SOUND INSULATION OF DOUBLE SKIN FACADE

Wei-Hwa CHIANG[1], Yi-Nuo CHAO[2], and Chi-Jeh WU[3]

ABSTRACT

This paper reports preliminary study of the sound insulation of double skin façade that allows natural ventilation. Model and field measurements were taken for several double façade designs. Experimental variables included use of absorbent material, angle of incidence, and frequency. Future works may include simulation using boundary element method, detailed full-scale measurements, implementing active noise control, and interaction with other indoor qualities.

Keywords: *sound insulation, double skin facade*

INTRODUCTION

Locating in subtropical area, Taiwan's climate is typically hot and humid, similar to those at southeastern areas of Asia, southern areas of northern America, eastern Australia, etc. Natural ventilation is valid in terms of both energy saving and indoor air quality, especially for residential and educational. However, buildings composed by single-skinned façade with large openings would be suffered from poor sound insulation against traffic noise. A variety of approaches have been used to improve the insulation performance for ventilated buildings (Lyons, 1996). In the past decade, the European designers have obtained great success in this dilemma by using double-skinned facades for many office buildings projects (Oesterle and Lutz, 2001). With proper designed openings, a double skin façade can also fulfill the needs for natural lighting and outdoor views.

The models derived from outdoor barriers can be used to predict the effect of simple overhang or vertical barrier around the opening (Cheng, 2000). However, a pair of double hung windows would only provide noise reduction in the range of 20-30 dB for an occupied classroom (TL in the range of 10-20 dB) (Stein and Reynolds, 2000). In terms of insulation against road traffic noise, a higher value in the region of 35-40 dB is generally recommended (De Salis *et al*, 2002). It has also been suggested that with careful design, adequate airflow rates for insuring indoor air quality can be provided in building with good sound insulation. Therefore, sophisticated mathematical modeling or experimental approaches are required for more complex design.

In the past five years, analyses of sound insulation have been conducted regarding several types of double skin facades that allow natural ventilation. This paper reports preliminary results of some actual projects and experimental works. All analyses considered free field condition. Because noise reduction (NR) would be influenced by room absorption and opening size of the inner skin, insertion loss (IL) has been used as another parameter that compared the measured data to the results with only the inner skin.

VENTILATION CHAMBER

Experimental Design

Scale model testing was employed to evaluate sound insulation of regular classroom in Tsi-Ji Middle and Elementary School at Hwalian. A ventilation chamber underneath the fixed window was designed to provide required air exchange. Absorbent treatments were applied to chamber surfaces and on top of the overhang (figure 1). Because noise from military craft is the major concern of this project, elevation angle of the sound source was in the range of 30° to 90° upward. A 1/20 model was built of double-sided cardboards on 6-mm foam with connections being properly sealed. Pink noise played through small loudspeaker 1 m (20 m in full

[1] *Associate Professor, National Taiwan University of Science and Technology, Taiwan, e-mail:whch@mail.ntist.edu.tw*
[2] *Ph. D. Student, National Taiwan University of Science and Technology, Taiwan*
[3] *Ph. D. Candidate, National Taiwan University of Science and Technology, Taiwan*

scale) away was used as the source and a CEL 593 analyzer (with extension cord) was used as receiver. Measurement was taken inside a NC20 rated INC testing chamber.

Results from Scale Model Testing

Figure 2 represents noise reduction and insertion loss for 1/1-octave bands from 100 to 400 Hz comparing various incident angles. While IR with 90° incident noises for 100 Hz and 400 Hz bands are 10 dB and 15 dB respectively, NR was as high as 30 dB at 400 Hz band. NR for lower incident angles drops significantly.

MULTI-STORY FACADES

The cavity space for a multi-story façade is adjoined vertically and horizontally by a numbers of rooms and may extend around the entire building. An acoustical evaluation was initiated during the early design phase of the International Building at National Taiwan University of Science and Technology where such a façade was proposed. The outer skin extended from the second floor to the top of building. The depth of the cavity was 1.5 m but with the bottom opening narrowed down to 0.4 m. Awning operable windows on the outer skin were used to improved natural ventilation. Absorption treatment was applied to the exterior side of the inner skin. Figure 3 represents model layout of the proposed multi-story façade.

