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Experimental study on sound absorption characteristics of granular material : Influence of lateral constraints of casing

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ABSTRACT

The sound absorption characteristics of flowable granular materials may vary owing to lateral constraints. In order to clarify the effect of lateral constraints on the sound absorption characteristics of granular materials, the normal incidence sound absorption coefficients of hollow glass beads filled in cylindrical containers of different diameters were measured. The measurement results demonstrated that the sound absorption coefficients varied depending on the diameters of the containers. As the diameter increased while the thickness of the granular material was constant, the first peak frequency of the sound absorption coefficient shifted towards a lower frequency. The amount of shift due to diameter expansion increased with larger thickness of the granular material. These results suggest that the sound absorption characteristics of granular materials can be controlled by adjusting the distance between the constraining walls without changing the thickness of the granular materials.

Keywords: Absorption, Granules, Constraint

1. INTRODUCTION

It is well-known that granular materials have sound absorption characteristics [1-4]. Glass beads and vermiculite, whose particle sizes are of the millimeter order, absorb sound energy at high frequencies in a manner similar to fibrous porous materials such as glass wool [1,2]. On the other hand, silica powder and fine polymer particles, whose particle sizes are of the micrometer order, show different sound absorption characteristics having a sharp peak at low frequencies [3,4]. For granular materials that possess sound absorption characteristics having a sharp peak at low frequencies, it is thought that vibrations of the particles contribute to sound absorption at the first peak frequencies of normal incidence sound absorption coefficient because these first peaks correspond to the first modal frequencies of the vibrating particles [3].

When granular materials are used for sound absorption, it is necessary to take measures to retain their shapes as a mass because of flowability. One such measure to retain the shape is to constrain the materials by walls. The sound absorption characteristics of constrained granular materials may be variable because the vibrations of the particles are suppressed by the walls. A formula has been proposed in literature to predict the first peak frequency of normal incidence sound absorption coefficient for a granular material filled in a container, using the apparent dynamic longitudinal elastic modulus and effective mass [5]. According to the formula [5], the first peak frequency depends on a diameter of cylindrical container. However, experimental verification of the effect of the diameter on the sound absorption coefficient is insufficient. Therefore, this study aims to experimentally clarify the effect of lateral constraints on sound absorption characteristics of granular materials. Measurements of normal incidence sound absorption coefficients are performed with a granular material filled in cylindrical containers of different diameters.

2. THEORETICAL DERIVATION OF FIRST PEAK FREQUENCY

This study assumes that the first peak frequency of the normal incidence sound absorption coefficient

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corresponds to the first modal frequency of vibration of granular materials. The first modal frequency of vibration is expressed as [6]

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{M_{\mathrm{eff}}}} \quad . \tag{1}$$

The first peak frequency of the normal incidence sound absorption coefficient is also given by Eq.(1). Here, k is the apparent dynamic longitudinal elastic modulus, and M_{eff} is the effective mass of granular materials.

The apparent dynamic longitudinal modulus of granular materials filled in a container is described as [6]

$$k = \frac{2}{3}\beta E_0\left(\frac{\rho g}{\beta} - P_0\right) h \left[\left\{\frac{\rho g}{\beta} + (P_0 - \frac{\rho g}{\beta})e^{-\beta h}\right\}^{\frac{2}{3}} - {P_0}^{\frac{2}{3}}\right]^{-1} \quad , \tag{2}$$

where ρ is the bulk density; g is the gravitational acceleration; P_0 is the external force applied to the material surface; h is the thickness of granular materials; S is the area of the surface on which sound is incident; E_0 is the constant inherent to the material. In this case, P_0 is the effective sound pressure on the surface. β is called the Janssen coefficient, which is given by

$$\beta = \frac{4K\mu_W}{d} \quad , \tag{3}$$

when the shape of the container is cylindrical [7]. Here, K is the ratio of horizontal force to vertical force in the direction of sound propagation. In this case, the vertical force corresponds to the sound pressure in a granular material in the direction of sound propagation, and the horizontal force corresponds to the force acting on the walls of a container. μ_{w} is the friction coefficient between the container wall and the granular material; d is the inner diameter of the cylindrical container. If the external force applied to material surface in the sound propagation direction is small enough to establish that $\frac{\rho g}{\beta} - P_0 \approx \frac{\rho g}{\beta}$, Eq.(2) is simplified to

$$k = \frac{2}{3} S E_0 (\rho g)^{\frac{1}{3}} \left(\frac{\beta}{1 - e^{-\beta h}}\right)^{\frac{2}{3}} \quad . \tag{4}$$

The effective mass of the granular material filled in a container is given as [5]

$$M_{\mathrm{eff}} = \frac{\rho S}{\beta}\left(1 - e^{-\beta h}\right) \quad . \tag{5}$$

The first peak frequency of normal incidence sound absorption coefficient is determined from Eq.(1) by substituting Eqs.(4) and (5).

