft. Therefore, it was difficult to apply the previous TSCM to the sensitivity analysis of a two-dimensional structure such as plate, panel and shell. In addition, the previous TSCM has drawback, which requires much computational time for sensitivity analysis.

In this paper, the authors apply FE-TSCM to the free vibration sensitivity analysis algorithm for a rectangular plate structure. In order to confirm the effectiveness of FE-TSCM, a simply supported rectangular plate structure is given as a computation model for obtaining sensitivities of eigenvalues and eigenvectors. The computational results of FE-TSCM are compared with those of Fox's method [3] in terms of computational accuracy, time, and memory. In addition, when the design variables are the thicknesses of the plate elements, the results computing the sensitivities of the first eigenvalues for the rectangular plate structures with clamped edges are illustrated in detail by using the computation program introducing the concept of FE-TSCM.

2. Algorithm

2.1. Modeling of rectangular plate structure

The rectangular plate structure of Fig. 1 consists of a rectangular plate and elastic springs supporting the plate from the base. The rectangular plate is divided into m strips, and each strip is subdivided into $n-1$ rectangular plate elements, as shown in Fig. 2. The sections between the strips are called nodal lines, which are designated as the nodal line 1, the nodal line 2, …, and the nodal line $m+1$ consecutively from the left-hand edge of the plate to the right-hand edge.

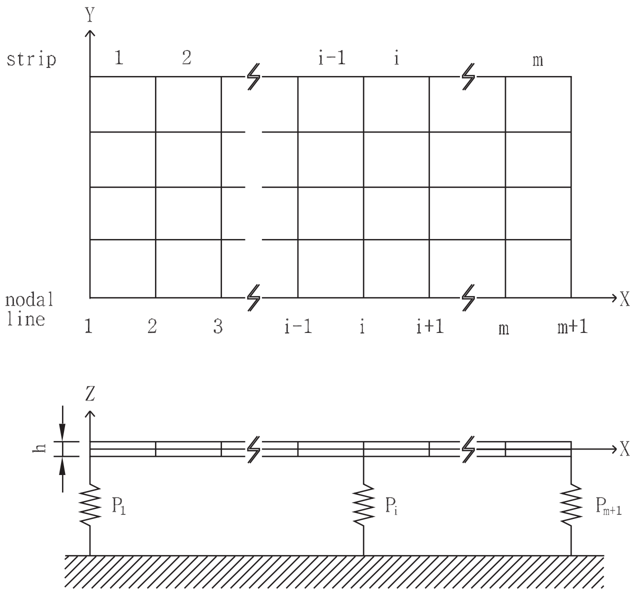

Fig. 1. Rectangular plate structure.

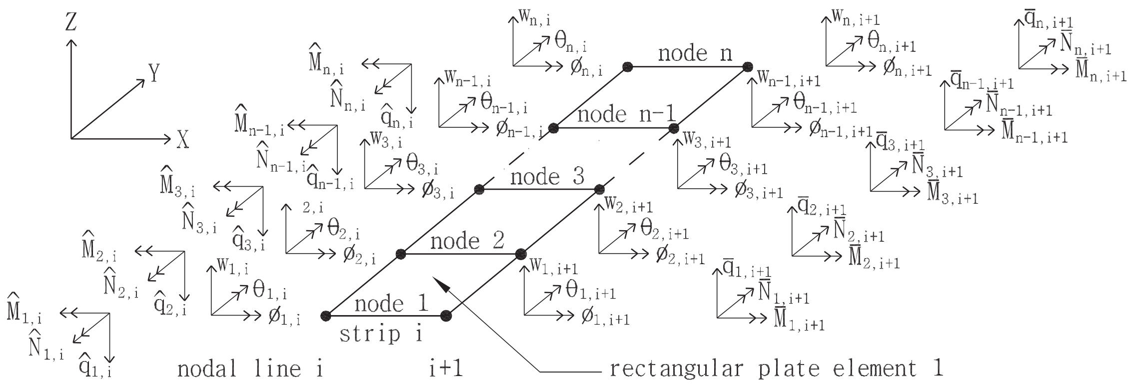

Fig. 2. Nodal lines, plate elements and nodes of strip i and the definition of positive direction of state variables.