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Attenuation characteristics of evanescent sound field by porous material
多孔質材料によるエバネッセント音場の減衰特性

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1. Introduction

Porous materials have been used in many fields such as architect, automobile, and underwater acoustics owing to its sound absorption and insulation characteristics. Especially, attenuation and reflection characteristics of plane wave by the porous materials are well studied.[1)] On the other hand, there are sound fields that differ from the plane wave in property, such as evanescent sound field whose amplitude attenuates exponentially with distance.[2,3)] Recently, the property of the evanescent sound field is utilized for near field acoustic communication system and loudspeaker generating sound locally.[4, 5)] However, the attenuation characteristics in the porous material and at the surface of the material has not been analyzed in detail when the material is put into the evanescent sound field. Therefore, we aim to analyze the attenuation characteristics of the evanescent sound field by the porous material. The analysis can offer new insight into design of sound absorber and insulator using the porous material. As a basic research, we simulate attenuation of sound pressure with respect to the thickness of the porous material put into the plane wave and the evanescent sound field generated from an infinite sound source using a finite element method (FEM).

2. Propagation characteristics of sound wave in porous material

Characteristic impedance Z and propagation coefficient γ of a porous material made of the fiber commencing with glass wool and rock wool are expressed as following functions of flow resistivity R_f and frequency f called Miki model.[6)]

$$Z(f) = R(f) + jX(f)\,, \tag{1}$$

$$\gamma(f) = \alpha(f) + j\beta(f)\,, \tag{2}$$

$$R(f) = \rho c\left[1 + 0.070(f / R_\mathrm{f})^{-0.632}\right], \tag{3}$$

$$X(f) = -0.107\rho c(f / R_\mathrm{f})^{-0.632}, \tag{4}$$

$$\alpha(f) = \frac{\omega}{c}\left[0.160(f / R_\mathrm{f})^{-0.618}\right], \tag{5}$$

$$\beta(f) = \frac{\omega}{c}\left[1 + 0.109(f / R_\mathrm{f})^{-0.618}\right]. \tag{6}$$

Where c and ω are sound velocity in air and angular frequency. The sound pressure at surface of the porous material p_t is obtained using Z and γ as following equation when the plane wave propagates in the material.

$$p_\mathrm{t} = u_\mathrm{in}\rho c Z / \left(\rho c \sinh \gamma d + Z \cosh \gamma d\right). \tag{7}$$

Where u_in, d, and ρ are input particle velocity, thickness of the porous material, and density of air. Equation (7) was treated as the theoretical equation in order to confirm applicability of FEM simulation in this study.

3. Comparison of attenuation of particle velocity between plane wave and evanescent sound field

3.1 Simulation procedure

Figure 1 shows sound field including the porous material and the air layer in the xz-plane. The sound field was assumed to be uniform in the y-direction. In addition, infinite sound field was calculated using the periodic boundary conditions that share sound pressure and particle velocity in common, as shown in Fig. 1. The plane wave was generated when input particle velocity of the boundary at z = 0 mm in the z-direction $u_\mathrm{in}(x)$ is unity. In the case of the evanescent sound field, $u_\mathrm{in}(x)$ is expressed as $\exp(-jk_\mathrm{p}x)$ using wavenumber k_p. Here, k_p has to be larger than wavenumber of plane wave in air, k, to generate the evanescent sound field. Therefore, v was determined as 30 m^{-1}. Flow resistivity R_f was 500,000 Pa s/m^2 and frequency f was 6 kHz. The sound pressure p_t of the observation point at z = 11 mm with respect to the thickness of the porous material d varying from 0 to 10 mm with 0.5 mm increments was simulated using FEM simulation software (COMSOL Multiphysics 4.4).

3.2 Results and discussions

Figure 2 shows attenuation of sound pressure level difference at an observation point with respect to the thickness of the porous material. Sound pressure in the

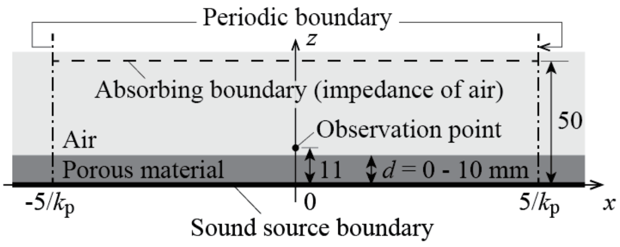


Fig. 1. Sound field including porous material and air layer in the xz-plane in FEM simulation

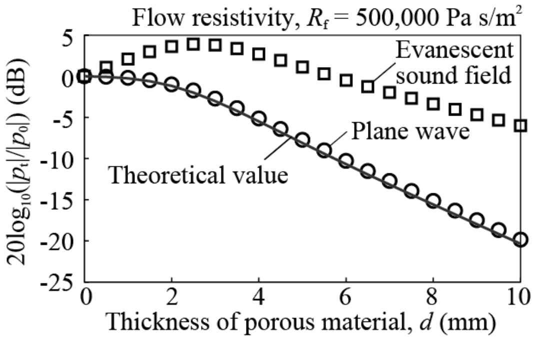


Fig. 2. Attenuation of sound pressure level difference at an observation point with respect to the thickness of the porous material.

