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Improvement of sound insulation performance at low frequencies by several fibrous absorbers in lightweight double leaf partition

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ABSTRACT

Sound insulation performance is generally increased by installing a fibrous absorber such as glass wool into cavity of double leaf partition. It usually increases further as the thickness and density of fibrous absorber increase. However, installing the absorber decreases occasionally the sound insulation. In this study, we have measured the sound insulation performance by use of test facility in which the fibrous absorber in the cavity could be replaced without removing boards from studs. From the results, we have clarified the relationship between the parameters, such as thickness and density, of fibrous absorber and the sound insulation performance at low frequencies. The performance is reduced at frequency bands not greater than the mass-air-mass resonance frequency as installing glass wool into the cavity. It is also presented that the performance does not absolutely increase with increasing the bulk density in the frequency range from 125 Hz to 250 Hz. The proper value of the bulk density is about 24 kg/m^3 for improvement of the sound insulation.

Keywords: glass wool, mass-air-mass resonance, sound insulation
I-INCE Classification of Subjects Number(s): 33

1. INTRODUCTION

Fibrous absorber such as glass wool is usually installed into the cavity of double leaf partition in order to improve partition's sound insulation. However, the absorber has less effect on the sound insulation at low frequencies as compared with one at high frequencies. Even if bulk density of fibrous absorber increases, the sound insulation is not significantly changed. For example, Warnock concluded that the benefits available from using absorbing material with higher bulk density were not evident at low frequencies (1). Uris has also concluded that the sound insulation could be increased by reducing rock wool's density in the frequency range below 1250 Hz (2). Moreover, the decrease of sound insulation also occurs occasionally, after installing fibrous absorber into the cavity.

On the other hand, the sound insulation performance at the region of low frequency determines usually the single-number quantity such as R_w and STC. Therefore, it is important to reveal effect of bulk density and thickness of fibrous absorber on the sound insulation performance at low frequencies in order to improve the single-number quantity. In this study, we measured the sound insulation performance of double leaf partition contained with glass wool of different density and thickness, by using the test facility in which it is possible to change only condition of glass wool while the other conditions of the partition remain constant. Based on these measured results, we discus the relationship between the sound insulation performance at low frequencies and the parameters such as the bulk density and the thickness. In addition, the parameters are optimized for improvement of the sound insulation.

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2. TEST FACILITY AND TEST SPECIMEN

2.1 Test facility

It is necessary that the other conditions, such as connectivity between board and stud, than one of glass wool are controlled constantly when glass wool is replaced. Thus, the measurement of sound reduction index R was carried out with use of the test rooms whose one room was movable. Each board which composed double leaf partition was constructed on each room, as striding over the boundary between two rooms. Consequently, it is possible to replace glass wool in the cavity without removing boards from studs by separating one room from another one. Therefore stud system of the walls tested was double rows of studs as shown in Figure 1. And an elastic material was inserted between two rooms so that the flanking transmission was reduced.

The measurement of sound reduction index R was conducted by two room method (3). Volumes of the two rooms are 51.4 m^3 and 56.7 m^3, and size of the opening is 3.65 m × 2.74 m (=10.0 m^2). Absorbing condition of rooms, position of microphones and sound sources, and averaging time for sound pressure level measurement were never changed through all of measurements. Therefore it is possible to compare measured results with each other in the frequency range from 50 Hz to 5000 Hz at least in the same type of walls shown in Figure 1.

2.2 Test specimen

Figure1 shows the structures for four types of the walls tested in this study. The walls had different structures in thickness of the air cavity and the boards. The wall's frame was composed of double rows of 47 mm wide steel runner and rectangle shaped steel stud (45 × 40 × t0.5 mm) for all types. Therefore, the sound bridge effect though runners and studs was reduced. Separation between studs was 455 mm.

Gypsum boards of 12.5 mm thickness were attached to studs by screws, but gypsum boards of 9.5 mm thickness used in the case of Type A-2 were bonded to gypsum boards 12.5 with steel staples. The gaps on four peripheral ends of wall were filled up with acrylic seal.

