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THE EFFECTS OF LOCAL MODES ON VIBRATION REDUCTION OF BUILDING ISOLATION

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Abstract

This paper investigates the vibration isolation performance of isolated box structures. Isolated box inside building is a one of the building isolation designs. Some experimental methods are developed to analyze the effects of bending mode of the box structure on vibration isolation efficiency. The vibration reduction performance of an isolated box inside building is found to be degraded by bending resonances of the isolated box. In the design of building isolation, apart from the conventional design of natural frequency of rigid body vibration, the control of local mode resonance frequencies is found to be also important.

1. INTRODUCTION

When a noise sensitive receiver is built after the rail track is established, the buildings may need to be isolated: box-within-box structure is used to reduce the energy transmission from the base to the receiver.
Southward and Cooper [1] mentioned that structure-radiated noise should be contributed to the local modes of viaduct structure. [2-3] found out that the bending modes of isolated slab can degrade the vibration isolation performance. Thus, the bending mode of isolated box maybe critical for structure-radiated sound and degrade the vibration isolation performance. Those will be investigation in this paper.
In this study, the resonant modes (frequency and mode shape), motion transmissibility and noise reduction of an existing isolated box structure were performed in experimental method, to understand the effects of bending modes on the vibration isolation performances. In the second part, a field noise and vibration test was conducted and analyzed at an existing isolated box (hotel); the two-storey hotel of isolated box design is constructed underneath a rail viaduct of ballast track in Japan (Tokyo). The resonant modes results of two isolated box structures were verified with Finite Element Model.

2. VIBRATION AND STRUCTURE-BORNE SOUND ANALYSIS ON ISOALTED BOX

2.1 Experimental setup

Vibration transmissibility and structure-borne radiated sound were measured in an existing isolated box structure with special design to achieve 6Hz natural frequency with spring isolators, the experimental set up, dimensions and material properties of an isolated box described in Figure 1. The dimensions of the isolated laboratory box were 6.57m (L) x 3.84m (W) x 3.24m (H).

The excitation force was generated by the free fall of a 3kg steel ball from a 0.6m height with five impacts for each measurement. The impact vibration spectrum was measured via an accelerometer which was mounted on the rigid floor as the reference, and the corresponding vibration responses were registered via another accelerometer, which was moving on surface of the isolated box. The input and output acceleration signals were processed by the B&K PULSE multi-channel analyzer worked in real-time modes at a frequency resolution of 1Hz from 0-200Hz. The motion transmissibility results of impact excitation source and response spectrums under the frequency response function analysis (FRFs) (Response (Acceleration) / Excitation (Acceleration)) were obtained. The value of the imaginary part of the FRFs at resonance was proportional to the modal displacement and therefore the mode shapes can be established.

The centre point vibration is the highest for symmetric bending modes and the vertical rigid body mode. Thus, the motion transmissibility at centre point of the floors was presented in narrow band (1Hz resolution).

The structure-radiated sound levels were measured 1m above the ground in two rooms with and without isolated, they have the similar volume of room and absorption area. The sound pressure levels of selected five points were averaged separately for two rooms and presented in one-third octave band (Figure 1).

2.2 Theoretical analysis

The free vibration results of the isolated room were predicted by a finite element software package Sap 2000 v.8. The isolated room was modelled with shell elements. For the room, the 6.57m length in the x-direction was divided into 20 elements, the 3.84m width in the y-direction was divided into 12 elements, and the 3.24m height in the z-direction was divided into 12 elements. The models took into consideration the bending in the x-y-z dimensions. The elasticity of isolator was selected to give the natural frequency of 6Hz.

2.3 Analysis of results

The measured centre motion transmissibility level is shown in Figure 2. The theoretical mode shapes and corresponding resonance frequency of the isolated box and the measured symmetric bending mode shapes are shown in Table 1, which confirms that the measured motion transmissibility peaks at 5Hz due to resonance of the spring isolation system and at 22Hz and 70Hz due to the first and second symmetric bending modes of the floor (Figure 2).

It is noted that the first symmetric bending modes have vibration amplification. However, because of the low natural frequency, the transmissibility could obviously be attenuated at frequencies higher than 30Hz.

The experimental sound pressure level measured are presented in Figure 3, the measured sound pressure level peaking at 20Hz an 63Hz bands in the isolated box should be due to the bending resonance at around 22Hz and 70Hz. The vibration and noise can be attenuated by around 20dB in the measured frequency of 100Hz to 200Hz due to the isolated box. The vibration isolation was amplified due to the bending mode at around 20Hz.