Scale model (1/20) testing was conducted regardless of the cross talk problem among rooms. Only the second floor spaces were examined. Pink noise played through small loudspeaker 1 m (20 m in full scale) away was used as the source and a CEL 593 analyzer (with extension cord) was used as the receivers inside the classroom. The incident angle is about 15° downward. The result from double skin construction was compared to the data with only the inner skin to derive insertion loss.

Figure 4 shows the results of insertion loss (IR) as a function of 1/1 octave band center frequency comparing opened operable windows to closed conditions and with (circle) to without (triangle) absorbent treatment of the cavity. Average IL for 5000 Hz and 1 kHz bands is in the range of 14 to 20 dB for various conditions. This, however, indicates a noise reduction value a few dB below the required 35 dB suggested in the literature. The regression lines suggests a 3-5 dB increase in IL per doubling of sound frequency for frequency bands up to 1000 Hz.

BOX-WINDOWS

Field Measurement of Noise Reduction

The box-window is the oldest form of double façade. It uses isolated cavity volume and outer skin for individual window units. Analysis of box-windows was initiated while the authors were dealing with insulation strategies against road noise for Yunshulin Elementary School at Taipei County. The façade consists of outer glass panels covered over individual existing sliding window at a distance of 300 mm. Absorption treatment was applied to the bottom side of the 0.9-m overhangs (also as sun shading devices) and to the inner skin below the opening. Acoustical measurement was taken at the field after completion of construction according to ISO140-Part V while vehicles from both directions were stopped by traffic lights. Pink noise was played through a Norsonic 223 dodecahedron speaker and a B&K 4224 speaker located across the street. CEL 593 analyzer was used as 4 receiving locations at each of 2 classrooms on the second floor above the main gate of the school with the reference level measured at the gate. The incident angle is about 20°.

Figure 5 represents noise reduction values as a function of 1/3 octave band center frequency at the two classrooms. The value rises significantly at the low end and reaches to a plateau starting 315 Hz band. It is believed that insulation performance on the third floor would be better for high frequencies because due to the shielding of the overhang. NR can also be improved by adding absorption materials inside the classroom.

Scale Model Testing with Various Cavity Depth and Incident Angle

Scale model testing was conducted to further analyze the effect of various cavity depth (d in m) and incident angle (θ in °) without the shielding of overhang. It was designed to derive regression formulas based on the two variables. As shown in figure 7, the opening was limited to the bottom of the cavity only. It was assumed that a smaller cavity depth and a smaller incident angle provided better sound insulation. The cavity depth was controlled between 100 to 300 mm in full scale. The bottom of the outer skin constantly extended 1 m below the opening. The measurement was taken at a semi-anechoic chamber. A 1/6.25 model scale was selected that regular measurement instrument can be used. Table 1 summarized the model layouts. Pink noise played through a Norsonic 260 speaker was used as the sound source. The reference level for calculating insertion loss (IL) was the average sound level from incident angles 22.5°, 45° and 67.5° with only the inner skin opened. IL values for individual frequency bands were used to derived the single number R rating based on the ISO 717 contour.

As shown in figure 8, R is in the range of 5 to 19 dB. The effect of cavity depth was significant only when incident angle is greater 30°. At a small incident angle, R is independent from cavity depth. Increasing incident angle from 0° to 75° causes a 9 dB decrease in R.

$$R = 21.4- 0.17\,d- 0.136\,\theta \qquad (1)$$

The R^2 is 0.948, suggesting that sound insulation of box window with bottom opening can be well predicted by statistical models. Further research will include in the effects of top openings and overhangs.

As for insertion loss for individual frequency bands, significant frequency fluctuation is found for low frequencies (figure 9). There are dips around 125 Hz and 320 Hz bands. Regression analysis is performed to the average data from incident angles 0°, 30°, and 60° with frequency band as the independent variable (figure 10). The slope of the regression line (4.03) for frequency band up to 1000 Hz is similar to the one derived from multi-story façade model (4.85) stated previously.

CONCLUDING REMARKS

Due to the needs for natural ventilation and day lighting, analyses of sound insulation have been conducted regarding several types of double skin facades that allow natural ventilation. Preliminary results showed that 20 dB in mid-frequency Insertion loss (IL) can be achieved. This is, however, a few dB below the suggested values for building inside heavy traffic zone. On-going study is conducted to test more sophisticated designs. Future works will also include simulation using boundary element method, detailed full-scale measurements, implementing active noise control, and interaction with other indoor qualities such as air movement.

