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Sound Insulation of Plenum Windows Installed with Rigid Cylinder Array

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ABSTRACT

In this study, a 1:4 scale down model was established to investigate the acoustical performance of plenum window installed with a rigid cylinder array. A total of 6 rigid cylinders were vertically placed as a 2x3 array inside the central cavity of a plenum window. A linear loudspeaker array consisted of twenty-five 6 inch loudspeakers was used as the sound source. Results show that the placement of rigid cylinder array has an effect on the sound insulation of the plenum window. The traffic noise reduction of plenum window has been significantly enhanced by up to ~3 dB in some one-third octave bands. With the increase of frequency, noise reduction of the plenum window also increases. Installation of the 2x3 rigid cylinder array in the plenum window can enhance the sound insulation by ~1 dB.

Keywords: Sound insulation, Plenum windows, Rigid cylinder array
I-INCE Classification of Subject Number: 33

1. INTRODUCTION

High density of population accelerates the speed of construction of high residential buildings besides traffic lines, exposing residents a high level of traffic noise. High level of traffic noise brings many health problems to residents [1]. According to the results of relative studies, traffic noise may lead to the problems of sleep disorder and ineffective work performance [2, 3, 4, 5]. Effective acoustical protection methods are strongly needed to protect residents from the pollution of traffic noise. Although there already are some acoustical options for noise attenuation, such as noise enclosures, barriers, extended podia and setback, due to the lack of space and security, the applications of these devices are limited in developed cities [6, 7, 8].

Double requirements for ventilation and noise reduction have spawned the plenum window. This kind of window effectively reduces energy consumption and improves

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noise reduction. Kerry and Ford firstly studied the sound transmission loss across a ventilation window [9]. Tang and Tong conducted a serious of parametric studies and found that the overlapping length and the gap width have an effect on the transmission loss of the plenum window for fixed window width [10]. Plenum window could provide 8 dB noise reduction more than the opened conventional window at minimum ventilation requirement [11]. In order to improve the noise reduction further and maintain the ventilation of the plenum window, some methods were tested, such as sound absorption combinations [12], transparent micro-perforation absorbers [13] and active noise control [14]. However, results were not so significant in practise. By using finite-element method, Tang found that the noise reduction improvement could be 4-5 dB when a simple rigid cylinder array was installed inside the plenum window [15].

In this study, experimental method was applied to verify the effective noise attenuation after the installation of a rigid cylinder array in the central cavity of plenum window. According to Tang's results, to maintain the ventilation, row of rigid cylinder array could be no more than two [15]. A 2x3 rigid cylinder array was tested in this measurement.

2. MEASUREMENT SETUP

One-third octave band frequency ranges from 400 Hz to 20 kHz, which corresponds to the range of 100 Hz to 5 kHz in the full scale, was considered in this study. Frequencies in this paper are all scaled back to full scale to eliminate misunderstanding.

2.1 Test Chamber

Measurements were conducted in an acoustic testing chamber with volume of ~240 m^3 and height of 5m, which is semi-anechoic and mimics an actual acoustic condition of residential buildings. Reverberation time inside this testing room was no more than 0.2s at frequencies higher than 20 Hz one-third octave band, it was ~0.5s at frequencies less than 100 Hz one-third octave band.

2.2 1/4 Scale Down Model and Plenum Window

In the present measurement, a 1/4 scale down reverberation model made of 18 mm-thick varnished plywood was adopted with no parallel internal surfaces. A Plenum window with the dimensions of 500 mm length (L), 98 mm (d), 250 mm height (H) was installed at the facade of the model. The model was placed on the floor of the test chamber. Two 3 mm thick Perspex panes were staggered at the window to create an air gap width (d) between the Perspex panes to form an air passage. The purpose of Perspex panes is to stimulate the glass panes of the full-size plenum window. Figure 1 shows the detailed dimensions of the scale model and the plenum window. There were two openings of plenum window, which are defined as outer side opening (167 mm wide) and inner side opening of the same width. A total of six rigid cylinders, made of aluminium, formed a 2x3 array and were vertically placed inside the central cavity of the plenum window. Diameter and length of the cylinder were 19 mm and 250 mm respectively. The distance between any two adjacent rigid cylinder rows or columns was d/3 as shown in figure 2.

