Low frequency sound transmission of stiffened panels

Hyun-Sil KIM[1]; Jae-Seung KIM[1]; Seong-Hyun LEE[1]; Yun-Ho SEO[1]

[1] Acoustics and Noise Research Team, Korea Institute of Machinery & Materials, Korea

ABSTRACT

In this paper low frequency sound transmission of stiffened panels is studied. The panels are rectangular plates with lattice stiffeners, and boundary of the plates is clamped. The sound transmission of the panels is measured using a mini reverberation chamber. The specimen is MDF board of 3 mm thickness, and size is 1.2 m x 1.0 m. Two different lattice size is tested: 205 x 255 mm for 4 x 4 cells and 280 x 280 mm for 3 x 3 cells, where stiffener is made of wooden rod whose cross section is 30 x 30 mm or 35 x 50 mm. Insertion loss is measured when impact is applied to the base panel with and without stiffened panel, where microphone position is fixed in the receiving room. It is found that insertion loss shows a dip around 220 Hz, while insertion loss becomes larger as frequency decreases. It is important that Young's modulus of the stiffener must be sufficiently larger than that of the plate so that unit cell may show modes of clamped plate.

Keywords: Sound, Transmission, Stiffener I-INCE Classification of Subjects Number(s): 25.4

1. INTRODUCTION

Sound insulation performance of a panel is generally represented by STL (Sound Transmission Loss). Although panel or wall in reality is finite, theoretical estimation of the STL is usually based on the assumption of infinite panel or wall. Mass law (1) is a simple, but useful formula to predict STL of an infinite plate for intermediate and high frequency range. Mass law assumes that the plate is perfectly limp, and STL is determined only by the inertia of the plate mass. If a plate has stiffeners whose size is comparable to plate thickness, STL of a stiffened plate may be obtained as if it were an equivalent isotropic plate whose density and Young's modulus represent equivalent values. However, when stiffener size is much larger than plate thickness, STL of the stiffened plate depends mostly on the local vibration behavior of a unit cell. Lee and Kim (2) studied STL of an infinite plate with periodic line stiffeners. They found that STL shows a dip in low frequency range, and STL increases as frequency decreases below the dip or increases above the dip. They also showed that as distance between stiffeners becomes smaller, dip moves into the high frequency ranges. Varanasi et al. (3) used an impedance tube to investigate STL of the unit cell of the stiffened panel, in which boundary is clamped. They also investigated STL of the unit cell using FEM. They revealed that STL shows a dip at the first natural frequency of the plate and increases beyond the dip

In this paper, we consider low frequency sound transmission of stiffened panels using a mini-chamber, in which two small scale reverberation chambers are connected. We also use FEM to compute natural frequency of the unit cell of the stiffened panels.

2. STL MEASURMENT OF STIFFENED PANELS USING A MINI-CHAMBER

The first natural frequency of a clamped rectangular plate with size of $a \times b$ and thickness h is given by

$$f_{1,1} = \frac{\lambda^2 h}{2\pi a^2}\sqrt{\frac{E}{12\rho(1-\nu^2)}}, \tag{1}$$

in which E is Young's modulus, ρ density, and ν Poisson's ratio. The parameter λ is dependent on the ratio of a/b. If $a = b$, it is given $\lambda^2 = 35.99$ (4). The specimen is a MDF board

[1] hskim@kimm.re.kr

of 3 mm thickness, and stiffeners are wooden rod with cross section of 30×30 mm or 35×50 mm. In Figure 1, we show a sketch of the mini-chamber in which two small scale reverberation chambers are connected via a specimen. The volume of the source and receiving room is 2.81 m^3 and 3.25 m^3 respectively, and specimen size is 1.0 m x 1.2 m.

To measure the Young's modulus of the MDF board of 3 mm thickness, we use the following formula

$$f_c = \frac{c^2}{\pi h}\sqrt{\frac{3\rho(1-\nu^2)}{E}}, \tag{2}$$

in which f_c is the critical frequency of the infinite plate and c the speed of the sound. We can identify the f_c from the STL measurement as shown in Figure 2.

