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Effect of acoustic liners on sound transmission of wall apertures for ventilation

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Abstract

Sound reduction techniques of the axial 1st mode transmission of an aperture for ventilation purpose in a plane rigid wall were studied by conducting boundary element numerical simulations. First, the effectiveness of the boundary element approach, and the dependence of the insertion loss of a wall with an aperture on the incidence angle were investigated. Then, the effectiveness of the sound reduction techniques, such as mounting acoustical liners to the aperture perimeter, attachment of a disk shape hoods, and insertion of a Helmholtz resonator were examined.

1. Introduction

To improve the sound insulation of a rigid plane wall with an aperture for ventilation as shown in Figure 1, the suppression of the axial 1st mode resonance of the aperture is most important. For this purpose, sound reduction techniques such as installment of a sound absorbent liner, attachment of a hood, and insertion of a Helmholtz resonator will be examined numerically.

2. Descriptions for sound insulation performance of a wall aperture

G. P. Wilson and W. W. Soroka [1] defined the sound transmission loss of a wall aperture as

$$R = 10\log_{10} P_{\mathrm{i}} / P_{\mathrm{t}} \qquad (1)$$

where P_{t} denotes the acoustic power of the transmitted wave of the aperture, P_{i} is the acoustic power of the incident wave passing through the area $S_{\mathrm{F}}\cos\theta$ (where S_{F} is the face area of the aperture and θ is the angle of incidence).

On the other hand, we can define a representation in terms of insertion loss of a rigid wall (i.e., a wall with infinitely large sound transmission loss) with an aperture as

$$D_{\mathrm{IL}} = L_{p,\mathrm{i}} - L_{W,\mathrm{t}} \qquad (2)$$

where $L_{p,\mathrm{i}}$ denotes the sound pressure level of the incident wave at the aperture location when the wall is not present. $L_{W,\mathrm{t}}$ refers to the sound power level of the transmitted wave. Since we can write as $L_{W,\mathrm{t}} \simeq L_{p,0.4\mathrm{m}}$ where $L_{p,0.4\mathrm{m}}$ denotes the sound pressure level at a position of 0.4m apart from the center of the aperture end section of the transmitted wave side, D_{IL} is equivalent to the sound pressure level difference $L_{p,\mathrm{i}} - L_{p,0.4\mathrm{m}}$. This implies that D_{IL} is equivalent to the difference between the sound pressure levels with and without the wall.

Incidentally Ohkawa, Tachibana and Koyasu introduced the normalized sound transmission loss [2], which is defined as the decibel expression of the ratio between the transmitted sound power and the incident sound power per unit wall area. Since the sound pressure level $L_{p,\mathrm{i}}$ is equivalent to the sound intensity level or the sound power level passing through unit area normal to the direction of the incident wave propagation, D_{IL} is equivalent to the normalized sound transmission loss when the incidence angle is normal to the wall. From Equations (1) and (2) we have a relationships

$$R - D_{\mathrm{IL}} = 10\log_{10}(S_{\mathrm{F}} \cos\theta) \qquad (3)$$

and D_{IL} will be primarily used in the succeeding sections.

3. Numerical simulation

To obtain the sound pressure and particle velocity distribution around an aperture of interest, a boundary element method of constant element is employed. The largest element size taken is 25mm. To provide a plane wave incidence around the aperture, the distance between the aperture and a point source (the amplitude of $s_{\mathrm{s}} = 100/4\pi$) taken was 1km. For the sound absorbent liner, the locally reacting model is employed for simplicity. A fiberglass board of the density of $32\mathrm{kg/m^3}$ and the flow resistivity of $8500\mathrm{Pa \cdot s/m^2}$ are assumed for the sound absorbing liner. Its acoustical property was estimated by using the empirical expression given by M. E. Delany and E. N. Bazley [3]. The insertion loss of a rigid wall (300 mm thick) with an aperture (the diameter of 100 mm) of a rigid perimeter was investigated. Figure 2 compares the analytical formula for normal incidence, the experiment (by the two reverberant chambers method) of G. P. Wilson and W. W. Soroka [1] and the present numerical simulation for normal incidence, in terms of the insertion loss. They agree excellent in the frequencies below 1000Hz, where the largest element size of the present numerical simulation is 1/12 of the wavelength. This implies the effectiveness of the numerical simulation. It is important to suppress the axial 1st mode sound transmission.