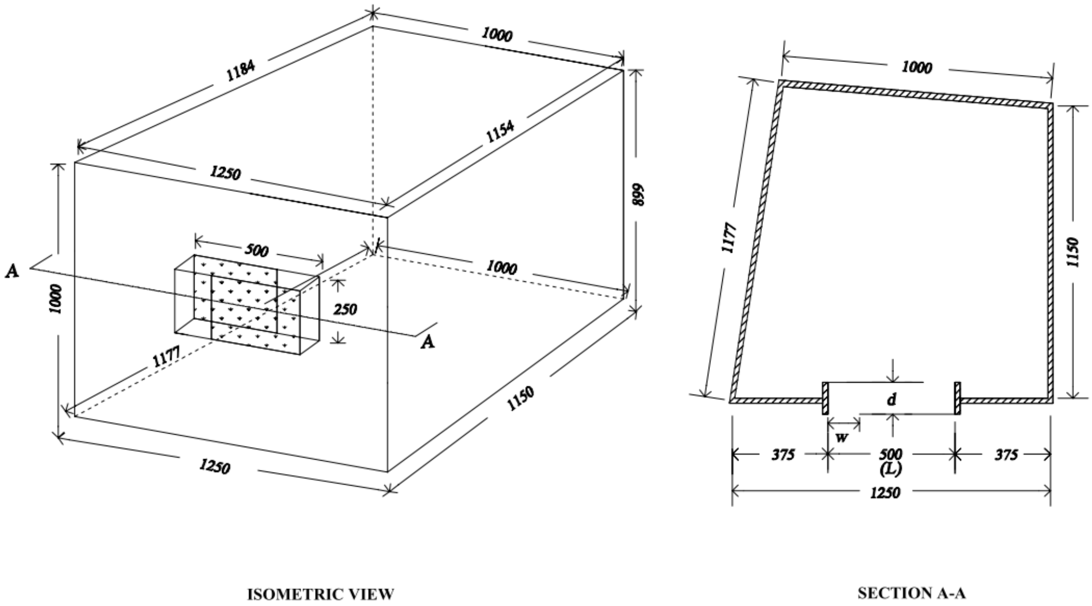

Figure. 1. *Scale down model. (dimensions in mm)*

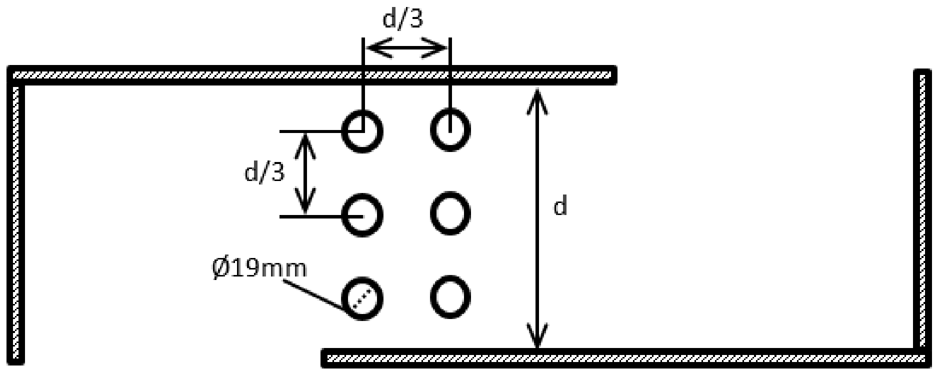

Figure. 2. *The layout of the cylinder array inside the central part of plenum window*

2.3 Sound Source

In this measurement, a line source which consisted of twenty-five 6 inch aperture loudspeakers with the frequency range between 400Hz and 20KHz was used to mimic the traffic noise source outside residential buildings. The output of the power of the amplifier was set to be constant and a reference microphone was placed close to the line source to monitor the performance of this sound source. The directivity, uniformity and repeatability of this line source were tested to prove the effectiveness of its application in this research.