Distances between boards were 100 mm and 65 mm respectively on Type A and Type B-1 so that the mass-air-mass resonance frequency f_{rmd} was included in the measureable frequency range. On the other hand, in the case of Type B-2 the distance increased excessively to 412 mm so that f_{rmd} was shifted to 45 Hz which was approximately the lower limited frequency.

Table 1 shows details of materials that comprise double leaf partition. Regarding Type A, three kinds of glass wool, GW10K, 24K and 48K, were used. The sound reduction index R was measured in two cases that those glass wools were filled and half-filled the cavity with. Concerning Type B, six kinds (GW10K, 16K, 24K, 32K, 48K and 64K) of 50 mm thick glass wool were installed into the cavity.

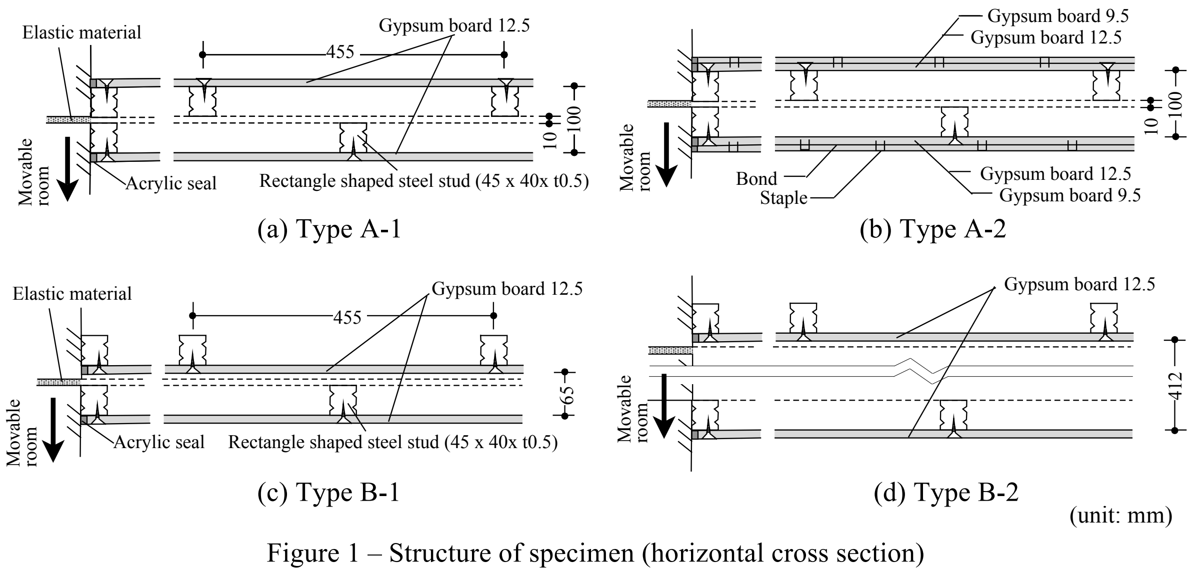

Figure 1 – Structure of specimen (horizontal cross section)

Table 1 – Detail of materials used as specimen

Type of wall	Thickness of air cavity, mm	Thickness of gypsum board, mm	Mass-air-mass resonance frequency f_{rmd}, Hz	Thickness of glass wool, mm	Measured value of bulk density of glass wool installed in air cavity, kg/m^3					
					GW 10K	GW 16K	GW 24K	GW 32K	GW 48K	GW 64K
A-1	100	12.5	93	50, 100	10.2	-	23.6	-	46.9	-
A-2	100	9.5+12.5	70							
B-1	65	12.5	114	50	10.0	15.6	22.3	31.3	47.7	62.9
B-2	412	12.5	45							

