Acoustical Performance of a Sonic Crystal Window

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***Abstract*—Experimental studies were performed on the sonic crystal (SC) window to investigate its acoustical performance at the reverberation room. The maximum insertion loss (IL) can be found at frequency of 1000 Hz which is about 9.11 dBA. The amount of noise attenuated by the SC window at frequencies of 700 Hz to 1400 Hz was 2.44 times as high as that of 100 Hz to 3100 Hz. The noise attenuation peaks at all receiver positions still remain at the same frequency as 0° even though the angles of louver blades were increased to 30° and 60°. The effects of louver blades angles on the SC window reduced with the increasing distance from the SC window. The amount of noise attenuated by the SC window was reduced by 59.81% when the rows of SC were reduced to half of its original numbers.**

***Index Terms*—acoustic, sonic crystal, noise, reverberation room**

I. Introduction

Quiet ambience, good natural ventilation and daylighting are desirable characteristics for every household but these are difficult to achieve at the same time in city dwellings. Transparent glass windows are good for natural daylighting. However, it will need to be fully closed for reducing noise which in turn will prevent natural ventilation. The main objective of the current study is to establish an innovative solution with the use of SC window. SC was defined as periodic distribution of sound scatterers in fluid environment to attenuate sound waves by their acoustic band gaps [1]. The destructive Bragg law was used to explain the phenomenon of band gaps. The center frequency (f_c) of the band gaps is defined as:

$$f_c = \frac{c}{2\alpha} \tag{1}$$

where c is the speed of sound in air and α is the distance between adjacent scatterers.

SCs have been reported for application as noise barriers. For example, a sculpture consisting of hollow stainless steel cylinders located in Madrid was identified to have a sound attenuation peak at 1670 Hz [2]. Kushwaha [3] concluded that multi-periodic system in tandem could create sound attenuation in the human audible range of frequency. Martinez-Sala *et al*. [4] demonstrated the possible use of periodic arrays of trees as green acoustic screens. A SC acoustic screen formed by cylindrical scatterers embedded in air was designed by Castineira-Ibanez *et al.* [5] to reduce the transport noise in cities. Although there are several reported studies and even patents (for example, Attenborough *et al*. [6] on SC noise barrier) on measuring the noise attenuation due to such periodic structures, there is no reported use of such structures for window components, with a primary role of providing both natural daylighting and ventilation.

There were reported studies of cutting slots in a SC to include Helmholtz resonators in the structure. These resonators allow noise of frequencies lower than the band gaps to be attenuated, therefore, improving the noise mitigation performance of these SCs [7]. For example, Lagarrigue *et al*. [8] studied the use of bamboos with holes, for the additional attenuation at the low frequencies of 200 to 300 Hz compared to the band gaps of 1600 to 2700 Hz.

The main objective of the current effort is to use the experimental method to study the acoustical performance of a SC window at the reverberation room. The outcome of the study will have a major impact for every household with reduced energy usage due to good balance of natural ventilation and daylighting with good noise mitigation.

II. Experim/Ental Methods

The SC window consisted of 8 rows and 4 columns of hollow rectangular aluminum tubes as shown in Fig. 1(d). The distance between the adjacent aluminum tubes are 0.102 m, 0.0795 m and 0.0668 m which will produce f_c of 1681 Hz, 2157 Hz and 2567 Hz, respectively, from Eq. 1. Louver blades were attached to the SC window in order to prevent the penetration of water into the room. The slit sizes of the Helmholtz resonators are 0.003 m, 0.0033 m, 0.0058 and 0.0113 m which were estimated to give resonant frequencies (f_r) of 719 Hz, 932 Hz, 1145 Hz and 1325 Hz, respectively, using [9]:

$$f_r = \frac{c}{2\pi}\sqrt{\frac{A}{V_r\left(n+0.9s\right)}} \tag{2}$$

where A is the cross sectional area of the resonator opening, V_r is the volume of the resonator, n is the length

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of neck and *s* is the slit size. These slit sizes were selected in order to attenuate the traffic noise at 1000 Hz [9].