2.4 Reverberation Times

A loudspeaker (8cm aperature) was placed at the corner of the receiver chamber and a 1/4" Brüel & Kjær Type 4935 microphone was used to capture the data. A total of 8 points irregularly spaced within the receiver room were selected to measure the average reverberation time using DIRAC system with MLS signal. The reverberation times (RT) inside the receiver room with and without 2x3 rigid cylinder array inside the central cavity of the plenum window were tested. Because both RTs are important to the value of sound transmission loss across the plenum window and the distinct difference between both RTs will also have an effect on the calculation of sound insertion loss. RTs of both conditions are shown in figure 3. The ratio of both RTs range from 0.95 to 1.13. One can conclude that the RT change is so infinitesimal that it will not affect the calculation of transmission loss. In the subsequent calculation, RT will be ignored in the formula.

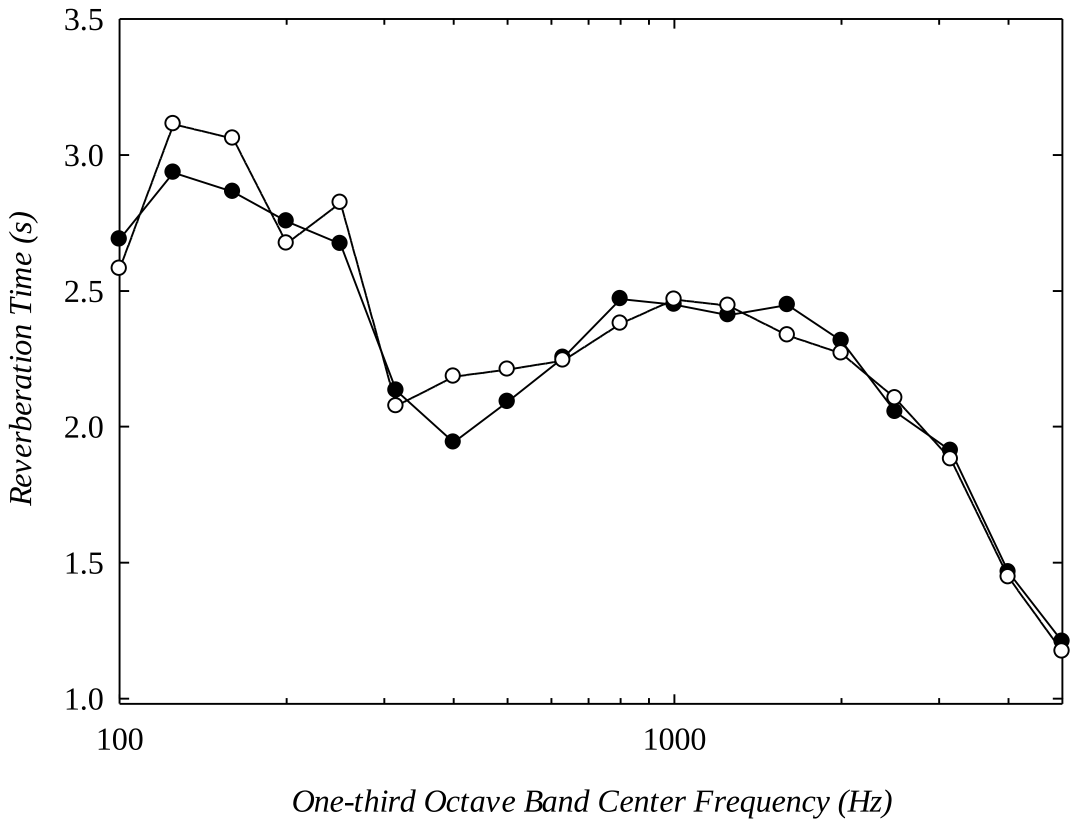

Figure.3. *Average reverberation times acquired inside scale down model. Plenum window installed with 2x3 rigid cylinder array (open circle); plenum window without rigid cylinder array (closed circle)*