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3. MEASURED REUSULTS

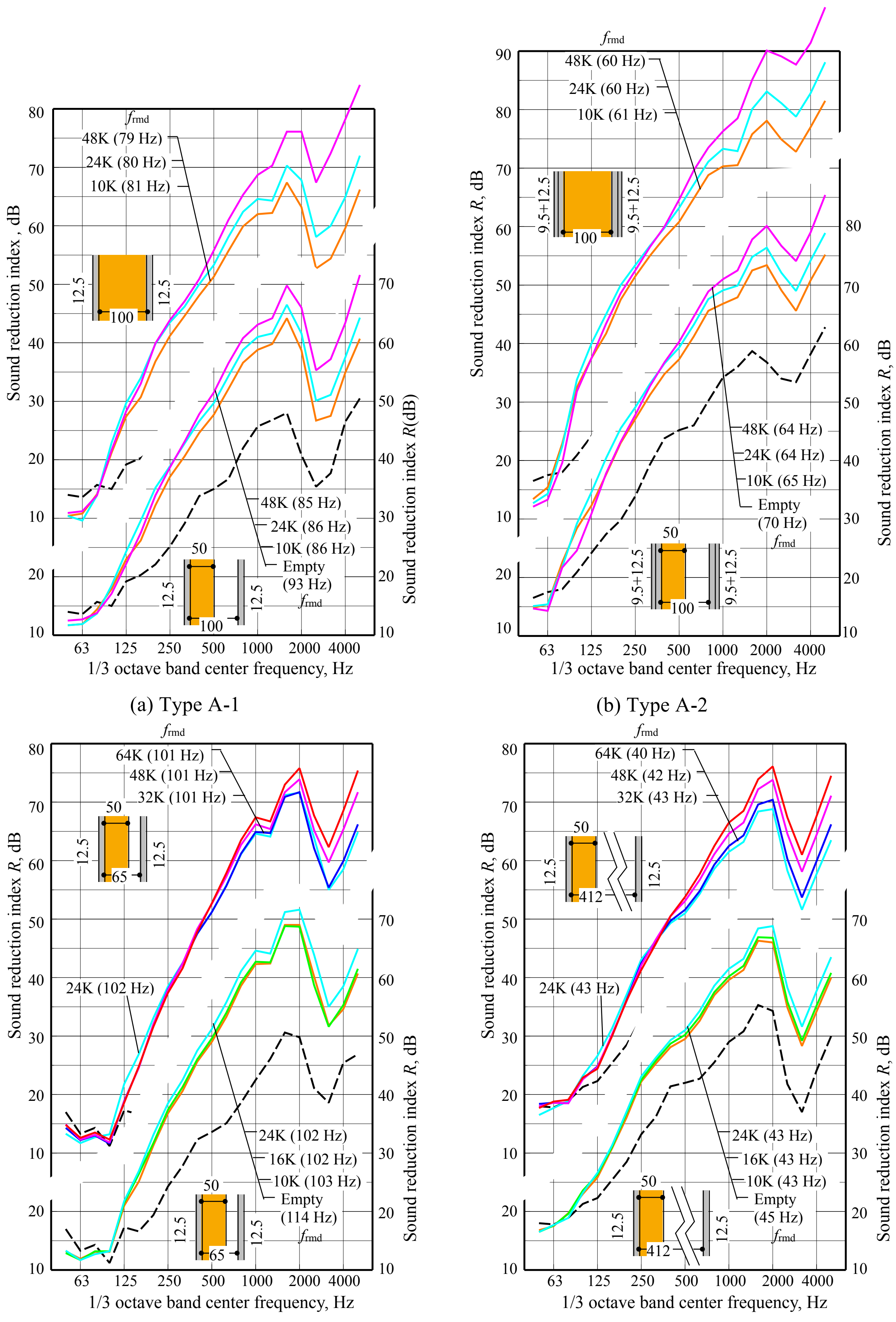
Figure 2 presents that measured results of sound reduction index R for the whole of specimen types. Regarding Type B, in order to make it easy to compare results, ones of 32K, 48K and 64K are plotted in the upper graph together with ones of 24K, while ones of 10K, 16K and 24K are compared in the lower graph. As installing glass wool into the cavity of double leaf partition, values of R increase at mid and high frequencies in comparison with the empty condition that there is no glass wool in the air cavity. However, they become lower than ones on the empty condition at low frequencies. With increase of bulk density of the glass wool, R increases at region of frequency higher than 500 Hz. But they are not absolutely higher as values of bulk density are higher at frequencies less than 500 Hz.

At high frequencies around the critical coincidence frequency, the dip in sound insulation becomes shallow concomitantly with increasing bulk density. As comparing between Type A-1 and Type A-2, it is found that attaching gypsum board 9.5 to gypsum board 12.5 increases the sound insulation over whole frequencies. However, even when thickness of the air cavity increases, the sound insulation remains almost constant at high frequencies and increases slightly at low frequencies according to comparison between Type B-1 and Type B-2.

