Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Acoustical Charcteristics of Newly Developed Perforated_Plates

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PACS: 43.55.Ev

ABSTRACT

We search materials which are hard but can absorb sound quite a bit, or are hard and do not affect the sound transmission. For this aim, we measured normal incident absorption coefficient of perforated plates with/without glass wool absorption materials by transfer function method. The perforated plates include commercial aluminum perforated plates with 22.6% and 8.2% perforation rate, and aluminum plates with 1% perforation rate. The thickness of the plates is 0.5 mm to 2 mm. The diameter of the holes in the plate is 0.5 mm or 1 mm. For comparison, the plates with a single hole of 22.6%, 8.2% and 1% perforation rate were measured. From the results, it is implied that the perforated plates act as low pass filters and, their cut-off frequency is due to the perforation rate and the thickness of the plates. If the perforation rate is the same, the cut-off frequency of the perforated plate is higher than that of the plate with a single hole. For simulations of this phenomenon, we analyzed using both FEM and electrical equivalent circuit model of the tube. It is shown that the particle velocity in the holes of the plate is higher than the other part. It is shown that for the perforated plate, wave front passing through the plate is not largely changed by way of comparison of that for the plate with a single hole.

INTRODUCTION

We search materials which are hard but can absorb sound quite a bit. Plates with high perforation rate are well known as having the almost same absorption characteristics as ones of absorption materials behind the paltes. But it is not known how absorption characteristics the plate have if changed perforation rate and how to transmit through perforated-plates. Therefore, we measure normal incident absorption coefficient of perforated-plates with/without glass wool absorption materials by transfer function method. Then, we analyze acoustical characteristics of the perforated-plates using both FEM and equivalent electrical circuit model of the tube.

MEASUREMENT METHOD

Measurement method of normal incident absorption coefficients

There are two systems. One, for Tube A, is available as measuring 200 to 2 kHz as shown as Figure 1. The diameter of the tube is 44.8 mm. The two microphones used here are 1/2 inch condenser ones, B&K 4133, and are set as 70 mm distance between them. A loudspeaker is inputed octave-noise with the center frequency 250, 500, 1 k, and 2 kHz from a noise generator, NODE 7030. The other, for Tube B, is available for measuring 500 to 6.5 kHz as shown as Figure 2. The two microphones are 1/4 inch condenser ones, Aco 4156N, and are set as 20 mm distance between them. Loudspeakers are inputed octave-noise with the center frequencies 500, 1 k, 2 k, and 4 kHz from the noise generator.

Sound velocity in the tube is calculated from the room tempereture. The outputs of the microphones are amplified by the amplifier and are taken for 20 seconds in a personal computer through an A/D converter. Samling frequencies are 1024, 2048, 4096, 8192, and 16384 Hz against the center frequency 250, 500, 1 k, 2 k, and 4 kHz of the noise generator. The norml incident absorption coefficients are calculated from the transfer functions of the values obtained by the two microphones.

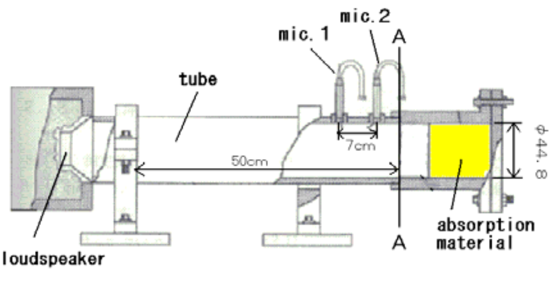


Figure 1 Measurement system of normal incident absorption coefficients from 200 to 2 kHz.(Tube A)

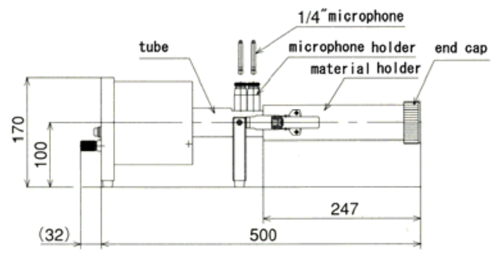


Figure 2 Measurement system of normal incident absorption coefficients from 500 to 6.5 kHz. (after booklet of ONO SOKKI CO.,LTD.) The inner diameter of the tube is 29 mm. (Tube B)

The normal incident absorption coefficients, α, are caluculated as follows. At first, 0.5 second data obtained from microphones 1 and 2 are multiplied by hanning window. Their FFTs are carried out. Autocorrelation of microphone 1 and cross-correlation between microphones 1 and 2 are calculated from their FFTs. The transfer function, H_{12}, is calculated from their 20 times average values. α is given as

$$\alpha = 1 - | (H_{12} - Hi) / (Hr - H_{12}) |^2$$

where $Hi = \exp(-jks)$、$Hr = \exp(jks)$、k is the wave number, and s is the distance between microphones 1 and 2, 70mm or 20mm.