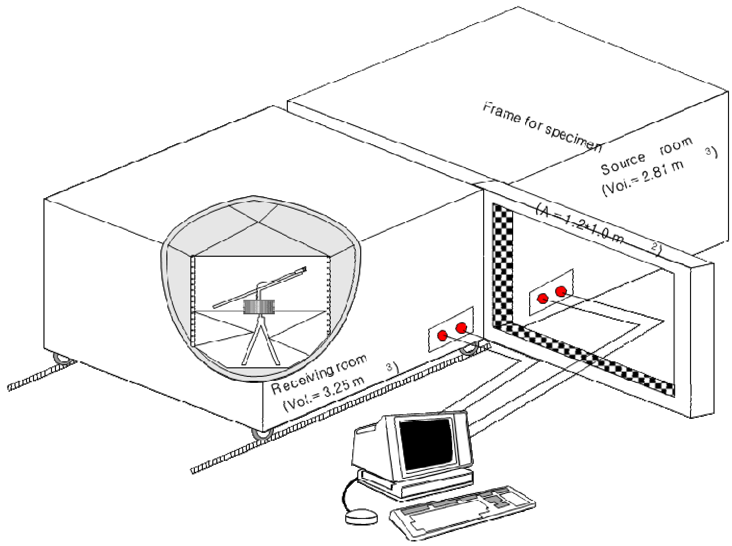

Figure 1. Mini-chamber

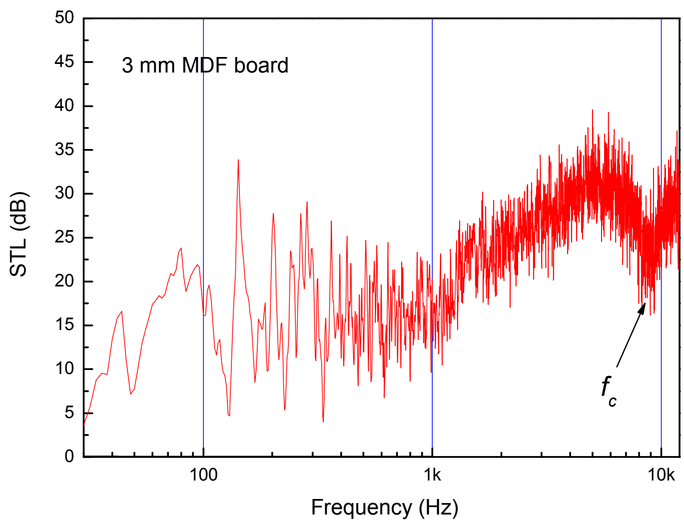

Figure 2. STL of a MDF board of 3 mm thickness

In Figures 3 and 4, we showed stiffened panels whose number of cells are 4×4 and 3×3. The unit cell size in Figure 3 is 205 mm x 255, while 280 mm x 280 mm in Figure. From Figure 2, $f_c \approx 9.0$ kHz. Since the density is 860 kg/m^3, we computed $E(1-\nu^2) = 4.6 \times 10^9$ Pa. Because Poisson's ratio ν of the MDF board is difficult to measure, we rather treat $E(1-\nu^2)$ as a single parameter. From Eq. (1), the first natural frequency of the unit cell with size of 205 mm x 255 mm and 280 mm x 280 mm is 235 Hz and 143 Hz respectively. In Figure 5, we showed STL measurement of the stiffened panel in Fig. 4 (205 mm x 255 mm), and observed a dip around 220 Hz. We also used FEM to compute natural frequency of the unit cell of 280 mm x 280 mm as shown in Figure 6, for which $f_{1,1} = 142$ Hz.

