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Equivalent modulus method for finite element simulation of the sound absorption of anechoic coating backed with orthogonally rib-stiffened plate

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ABSTRACT

The finite element method is often used to investigate the sound absorption of anechoic coating backed with orthogonally rib-stiffened plate. Since the anechoic coating contains cavities, the number of grid nodes of a periodic unit cell is usually large. An equivalent modulus method is proposed to reduce the large amount of nodes by calculating an equivalent homogeneous layer. Applications of this method in several models show that the method can well predict the sound absorption coefficient of such structure in a wide frequency range. Based on the simulation results, the sound absorption performance of such structure and the influences of different backings on the first absorption peak are also discussed.

1. Introduction

The Alberich anechoic coating with embedded air-filled cavities is often used in underwater vehicles to absorb sound energy. Two absorption peaks always exist in the low-frequency band when periodically distributed cavities are contained in the anechoic coating. The acoustic resonances of the cavities result in strong vibration of the coating; for transverse waves rapidly dissipated in viscoelastic media, a vigorous redistribution of sound waves in the lateral directions of the cavities causes substantial energy dissipation in the vicinity of the resonance frequencies [1]. Therefore, the coating exhibits significant sound absorption at the acoustic resonances of the cavities.

The finite element method (FEM) combined with the Bloch theorem has been developed to analyze the sound absorption performance of singly periodic structures, such as compliant gratings [2,3], and also doubly periodic structures, such as the Alberich anechoic coatings [4,5]. It is widely used to predict the sound absorption performance of periodic structure with different shapes. To compute the acoustic performance, one periodical unit cell of the structure needs to be meshed using the Bloch theorem. The criterion of mesh size was discussed in the literature [4] which pointed out that if the transverse wave velocity and longitudinal wave velocity were relevant parameters, the $\lambda/4$ criterion with respect to transverse wave would be sufficient; otherwise, the $\lambda/4$ criterion with respect to flexural wave would be needed when the flexural wave velocity was relevant.

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Furthermore, to reveal the absorption mechanism of the Alberich anechoic coating, the influences of locally resonant modes on sound absorption were investigated [6]. In recent studies, the acoustic performance of anechoic coating backed with steel plates was discussed, and the coating and backing were treated as a whole structure [1]. Then, the optimization scheme for the physical and structural parameters was discussed, and it was verified by experiments that combinations of different locally resonant units could provide significant sound absorption at low frequencies over a broad band when the optimized parameters were used [7].

In engineering practice, the anechoic coating adheres to shells internally and orthogonally stiffened by sets of stringers and frames, such as ship hulls. Usually, the distance between the stringers or frames is larger than the distance between the cavities embedded in the coating. Thus, the periodical unit cell of the hull contains an orthogonal stiffener and lots of cavities. To precisely capture the geometrical features of cavities in the FEM, a large number of grid nodes is required if the unit cell is directly meshed, making the numerical operation difficult.

The acoustic performance of rib-stiffened homogeneous plates has been studied with analytical methods [8,9], but without plate with embedded cavities. Recently, a 2-D FEM was used to investigate the vibro-acoustic response of an infinite rib-stiffened thick-plate assembly that contains infinitely long cavities [10]; however, the actual features of cavities with finite sizes could not be modeled. The sound absorption performance of a rib-stiffened plate covered by the Alberich anechoic coating has just been investigated using a simplified FEM [11], in which the ribs were arranged along only one direction and the shifting of the main absorption peak was treated by the impedance transfer approach. This simplified method can significantly reduce the calculation time, but the calculation is limited in a narrow frequency band containing only one main absorption peak.

In this paper, an equivalent modulus method also based on the impedance transfer formula is proposed for the homogenization of the finite element model simulating the absorption performance of structures with large-size unit cells over a broader frequency band. With this method, the number of grid nodes of the finite element meshes is greatly reduced, and the low-frequency response of an Alberich anechoic coating backed by orthogonally rib-stiffened plate can be predicted more accurately in a wider frequency range. The paper is organized as follows: Section 2 describes a finite element model constructed to simulate the acoustic performance of an infinite anechoic coating backed with steel plate periodically stiffened by orthogonal sets of ribs, and verification of the numerical algorithm; the proposed equivalent modulus method with two schemes and the applications of the two schemes in the same finite element model is introduced in Section 3; Section 4 presents further applications and discussions on the second equivalent modulus scheme; based on the simulation results of several models, some patters of variation of the first absorption peak of Alberich anechoic coating backed by orthogonally rib-stiffened plates are discussed in Section 5; finally, the conclusion of this research is presented in Section 6.

2. Finite element model

In this section, a finite element model is constructed to simulate the acoustic performance of an infinite anechoic coating backed with a plate periodically stiffened by orthogonal ribs. The numerical algorithm is then verified by solving a problem with known solution.

2.1. Finite element modeling and the Bloch theorem

The physical problem under consideration is the incidence of a pressure wave traveling in the z-direction on the bottom surface of a structure composed of the Alberich anechoic coating and an orthogonally rib-stiffened steel plate, as shown in Fig. 1. The anechoic coating that contains air cavities (cylinder-shaped) is made up of viscoelastic rubber material. The steel plate is bonded to the coating and orthogonal ribs are affixed to the steel plate. Such a structure is assumed to be infinite in the x and y directions. In this study, the fluid loaded on the side of anechoic coating is semi-infinite water, and that above the steel plate and ribs is the air, which is neglected in the finite element analysis. The cavities are periodically arranged in both the x and y directions, and the ribs attached to the steel plate are also equally spaced in the x and y directions, so both the cavities and ribs are periodically distributed.

In the FEM model of such a structure, the Bloch theorem for periodic structures is applied, so only one unit cell of the structure needs to be meshed. Fig. 2(a) shows a sketch of the unit cell, which consists of a set of orthogonal ribs, a

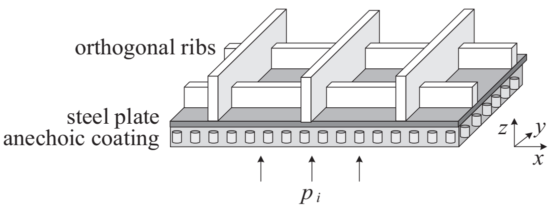

Fig. 1. Sketch of an Alberich anechoic coating backed with orthogonally rib-stiffened plate. A plane wave is incident from the semi-infinite water domain.