The perforated-plates are set as A-A side as shown in Figure 1, and as 36 mm distance from the right microphone as shown in Figure 2. We measure α for the perforated-plates with/without 96 kg/m^3 glasswool absorption materials when the tube lengths from the right end are 50 mm, 70mm, and 90mm.

Measured perforated-planes

There are four kinds of perforated-plates as follows.

(1) Commercial alminum perforated-plate with 22.6% perforation rate and 0.5 mm thickness and ones pasting two from four planes together. The diameter of holes is 0.5mm, and partially 1.5mm.

(2) Commercial Alminium perfotated-plate with 8.2% perforation rate and 1 mm thickness. The diameter of holes is 1 mm.

(3) Alminum perforated-plate with about 1% perforation rate, and 0.5 and 1 mm thickness. The diameter of holes is 1 mm.

(4) Alminum plates with single hole, 1mm thickness, and 22.6%, 8.2% and 1% perforation rate.

MEASUREMENT RESULTS

Results using Tube A

(1) Commercial alminum perforated-plate with 22.6% perforation rate and 0.5 mm thickness

There is a 20mm air space between the perforated-plate andthe glass-wool absorption materials. The normal incident absorption coefficients are little changed, even when the thickness of the plate changes. So, Figure 3 shows normal incident absorption coefficients for perforated-plates with 2 mm thickness. The normal incident absorption coefficients for 0.5mm diameter of holes are almost the same as for 1.5 mm diameter of holes and similar to for only glasswool absorption materials.

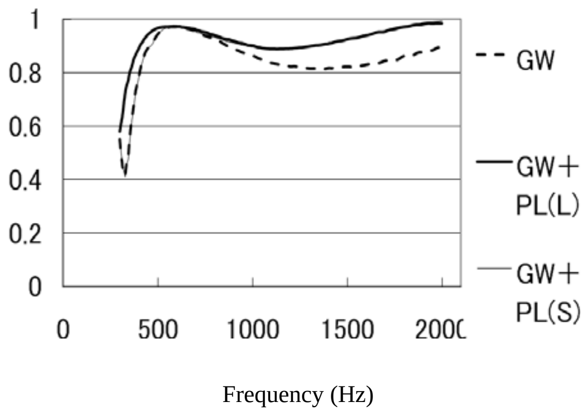


Figure 3 Normal incident absorption coefficeints with/without perforated plate (thickness 2mm). GW: only glass-wool. GW+PL(L): plate with1.5ϕ holes and glass-wool. GW+PL(L): plate with 0.5ϕ holes and glass-wool.

(2) Commercial alminum perforated-plate with 8.2% perforation rate and 1 mm thickness

The holes in the plate are not zigzag alignments but are square ones. The normal incident absorption coefficients are shown in Figure 4. (a), (b) in Figure 4 shows when air spaces between the plate and the glass-wool are 0cm and 2cm, respectively. For the both cases with the plate and glass-wool, the normal incident absorption coefficients are almost the same and are similar to for only glass-wool. Fot the case of the plate only, the normal incident absorption coefficients have less than 0.3 and do not have sharp peaks.

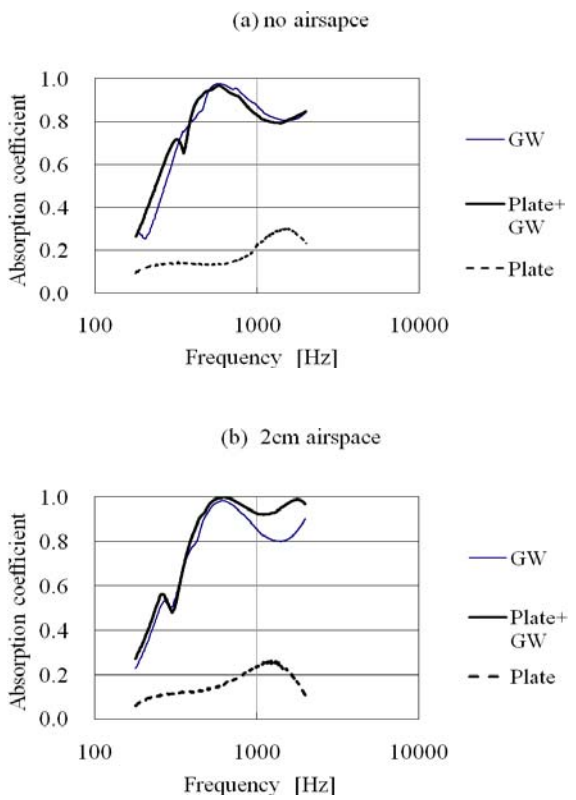


Figure 4 Normal incident absorption coefficients ot perforated-plate with 8.2% perforation rate and 1mm thickness.

