Numerical study on sound absorption characteristics of brick/block absorbing walls

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Abstract: Brick/block absorbing walls with openings and backing air space with porous materials have frequency-selective sound absorption not only in low frequencies (caused by the Helmholtz resonance) but also in higher frequencies (caused by open-tube resonance in neck parts). In this paper, a numerical analysis by a method combining the FEM with the Deryugin’s method is made on the absorption characteristics of the brick/block walls.

INTRODUCTION

Brick/block absorbing walls with openings and backing air space with porous materials, which are often used for the aim of absorption in low frequencies, have unexpectedly high absorption at higher frequencies than the predicted one from the Helmholtz resonance. Focusing on this problem, we investigated the sound absorption characteristics experimentally and theoretically and found that the excess absorption is caused by the open-tube resonance in the neck.[1]. Following these studies, advanced numerical analysis using the combination of the FEM and the Deryugin’s method[2] is carried out on simple 2-D models. Using the calculation method, the mechanism of the absorption is investigated. In addition, a way of avoiding the excess absorption is investigated. In order to examine the calculation result, 1/10 scale model experiment is made.

THEORY

A plane wave is assumed to be incident on a 2-dimensional brick/block structure that is infinitely extended with a period of L (FIGURE 1). For numerical calculation, a sound field is divided into three domains. In the domain-1 and -3 with rectangular sound fields, the sound pressure is expressed in the form of the summation of plane waves.

\[ p(x, y) = e^{-j(\alpha_x x - \beta_y y)} + \sum_{m=-N}^{N} A_m e^{-j(\alpha_m x + \beta_m y)} \] (in domain-1) \[ p(x, y) = \sum_{m=-N}^{N} B_m e^{-j\alpha_m x} \left( e^{-j\beta_m y} + R_m e^{j\beta_m y} \right) \] (in domain-3) (2)

where, \( \theta \) is the incidence angle, \( k \) is the wave number, \( \alpha_m \) and \( \beta_m \) are \( x \)- and \( y \)- components of \( k \), respectively, and they have discrete values of \( \alpha_m = \alpha_0 + 2\pi m/L \) and \( \beta_m = \left( k - \alpha_m \right)^2 / 2 \) by considering the periodicity of the sound fields. \( A_m \) and \( B_m \) are unknowns representing the complex amplitude of reflected plane waves, \( R_m \) is the reflection coefficient of the back wall.

For the domain-2 with an arbitrary boundary shape, the FEM analysis is applied. The relationship between the sound pressures and the particle velocities at nodal points are expressed as follows.

\[ \begin{bmatrix} [K] - k^2 [M] \end{bmatrix} \begin{bmatrix} p \end{bmatrix} - \begin{bmatrix} C \end{bmatrix} \begin{bmatrix} u_n \end{bmatrix} = \begin{bmatrix} 0 \end{bmatrix} \] (in domain-2) (3)

where, \([K]\), \([M]\) and \([C]\) are the stiffness, mass and damping matrix, \(\{p\}\) and \(\{u_n\}\) are sound pressures and particle velocities at nodal points, respectively.

By considering continuity conditions for sound pressure and particle velocity on the connecting boundaries b-1 and b-2 (see FIGURE 1), the following equations are obtained.

\[ 2e^{-j\alpha_0 x} - \sum_{m=-N}^{N} e^{j\alpha_m x} \int_{0}^{L} u_n(x, 0) e^{j\beta_m x} dx = p(x, 0) \] (4)
A component of reflected plane wave $A_m$ is also obtained as follows.

$$A_m = \delta_m \frac{1}{\beta_m L} \int_{-\infty}^{\infty} u_n(\xi,0) e^{j2\pi\alpha z} d\xi$$  \hspace{1cm} (6)

The sound pressures and particle velocities at nodal points in the domain-2 can be obtained by solving Eqs. (3), (4) and (5) simultaneously. From the calculated particle velocities, components of reflecting plane waves are calculated by Eq. (6). Consequently, the absorption coefficient $\alpha$ can be calculated as follows.

$$\alpha = 1 - \sum \frac{\beta_m}{\beta_0} |A_m|^2$$  \hspace{1cm} (7)

INVESTIGATIONS BY CALCULATION AND EXPERIMENT

The sound absorption characteristics of the 2-D brick/block walls shown in FIGURE 2 were investigated. As the absorbing condition in the back cavity, homogeneous porous material with flow resistance of 10,000 N/m$^4$ and 50 mm thickness was assumed to be set on the back wall. Statistical absorption coefficient was calculated by averaging oblique incident absorption coefficients between 0° to 78°. In the result shown in FIGURE 3, the type 0 shows high absorption caused by both of the Helmholtz resonance (at about 300Hz) and the open-tube resonance (at 1kHz and 2kHz). In addition, a possibility to reduce the excess absorption was investigated. The type 1 and 2 have necks with irregular shapes so as to avoid the open tube resonance. In the type 1, peaks of absorption coefficient in high frequencies are reduced. On the other hand, in the type 2, absorption coefficient becomes small at all frequencies above the Helmholtz resonance frequency. This might be caused by the reduction of the apparent open ratio.

In order to examine the calculation result, 1/10 scale model experiment was performed by the reverberation room method. The result (FIGURE 4) shows similar tendencies as seen in the calculation results.

CONCLUSIONS

It was confirmed that brick/block walls have high absorption characteristics not only by the Helmholtz resonance but also by the open-tube resonance through the numerical analysis. Such a sound absorption characteristics should be noted when this kind of walls are used. To reduce the excess absorption at high frequencies, it is effective to make the neck shape irregular.

REFERENCE


![FIGURE 2. 2-D brick/block absorbing walls under investigation](image)

![FIGURE 3. Calculation result](image)

![FIGURE 4. Experimental result](image)