A study on sound insulation using rectangular plenum chamber arrays

Seong-Hyun LEE[1]; Sang-Hoon KIM[2]

[1] Korea Institute of Machinery & Materials, South Korea

[2] Mokpo National Maritime University, South Korea

ABSTRACT

For an energy-efficient and environmental-friendly building, natural ventilation has become an increasingly attractive method. Traditional windows and barriers are not suitable for a natural ventilation, because leaks decrease acoustic performance. Resonators in duct systems have been extensively used in many industrial fields to reduce noise and air can flow through them. If concepts of resonators applied to noise barriers, air can propagate through them and noise cannot. Resonators could be tuned with varying parameters because acoustic performance can be determined by dimensions. In this study, rectangular plenum chamber arrays were used as noise barriers. To improve sound insulation, parametric study and higher order modes wave propagation analysis were performed. For application examples, noise barriers using plenum chambers were made and the sound transmission loss was measured using mini-scaled reverberation chambers. The measured transmission loss showed good agreements with a theoretical prediction.

Keywords: Noise Barrier, Insulation, Ventilation, Resonator
I-INCE Classification of Subjects Number(s): 31.1

1. INTRODUCTION

Natural ventilation is energy efficient and environmentally friendly method of ventilating building. Natural ventilation is an alternative to air conditioning systems in modern buildings. Resonators in duct systems have been widely used in many industrial fields to reduce noise. In this study, a concept of resonators applied to noise barriers to enable walls or windows to ventilate naturally. The acoustic performance of plenum chambers was already researched using 4-pole parameters (1~3). The acoustic design of soundproofing doors and windows were introduced by using plenum chambers (4~6). The acoustic performance of plenum chambers can be explained by both plane wave and higher order mode propagation. The attenuation goes to zero at the higher order mode cut-on frequency and half-wavelength frequency due to the length of a chamber. The acoustic and ventilation performance can be controlled by varying dimensions of chambers. In this paper, transmission loss of barriers composed by plenum chambers was presented considering higher order mode characteristics inside chambers.

2. ACOUSTIC PERFORMANCE OF PLENUM CHAMBER

Figure 1 shows through-flow type rectangular plenum chambers with rectangular/circular inlet and outlet. The transfer matrix of them were derived by Ih (3). In this paper, noise barriers composed by rectangular chambers were presented to achieve natural ventilation. The acoustic performance of a noise barrier made by 30 acryl plenum chambers with rectangular inlet/outlet is predicted in this chapter. The geometry of each chamber is as follows: $a = b = 0.2\ m$, $a_1 = b_1 = a_2 = b_2 = 0.02\ m$, $l = 0.1\ m$. The higher-order mode cut-on frequency is shown in Table 1 and nodal lines due to higher-order modes are show in Fig. 2. Because of nodal lines and higher order mode characteristics, inlet and outlet positions affect the acoustic performance of noise barriers. To verify effects of inlet/outlet positions, transmission loss of three types of plenum chambers are predicted as shown in

[1] sh.lee@kimm.re.kr
[2] shkim@mmu.ac.kr

Fig. 3. Figure 4 shows predicted transmission loss. If there is only plane wave, the attenuation goes to zero at only harmonics of the half-wavelength frequency (f_c) due to a length of the chamber. Because of higher order mode propagation, transmission loss has troughs at a cut-on frequency. When the inlet/outlet are located at the center, the acoustic performance of a noise barrier has minimum number of troughs. It can be explained by that higher order mode doesn't propagate when inlet/outlet are located at nodal line.

Table 1 - Higher-order mode cut-on frequency, $f_{m,n}$ (Hz)

m \ n	0	1	2	3	4
0	0	850	1700	2550	3400
1	850	1202	1901	2688	3505
2	1700	1901	2404	3065	3801
3	2550	2688	3065	3606	4250
4	3400	3505	3801	4250	4808

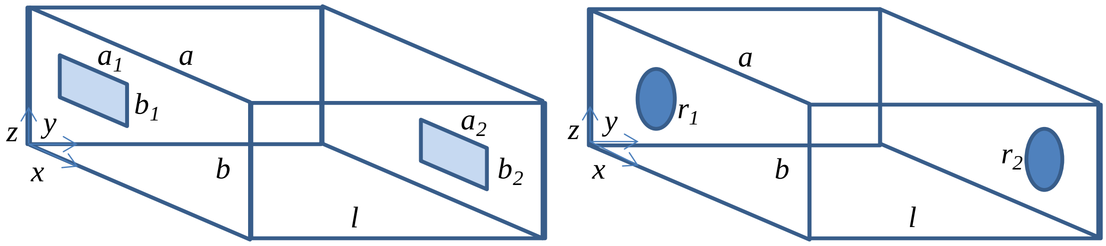

Figure 1 - Through-flow type rectangular chambers.

