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NODALIZATION OF ISOLATOR FOR FLOATING FLOOR DESIGN

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Abstract

In this paper, a new design concept of an isolated honeycomb floor with a special arrangement of isolators is proposed to improve the vibration isolation performance of conventional lightweight cement floor panels in the frequency range of 120 Hz to 600 Hz. The symmetric bending resonance frequencies and mode shapes of a honeycomb floor panel were identified by a shaker test. The effects on vibration isolation of isolator position were then investigated using experimental modal analysis. The analysis suggests that to ensure the optimum vibration isolation performance the isolators must be placed at the nodal points of the symmetric bending modes of the floor panel. The proposed floating floor design achieved a vibration reduction of 20dB to 30dB in the frequency range of 120 Hz to 600 Hz. In addition, the proposed floor was found to have a 20-dB lower vibration level at the first bending resonance frequency than the conventional design with isolators that are placed at the edges.

1. INTRODUCTION

The size of conventional floating floor panels is usually rather large (about 1 m x 2 m) for production and installation convenience. Experimental investigations on these large floor panels have been conducted by various authors [1-3]. However, Kawaharazuka et al. [4] concluded that the vibration isolation efficiency of floating slabs is degraded by the low bending resonance frequencies that are induced in floor panels of this size. It is therefore logical that floating floor panels should be made smaller to increase their bending resonance frequencies.
Floating floor panels are usually made of concrete, wood, or steel. Heavy concrete slabs have generally lower acoustic transmission levels than lightweight floor panels at high frequencies [5], but are not commonly used due to their heavy weight. Thinner cement panels that are 15 to 40 mm thick are used, but their vibration isolation performance is still unsatisfactory. Honeycomb floor panels have a greater stiffness to mass ratio, and are used extensively in aircraft for vibration reduction and sound insulation [6] and [7]. To enhance the vibration isolation performance of typical lightweight cement floor panels, small honeycomb panels

with a high stiffness to damping ratio should be employed.

Most research in this area has focused on the identification of the best combination of material parameters in floating floor systems to enhance the vibration isolation performance at the receiver. Mead [8] suggested the method of nodalization to reduce the vibration input from a source by placing the source at the nodal points of a beam. Yan and Xie [9] analyzed the effect of positioning isolators at the base of electronic equipment to achieve rigid body vibration attenuation. However, there no theoretical model or experimental study has developed the concept of arranging the isolators at the nodal points of a plate to attenuate the bending mode vibration.

In this paper, experimental modal analysis is conducted to examine the method of increasing the vibration isolation performance of typical lightweight cement panels by the addition of a honeycomb floor panel with a high stiffness to mass ratio. An isolator position design is proposed to reduce the bending mode resonance of floor panels, which is the main cause of poor vibration isolation performance.

2. MODE SHAPE MEASUREMENT AND NODAL LINE IDENTIFICATION

2.1 Experimental setup

This experiment aims to find the resonance response and mode shape of cement and honeycomb panels and to identify the nodal points. The dimensions and material properties of the honeycomb panel (including the core design) and the cement panel that are studied are given in Table 1. Soft rubber was placed between the center of the panels and the vibrating shaker head. The boundary conditions were assumed to be free along the circumference of the plate. A white noise signal was used to drive the shaker to generate a wide band frequency (0-1.6 kHz) force, and an accelerometer was mounted on the shaker head to register the input acceleration to the panels. A lightweight accelerometer was mounted at various points on the panels to measure their acceleration response. The two acceleration signals were fed into the analyzer and a computer for data processing. The analyzer worked in real time at the frequency resolution of 6,400 lines in the range of 0 Hz to 1.6 kHz. The frequency response functions (FRFs; acceleration on the panel/ acceleration on shaker head), which are also known as the motion transmissibility, were obtained.

For the mode shape measurement, the center excitation acceleration with response acceleration along the surfaces of the panels was measured. The value of the imaginary part of the FRFs for a given resonance was assumed to be proportional to the modal displacement, and thus the mode shapes were established.