Calculated results of mass-air-mass resonance f_{rmd} are also described in Figure 2. Values of f_{rmd} for double leaf partition including glass wool are calculated as the following. Airflow resistivity σ can be estimated form bulk density ρ according to the empirical formula (4) obtained as

$$\sigma = 2.7\rho^2 + 300\rho + 420 . \qquad (\text{Pa s/m}^2) \qquad (1)$$

According to the laws of Delany and Bazley modified by Miki (5), characteristics impedance and propagation constant are calculated from the airflow resistivity σ. The sound reduction index R_0 at normal incidence can be calculated from them using the impedance transfer method (6), where the characteristic impedances for board layers are obtained as only mass-reactance. Therefore the values of f_{rmd} are calculated as the frequency at which R_0 is minimized. Figure 2 shows that value of f_{rmd} is shifted to lower frequency as installing glass wool, however it does not significantly decrease with increasing the bulk density.



(a) Type A-1

(b) Type A-2

(c) Type B-1

(d) Type B-2

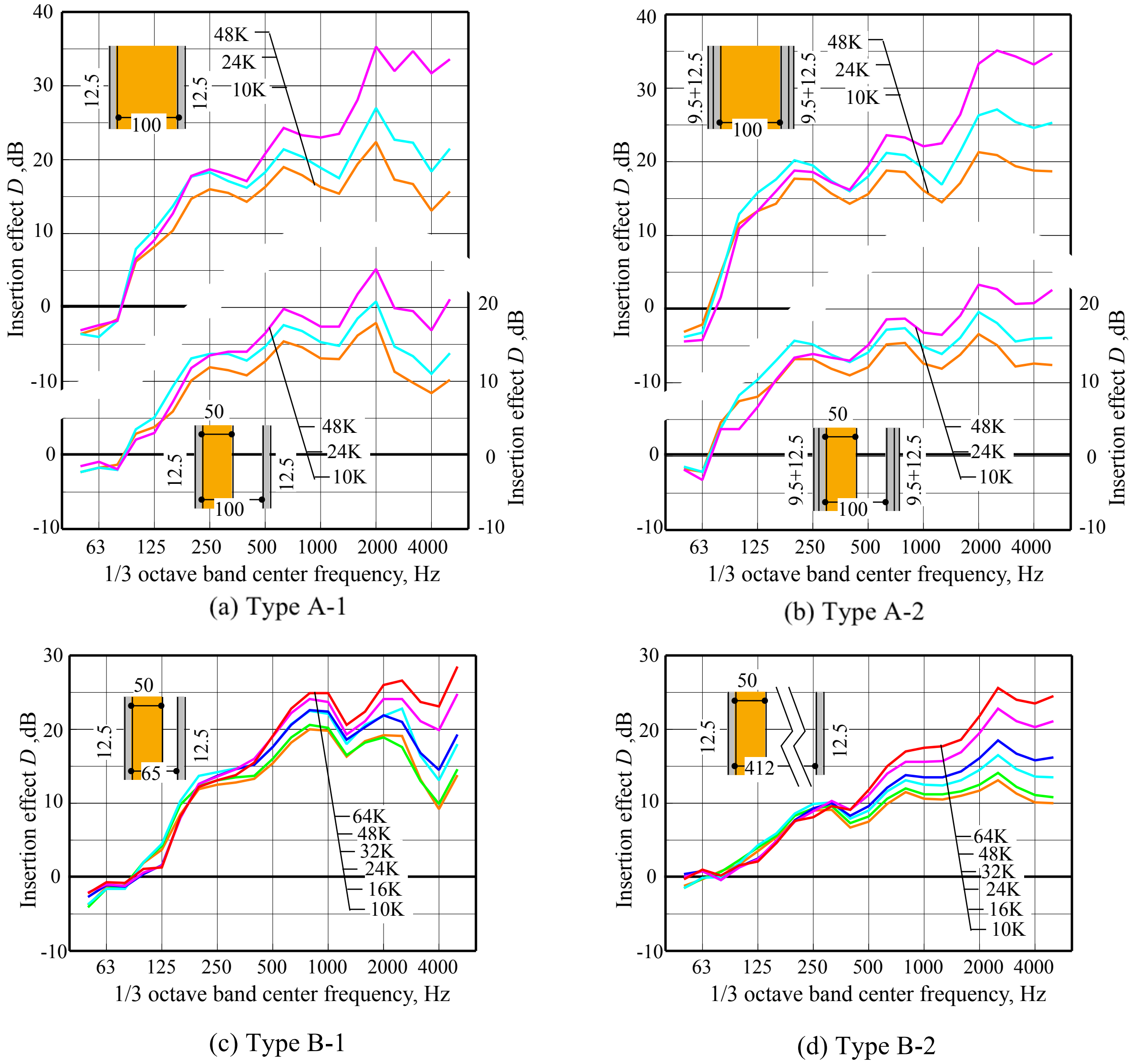
Figure 2 – Measured results of sound insulation for various values of density and thickness of glass wool