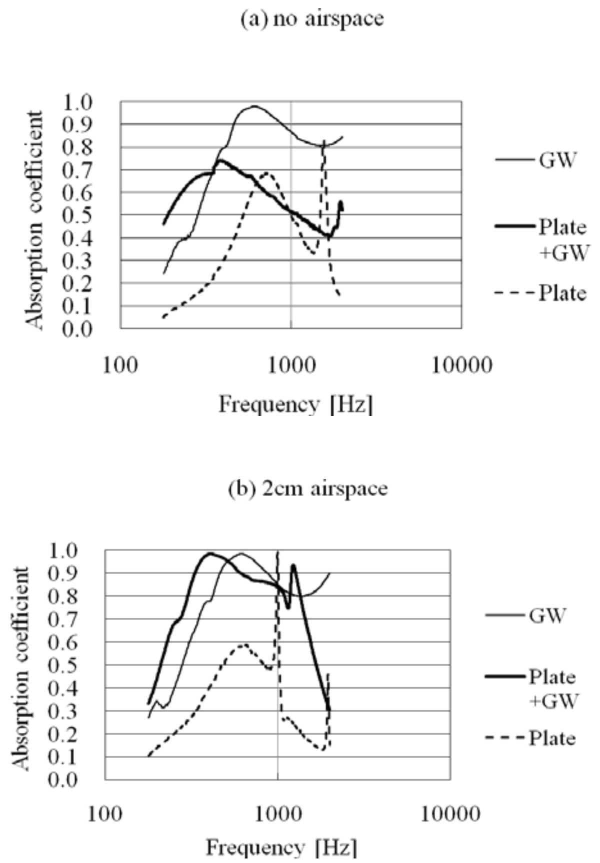


Figure 5 Normal incident absorption coefficients of perforated plate with 0.5 mm thickness and 1% perforation rate.

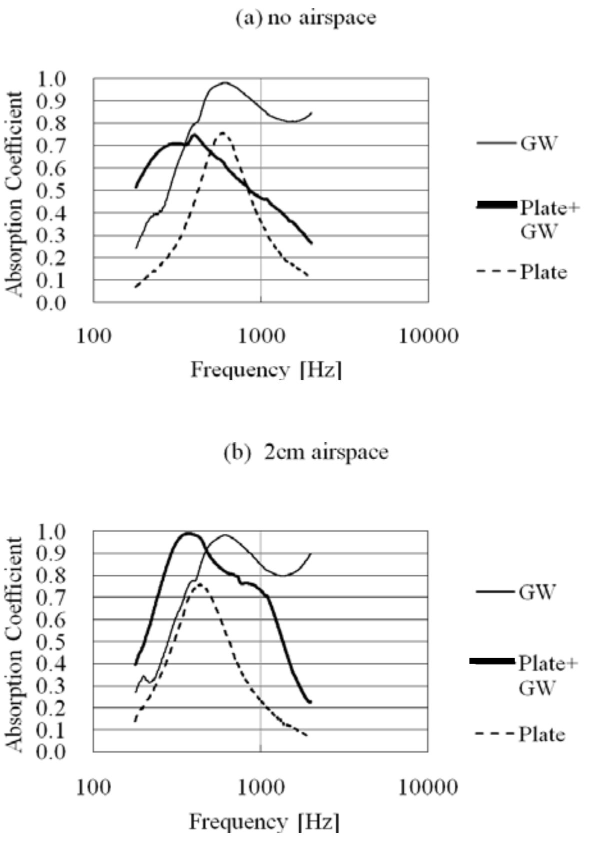


Figure 6 Normal incident absorption coefficients of perforated plate with 1 mm thickness and 1% perforation rate.

(3) Alminum perforated-plate with about 1% perforation rate

Figures 5 and 6 show the normal incident absorption coefficients of the plate with 0.5 mm and 1 mm thickness, respectively. In cases of only the plate, the normal incident absorption coefficients have peaks, and the values of the peaks are 0.6 to 0.8. These results are different from the plate with 8.2% perforation rate. The peak frequency is lower, when the length of backward tube is longer. These results are known as microperforated panel, or mpp [1], [2]. For no air space between the palte and glass-wool, the normal incident absorption coefficients have a broader band up to 0.7. For 2cm air space between the palte and glass-wool, the normal incident absorption coefficients have up to 1 and its upper limit frequency, when it becomes 0.7, is more than 1 kHz. The peak frequency of the palte with 0.5mm thickness is higher than that of the plate with 1mm thickness.

