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Improvement of sound insulation performance of double-glazed windows by using viscoelastic connectors

D. Takahashi [a,*], S. Sawaki [a], R.-L. Mu [b]

[a] Department of Architectural Engineering, Kyoto University, Japan
[b] School of Mechanical Engineering, TianJin University of Science and Technology, China

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ABSTRACT

A new method for improving the sound insulation performance of double-glazed windows is proposed. This technique uses viscoelastic materials as connectors between the two glass panels to ensure that the appropriate spacing is maintained. An analytical model that makes it possible to discuss the effects of spacing, contact area, and viscoelastic properties of the connectors on the performance in terms of sound insulation is developed. The validity of the model is verified by comparing its results with measured data. The numerical experiments using this analytical model showed the importance of the ability of the connectors to achieve the appropriate spacing and their viscoelastic properties, both of which are necessary for improving the sound insulation performance. In addition, it was shown that the most effective factor is damping: the stronger the damping, the more the insulation performance increases.

1. Introduction

The total level of sound insulation of a building strongly depends on the sound insulation performance of the windows, which are also important for light transmission and heat insulation. This importance leads to the adoption of a double-panel window; however, the double panels cause sound insulation deficiencies at frequencies near that of mass–air–mass resonance. In an attempt to eliminate these deficiencies and increase the sound insulation performance of double-panel partitions, Mason and Fahy [1] added Helmholtz resonators to the perimeter of the air layer of the partition, and studied the effect on sound insulation both theoretically and experimentally. Mao and Pietrzko [2] conducted similar theoretical investigations and reported some progress on improving sound insulation via experimental investigations [3].

Other ways to suppress the effect of mass–air–mass resonance were also proposed; for example, Idrisi et al. [4] studied the effect of absorptive materials with additional mass, and Sugie et al. [5] reported the effects of introducing Helmholtz resonators into the air layer. Lin et al. [6] proposed attaching a vibration absorber to one side of the panel and discussed its effects by means of a simple one-degree of freedom model and experiments. However, these techniques [4–6] cannot be used for improving the sound insulation performance of double-glazed windows, because they impair translucency. Mu et al. [7] studied a new method for suppressing the effect of mass–air–mass resonance by applying micro-perforation to the transmission side of the panel. Although the sound insulation around the resonance frequencies improved, degradation at high frequencies was also detected.

* Corresponding author.
E-mail address: tkhs@archi.kyoto-u.ac.jp (D. Takahashi).

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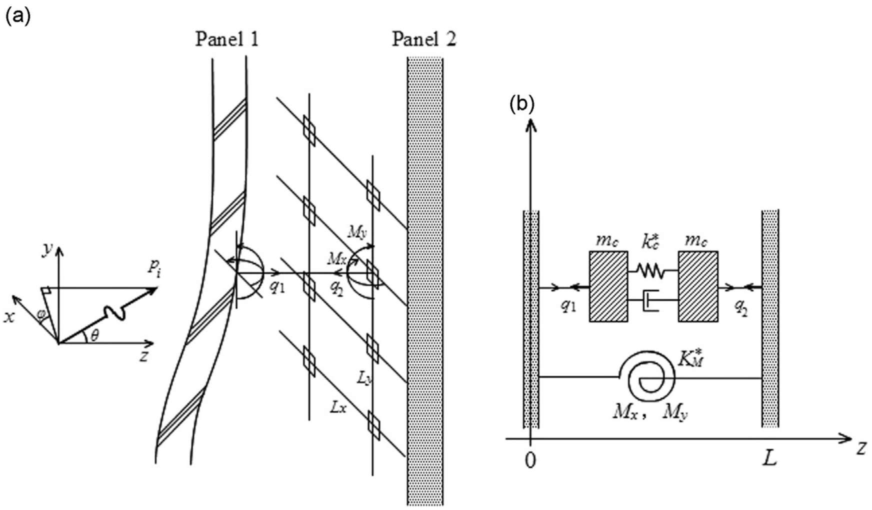

Fig. 1. (a) Schematic illustration of a double-panel structure with viscoelastic connectors, and (b) model of force and moment transmission of a connector.

Here, we present a new method for improving the sound insulation performance of double-glazed windows. Our technique includes the use of viscoelastic materials, which are used to connect the two panels at certain intervals. Related theoretical investigations were reported in our previous work [8], in which favorable effects were predicted. However, we used a special kind of analytical model using a tube of infinite extent with simply supported rectangular panels. Moreover, the connectors in our previous study needed to be improved as they are supposed to form a point connection with normal-force transmission alone.

In this study, periodically connected double-panel structures of infinite extent with a plane wave incidence are analyzed with respect to sound transmission, which is statistically averaged by using a weighting function suggested by Kang et al. [9]. Taking into consideration the effect of a contact point area, the connection is modeled as moment transmission as well as the normal force transmission. The effects of viscoelastic connectors on the sound transmission are discussed both theoretically and experimentally for a double-glazed window manufactured of two 3-mm-thick glass panels with a 1-cm-thick air layer between them. Differences between our previous work [10] and the present study are the dimensions of the double-panel system and the existence or non-existence of moment transmission. In both studies, the related parameters are the same except for those attributed to the difference in the analytical model.

2. Theory

2.1. Formulation of the problem

A double-panel structure with an air layer thickness L vibrates under an incident plane wave of sound pressure p_i with unit amplitude; thus, $p_i = \mathrm{e}^{\mathrm{i}(k_x x + k_y y + k_z z)}$ (Fig. 1(a)), where $k_x = k \sin\theta \cos\phi, k_y = \sin\theta \sin\phi, k_z = k\cos\theta$, and $k\ (=\omega/c)$ is the wavenumber, ω is the angular frequency and c is the speed of sound. The time factor is assumed to be $\mathrm{e}^{-\mathrm{i}\omega t}$, and suppressed throughout. The connectors between two panels are placed at equal intervals l_x and l_y in the two directions x and y, respectively. Fig. 1(b) shows the model of force and moment transmission of the connector made of viscoelastic material of mass of $2m_c$ and complex spring constant k_c^*, where $k_c^* = k_c - \mathrm{i}\omega C$. For a connector of length L, cross-sectional area S_c and Young's modulus E_c, the spring constant k_c is given by $k_c = S_c E_c / L$. The damping coefficient C can be expressed by using the apparent mass of the panel $\rho_j h_j l_x l_y$ associated with one connector, as follows:

$$C = 2\zeta\sqrt{k_c \frac{m_1 m_2}{m_1 + m_2}}, \tag{1}$$

where $m_j = \rho_j h_j l_x l_y + m_c$, ρ_j and h_j are the density and thickness of a panel $j\ (=1,2)$, respectively, and ζ is the damping ratio of the connector.

The normal forces q_1 and q_2 that act at a connector are given by $q_1 = -(k_c^* - m_c\omega^2)w_1 + k_c^* w_2$ and $q_2 = -k_c^* w_1 + (k_c^* - m_c\omega^2)w_2$, and the moments M_x and M_y are given by $M_x = K_M^*\left(\frac{\partial w_1}{\partial x} - \frac{\partial w_2}{\partial x}\right)$, $M_y = K_M^*\left(\frac{\partial w_1}{\partial y} - \frac{\partial w_2}{\partial y}\right)$, respectively.