Signals	Coordinates (x y z)
S1	500 625 500
S2	540 280 300
S3	580 875 400
S4	650 580 450
S5	800 250 550
S6	950 750 600
S7	-50 792 600
S8	-50 792 500
S9	-50 792 400

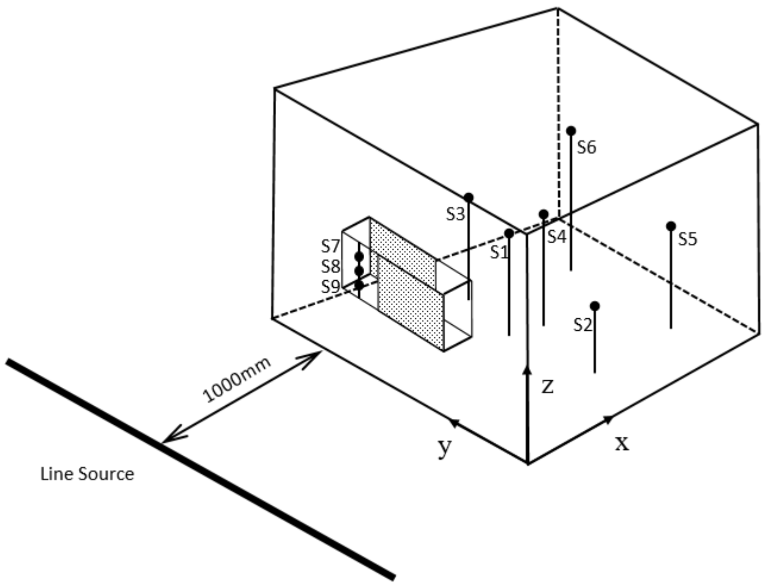

Figure. 4. *Microphone locations during the measurement (dimensions in m),*
●: *measurement points.*

3. MEASUREMENT PROCEDURE

The loudspeaker array was placed at 1 m horizontally away from the facade of the scale model to provide a normal incidence sound wave. Three Brüel & Kjær Type 4935 microphones were set on the inlet of the plenum window vertically to capture the inlet average sound pressure level for calculation of sound pressure level from the inlet. Six Brüel & Kjær Type 4935 microphones were scattered inside the scale down model room to record sound pressure levels. Figure 4 illustrates the locations of microphones used in this measurement. All data were acquired by the Brüel & Kjær 3506D PULSE system. For each test setting, there were 3 measurements conducted and each lasts for 20 seconds.

In this study, the performance of installation of the rigid cylinder array inside the plenum window is defined as the sound insertion loss (IL) which is referred as the average sound pressure level difference in receiver chamber before and after installation of rigid cylinder array.

As the RTs inside the receiver chamber did not change significantly after the installation of rigid cylinder array, they were omitted from the calculation, as equation (1) The sound insertion loss is defined as the change in the average sound pressure levels before and after the installation of the rigid cylinder array. In order to present the performance of both windows in front of traffic noise, the normalized traffic noise spectrum in the standard EN 1793-3 [16] was adopted to obtain the single rating results as equation (2):

$$NR = SPL_{i,cyl} - SPL_{i,ref} \quad (1)$$

$$IL = -10\log_{10}\left(\sum_{i=1}^{18} 10^{0.1(N_i - NR_i)} \Big/ \sum_{i=1}^{18} 10^{0.1N_i}\right) \quad (2)$$

where i represents the ith one-third octave band data, from 100 Hz to 5 kHz, N_i is the corresponding normalized noise band level [16], the suffices *cyl* indicates the case with rigid cylinder array inside the plenum and the *ref* indicates the case without rigid cylinder array inside the plenum window.