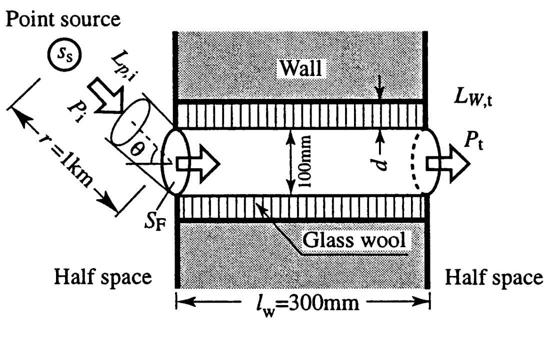

Fig.1 Sound transmission through a wall aperture

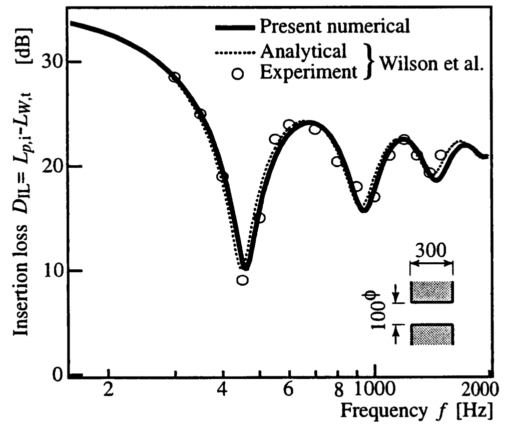

Fig.2 Insertion loss of a wall with an aperture

4. Acoustic lining on aperture perimeter

To reduce the transmission at the resonant frequency of the axial 1st mode, f_1, the effect of mounting a sound absorbent liner to the aperture perimeter was investigated for a simple wall aperture case. Figure 3 shows the effect of a sound absorbent liner on the insertion loss.

Incidentally, the dependence of the insertion loss D_{IL} on the incident angle θ is practically small enough to ignore. The sound absorbent liner shifts the resonant frequency toward remarkably smaller, as the liner becomes thicker. However the liner improves only 5dB, at most, the insertion loss D_{IL} around the resonant frequency f_1.

5. Resonant frequency of axial mode

For an aperture as shown in Figure 4, nth (n being an integer) mode resonant frequency takes place when the phase difference of the traveling wave between the effective open ends of incident and transmitted wave sides coincides with $n\pi$, i.e.,

$$f_n = n/2(l_{\mathrm{M,i}}/c + l_{\mathrm{w}}/c_{\mathrm{w}} + l_{\mathrm{M,t}}/c) \qquad (4)$$

where c denotes the sound speed in the free field, c_{w} denotes the phase velocity in the airway of the aperture, $l_{\mathrm{M,i}}$ and $l_{\mathrm{M,t}}$ are the end correction length of the incident and transmitted wave side, respectively. When the perimeter is unlined and rigid, $c_{\mathrm{w}} = c$, and $l_{\mathrm{M,i}} = l_{\mathrm{M,t}} \simeq 0.38D$ around $f \simeq 500\mathrm{Hz}$. For these values, Equation (4) gives $f_1 \simeq 450$ which agrees very well with $f_1 \simeq 460\mathrm{Hz}$ for $d = 0\mathrm{mm}$ of Figure 3.

On the other hand, when the aperture perimeter is lined, the values of $c_{\mathrm{w}} (\neq c)$, $l_{\mathrm{M,i}}$ and $l_{\mathrm{M,t}}$ are unknown. To determine c_{w}, attaching pipes (with the same diameter as the aperture) both side of the aperture, a 2-port equation set was composed for the characteristic impedance and the propagation constant of the aperture [4]. To determine either $l_{\mathrm{M,i}}$ or $l_{\mathrm{M,t}}$, removing the pipe corresponding $l_{\mathrm{M,i}}$ or $l_{\mathrm{M,t}}$, the impedance of another pipe was used. For these, the sound fields of the pipes were observed numerically. In this way $c_{\mathrm{w}} \simeq 189\mathrm{m/s}$, $l_{\mathrm{M,i}} = l_{\mathrm{M,t}} \simeq 0.89D$ around $f \simeq 250\mathrm{Hz}$ were obtained when $d = 50\mathrm{mm}$. For these values Equation (4) gives $f_1 \simeq 232\mathrm{Hz}$ which agrees excellently with $f_1 \simeq 240\mathrm{Hz}$ for $d = 50\mathrm{mm}$ of Figure 3.

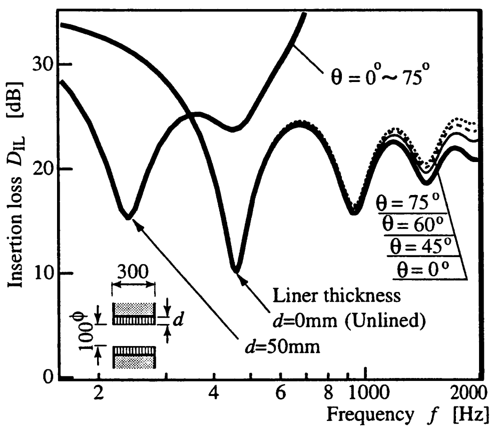

Fig.3 Insertion of acoustic liners

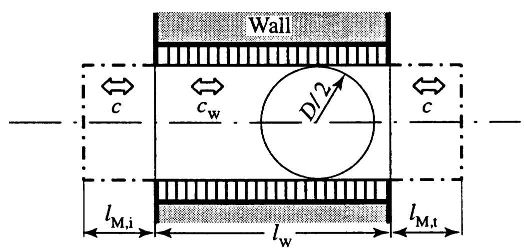

Fig.4 Mass end corrections $l_{\mathrm{M,i}}$ and $l_{\mathrm{M,t}}$ of a open-ended duct, and phase speed in aperture, c_{w}

6. Attachment of a hood

As an alternative sound suppression technique, a disk shape hood was attached to the sound source side of the aperture as shown in Figure 5. When the hood is rigid, at the resonant frequency f_1, the sound insulation becomes poorer as the hood size increases. When the hood is acoustically lined, although the improvement in the insertion loss is extensive for higher frequencies, that around the resonant frequency f_1 is only a few dB.