(4) In the cases of single hole

Figures 7 and 8 show the normal incident absorption coefficients for the plates with 4.4mm, about 1% perforatin rate, and 12.5 mm, about 8.2% perforation rate, in diameter of single hole, respectively. For only the plates with 1% perforation rate, the normal incident absorption coefficients have a peak, and the peak frequency is lower than for multi holes. For only the plate with 8.2% perforation rate, the normal incident absorption coefficients have a low peak and the peak frequency is lower than for multi holes. For no air space between the plate and glass-wool, the normal incident absorption coefficients have a low peak in the case of 1% perforation rate and have a peak in the case of 8.2% perforation rate. For both cases, the peak frequencies are lower than for multi-holes. For 2 cm air space between the plate and glass-wool the normal incident absorption coefficients have a peak or a broad band peak, but the peak frequencies are exactly lower than for multi holes.

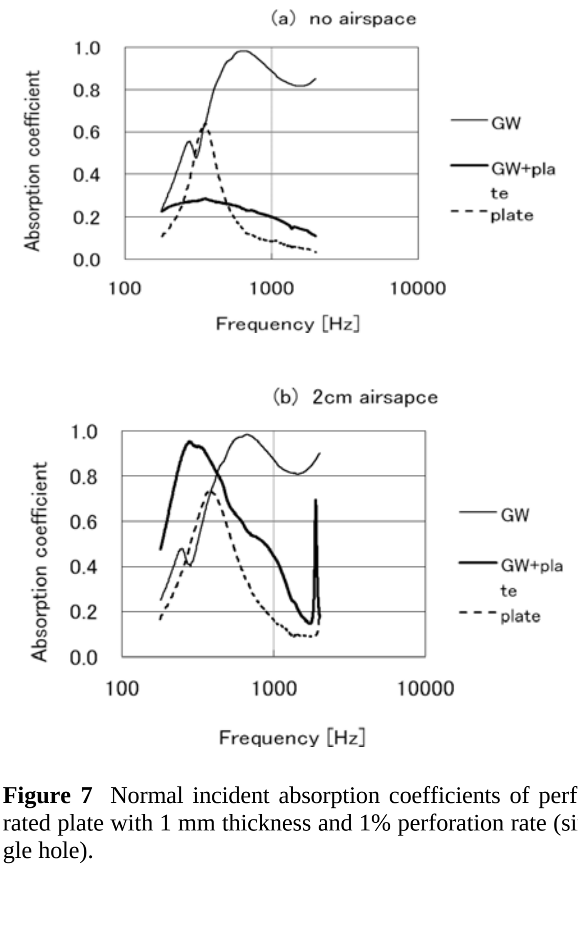


Figure 7 Normal incident absorption coefficients of perforated plate with 1 mm thickness and 1% perforation rate (single hole).

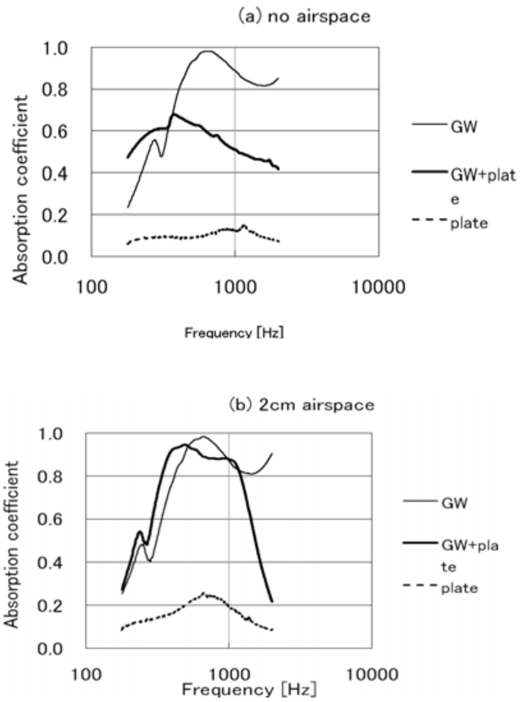


Figure 8 Normal incident absorption coefficients of perforated plate with 1 mm thickness and 8.2% perforation rate (single hole).