4. DISCUSSIONS

4.1 Decreased performance by cavity absorber

As mention above, installing fibrous absorber in a cavity of double leaf partition causes not only advantage but also disadvantage in sound insulation. Thus, in order to make it clear, the insertion effect D is defined as the difference between values of R for double leaf partitions with and without glass wool in the air cavity in respect of all measured results in section 3. Figure 3 presents values of the insertion effect D for various thicknesses and bulk densities of glass wools. Figure 3 shows that D becomes absolutely negative value in the frequency range from 50 Hz to 80 Hz for any types of walls.

Here, the critical point band is defined as the highest band of frequency bands at which values of D are less than - 1 dB. For example, the center frequency of the critical point band is 80 Hz as regards Type A-1. The critical point band is independence of the bulk density according to Figure 3. The mass-air-mass resonance frequency f_{rmd} does not considerably decrease with increasing the bulk density according to the description of f_{rmd} in Figure 2. Thus, Figure 4 presents the relation between the critical point band and f_{rmd} in respect of the partitions with GW24K. The center frequency f_0 of the critical point band corresponds approximately to f_{rmd} except the case in which f_{rmd} =102 Hz (Type B-1), because Figure 4 shows that f_0 is shifted to lower frequency as f_{rmd} decreases.



(a) Type A-1 (b) Type A-2

(c) Type B-1 (d) Type B-2

Figure 3 – Relation between insertion effect D and bulk density of glass wool

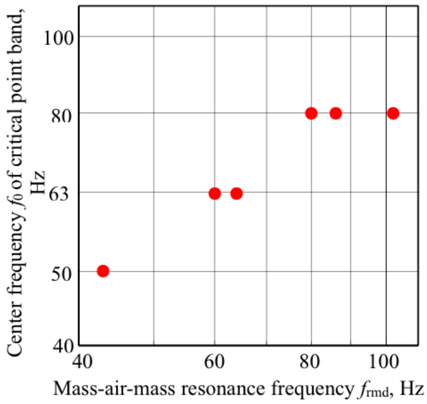


Figure 4 – Relation between the critical point band, at which D changed to negative value, and f_{rmd} for the partitions with GW24 K

Next, Figure 5 presents the thickness effect $D_{thickness}$ as the amount to which the sound insulation increases with increasing thickness of glass wool in respect of Type A-1 and Type A-2. $D_{thickness}$ is defined as the difference between values of R for double leaf partitions with 50 mm thick and 100 mm thick glass wool. Solid line and broken line represent values of $D_{thickness}$ for Type A-2 and Type A-1 respectively. Figure 5 shows that $D_{thickness}$ decreases to negative value in the frequency range of not greater than f_{rmd}.

Therefore, those results show that the decrease in sound insulation occurs in the frequency range of not greater than mass-air-mass resonance frequency f_{rmd}, as installing glass wool in the cavity. Moreover, the sound insulation decreases concomitantly with increase of thickness of cavity absorber.

Considering the results described above, Figure 6 presents an example of calculated results of sound insulation for double leaf partition with various thicknesses of glass wool by using the impedance transfer method (refer to section 3). The boards are gypsum boards of 12.5 mm and 9.5 mm thickness and wide of the air cavity is 100 mm as the parameters for the calculation. Figure 6 shows that f_{rmd} is sifted to lower frequency with increasing thickness L of glass wool. Consequently values of the sound insulation decrease with increase of L at frequencies less than f_{rmd}.