Figure 3. Stiffened panel with 4×4 cells (205 mm x 255 mm)

Figure 4. Stiffened panel with 3×3 cells (280 mm x 280 mm)

To see how a stiffened panel shows sound insulation performance at low frequency range, we measured insertion loss (IL) that is defined the SPL (sound Pressure Level) difference with and without the stiffened panel as

$$\text{IL} = \text{SPL\_base} - \text{SPL\_(base + stiffened panel)}. \tag{3}$$

We impact the base material as shown in Figure 7 without the stiffened panel (see Figure 8), and with the stiffened panel (see Figure 9). The base material is a MDF board of 6 mm thickness. The distance between base material and the stiffened panel is 80 mm. We used an impact hammer and measured SPL per unit force so that the unit is Pa/N. We impacted five points on the base material and measured SPL at 6 points inside the reverberation chamber, and averaged the results.

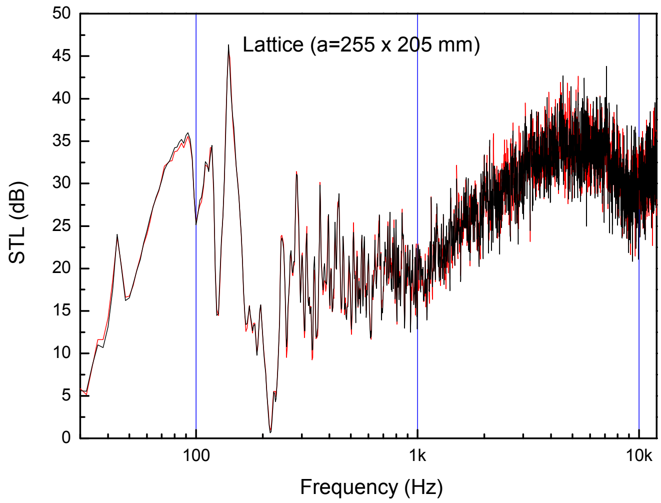

Figure 5. STL measurement of the stiffened panel with 205 mm x 255 mm unit cell

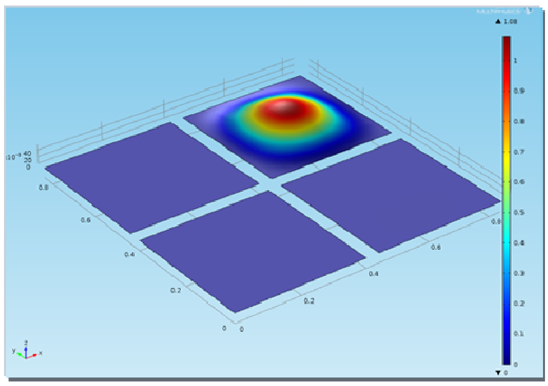

Figure 6. Computation of the first natural frequency of 280 mm x 280 mm unit cell using FEM

