SOUND TRANSMISSION THROUGH MULTILAYER STRUCTURES WITH ISOTROPIC ELASTIC POROUS MATERIALS

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ABSTRACT. This paper discusses the prediction of transmission loss through multilayer structures with porous materials. Firstly, a brief review of recent formulations for multilayer structures with poroelastic materials is presented. Secondly, the transmission loss problem is described and formulated using a coupled finite element and boundary element procedure. Issues such as poroelastic-elastic coupling, poroelastic-fluid coupling and radiation from a poroelastic material will be addressed. The developed model is validated through numerical examples. Its advantages and limitations are discussed. Finally, typical results showing the vibroacoustic effects of several parameters such as the multilayer configuration, the types of porous materials and the mounting conditions are presented. [Work supported by Bombardier Inc. Canadair and N.S.E.R.C.]

INTRODUCTION

To control the vibration and noise radiation from industrial structures, composite panels made up from a combination of elastic, viscoelastic, poroelastic and air layers are commonly used. Several approaches have been devised to predict the transmission loss of such structures. They range from modal and finite element approaches at low frequencies to analytical techniques (= infinite plane panels) at high frequencies [1,2]. This paper concentrates on the low frequency transmission loss of finite composite panels with complex geometry. Since the modeling of the vibroacoustic behavior of elastic, viscoelastic and air media is classical, this paper concentrates mainly on the low frequency modeling of poroelastic medium. It presents a combined finite element-boundary element formulation for the transmission problem.

THEORY

The model for poroelastic media is based on a novel mixed \((u,p)\) formulation [3]. It derives directly from Biot's poroelasticity equations [2]. For the sake of conciseness, the weak integral form of the governing differential equations is given directly without developments. Details may be found elsewhere [2]. For harmonic motions, this equation reads in terms of the skeleton displacement and pore pressure variables:

\[ \int_{\Omega_p} \tilde{\sigma}^s (u) : \varepsilon^s (\delta u) \, d\Omega - \omega^2 \int_{\Omega_p} \tilde{\rho} u \, \delta u \, d\Omega - \int_{\Omega_p} \tilde{V} \tilde{V} p \, \delta u \, d\Omega - \int_{\partial \Omega_p} \left[ \tilde{\sigma}^s \cdot n \right] \delta u \, dS = 0 \]

\[ \forall (\delta u, \delta p) \]  

where \( \Omega_p \) and \( \partial \Omega_p \) denote the poroelastic domain and its boundary. \( \tilde{\rho} \) is the effective density of the skeleton, \( \tilde{\sigma} \) is the in vacuo stress tensor of the skeleton, \( \tilde{\gamma} \) is a pore-skeleton (fluid-solid) coupling coefficient, \( \tilde{\rho}_{22} \) and \( \tilde{K}_e \) are the effective density and bulk modulus of the air in the pores, and \( h \) is the material porosity. The tilde symbol indicates that the associated variable is complex and frequency dependent.

Equation (1) exhibits the classical form of a coupled fluid-structure equation. Note the volume nature of the symmetric coupling between the two phases. When the skeleton is rigid (no motion), only the second equation is kept, and eq. (1) leads directly to the classical equivalent fluid formulation for rigid sound-absorbing media [2]. For the finite element implementation, analogy with three-dimensional elastic and fluid elements is used. Consequently, solid elements with only four degrees-of-freedom per node are obtained. They account for the three displacement components of the skeleton and the pore pressure. This poroelastic finite element formulation can be coupled with classical elastic, viscoelastic and acoustic finite element formulations. The coupling conditions can be found elsewhere [3].

For the transmission problem, the incident pressure is expanded in terms of blocked pressure and radiated pressure. The radiated pressure is accounted for using a variational integral formulation. Using the porous-air coupling conditions:
it is shown that a symmetric variational coupled equation may be obtained. A similar approach is used for the calculation of the transmitted power. The oral presentation details the formulation and presents several numerical examples.

**NUMERICAL EXAMPLE**

Figure 1 presents the transmission loss through a double plate system with poroelastic layers calculated using the presented approach. It presents the transmission loss of two identical aluminum plates (35 cm x 22 cm x 1 mm) separated with: (a) a 52 mm airspace; (b) a 50 mm layer of fiberglass placed 1 mm away from each plate; (c) the 50 mm fiberglass is divided into two 24.9 mm porous layers separated by a 0.2 mm loaded vinyl septum. Figure 1 depicts the typical behavior, at low frequencies, of the transmission loss through a double plate system. Symbols ● and ■ denote the natural frequencies of the plate and the plate-air-plate resonance, respectively. In particular, the benefits of adding the septum is clearly demonstrated.

**References**