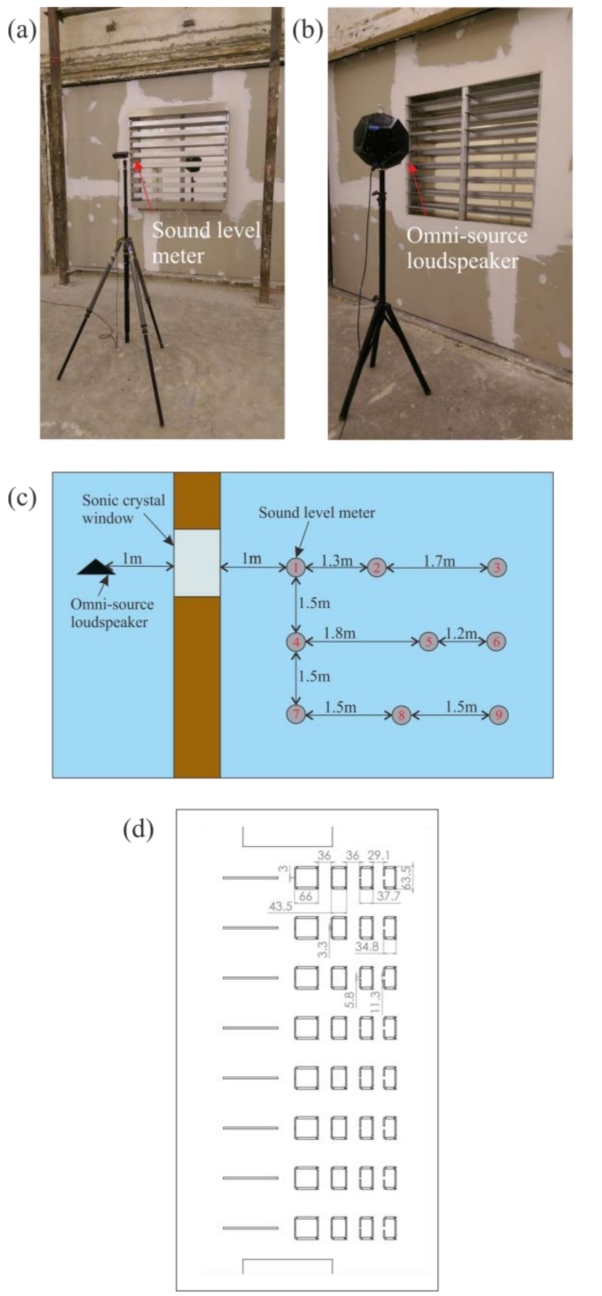


Figure 1. (a) Experimental set-up of the SC window at the reverberation room with Omni-source loudspeaker at the front side of the SC window (b) sound level meter at the back side of the SC window (c) positions of sound level meter at the reverberation room, top view (d) dimension of the SC window with louver blades (fully open), side view (unit in mm).

The experiment was consisted of a Larson Davis Omni-source loudspeaker (model BAS001), a B&K power amplifier (model 2734-A) and a B&K sound level meter (model 2238) as shown in Fig. 1(a) and (b). White noise was generated by the loudspeaker and the sound level meter (receiver) was placed at 9 different positions in the reverberation room as shown in Fig. 1(c). The angles of louver blades were adjusted from 0 °(fully open) to 30 ° and 60 ° (experiment I) in order to investigate the effects of blade opening angles on the performance of the SC window. In addition, another set of experiment (experiment II) where the alternate row of aluminum tubes were removed in order to investigate the effects of reducing number of SC on the acoustical performance of the SC window. Therefore, the SC window only consisted of 4 rows and 4 columns of aluminum tubes. All data were recorded using sound level meter from 100 Hz to 3100 Hz with interval of 100 Hz. The data was analyzed using M+P VibPilot SO Analyzer. Three samples were recorded and averaged for each data set and the sampling time for each sample is one minute. Sound Pressure Levels (SPLs) without SC window were also measured in order to obtain the IL which is defined as:

IL=SPL (without SC window)–SPL (with SC window) (3)