However, the measured results of $D_{thickness}$, as shown in Figure 5, are almost zero or negative value at the frequency band including f_{rmd}, although the dip in sound insulation at f_{rmd} becomes shallow with increasing the thickness in the calculated results. Therefore the shift of f_{rmd} is one of causes in the decline of sound insulation installing fibrous absorber into the cavity, but there are factors other than the shift.

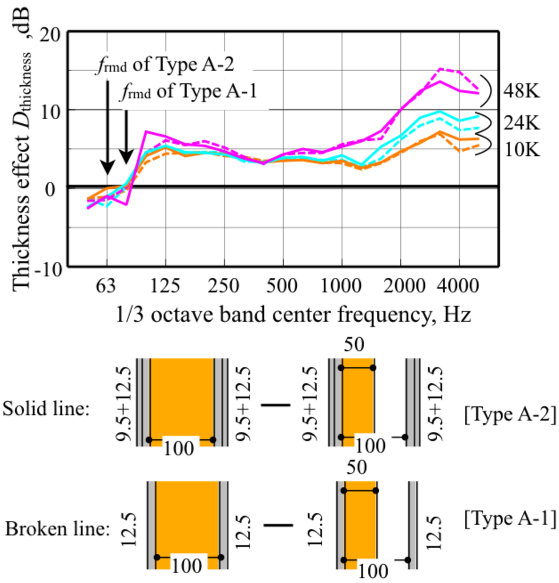


Figure 5– Thickness effect $D_{thickness}$ for various values of density of glass wool

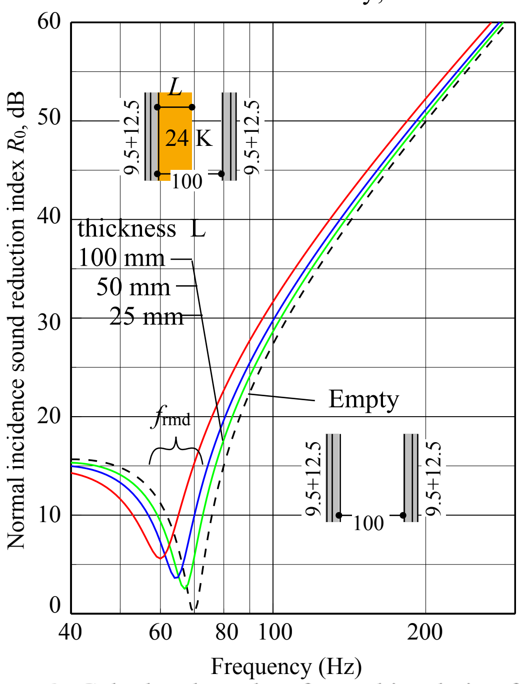


Figure 6– Calculated results of sound insulation for various values of thickness of glass wool

4.2 Influence of bulk density

Figure 3 shows that sound insulation is not absolutely higher as bulk density are higher at frequencies less than 500 Hz. For example, the sound reduction index *R* for double leaf partition installing glass wool of 24K is the highest of ones of the others at 125 Hz. Thus, Figure 7 presents the relation between insertion effect *D* and bulk density of glass wool installed in the cavity on each 1/3 octave bands in respect of all results of *D*. The plots show the difference in *D* as function of bulk density relative to the case where glass wool of 24 kg/m^3 density is installed in the cavity. That is, the relative insertion effect *D'* remains zero when the bulk density is 24 kg/m^3.

Figure 7 shows that *D*' at 50 Hz becomes slightly positive value in the density range of more than 32 kg/m^3. *D*' at 80 Hz remains almost zero even when the bulk density is changed. However, all values of *D*' except the case of 24 kg/m^3 become negative at the bands of 125 and 200 Hz. *D*' at 315 Hz remains zero for bulk density of more than 24 kg/m^3. *D*' increases along with increasing the bulk density at 500 Hz.