2.2 Experimental results

The motion transmissibility at the center point of the cement panel and the honeycomb panel is shown in Figure. 1. The damping ratio of each mode, which was identified using the half-power point method, is also given in Figure. 1. The resonance frequencies are 37.25 Hz, 300.5 Hz, and 556 Hz for the honeycomb panel, and 21.5 Hz, 145.5 Hz, and 337.5 Hz for the cement panel. The lowest resonance frequency is the rigid body mode, and the others are the bending modes. The negative value of the motion transmissibility implies that there was some vibration reduction from the vibration source to the receiver on the panel. The first bending resonance frequency of the honeycomb panel is much higher than that of the cement panel due to the higher stiffness to mass ratio. It can also be observed in Figure. 1 that there is a weak point of vibration isolation on the conventional cement panel at the first bending resonance frequency of 145.5 Hz. Fortunately, the honeycomb panel has an anti-resonance dip, and thus reduces the first bending mode of the cement panel at 145.5 Hz if it is added to the cement panel as a type of floating floor. However, the cement panel still has an additional resonance at 337.5 Hz that is close to that of 300.5 Hz of the honeycomb panel. This problem must be tackled by the suitable positioning of the isolators to isolate the vibration resonance near 300 Hz.

The identified mode shapes of the honeycomb panel at 300.5 Hz and 556 Hz are shown in Figure. 2. In the contour plot graphs, the solid lines and the dashed lines represent the positive and negative displacement, respectively. The transition regions between the solid lines and dashed lines are the nodal lines without displacement. The common nodal point of the two lowest symmetric bending modes is located and marked with circles in Figure. 2.

3. THE EFFECT OF ISOLATOR POSITION

3.1 Experimental setup

In this experiment, the cement panel used in the shaker test was selected as the structure base. The panel was a lightweight floor structure of the type that is commonly used in buildings with steel or wood frames. The honeycomb panel used in shaker test was applied as the floating floor. The experimental setup in Figures 3a and b aims to verify the effectiveness of the improvement in vibration isolation that is achieved by the installation of a honeycomb floor panel with a nodal point isolator design.

As shown in Figures 3a and b, four wooden blocks ($70mm^3$ cubic) were designed to support the rubber isolators at both the edge and nodal positions .This ensured that the vibration energy transmission from the cement panel via the wooden blocks to the honeycomb floor panel was constant for different isolator positions. The acoustic path was insulated using a vinyl sheet to cover the porous foam material. Vinyl sheeting is a flexible and highly damped material that is widely used in acoustic isolation in lightweight floor panels.

A steel hammer was employed to excite the structure base to generate vibration in the frequency range of 120 Hz to 600 Hz. The generated acceleration on the base structure and the response acceleration on the center point of the floor panel were then measured using two accelerometers. The FRFs (acceleration on the floor panel/acceleration on the base structure), which are known as the motion transmissibility, were identified.

3.2 Experimental results

The motion transmissibility when the isolators were placed at the identified nodal points (Figure. 3a) and when they were placed at the edge (Figure. 3b) was studied. A sound insulation device was installed in both cases. As shown in Figure. 4a, there was a 20 dB to 30 dB vibration reduction in the frequency range of 120 Hz to 600 Hz. This was due to the reduction in both the structure-borne and air-borne energy communication paths through the placement of the isolators at the nodal points and installation of acoustic insulation material. The importance of the position of the isolators can also be observed in Figure.4a, which shows a significant vibration reduction of between 5 dB and 30 dB in the range of 120 Hz to 550 Hz when the isolators were placed at the nodal points.

The vibration spectrum of the cement and honeycomb panels is shown in Figures 4b and c, respectively, for the edge and nodal point isolator positions. It is noted that there is a significant peak at 145.5 Hz for the cement panel that is reduced in the honeycomb panel in both cases. Figure. 4b confirms that the bending resonance of the honeycomb panel at 300 Hz degraded the vibration isolation performance of the base panel when the isolators were placed at the edge. However, when the isolators were placed at the nodal points of the honeycomb floor panel, the vibration magnitude of the bending resonance at 300 Hz was considerably reduced (see Figure. 4c).

4. CONCLUSIONS

Experiments in laboratory have been conducted to examine the effects of structure-borne and air-borne vibration transmission paths and confirm that an improved vibration isolation performance is achieved by the proposed new floating floor design. The results also confirm that the vibration isolation performance of a typical lightweight cement floor panel can be improved by pairing it with a honeycomb floor panel.

In general, to achieve the optimum vibration isolation performance, the following design features should be selected. First, a small floor panel with a high stiffness to mass ratio is recommended to increase the bending resonance frequencies of the system. Second, the isolators should be placed at the common nodal point of the lowest two symmetric bending modes of the floor panel. Third, lightweight and highly damped acoustic insulation material should be installed, together with acoustic absorption material, in the air cavity.

The new floating floor design achieved a vibration reduction of 20dB to 30dB in the frequency range of 120 Hz to 600 Hz. In addition, the proposed floor was found to have a 20-dB lower vibration level at the first bending resonance frequency than the conventional design in which the isolators are placed at the edges.