Figure 7. An impact hammer on the base material

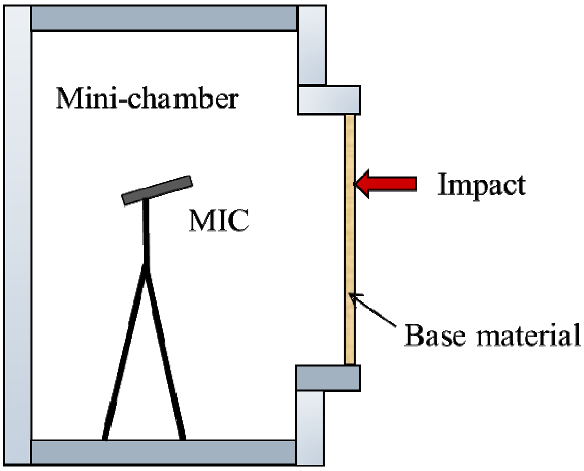

Figure 8. Impacting base material without the stiffened panel

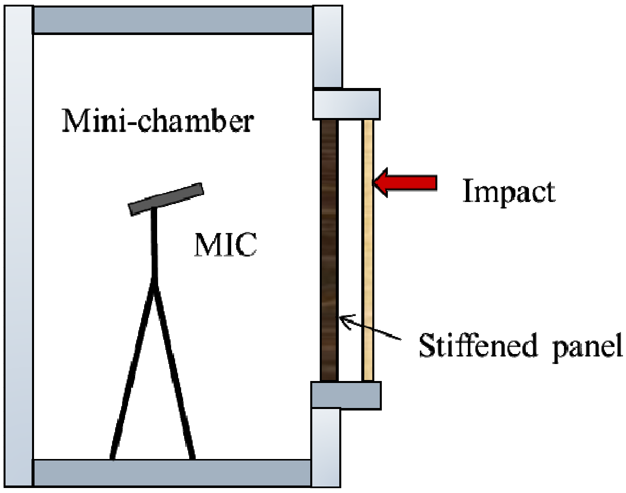

Figure 9. Impacting base material with the stiffened panel

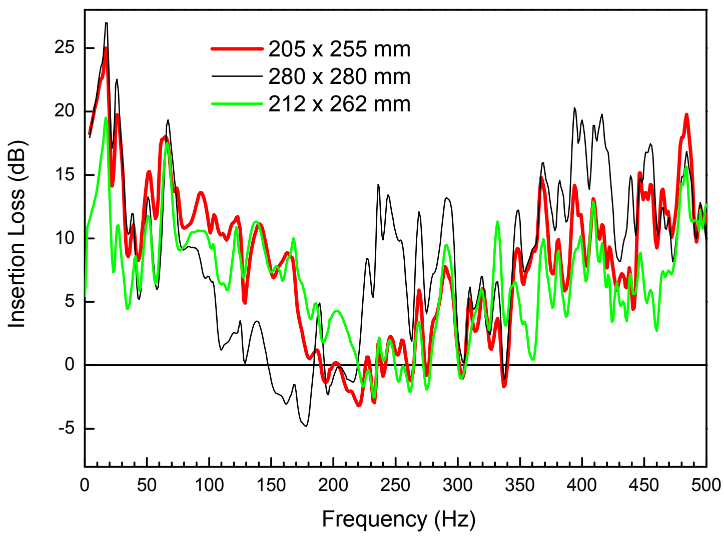

Figure 10. IL of stiffened panels of three different unit cell size

In Figure 10, we compared IL measurement of the stiffened panels having three different unit cell size, which shows dip around 150 Hz for 280 mm x 280 mm, and dip around 200 Hz for 205 x 255 mm.

3. INSERTION LOSS MEASUREMENT OF THE FULL SCALE SPECIMEN

We installed the stiffened panels below the ceiling in the full scale reverberation chamber. The sketch of the ceiling from the upper view is given in Figure 11. We apply impact on the specimen that is the concrete slab of 150 mm thickness, and size is 4.28 m x 2.78. Along the perimeter of the specimen, rubber isolation is installed between specimen and surrounding floor structure that is double concrete structure of 300 mm thickness. Figure 12 shows ceiling and the specimen. Figures 13 and 14 show installation of a stiffened panel below the ceiling. The stiffened panel covers only the specimen, not the whole ceiling. The distance between the specimen and panel is 200 mm.