3. FI ELD TEST OF ISOALTED BOX (HOTEL) IN TOKYO JAPAN

The two-storey hotel with isolated box design was constructed underneath a rail viaduct station in order to utilize the unused space under the viaduct rail line, and to satisfy the increased demand of tourists to the new Tokyo Disney Sea opened in 2001 [4]. The outside view of the hotel under the rail viaduct is shown in Figure 4. The building was designed to attenuate the vibration generated from trains and earthquakes. The two-story structure was built with isolated reinforced concrete box. The hotel is a suspended building with suspension rods connected with rubber cushions on the top to the primary viaduct column structure. Dampers were also installed under the floor as described in Figure 5. This special design has a vertical resonance frequency of 3Hz. The viaduct rail is a conventional ballast track.

The sound and vibration time-history data were recorded inside a guest room with isolation, and near the reception outside the suspended building and were reordered when trains passed through with a speed of 100km/h. The signals at isolated place and non-isolated place were recorded separately due to the assessment problem. To reduce the inconsistence of measured data, measurements were conducted five times and averaged for each place.

The spectrums of measured vibration velocity, vibration reduction level and the corresponding measured sound pressure levels are shown in Figures 6a-b and 7 separately. The vibration was amplified at 13Hz which should be due to the first bending resonance in the long span of the measured floor in the guest room, and the other peak at 44Hz should be contributed by the second symmetric bending resonance of the floor. The dips appeared at 24Hz, 62Hz and 84Hz of the floor without isolation (Figure 6a) and thus the peaks resulted in the vibration reduction spectrum as shown in Figure 6b. Therefore, those peaks should not appear if the correlation of vibration signals at with or without isolation positions.

The sound reduction performance is degraded at 50Hz band due to the first symmetric bending mode of the box at 44Hz. The bending mode shapes of the measured isolated room were verified with site measured with free fall a mass of 3kg from height of 0.6m, the same as the laboratory test on the pervious isolated box. Two accelerometers registered the vibration monition along the cross-section of the isolated room, one was used as the reference and the other being moved along the room. The measured and sketched mope shapes and corresponding resonance frequencies are shown in Table 1. The first and second symmetric bending mode shapes are similar to the isolated box found in pervious section, and the resonance frequencies at 12Hz and 45Hz agree well with the peaks at 13Hz and 44Hz in vibration reduction as show in Figure 6.

In general, the sound and vibration reduction performance above 100Hz is around 25dB. This is an innovative design ensuring that the space under the rail viaduct can be fully used. The local bending modes, however, can degrade the vibration isolation performance of the isolated hotel below 50Hz.

4. CONCLUSIONS

The special design of the isolated box underneath rail viaduct can, in general, reduce noise and vibration from rail traffic. However, the noise and vibration measurements for the two isolated boxes confirmed that the bending vibration of them resulting in the degradation of vibration isolation efficiency of isolation systems. The designed natural frequency of isolated box can be lower compared with traditional isolated floor since the higher structure loading, and thus a higher vibration isolation performance should be gained except the at the bending resonances.

ACKNOWLEDGEMENT

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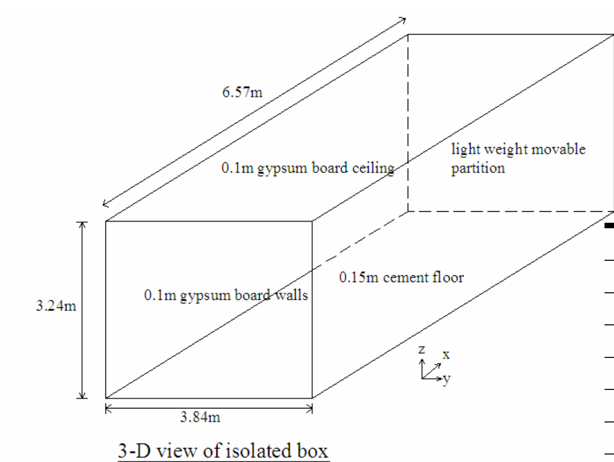

Marital Properties	cement floor
Young’s modulus(Nm^{-2})	19.6 x10^9
Material Density (kgm^{-3})	1700
Possion’s ratio	0.1
Marital Properties	gypsum walls & ceiling
Young’s modulus(Nm^{-2})	2 x10^9
Material Density (kgm^{-3})	760
Possion’s ratio	0.1