3. MEASUREMENT OF SOUND ABSORPTION COEFFICIENT

3.1 Granular Material

Hollow glass beads were used as the granular material in the measurements. Table 1 shows the basic properties of the hollow glass beads. These beads were filled in cylindrical containers made of polylactic acid resin, and no additional force was applied as the material was constrained by the container walls. The surface of the material in the container was leveled smoothly by light tapping after pouring. Figure 1 shows the material used in the measurements.

Table 1 Basic properties of the specimen.

Granular material	Hollow glass beads
Mean Particle Diameter (μm)	60
Bulk Density (kg/m^3)	120
True Density (kg/m^3)	200
Porosity	0.4

3.2 Measurement Set-up

The sound absorption coefficients of the hollow glass beads were measured by the transfer function method using acoustic tubes [8]. Figure 2 illustrates the measurement set-up. The measurements were conducted using two types of cylindrical steel acoustic tubes with inner diameters of 100 and 200 mm, respectively. The acoustic tubes were positioned such that the axial direction was perpendicular to the ground, and the specimens were installed at the bottom. A maximum length sequence pseudo-random noise was used as a sound source. The frame of the container was attached to the wall of the acoustic tube, and the contact gap between the container and the tube was sealed by petrolatum. The back of the container was attached to a hard steel plate, which can be regarded as rigid. The sound absorption coefficient with an empty container was approximately 0.01 in the frequency range from 40 to 2k Hz. It was confirmed that the effect of the container itself and the contact gap of the sound absorption coefficients were small. The sound absorption coefficients were measured for material thicknesses of 40, 80, 160, and 320 mm.

Figure 1 Hollow glass beads used in the measurements.

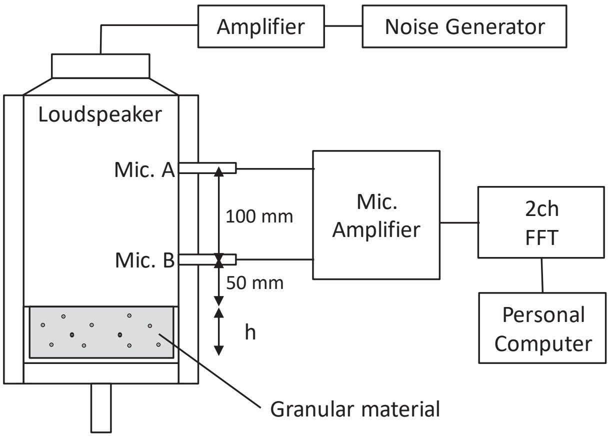

Figure 2 Measurement set-up of normal incidence sound absorption coefficient.

4. RESULTS

The experimental results of the sound absorption coefficients of the hollow glass beads are shown in Fig. 3. Furthermore, Fig. 4 shows the experimental results of the first peak frequency of the sound absorption coefficients based on the material thickness. Figure 3 depicts that the values of the sound absorption coefficients at first peak frequency are almost similar regardless of the diameter of container. Figure 4 shows that the first peak frequency shifted towards lower frequency with larger diameter under a constant material thickness. The larger the thickness, the larger the change in the first peak frequency due to the diameter variation.

The first peak frequency is theoretically derived as described in Section 2. The derivations require constants E_0, K, μ_w as the physical properties of the material. However, it is difficult to measure them directly. Therefore, they were estimated by curve-fitting the calculated results to experimental results by the least-squares method for the case of 100 mm diameter. As a result, they were estimated as $E_0 = 1.43 \times 10^5$ and $K\mu_w = 0.29$. Using the estimated values for E_0 and $K\mu_w$, the first peak frequency of the hollow glass beads filled in the container of diameter of 200 mm are obtained. Figure 4 shows the theoretical values of the first peak frequency for two different diameters. In case of 200 mm diameter, the theoretical values of the first peak frequency using the estimated E_0 and $K\mu_w$ for the case of 100 mm diameter show good agreement with the experimental results, which validated the theory described in section 2. Furthermore, theoretical values shown in Fig. 4 suggested that the first peak frequency of the hollow glass beads filled in the container may converge to a specific value as the material thickness increases.

Additionally, the first peak frequency in case of an infinite diameter is shown in Fig. 4 to exclude the effect of the wall constraints. The first peak frequency in this case can be regarded as a specific value inherent to the material, and it is predicted to decrease in proportion to the thickness in this case. The first peak frequency in case of an infinite diameter is lower than the ones in case of a finite diameter.