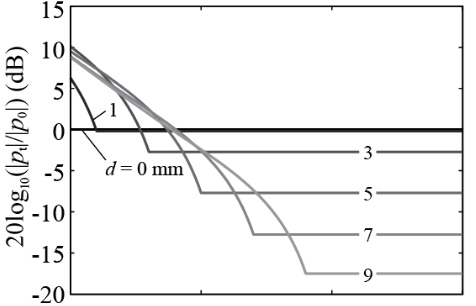
case of d = 0 mm was defined as p_0. Here, the solid line show sound pressure level difference $20\log_{10}(|p_t|/|p_0|)$ calculated using Eq. (7). The circle and triangle marks show the sound pressure level difference with respect to the thickness of the porous material d in the cases of the plane wave and the evanescent sound field in the simulation. It is found that the sound pressure level difference of theoretical value obtained using Eq. (7) and simulation value were in good agreement in the case of the plane wave. It was suggested that the simulation can calculate sound wave propagation in the porous material correctly. The sound pressure level difference decreased monotonically with increasing d. On the other hand, the sound pressure level difference increased within d = 2.5 mm. In addition, the sound pressure level difference was larger than 0 within d = 5 mm. To confirm the cause, the distribution of the sound pressure level difference was also simulated.

Figures 3(a) and **3(b)** show the distribution of the sound pressure level difference $20\log_{10}(|p_t|/|p_0|)$ at x = 0 mm in the cases of the plane wave and the evanescent sound field. The sound pressure level difference attenuated rapidly near the boundary of the porous material and the air layer because reflected wave also attenuated. In addition, the attenuation of the evanescent sound field in the porous material in comparison with that of the plane wave was small. Therefore, $|p_t|$ was larger than $|p_0|$ within d = 5 mm, as shown in Fig. 2. According to the result, it was clarify that the attenuation characteristics is different from that of the plane wave when the medium, which has the characteristic impedance and the propagation coefficient obtained using Miki model, is put into the evanescent sound field.

4. Conclusions

In this study, we aimed to analyze the attenuation characteristics of evanescent sound field by porous material. The attenuation of sound pressure with respect to a thickness of the porous material put into plane wave and the evanescent sound field generated from an infinite sound source was simulated. The sound pressure level attenuated rapidly near the boundary of the porous material and the air layer because reflected wave also attenuated, and the attenuation of the evanescent sound field in the porous material in comparison with that of the plane wave was small. Therefore, it was confirmed that the attenuation characteristics was different from that of the plane wave when the porous material is put into the evanescent sound field. As further study, we will measure the attenuation characteristics by experimental investigation.

(a) Plane wave



(b) Evanescent sound field

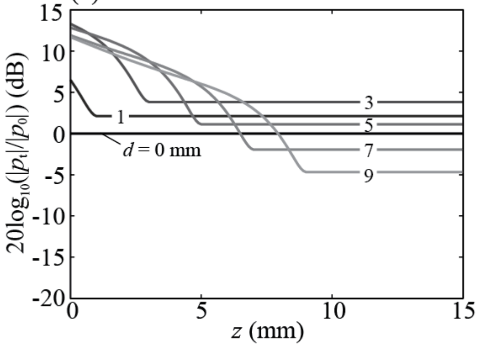


Fig. 3. Distribution of the sound pressure level difference at x = 0 mm, (a) plane wave and (b) evanescent sound field

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References

1. J. Allard and N. Atalla: *Propagation of Sound in Porous Media: Modeling Sound Absorbing Materials* (Jhon Wiley & Sons, 2009) 2nd ed., p. 1.
2. A. Fujii, N. Wakatsuki, and K. Mizutani, Jpn. J. Appl. Phys. **54**, 07HB08 (2015).
3. K. Yamada, D. Yamazaki, and K. Nakamura, Jpn. J. Appl. Phys. **43**, 2996 (2004).
4. A. Fujii, N. Wakatsuki, and K. Mizutani, Jpn. J. Appl. Phys. **53**, 07KB07 (2014).
5. H. Ito, K. Furuya, and Y. Haneda, Proc. IEEE Int. Conf. Acoustics, Speech and Signal Processing, 2012, p. 221.
6. Y. Miki, J. Acoust. Soc. Jpn. (E) **11**, 1 (1990).