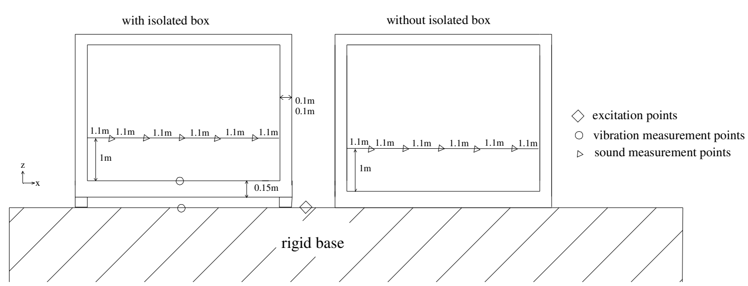

Figure 1 Measurement setup, dimension and material properties of isolated box

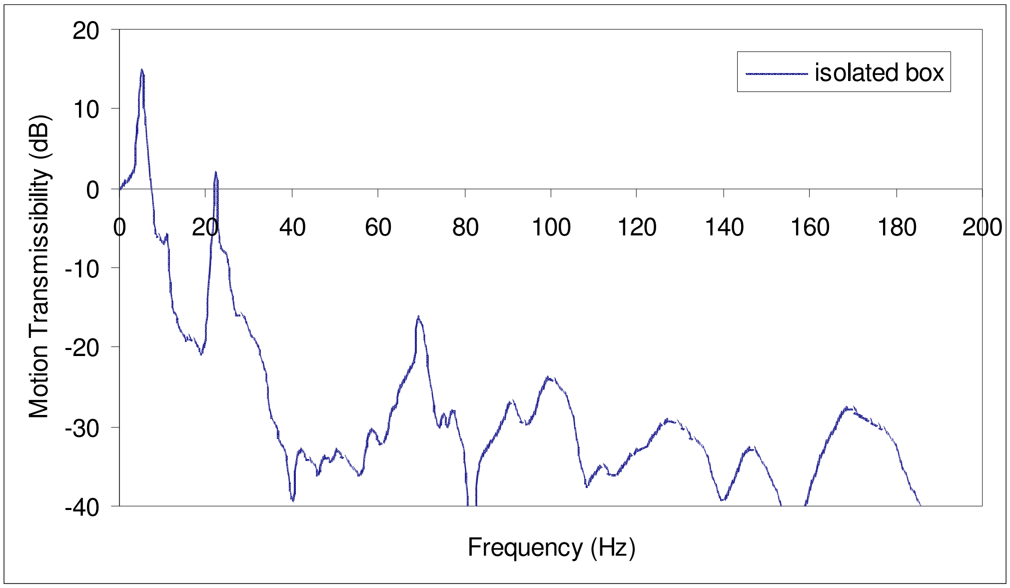

Figure 2. Motion transmissibility levels center point of isolated box

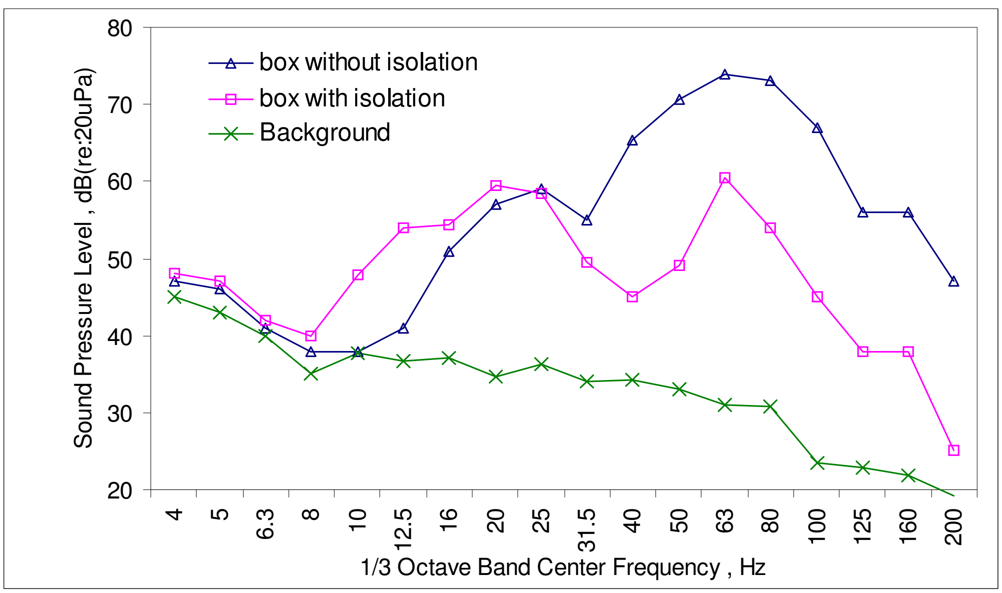

Figure 3. Sound Pressure level measured inside and outside isolated area in isolated box