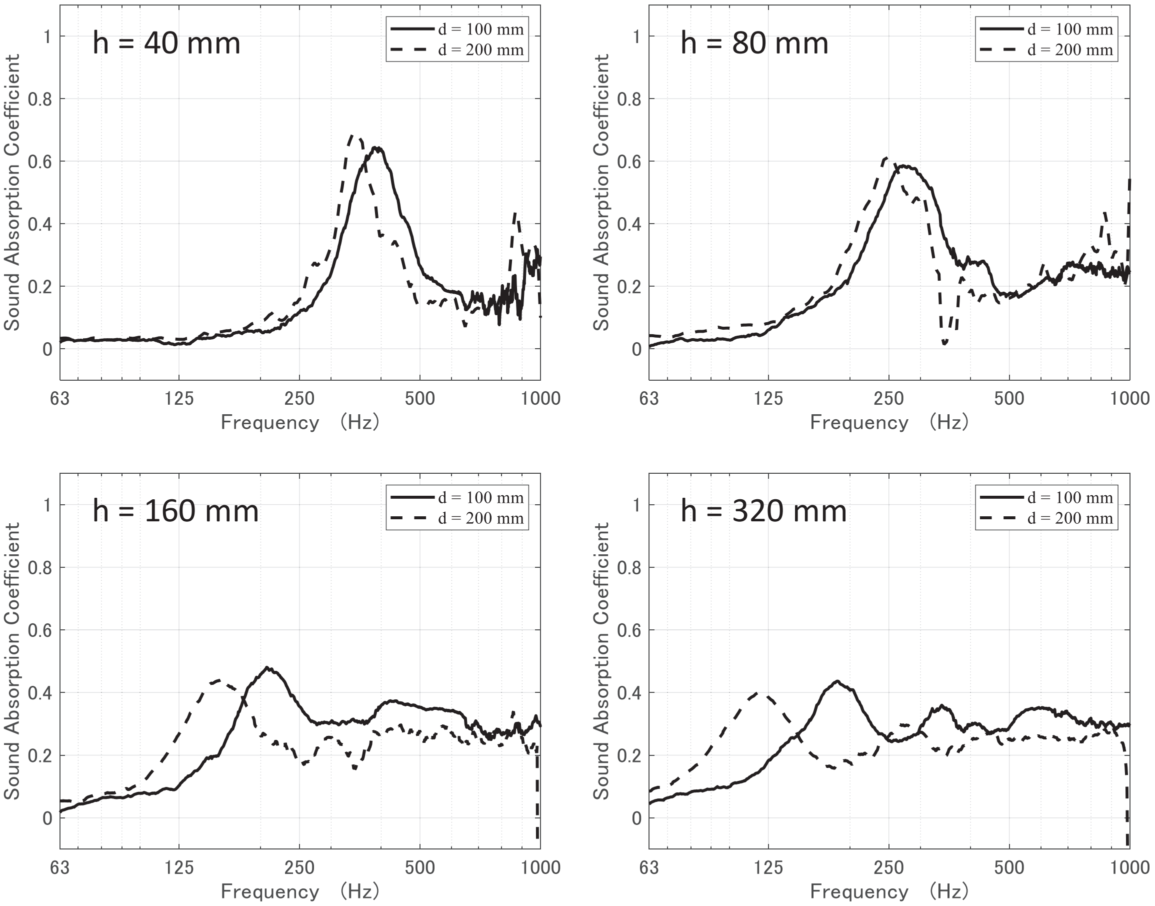

Figure 3 Normal incidence sound absorption coefficients of hollow glass beads using acoustic tubes with different diameters.

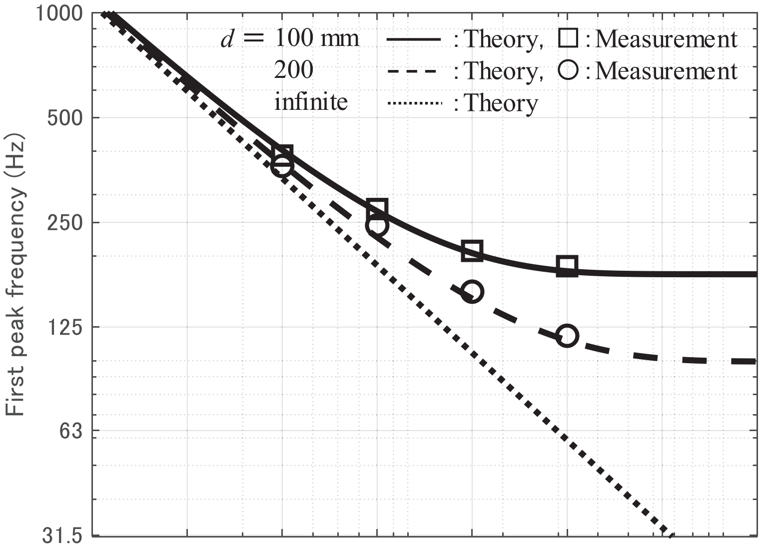

Figure 4 First peak frequency of normal incidence sound absorption coefficients of hollow glass beads for various thickness.

5. CONCLUSION

By measuring the normal incidence sound absorption coefficients of the hollow glass beads filled in containers of different diameters, the effect of constraints by the walls on the sound absorption coefficient of granular material was verified. The results reveal that, for the hollow glass beads, the first peak frequency varies depending on the distance between the constraining walls; the variations of coefficients due to the variation of the distance are larger as the material thickness increases. These results suggest that the sound absorption characteristics of granular materials can be controlled by adjusting the distance between the constraining walls without changing the material thickness. The lower limit of the first peak frequency can be determined from the physical properties of the material according to the material thickness.

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