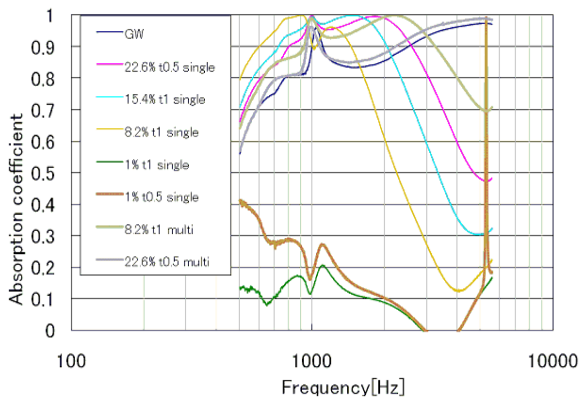


Figure 9 Normal incident absorption coefficients with 1cm air space between the plate and glass-wool. %: perforation rate, t: thickness of plate (mm), single: single hole, multi: multi holes.

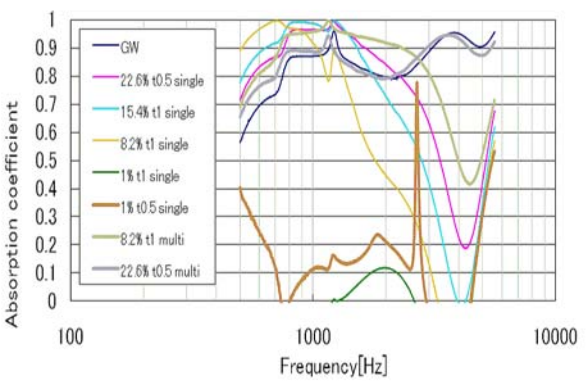


Figure 10 Normal incident absorption coefficients with 2cm air space between the plate and glass-wool. %: perforation rate, t: thickness of plate (mm), single: single hole, multi: multi holes.

Results using Tube B

Figures 9 and 10 show the normal incident absorption coefficients for 10 mm and 20 mm air spaces between the plates and glass-wool, respectively. For the perforated plate with 0.5 mm diameter of holes, 0.5 mm thickness, and 22.6% perforation rate, the normal incident absorption coefficients are almost the same up to 5.6 kHz as for only glass-wool, when air spaces are 10 mm and 20 mm. For the perforated plate with 1 mm diameter of holes, 1 mm thickness, and 8.2% perforation rate, upper limit frequencies when the coefficient becomes 0.7, are 5 kHz in the case of 1 cm air space, and 3.7 kHz in the case of 2 cm air space. It is seen that the upper limit frequency changes due to the length of the air space. For the single hole, every the upper limit frequency is lower than for the multi holes and for 1 cm air space is higher than for 2 cm air space.

SIMULATION USING FINITE ELEMENT METHOD

We analyse a tube with the plate and absorption wall using FEM by Sysnoise version5.5, LMS Co..

2-D models

2-D models are a rectangle shape, 151 mm long and 45 mm wide. Every element is 1 mm long and 1mm wide. There is an almimum plate with 1mm thickness at a distance of 100 mm from the left end. Density of alminum is 2.7g/cm^3 and sound velocity in alminum is 3150 m/s. There are four kinds of hole(s): first is a 5mm single hole (11.1% perforation rate), second is a 11mm single hole (24.4% perforation rate), third is 5 holes equally spaced with 1 mm wide, fourth is 11 holes equally spaced with 1mm wide. As boundary conditions, impedance of the left and right ends is ρc, where the density of air, ρ, is 1.4kg/m^3 and the sound velocity is 340m/s. The soud pressure at the left end is given 1 Pa. The upper and lower wall is rigid.

3-D models

For 3-D models, a rectangular box is x-directional and y-directional symmetry because input pressure is uniform in the tube. The box is 21mm wide, 21mm high, and 151mm long; the real size is 42mm wide, 42mm high, and 151mm long. There is an almimum plate with 1mm thickness at a distance of 100 mm from the left end. There are two kinds of hole(s): first is a 7 mm wide and 7 mm high single hole (11.1% perforation rate, the real hole is a 14 mm wide and 14 mm high and centerally-placed on the plate), and second is 49 holes equally spaced with 1 mm wide and 1 mm high. As boundary conditions, impedance of the left and right ends is ρc, where the density of air, ρ, is 1.4kg/m^3 and the sound velocity is 340m/s. The soud pressure at the left end is given 1 Pa. The other walls are rigid .

Analysis frequencies are 100, 300, 500, 1 k, 2 k, 5 kHz (partially 7 kHz).