Figure 4. Photograph of a train pass over the isolated box (hotel) in Japan (Tokyo)

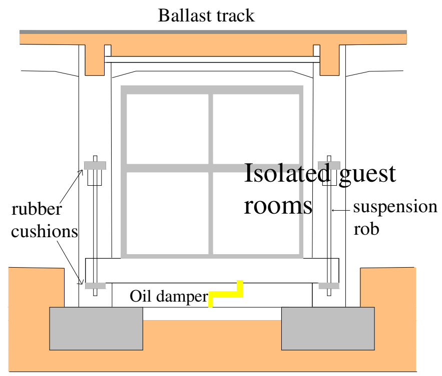

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Figure 5. Sketch of vibration isolation systems and vibration measurement room in isolated box (hotel)

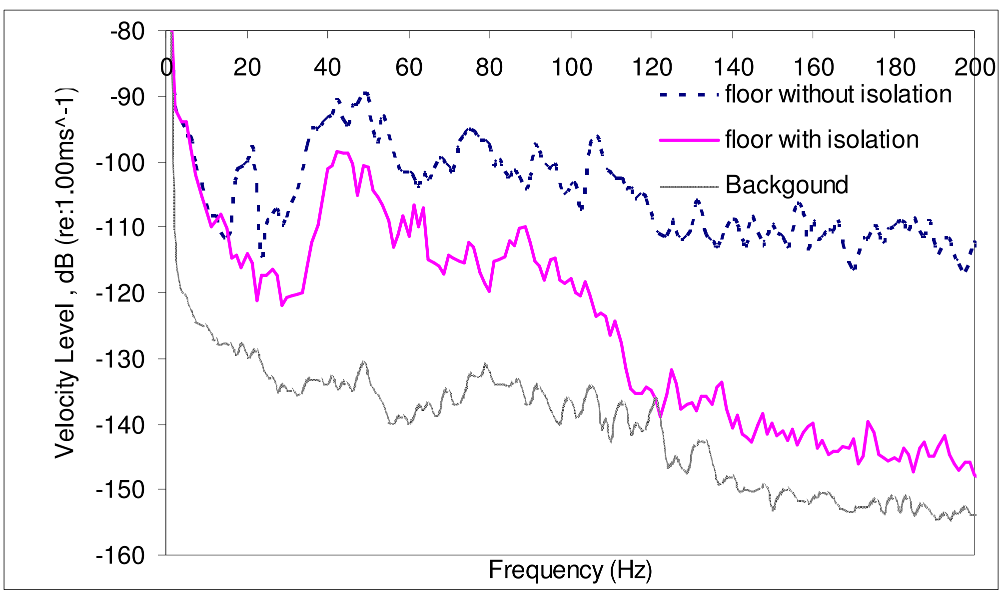


Figure 6a. Vibration velocity levels measured inside and outside isolated area in the isolated box (hotel)