Table 1.Dimensions and material properties of the testing panel

Panel	Description	Panel Size(mm) (Length x width x height)	Young's Modulus (E) ($\times 10^9$ N/m^2)	Density(ρ)
Paper honeycomb	Sandwich structure with Nomex paper core and covered with two glass reinforced plastics surface sheets (0.5mm thickness for each surface sheet)	415x415x15	overall=3.0 surface sheet= 4.0 core shear=0.9	overall=5.8kg/m^2 surface sheet=2550kg/m^3 core=244kg/m^3
Cement	Wood fibre chemically treated and mixed with Portland cement, compressed and cured under temperature controlled conditions	520x520x15	6.8	21.4 kg/m^2

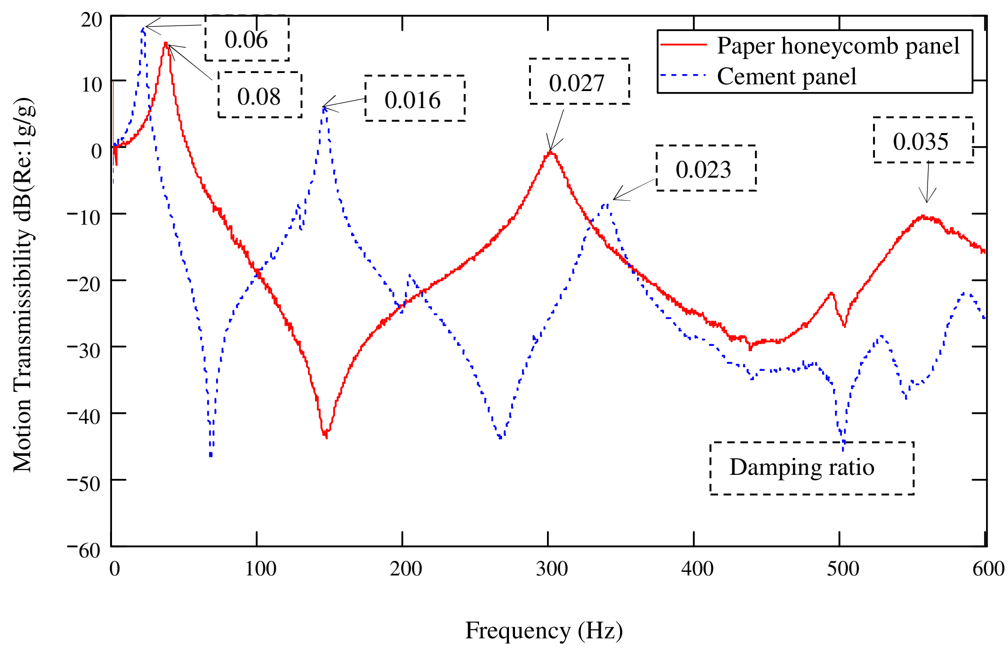

Figure 1. Motion transmissibility (magnitude) and
damping ratio of paper honeycomb panel and cement panel