Calculation of normal incident absorption coefficient

The normal incident absorption coefficient, α, is given as follows. From sound pressure, P_1 and P_2, on the wall obtained from FEM analysis, the transfer function, $H_{12}=P_2/P_1$. The reflection coefficient, R, is given as follows.

$$R = \{H_{12} - \exp(-jkd)\} / \{\exp(jkd) - H_{12}\}$$

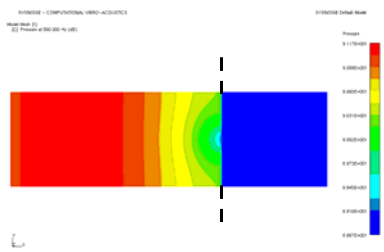
$$\alpha = 1 - |R|^2$$

where the locations obtaining P_1 and P_2 are at 30mm and 87 mm distance from the left side at less than 2 kHz, and are at 30 mm and 50 mm distance from the left side at 5 kHz. The distance between them is *d*, and *k* is the wave number.

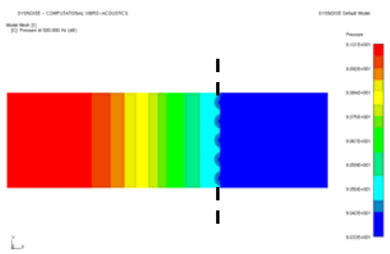
Results and discussion

Figure 11 shows pressure distribution of 2-D models. For single hole, (a) and (c), it is seen that sound pressure contours are not perpendicular on the left side of the hole. For 5 holes and 11 holes, (b) and (d), sound pressure contours are almost perpendicular on the left side of the hole. Figure 12 shows distributions of x-directional particle velocity. The particle velocity is large in the holes. When the absorption coefficients are nearly 1, the particle velocity in the holes varies inversely with perforation rate.

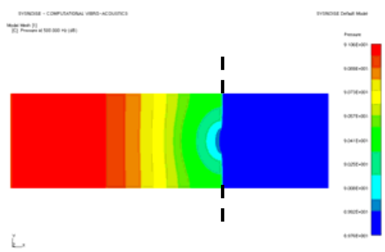
(a) Single hole(5mm), 500Hz, 88.7dB(blue)-91.2dB(red)



(b) 5 holes, 500Hz, 90.3dB(blue)-91.0dB(red)



(c) Single hole(11mm), 500Hz, 89.8dB(blue)-91.1dB(red)



(d) 11 holes ,5kHz, 88.5dB(blue)-92.9dB(red)

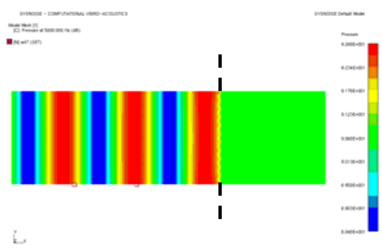
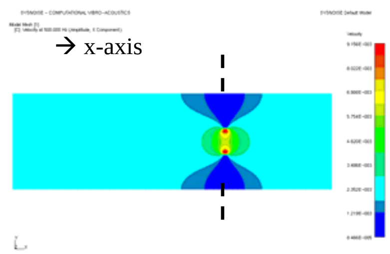


Figure 11 Pressure distributions of 2-D models. Broken line: position of aluminum plate.

Figure 13 shows pressure distribution of 3-D models. It is seen that even for single hole, sound pressure contours are more perpendicular against propagation direction on the left side of the hole than for 2-D models. For multi-holes, sound pressure contours in front of and behind the plate are perpendicular, and are the almost same as in the case that the plate do not exist. Figure 14 shows distributions of z-directional particle velocity. The z-directional particle velocity is large in the holes as same as in 2-D models. For multi-holes, the z-directional particle velocity is larger than in 2-D model.

Figure 15 shows normal incident absorption coefficients obtained from FEM analysis. For single hole, the coefficients of 3-D model are more affected than those of 2-D model, or the cut-off frequency of 3-D model is lower than that of 2-D model. For multi-holes, the coefficients of 2-D model are more affected than those of 3-D model. It is seen that results of 3-D model is not well known from results of 2-D model. Compared to the results of the measurement as written above, results of 3-D models is better than those of 2-D models.

(a) Single hole(11mm),500Hz,0.08mm/s(blue)-9.1mm/s(red)



(b) 11 holes, 500Hz, 0.31mm/s(blue)-4.6mm/s(red)

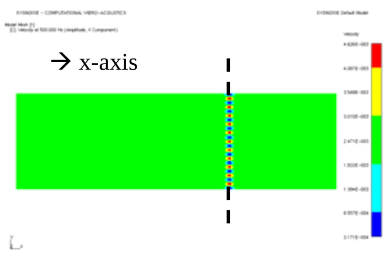
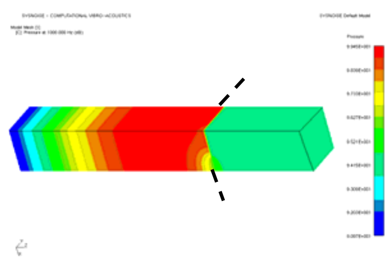


Figure 12 X-directional particle velocity distributions of 2-D models.