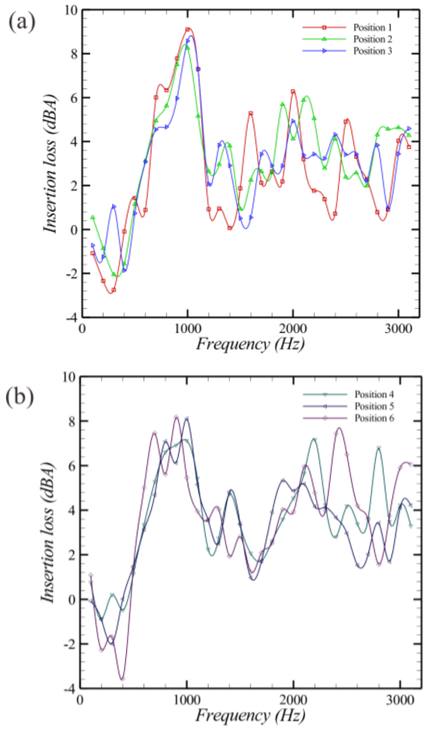
Equivalent SPL (LA_{equi}) was calculated for each receiver position by including the noise from each frequency range which is defined as:

$$LA_{equi} = 10Log\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right) \qquad (4)$$

Reduction of LA_{equi} (LA_{equiRE}) is defined as:

LA_{equiRE} = LA_{equi} (without SC window)–(with SC window) (5)

Two LA_{equiRE} were calculated where they are $LA_{equiRE1}$ for whole frequency range and $LA_{equiRE2}$ for frequencies ranged from 700 Hz to 1400 Hz in order to highlight the performance of the SC window at frequency range of traffic noise [10]. Average values of $LA_{equiRE1}$ and $LA_{equiRE2}$ were also calculated in order to justify the overall performance of the SC window.



(c)

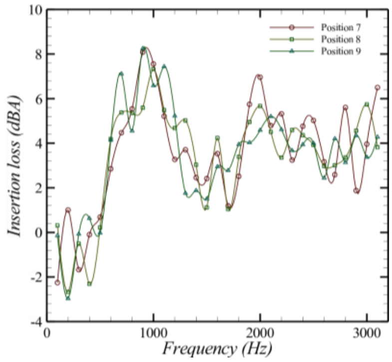


Figure 2. Comparison of IL of the SC window at different receiver positions when angles of louver blades are fully opened. (a) Positions 1, 2 and 3 (b) Positions 4, 5 and 6 (c) Positions 7, 8 and 9.

III. Results and Discussion

Fig. 2 shows the comparison of IL of the SC window at different receiver positions when the louver blades are fully opened. It can be observed that at receiver position 1, the maximum IL can be found at frequency of 1000 Hz which is about 9.11 dBA. The IL at frequencies of 900 Hz and 1100 Hz are also high which are about 7.79 dBA and 7.31 dBA, respectively. These frequencies correspond to the f_r produced by the Helmholtz resonators. Generally, the receiver positions at the same row, for example, positions 4, 5 and 6 exhibit similar trend of IL. The maximum $LA_{equiRE1}$ and $LA_{equiRE2}$ are found at receiver positions 4 and 9 which are about 2.54 dBA and 5.33 dBA as shown in Table I and Table II, respectively. By comparing the average values of $LA_{equiRE1}$ and $LA_{equiRE2}$, it can be concluded that the amount of noise attenuated by the SC window at frequencies of 700 Hz to 1400 Hz is 2.44 times as high as that of 100 Hz to 3100 Hz.

TABLE I. $LA_{equiRE1}$ OF THE SC WINDOW. ALL VALUES ARE IN DBA.

Position / Experiment	1	2	3	4	5	6	7	8	9	Average
I (0°)	1.47	1.53	2.02	2.54	1.95	2.12	2.46	2.20	2.48	2.09
I (30°)	0.90	2.45	1.87	2.33	2.18	2.09	2.39	2.04	2.82	2.13
I (60°)	1.96	1.91	2.75	2.78	2.51	2.71	1.86	2.21	2.76	2.39
II	-0.46	0.84	0.82	1.17	0.89	0.76	1.08	0.87	1.46	0.84

TABLE II. $LA_{equiRE2}$ OF THE SC WINDOW. ALL VALUES ARE IN DBA.

