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Characteristics of Wave Propagation on Honeycomb Sandwich Panel in Audible Frequency Range

ハニカムサンドイッチパネルの可聴域における波動伝搬特性

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1. Introduction

Audio guidance in public spaces has been attracting attention as a method of presenting information that is not visual based. Hence, a loudspeaker that can indicate the right direction regardless of position on a pathway is necessary. To meet such demand, we have proposed a panel loudspeaker that emits sound with an inclined angle from a flexural wave propagating in an elastic plate (hereafter, we call this "inclined sound") [1]. The inclined sound is radiated in the air when the phase velocity of the flexural wave is larger than the sound velocity in air, and people perceives the direction of arrival of the sound wherever the inclined sound propagates [2]. Hence, if we can cover a ceiling of corridors with large panel speakers, an evacuation guidance system that enables people to perceive the destination direction intuitively would be achieved [3]. this loudspeaker was suggested a numerical analysis method for the propagation properties of flexural wave in honeycomb sandwich panel [4].

We studied the reflection of the flexural wave when there exists a gap in honeycomb sandwich structure using FEM [5]. In the process, we needed to investigate where the energy was propagating on panel. Wave propagation on honeycomb sandwich panel was studied in 50 - 500 (kHz) [6]. that in audible frequency range has not been investigated yet, to our knowledge. Hence, in this paper, we investigate the energy flux on honeycomb sandwich panel in audible frequency range.

2. Modeling of honeycomb core as an orthotropic continuum

In honeycomb sandwich panel, evaluating the energy flux of honeycomb core due to the presence of cavities. Therefore, we simulate the honeycomb core as an orthotropic continuum. In order to verify the appropriateness of modeling honeycomb core as an orthotropic continuum, we compared the physical properties of a numerical model with two model. Figure 1(a) shows the honeycomb sandwich panel modeled by shell elements in three dimension using FEM simulation software (COMSOL Multiphysics 5.4). Figure 1(b) shows the honeycomb sandwich panel modeled by solid elements as an orthotropic continuum. This model is called the simplified model in this paper. This model was represented by 2D plane - strain model to ignore the displacement in the y-direction. This model is called the honeycomb model in this paper. Table I shows the physical parameters of honeycomb model. In addition, Table II shows the physical property of honeycomb core as an orthotropic continuum obtained using the parameters listed in Table I. The core ratio R in Table

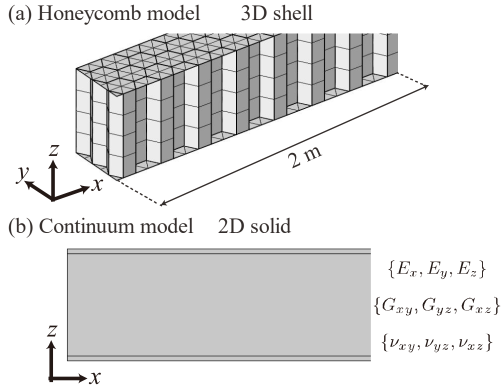

Fig. 1 Two types of honeycomb sandwich panel [3]. (a) honeycomb model, (b) simplified model.

Table. I Properties of honeycomb sandwich panel

Parameter	Value
Thickness of face plate, h_f	1 mm
Height of honeycomb core, h_c	23 mm
Core ratio, R	0.011
Density of face plate	2700 kg/m^3
Density of honeycomb core	79.2 kg/m^3
Young's modulus, E	70 GPa
Poisson's ratio, ν	0.33

Table. II Equivalent physical properties of honeycomb core in simplified model

Young's modulus	Modulus of rigidity	Poisson's ratio
$E_x = 12R^3E$	$G_{xy} = \frac{36}{5}RG$	$\nu_{xy} = 0.999$
$E_y = 12R^3E$	$G_{yz} = \frac{5}{3}RG$	$\nu_{yz} = \frac{E_y}{E_z}\nu$
$E_z = \frac{8}{3}RE$	$G_{xz} = RG$	$\nu_{xz} = \frac{E_x}{E_z}\nu$

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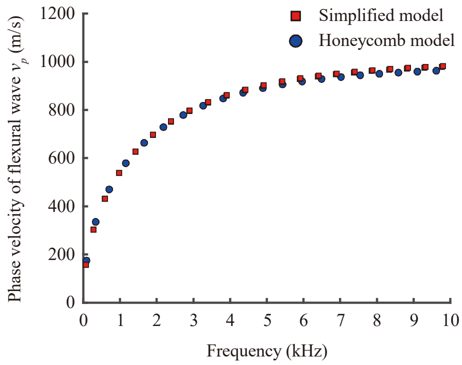

Fig. 2 Frequency characteristics of phase velocity of the flexural wave in FEM.