7. Insertion of a Helmholtz resonator

Figure 6 shows the effect of the insertion of the Helmholtz resonator (the cavity volume of 0.55ℓ, the neck length of $5\mathrm{mm}$, the neck cross-sectional area of $3.5\mathrm{cm}^2$) side-branched at the midway of the aperture. The insertion of the Helmholtz resonator is effective and promising for the purpose.

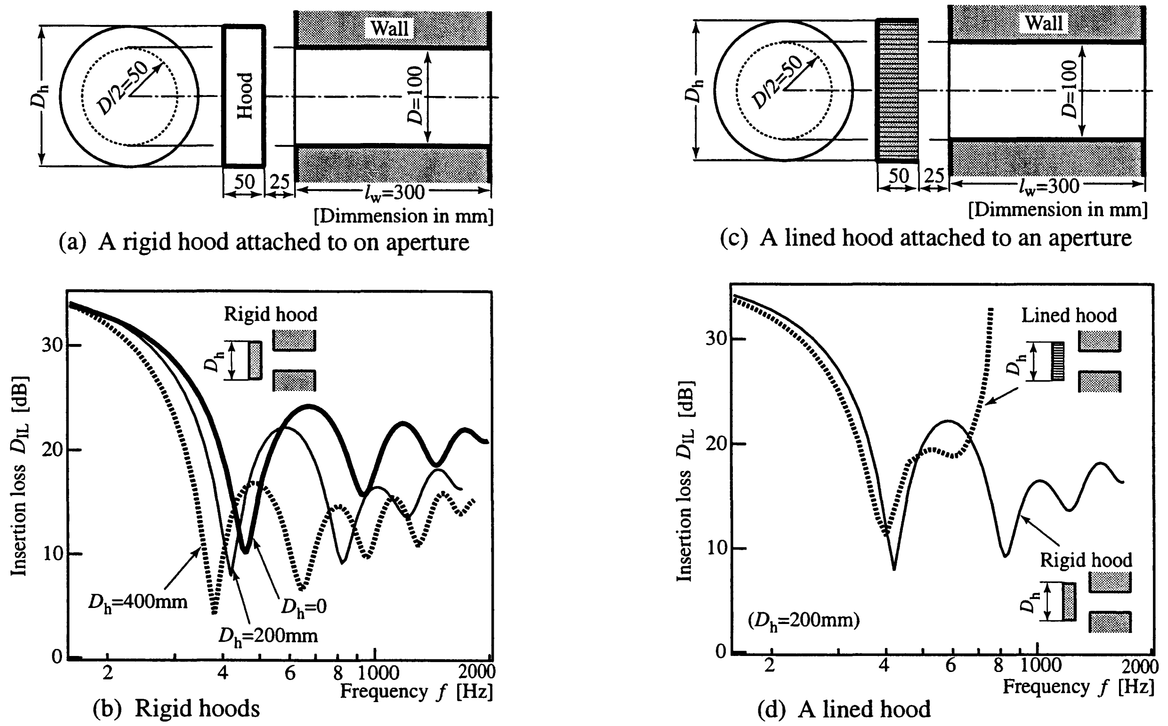

Fig.5 Attachment of hoods

Conclusions

Sound reduction techniques of the axial 1st mode transmission of a wall aperture for ventilation purpose were investigated by conducting a boundary element numerical simulation. The important findings are as follows: The dependence of the insertion loss on the incident angle is small. A sound absorbent liner mounted to the aperture perimeter decreases considerably the resonant frequency, as the liner becomes thicker. The attachment of a hood shifts the resonant frequency downward and decreases the sound insulation, as the hood size increases. To suppress the 1st mode sound transmission of an aperture, the insertion of a Helmholtz resonator is promising while the sound absorbent liners and the hoods are not effective enough.

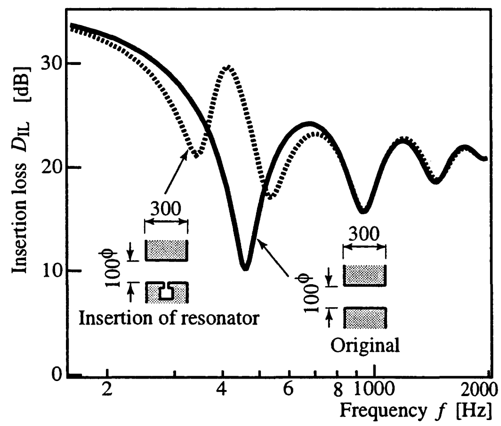

Fig.6 Insertion of a Helmholtz resonator

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