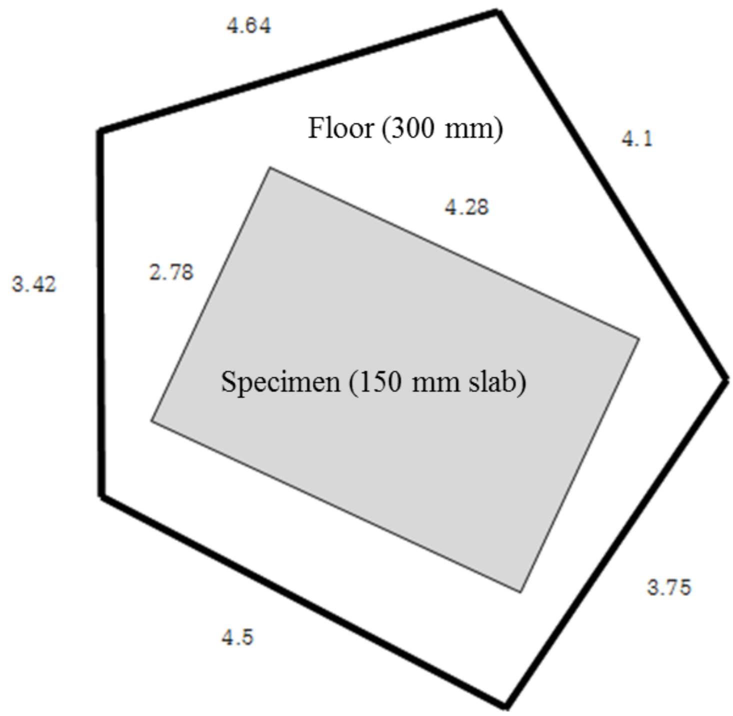

Figure 11.Upper view of the reverberation room (unit in meter)

Figure 12. Ceiling and the specimen

Figure 13. Installation of the stiffeners below the specimen

Figure 14. Installation of the stiffened panel below the specimen

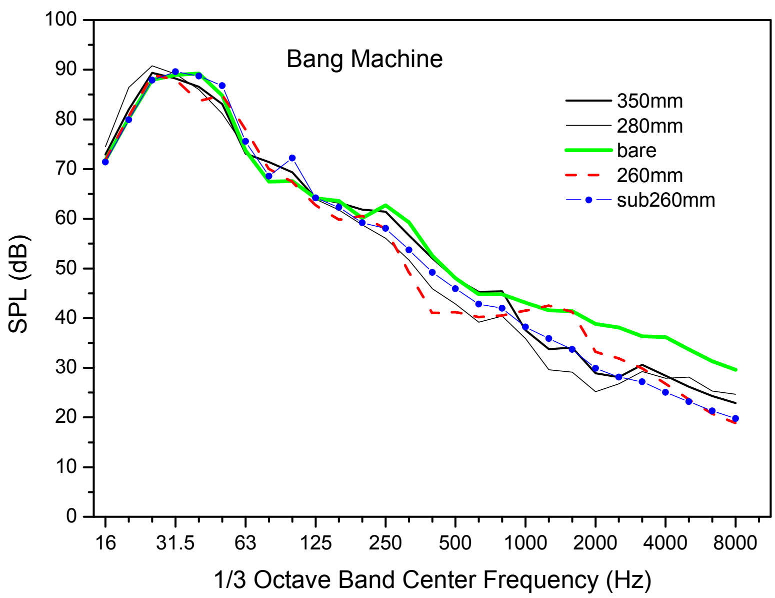

Figure 15. Impact noise in the full scale reverberation chamber for different stiffened panels

In Figure 15, we compared impact noise inside the reverberation chamber with and without several different stiffened panels, in which we used a bang machine for the impact noise source. It is observed that SPLs show almost no meaningful difference below 200 Hz when there exist stiffened panels or not.

4. DISCUSSION AND CONCLUSIONS

Although we observed significant impact sound insulation in the mini-chamber at low frequency range which is below the first natural frequency of the unit cell, the full scale measurement showed that adding stiffened panel below the specimen does not provide impact sound insulation in the low frequency range. The reason may be due to the flanking noise path for structure-borne noise along the perimeter of the specimen. We installed stiffened panel only below the specimen, in which the area ratio of the specimen and the total ceiling is 0.43. It may be concluded that complete block of the flanking noise path is the most important parameter for achieving the sound insulation using the stiffened panels in the low frequency range.

REFERENCES

1. Junger MC, Feit D. Sound, Structures, and Their Application. 2nd ed. The MIT Press; 1986.
2. Lee JH, Kim J. Analysis of sound transmission through periodically stiffened panels by space-harmonic expansion method. J. Sound Vibration. 2002;251(2):349-366.
3. Varanasi S, Bolton JS, Siegmund TH, Cipra RJ. The low frequency performance of metamaterial barriers based on cellular structures. Appl. Acoustics. 2013;74:485-495.
4. Blevins RD. Formulas for Natural Frequency and Mode Shape, Page 261, New York, Van Nostrand Company; 1979.