II is the ratio of the one side thickness to the diagonal length of the hexagons in the honeycomb core. In honeycomb models, the face plate was divided into triangular elements and the honeycomb core was divided into quadrangular elements. In simplified models, the face plate and honeycomb core was divided into quadrangular elements. we compared frequency characteristics of phase velocity in both model. The wavenumber k in the x-direction was calculated using the wavenumber spectrum of flexural wave in the natural frequency f_N, and the phase velocity v_p was given by the general expression $v_p = f_N/k$. Figure 2 shows the frequency characteristics of phase velocity of the flexural wave v_p. The square and circle marks also show v_p in FEM simulation in the honeycomb model and continuum model. the simplified model shown as squares marks were in good agreement with the honeycomb model shown as circles. Therefore, the characteristics of wave propagation in honeycomb panels can be represented by the simplified model.

3. Energy flux in honeycomb panel

The energy flux of panel was calculated by simulation of forced vibration in audible frequency range. Driving force of 1 N in z-direction was applied at x = 0, Rayleigh damping of 5.0×10^3 (1/s) is introduced in panel. The length of panel in the x direction is 2 (m). Figure 3(a) and 3(b) shows the energy flux of panel in 4 and 8 (kHz). maximum relative deformation of displacement is 0.03. According to Figs. 3(a) and 3(b), The energy flux of honeycomb in peak and dip of wave increases as frequency is raised. On the other hand, the energy flux of face plate in peak and dip of wave decreases as frequency is raised.

At high frequency, the energy flux in the honeycomb core become large rather than in the face plate. This may result in the shear stress becoming large rather than the tensile stress. And vice versa. it is assumed that the honeycomb core transfers the shear stress instead of the face plate and the face plate transfers the tensile stress instead of the honeycomb core. This suggests that flexural wave propagates in panel with shear stress of honeycomb core and tensile stress of face plate.

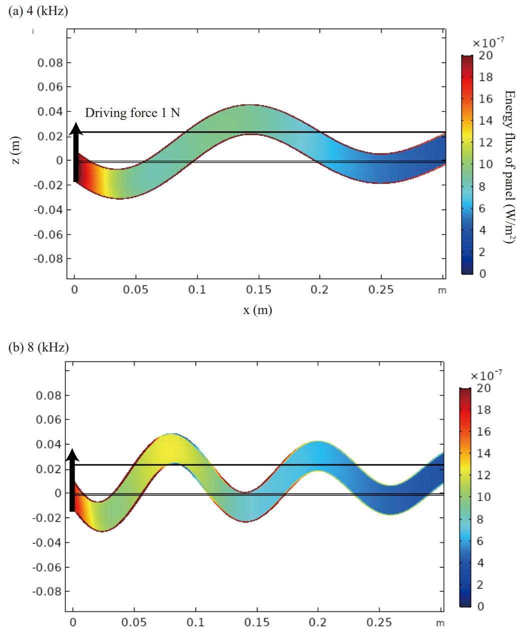

Fig. 3 Energy flux of panel in audible frequency range. (a) 4 (kHz), (b) 8 (kHz)

4. Conclusion

We calculated the energy flux in a honeycomb sandwich panel as an orthotropic continuum. As a result, the energy flux of honeycomb in peak and dip of wave increases as frequency is raised. And vice versa. This suggests that flexural wave propagates in panel with shear stress of honeycomb core and tensile stress of face plate. In the future, numerical analysis of shear stress and tensile stress in panel when there is a gap on the face plate and the honeycomb core is planned.

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