(a) With rectangular inlet and outlet, (b) with circular inlet and outlet.

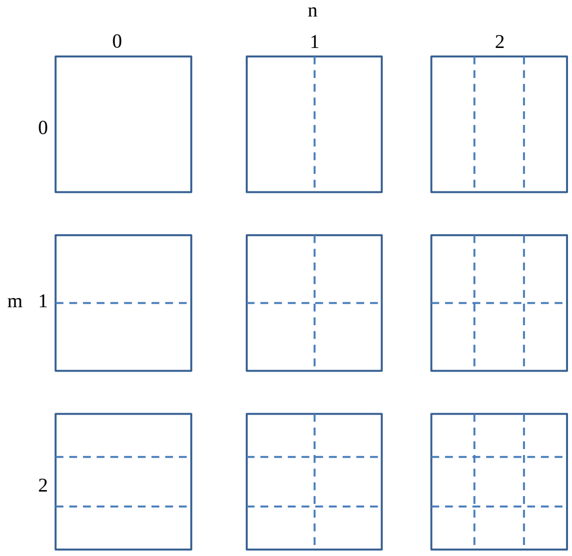

Figure 2 - Nodal lines for transverse pressure distribution in a rectangular duct

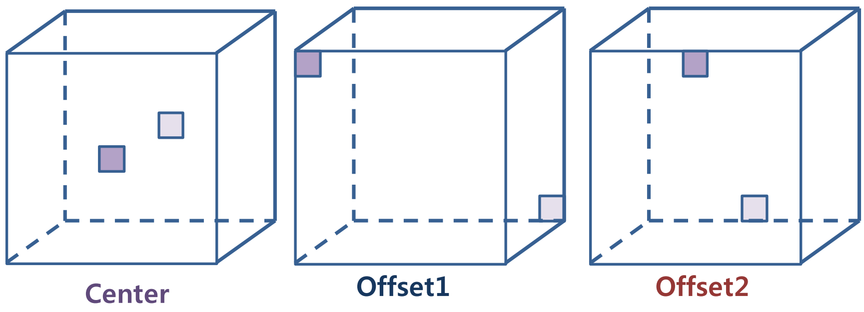

Figure 3 - Three types of rectangular chambers used to verify effects of inlet/outlet position