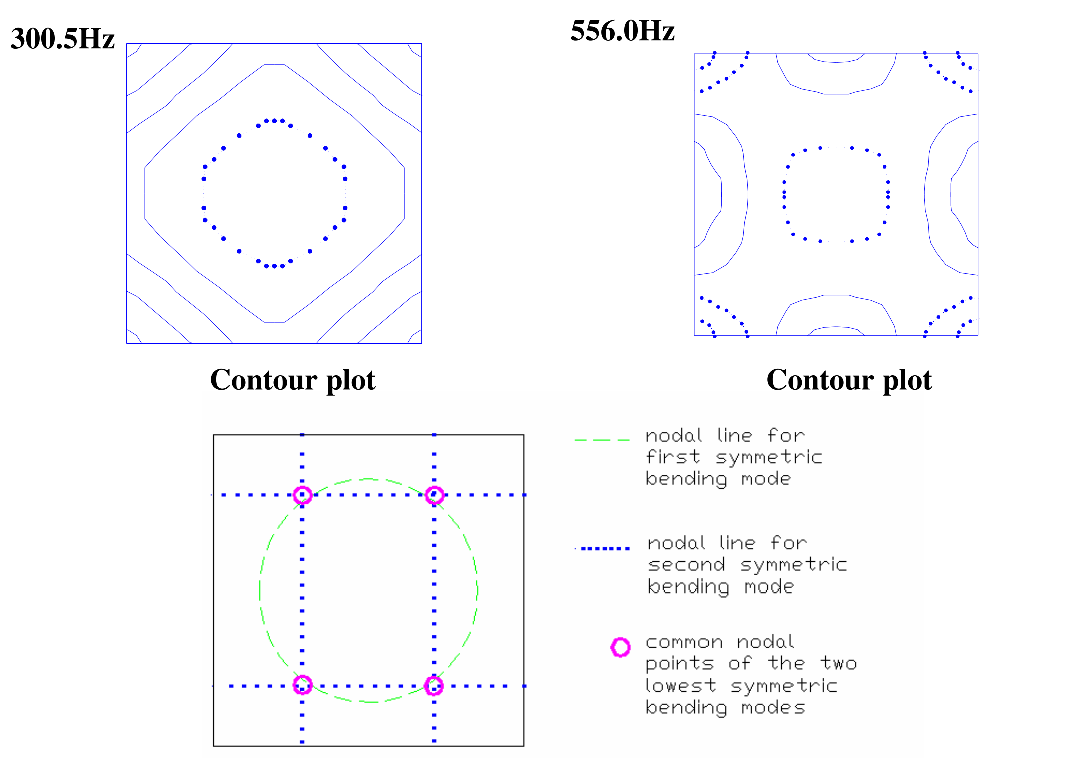

Figure. 2 The mode shapes and identified common nodal points for the lowest two symmetric
bending modes of paper honeycomb panel

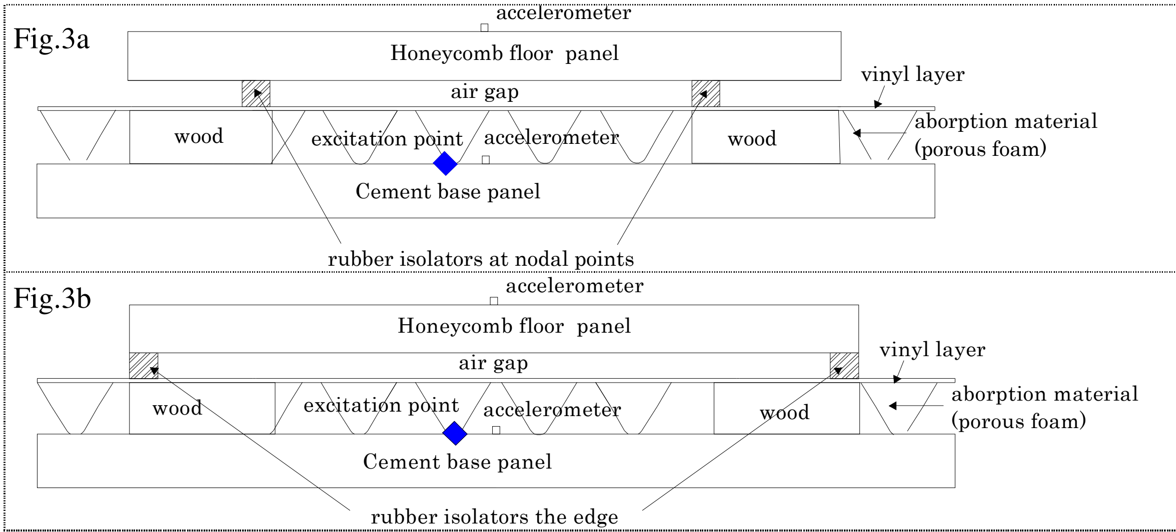

Figure. 3 Experimental setup for the motion transmissibility measurement for the conventional and new floating floor design investigation.
(3a) isolators were placed at identified nodal points and with sound insulation
(3b) Isolators placed at the edge and with sound insulation