(a) Single hole, 1kHz, 91.0dB(blue)-99.5dB(red)



(b) 49 holes, 1kHz, 91.0dB(blue)-92.3dB(red)

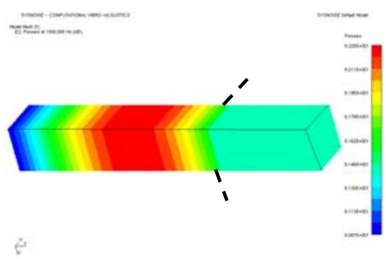
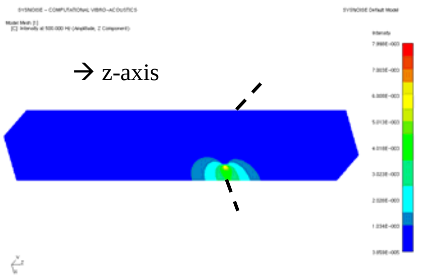


Figure 13 Pressure distributions of 3-D models.

(a) Single hole, 500Hz, 0.04mm/s(blue)-7.9mm/s(red)



(b) 49 holes, 1kHz, on xz cross-sectional surface with holes 0.28mm/s(blue)-5.2mm/s(red)

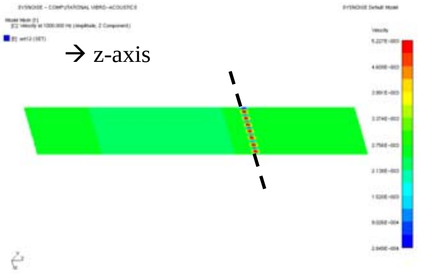
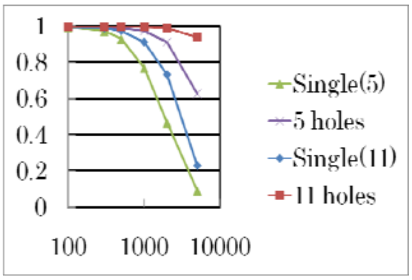


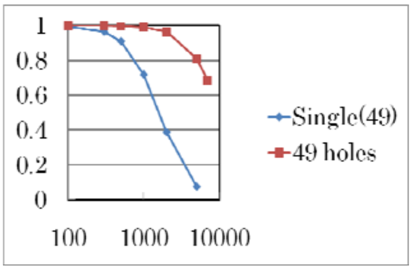
Figure 14 Z-directional particle velocity distributions of 3-D models.

(a) 2-D models



Frequency [Hz]

(b) 3-D models



Frequency [Hz]

Figure 15 Normal incident absorption coefficients by FEM.

ANALYSIS USING EQUIVALENT ELECTRICAL CIRCUIT MODEL OF TUBE

We assume that sound in the tube propagates as planar wave. From this assumption, propagating sound in the tube is described as equivalent electrical circuit model. The normal incident absorption coefficients of glass-wool are frequency-dependent, however we assume that they are 1, or are equal to impedance of air, ρc. The inductance, L, and the capacitance, C, of each section of the tube are given as

$$L = (\rho/A)\,\Delta L, \qquad C = (\rho c^2/A)\,\Delta L$$

where density of air, ρ, is 1.14kg/ m^3, sound velocity in air, c, is 340m/s, A is a cross-sectional area [m^2], and ΔL is a length of the tube [m]. For the equivalent electrical circuit model, cross-sectional area is lelative, so the cross-sectional area of the tube except the perfotated-plate is 1 m^2 and that of the perfotated-plate is P/100 m^2, where P is perforation rate [%]. ΔL[m] is the length of the tube. If ΔL is 1 mm, upper computable frequency is 20 kHz.

The normal incident absorption coefficient is given as the ratio of effective power, VIcosθ, to $V^2/\rho c$, where V is a voltage of both end of the perforated-plate, I is a current in the perforated-plate, and θ is phase difference between V and I. Figure 16 shows normal incident absorption coefficients of the perforated-plate with 8.2% perforation rate and 2 mm thickness. This characterisitics is a LPF, or lowpass filter. The normal incident absorption coefficient is 0.9 at 1.5 kHz, and is 0.7 at 3kHz. The frequency of the absorption coefficient 0.9 is a half of the frequency of absorption coefficient 0.7. This frequency is proportional to

perforation rate(%) / thickness (mm).