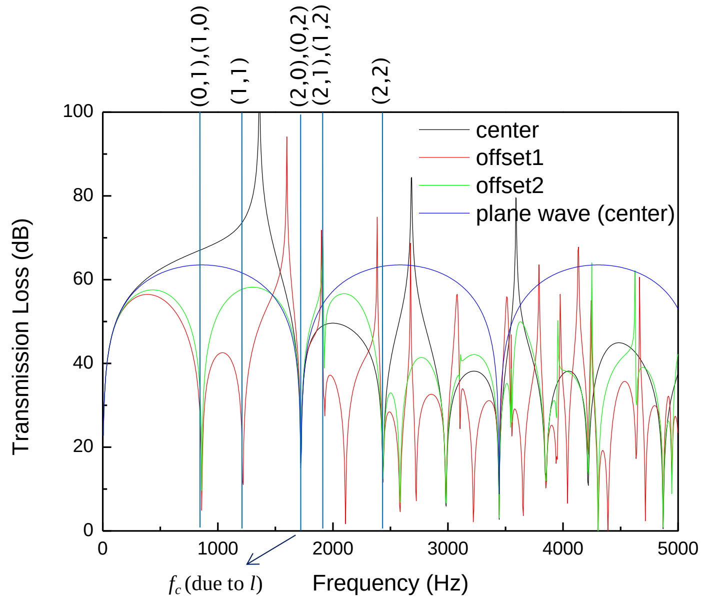

Figure 4 - Transmission loss of three types of rectangular chambers

3. MEASUREMENT

Noise barrier was made by 30 acryl plenum chambers. The geometry of each chamber is as follows: a = b = 0.185 m, l = 0.07 m, r1 = r2 = 0.025 m (refer Fig. 1 and 5). The sound transmission loss was measured using small reverberation chambers. The measurement was carried out in accordance with the test standards for large reverberation chambers: ISO 10140:2010 and ASTM E 90:2004. The test facility consists of two adjacent chambers with a test opening between them in which the test specimen is inserted. Sizes of specimen are 1.2 m (width) and 1.0 m (height), volume of source and receiving room are 2.808 m^3 and 3.252 m^3. Kang et al. established the characteristics of sound insulation in the small chambers (7). The shape of chambers is designed to be irregular in order to avoid the occurrence of standing waves. Two speakers (JBL, CONTROL 1X) were used to generated random noise in a source chamber. A half-inch microphone (GRAS) was used to measure the sound pressure levels at six microphone positions in each chamber. The volume of a chamber limits the lowest test frequency band due to the lack of mode count. The receiving room has about 8 modes in 315 Hz of 1/3 octave band. As a rule of thumb, it is expected that the frequency band above 315 Hz give reasonable data. Figure 6 shows comparison between prediction and measurement of transmission loss. The predicted transmission loss shows good agreements with measurements. Measured data can be divided by two parts. The one is the acoustic performance of the plenum chamber and the other is that of double partitioned wall made by acryl. But in prediction only plenum chamber is considered. Discrepancies between prediction and measurement can be explained by that.

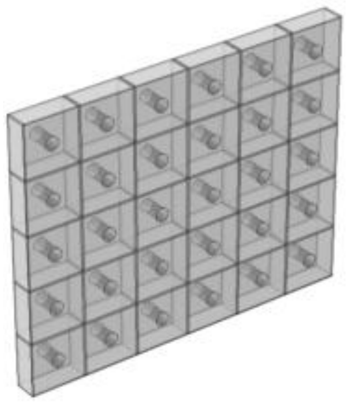

Figure 5 - A noise barriers using rectangular chambers

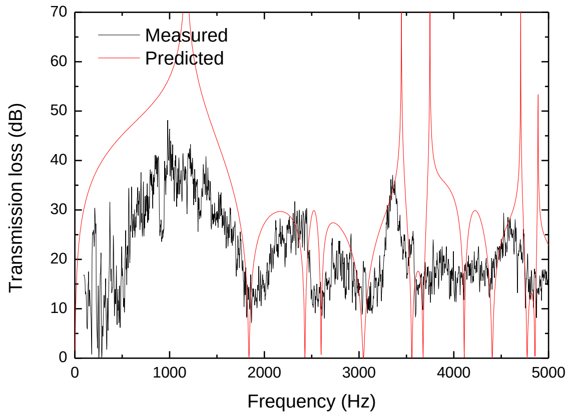

Figure 6 - Comparison between measurement and prediction

4. CONCLUSIONS

The transmission loss of the noise barrier composed by rectangular chambers were predicted and measured. The acoustic performance of noise barrier can be controlled by varying dimensions of chambers. For the purpose of walls or windows, the optimized design of resonator arrays will be found. Pressure drop through noise barriers can represent the natural ventilation performance. Analysis about pressure drop through chambers will be done.

REFERENCES

1. J.-G. Ih and B.-H. Lee. Analysis of higher-order mode effects in the circular expansion chamber. Journal of the Acoustical Society of America. 1985; 77: 1377-1388.
2. J.-G. Ih and B.-H. Lee. Theoretical prediction of the transmission loss of circular reversing chamber mufflers. Journal of Sound and Vibration. 1987; 112: 261-272.
3. J.-G. Ih. The Reactive Attenuation of rectangular plenum chambers. Journal of Sound and Vibration. 1992; 157: 93~122.
4. N. Yuya, N. Sohei, N. Tsuyoshi and Y. Takashi. Sound propagation in soundproofing casement windows. Applied Acoustics. 2009; 70: 1160~1167.
5. N. Yuya, N.H. Quang, N. Sohei, N. Tsuyoshi and Y. Takashi. The acoustic design of soundproofing doors and windows. The Open Acoustics Journal. 2010; 3: 30~37.
6. H. Nguyen, T. Yusuke, N. Yuya, N. Sohei, N. Tsuyoshi and Y. Takashi. Prediction and experimental study of the acoustic soundproofing windows using a parallelepiped SVU. The Open Acoustics Journal. 2012; 5: 8~15.
7. H.-J. Kang, B.-K. Kim, J.-S. Kim and J.-S. Lee. Characteristics of sound insulation in the scaled chambers. Proc INTER-NOISE 2004; 22-25 August 2004; Prague, Czech Republic 2004.