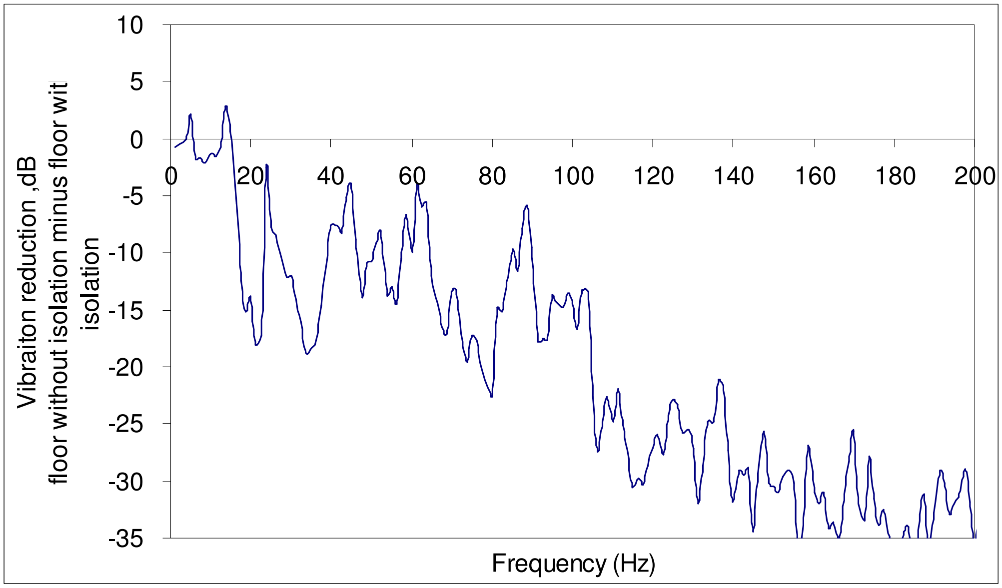


Figure 6b. Vibration reduction levels calculated for isolated box (hotel)

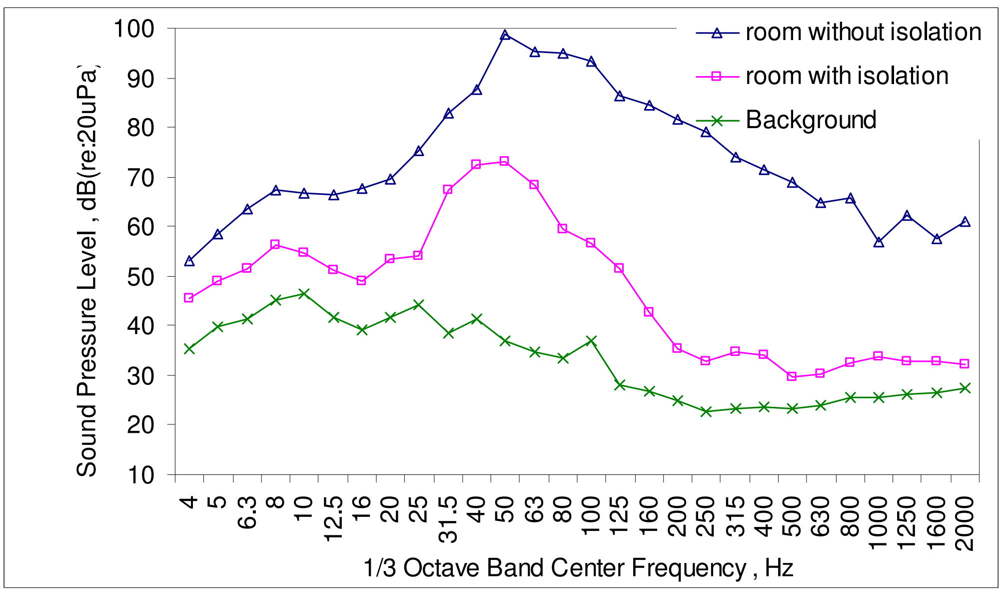
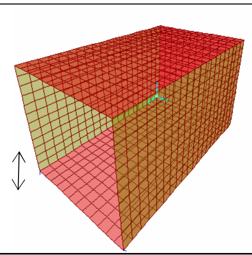
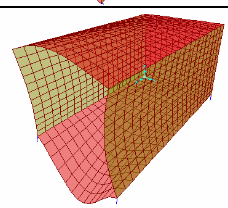
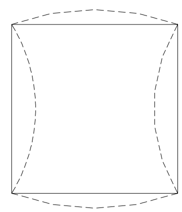
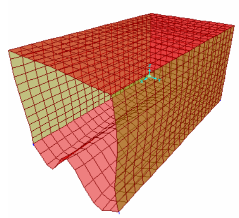
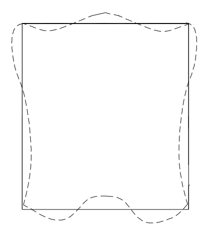


Figure 7. Sound Pressure level measured inside and outside isolated area in isolated box (hotel)

Table 6.4. Theoretical and measured symmetric bending mode shapes and resonance frequencies of two isolated box structures

	Mode shapes of isolated boxes		Isolated box-laboratory		Isolated box-hotel	
	FEM Mode shape	Sketch of measured cross-section bending mode shape	FEM resonance frequency	Measured resonance frequency	FEM resonance frequency	Measured resonance frequency
Vertical rigid body mode			6 Hz	5 Hz	3Hz	4Hz
1st symmetric bending mode			25 Hz	22 Hz	12 Hz	14 Hz
2nd symmetric bending mode			76 Hz	70 Hz	45 Hz	44 Hz