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# 主 論 文 の 要 旨

論文題目 A study on numerical analysis based on boundary element method for wave propagation properties of phononic periodic structures （フォノニック周期構造の波動伝播特性の境界要素法による解析法に関する研究）

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## 論 文 内 容 の 要 旨

The frequency-banded nature of phononic crystals is determined by plotting the dispersion relation between ω and k. Here, ω is the circular frequency and k is the wave number. For a homogenous elastic material, the dispersion relation has a simple linear relation, however, for phononic periodic structures, the dispersion relation becomes complicated, and some certain ranges of ω which have no eigenfrequency exist at any value of k, are called band gaps or stop bands while the rest of ranges are called pass bands. To investigate the band structure given by the dispersion relation, we need to solve Bloch eigenvalue problems. Using boundary element method (BEM), nonlinear eigenvalue problems are formulated for both homogenous and periodic structures originated from the nonlinear property of the fundamental solutions. To solve the nonlinear eigenvalue problems, a contour integral method so-called Sakurai-Sugiura (SS) method is employed to extract the eigenfrequencies in a certain selected complex domain of ω surrounded by a closed Jordan curve. The proposed technique requires the evaluation of the contour integral along the Jordan curve and converts the nonlinear eigenvalue problem to a generalized eigenvalue problem formed by two Hankel matrices. Furthermore, the eigenspace is reduced to that defined within the contour integral. We apply this combined methodology to homogenous and composite structures in acoustic and linear elastodynamic problems. For finite unidirectional phononic structures, a size-reduced system matrix is formulated for the transmission problem of acoustic and elastic structures. In the size-reduced system matrix, the unknown quantities on the free boundary of a unit cell are removed by formulating the transfer matrix of the unit cell by BEM. The transmission problem of several finite unidirectional structures are calculated, and compared with the band structures of the corresponding infinite structures obtained by the BEM combined with the SS method. The correlation of the number of layers and the frequency-banded nature is investigated.

In chapter I, an introduction to the research background is given, and the organization of the thesis is presented.

In chapter II, a new BEM-based methodology is proposed for calculations of band structures of given phononic structures. The difficulties arising in applying BEM to eigenvalue problems are described. The nonlinear eigenvalue problems formulated by BEM are presented by considering a simple case of the Helmholtz equation. Starting from the weighted residual form, a boundary integral equation that shows a nonlinear expression for the eigenvalue parameter is derived. In particular, spurious eigenvalue problems are also introduced by showing a spurious eigenequation for an annular structure that is an interior problem consisting of a multiply connected domain. Since phononic structures are always considered as multiply connected domains, spurious eigenvalues are also obtained in the numerical simulations. To overcome the spurious solutions, Burton-Miller's method that combines the hypersingular boundary integral equation is introduced. Similar properties of photonic crystals for phononic structure are introduced. The Bloch wave function for the mechanical waves propagating in phononic structures is described. Various structures of crystals and their first Brillouin zones are introduced, then the corresponding phononic structures that exhibit the same characteristics are presented. Next, the BEM modeling for the phononic structures is given. Without domain discretization, simple models are created.

In chapter III, the methodology proposed in chapter II is applied to the analyses of a 2D square acoustic cavity. Furthermore, the eigenfrequencies of 3D acoustic cavities are computed. The real spurious eigenvalues are identified using Burton-Miller's method.

In chapter IV, a new approach based on the BEM and the block SS method for the analyses of band structure of phononic structures is proposed and applied to the band calculation of acoustic-phononic structure governed by the Helmholtz equation. The band gaps are observed correctly both in homogenous and composite phononic structures. By applying the Bloch periodic boundary condition on the virtual boundary of a unit cell, the analyzed problem can be considered as an interior problem with a multiply connect domain. Therefore, the real spurious eigenfrequencies are also observed as horizontal lines in the band structures. Again, we use Burton-Miller's method for eliminating the spurious solutions. In chapter V, the proposed approach is applied to the band calculation for elastic phononic structures. In order to improve the efficiency of the contour integral method for computing the real eigenfrequencies, a fusiform contour integral path is employed to exclude the complex solutions. Numerical results demonstrate the effectiveness of the method for elastic materials.

In chapter VI, considering more practical problems, an investigation on finite/infinite unidirectional phononic plates, which have 2D cells arranged along one direction periodically, is carried out. The band structures of the infinite unidirectional phononic plates are computed by using the proposed approach. The dispersion relations for both acoustic and elastic infinite unidirectional phononic plates are obtained. In the dispersion relations, the stop bands and pass bands are identified. For the finite case, the input and output domains are connected with finite layers of unidirectional periodic plates. To investigate the wave transmission in these finite structures, a size-reduced coefficient matrix is derived utilizing the transfer matrix formulated by BEM repeatedly.

In chapter VII, conclusions of the thesis are presented.