Position / Experiment	1	2	3	4	5	6	7	8	9	Average
I (0°)	4.55	5.04	5.05	5.27	5.26	5.14	5.06	5.19	5.33	5.10
I (30°)	4.45	5.36	5.11	5.88	5.22	5.95	5.65	5.10	5.64	5.38
I (60°)	5.17	5.91	5.07	6.20	5.60	5.96	5.57	5.36	5.64	5.62
II	1.72	2.29	2.02	2.49	1.99	2.30	1.78	2.34	2.28	2.14

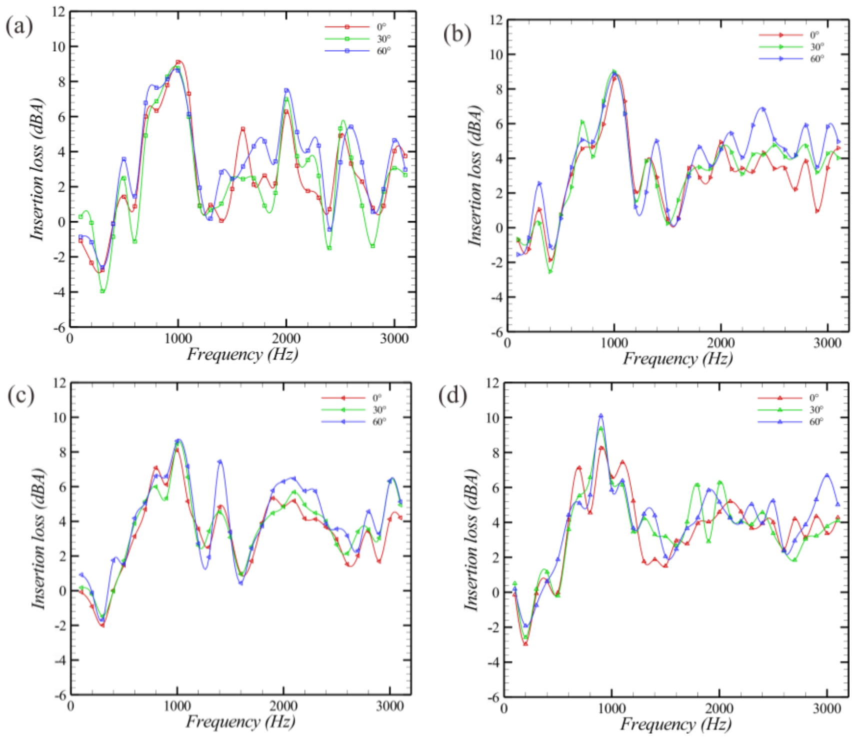


Figure 3. Comparison of IL of the SC window at different receiver positions when angles of louver blades are adjusted from 0° to 60°. (a) Position 1 (b) Position 3 (c) Position 5 (d) Position 9.