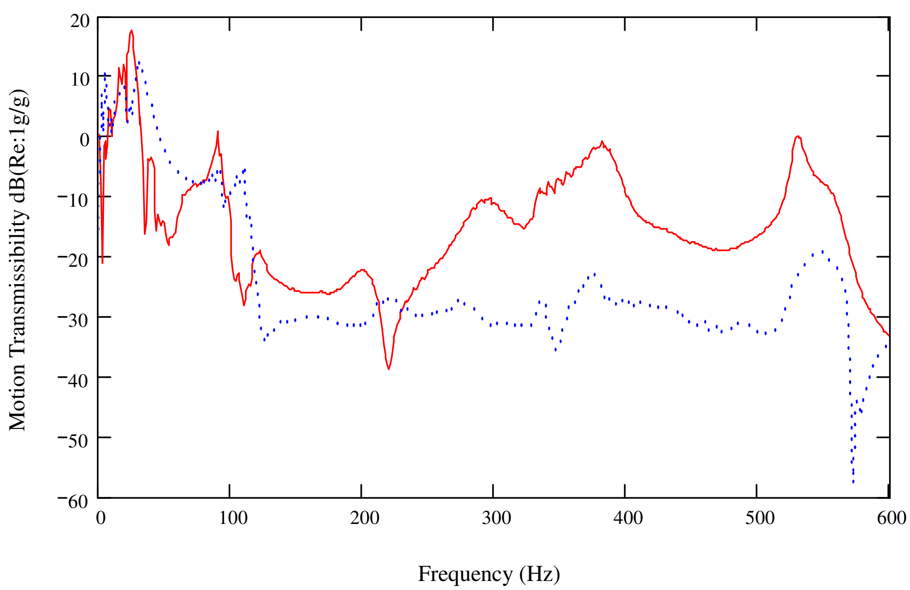

Figure. 4a Comparison of vibration isolation performance with the conventional and new floating floor design.
---- result for setup in Figure 3a) —— result for setup in Figure 3b)

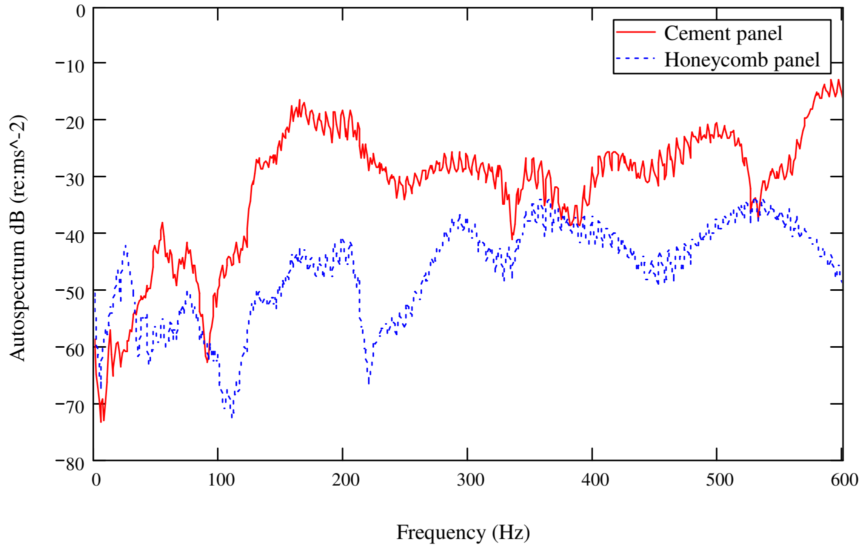

Figure. 4b Autospectrum of vibration on cement base
and honeycomb floor panel when the isolator placed at the edge of the honeycomb panel (see Figure3b)

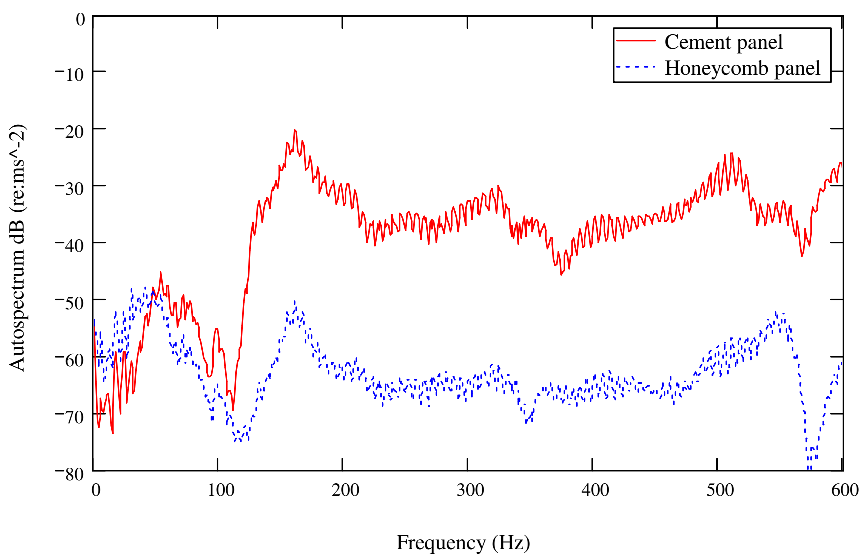

Figure. 4c Autospectrum of vibration on cement base and honeycomb floor panel when the isolator placed at the nodal points of the honeycomb floor panel (see Figure 3a)

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