Therefore, the increase of bulk density increases sound insulation at the range of more than 500 Hz. However, it affects hardly sound insulation at low frequencies form 50 Hz to 100 Hz including f_{rmd}. In the frequency range from 125 Hz to 250 Hz, sound insulation decreases as increasing bulk density above 24 kg/m^3.

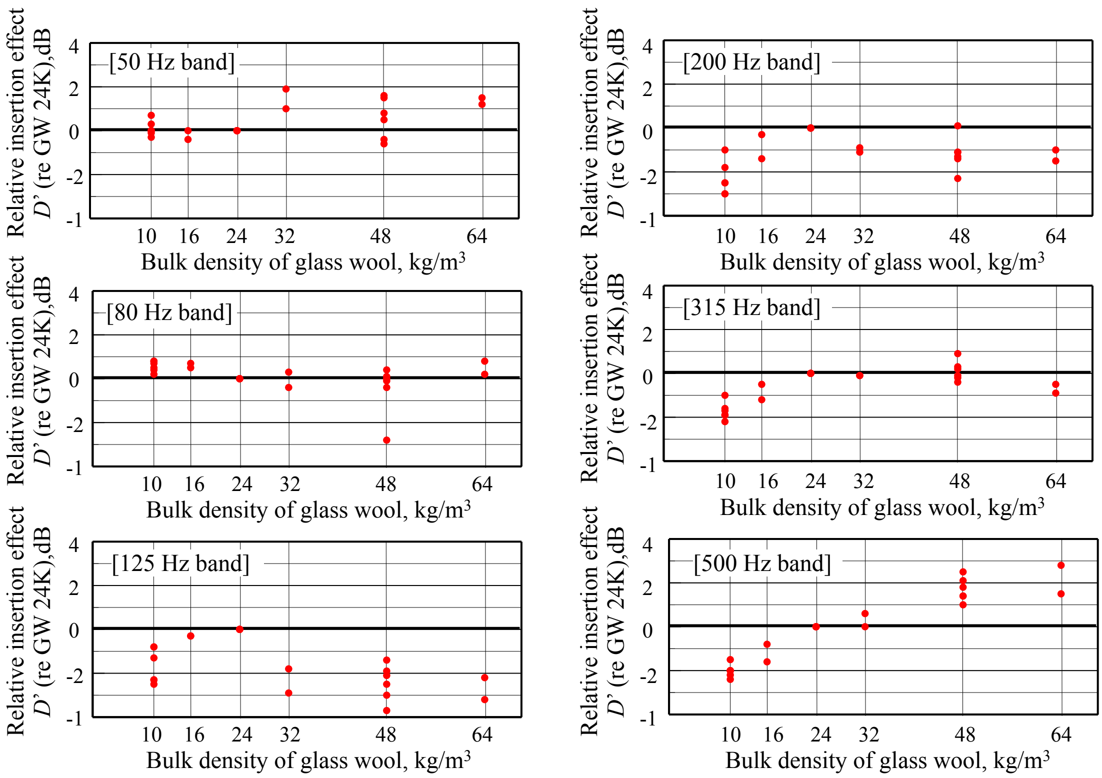


Figure 7– Relation between insertion effect and bulk density of glass wool in the cavity

5. CONCLUSIONS

We have measured sound insulation performance of double leaf partition installed glass wool of different bulk densities and thicknesses in the cavity by using the test facility in which the cavity absorber could be replaced without removing boards from studs. The main results are obtained as the following from these measured results.

(1) The slight decrease in sound insulation occurs at frequency range of not greater than mass-air-mass resonance frequency f_{rmd} because of installation of fibrous absorber into the cavity. The decreased performance decreases further with the increase of its thickness. The increase of the bulk density affects hardly sound insulation performance in this frequency range.

(2) The performance does not absolutely increase with increasing the bulk density in the rage from 125 Hz to 250 Hz. The proper value of the bulk density is about 24 kg/m^3 for maximizing the performance. On the other hand, the performance increases with increasing the thickness in this frequency range.

(3) At high frequencies above 500 Hz, the performance increases concomitantly with increase of bulk density and thickness of fibrous absorber.

(4) From results above, it is necessary to use about 24 kg/m^3 dense and thicker glass wool as cavity absorber in order to improve the performance at low frequencies. However, the thick absorber should not be installed when f_{rmd} is included in the interested frequency range.

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