The proportionality factor is 0.72 in the case of the absorption coefficient 0.7. This result is somewhat different to the results of Figures 9 and 10. This is due to that the absorption coefficient of glass-wool is 1.

We analyze equivalent elecrtrical ciruit model in the case that the absorption coefficient of glass-wool is 0.9. Figure 17 shows the results. If the air space between the plate and glass-wool changes, the absorption coefficient changes, and results of equivalent elecrtrical ciruit model close in results of measuring.

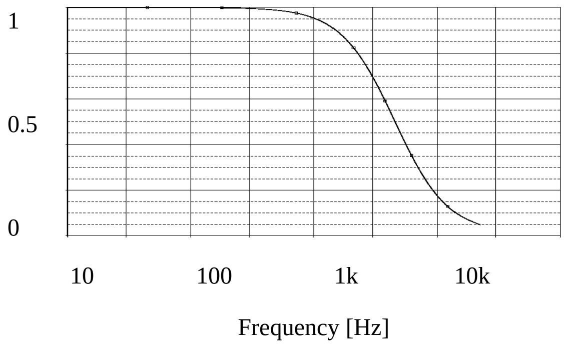


Figure 16 Normal incident absorption coefficient of perforated-plate with 8.2% perforation rate and 2mm thickness.

CONCLUSIONS

We measured the normal incident absorption coefficients of some kinds of perforated-plates with/without glass-wool. From the results with glass-wool, it is implied that the perforated plates act as low pass filters and their cut-off frequency is due to the perforation rate and the thickness of the plates. If the perforation rate is the same, the cut-off frequency of the perforated plate is higher than that of the plate with a single hole. It is shown that the particle velocity in the holes of the plate is higher than the other part from FEM. It is shown that for the perforated plate, wave front passing through the plate is not largely changed by way of comparison of that for the plate with a single hole from FEM. From analysis using equivalent electrical circuit model of the tube, it is shown that upper cut-off frequency is proportional to

perforation rate(%) / thickness (mm).

We showed the reason why the normal incident absorption coefficients are changed by the air space between the plate and glass-wool.

The future works will be to simulate the perforated plates without glass-wool.

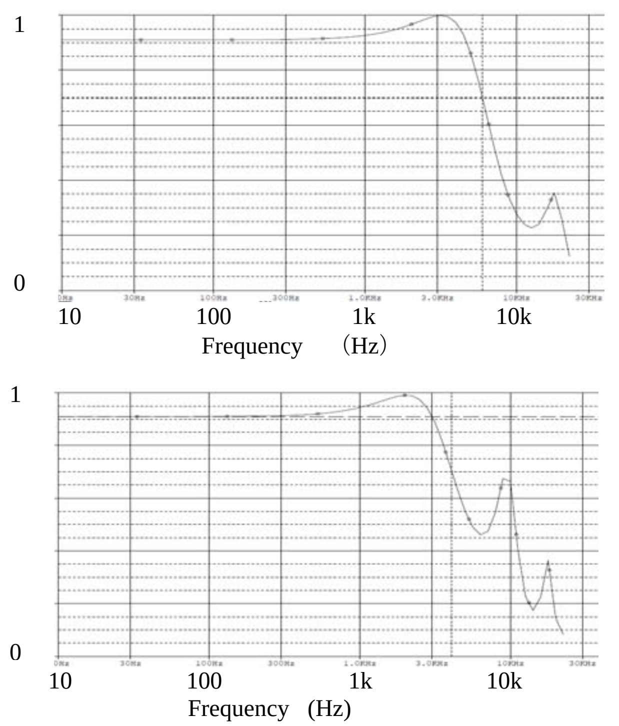


Figure 17 Normal incident absorption coefficients of simulation in the case that absorption ciefficeint of glass-woo is 0.9. Upper: 10 mm air space, and lower: 20 mm air space.

REFERENCES

1 D. Y. Maa, "Theory and design of microperforated-panel sound-absorping constraction," Sci. Sin., 18, pp.55-71 (1975).

2 K. SAKAGAMI, M, MORIMOTO, and M. YAIRI, "Application of microperforated panel absorbers to room interior surfaces, " International Journal of Acoustics and Vibration, 13 (3), pp.120-124 (2008.9)

3 T. Nakai, F. Kawakami, K. Wada, and T. Sano, "Acoustical characteristics of perforated panel," Acoustical Society of Japan Technical Report, AA2009-18 (2009.3) (in Japanese)