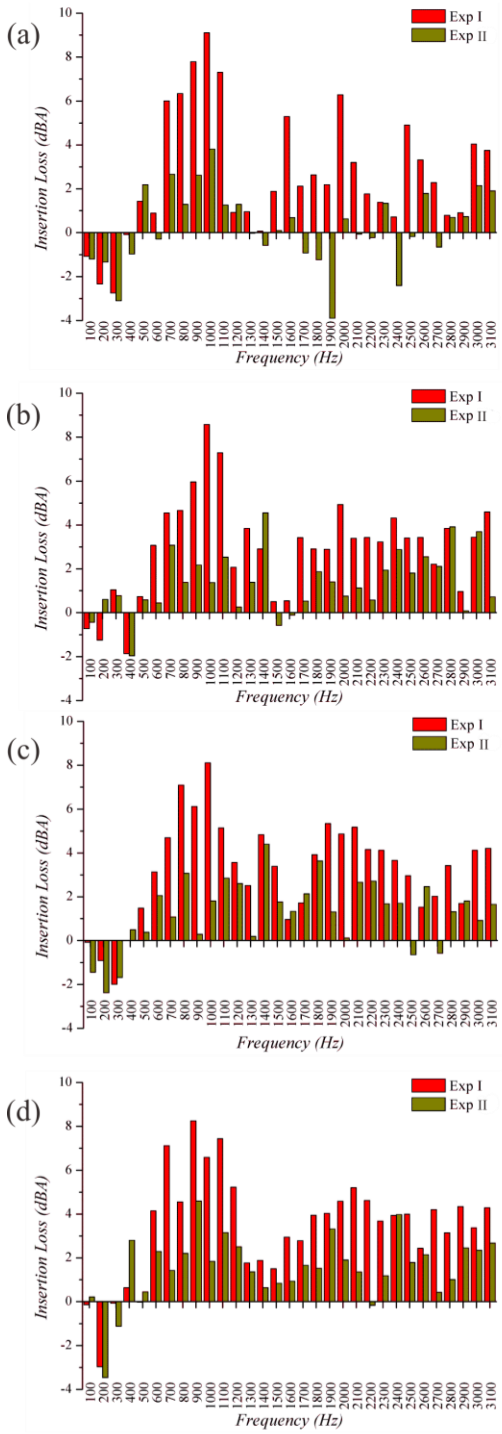


Figure 4. Comparison of IL of the SC window for experiments I and II at different receiver positions when angles of louver blades are fully opened. (a) Position 1 (b) position 3 (c) position 5 (d) position 9.

Fig. 3 shows the comparison of IL of the SC window at different receiver positions when angles of louver blades are adjusted from 0° to 60°. As expected, the highest IL was obtained at blade opening angles of 60° and then followed by 30° and 0° at all receiver positions. The noise attenuation peaks at all receiver positions still remain at the same frequency as 0° even though the angles of louver blades are increased to 30° and 60°. The maximum $LA_{equiRE1}$ and $LA_{equiRE2}$ are found at receiver position 4 which are about 2.78 dBA and 6.20 dBA at 60° as shown in Table I and Table II, respectively. In addition, the effects of louver blades angles are reduced with the increasing distance from the SC window as the increment of $LA_{equiRE1}$ when blades angles increase are lower at positions 7, 8 and 9 compared to the other two rows of receiver positions.

Fig. 4 shows the comparison of IL of the SC window for experiments I and II at different receiver positions when angles of louver blades are fully opened. For experiment II, it can be observed that IL reduces significantly at all receiver positions for whole frequency range. By comparing the average $LA_{equiRE1}$ and $LA_{equiRE2}$ that obtained from experiments I and II in Table I and Table II, it can be concluded that the amounts of noise attenuated by the SC window are reduced by 59.81% and 58.01%, respectively, when the rows of SC are reduced to half of its original numbers.

IV. Conclusions

Experimental studies were performed on the SC window to investigate its acoustical performance. Experiments at the reverberation room show that the maximum $LA_{equiRE1}$ and $LA_{equiRE2}$ were found at receiver positions 4 and 9 which were about 2.54 dBA and 5.33 dBA, respectively, when the angles of louver blades were fully opened. The amount of noise attenuated by the SC window at frequencies of 700 Hz to 1400 Hz was 2.44 times as high as that of 100 Hz to 3100 Hz. The noise attenuation peaks at all receiver positions still remain at the same frequency as 0° even though the angles of louver blades were increased to 30° and 60°. The effects of louver blades angles reduced with the increasing distance from the SC window. The amount of noise attenuated by the SC window was reduced by 59.81% when the rows of SC are reduced to half of its original numbers.

With the demonstration of the attenuation capability of the SC window, the next step would be the installation of the SC window in a real high-rise apartment unit and comparing its performance with the existing window grilles.

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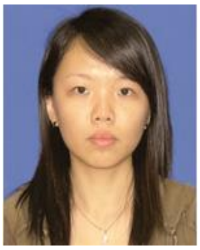

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