4. RESULTS AND DISCUSSIONS

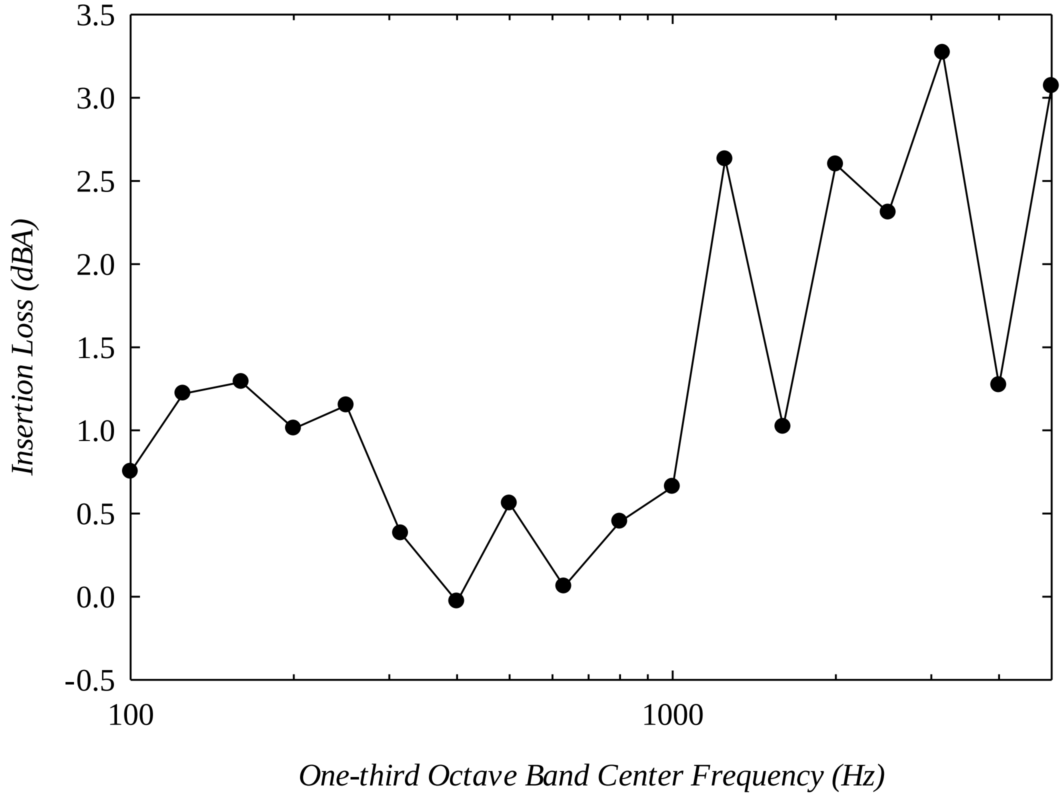

Figure. 5. *Insertion loss of installing the rigid cylinder array*

Figure 5 illustrates the difference of sound pressure level between the case with installation of rigid cylinder array inside the central cavity of plenum window and the case without installation of rigid cylinder array. Results indicate that the placement of a 2x3 rigid cylinder array has significantly improved the acoustical performance of the plenum window. It contributes to an increase of ~1.1 dB for the noise attenuation in single rating form. The sound insulation of plenum window is enhanced by up to ~3.3 dB in some one-third octave bands. At frequencies below 1000Hz, the enhancement of noise reduction could be as high as ~1.5dB. For frequencies between 300Hz and 800 Hz, IL has been slightly influenced by the height of the plenum window (98 mm) and the distance between rigid cylinder array and the window sidewall close to inlet (167mm). There is a dip around 1800Hz, it may be caused by a standing wave along the distance between the adjacent cylinder rows and columns. Above 1000 Hz, IL increases rapidly, though there are still some dips.

5. CONCLUSIONS

In present study, a 1/4 scale down model test was conducted inside a semi-anechoic chamber to verify the possible enhancement of plenum window acoustical performance by the installation of rigid cylinder array in its cavity. Measurement results show that the addition of a 2x3 rigid cylinder array has effectively enhanced the acoustical performance of the plenum window by up to ~1dBA under traffic noise condition. The broadband improvement of sound attenuation of plenum window by placement of a 2x3 rigid cylinder array is acceptable and even significant.

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