REFERENCES

Cheng, W.F. (2000), "The theoretical model to optimize noise barrier performance at window of a high – rise building". *J. Sound Vibr.* 238(1), 51-63.

De Salis, M.H.F., Oldham, D.J. and Sharples, S. (2002) "Noise Control Strategies for Naturally Ventilated Buildings," *Building and Environment*. Vol. 37, 471-484.

Lyons, R. (1996), "Investigation of an Open Screen Acoustic Performance," *Applied Acoustics*. V49, No3, 263-282.

Oesterle, L. and Lutz, H. (2001), *Double-skin Facades*. Prestel Verlag, Berlin.

Stein, B, & Reynolds, J.S. (2000), *Mechanical and Electrical Equipment for Buildings (9th edition)*, John Wiley & Sons, Inc., New York.

Table 1. Summary of the 1/6.25 model layout for box windows construction.

	Model scale (1/6.25)	Full scale
Widow dimension (m)	0.24×0.195	1.5×1.2
Outer skin dimension (m)	0.40×0.195	2.5×1.2
Absorption material dimension (m)	0.16×0.195×0.01	1×1.2×0.0625
Cavity depth (m)	0.016 – 0.048	0.1 – 0.3
Receiving room dimension (m)	0.912×0.613×0.383	3.7×3.88×2.4

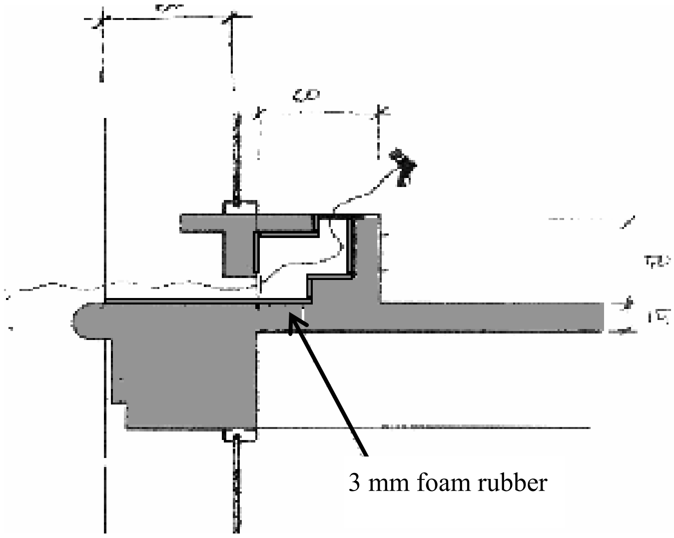

Figure 1. Sectional Sketch of the ventilation shaft used in Tsi-Ji Middle and Elementary School.

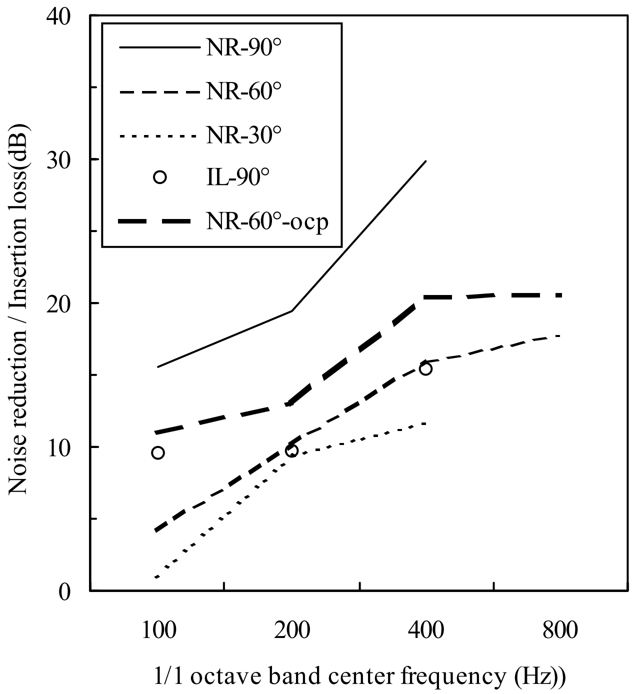

Figure 2. Noise reduction (NR) and insertion loss (IL) as a function of 1/1 octave band center frequency comparing various incident angles for a single-story type double skin façade.

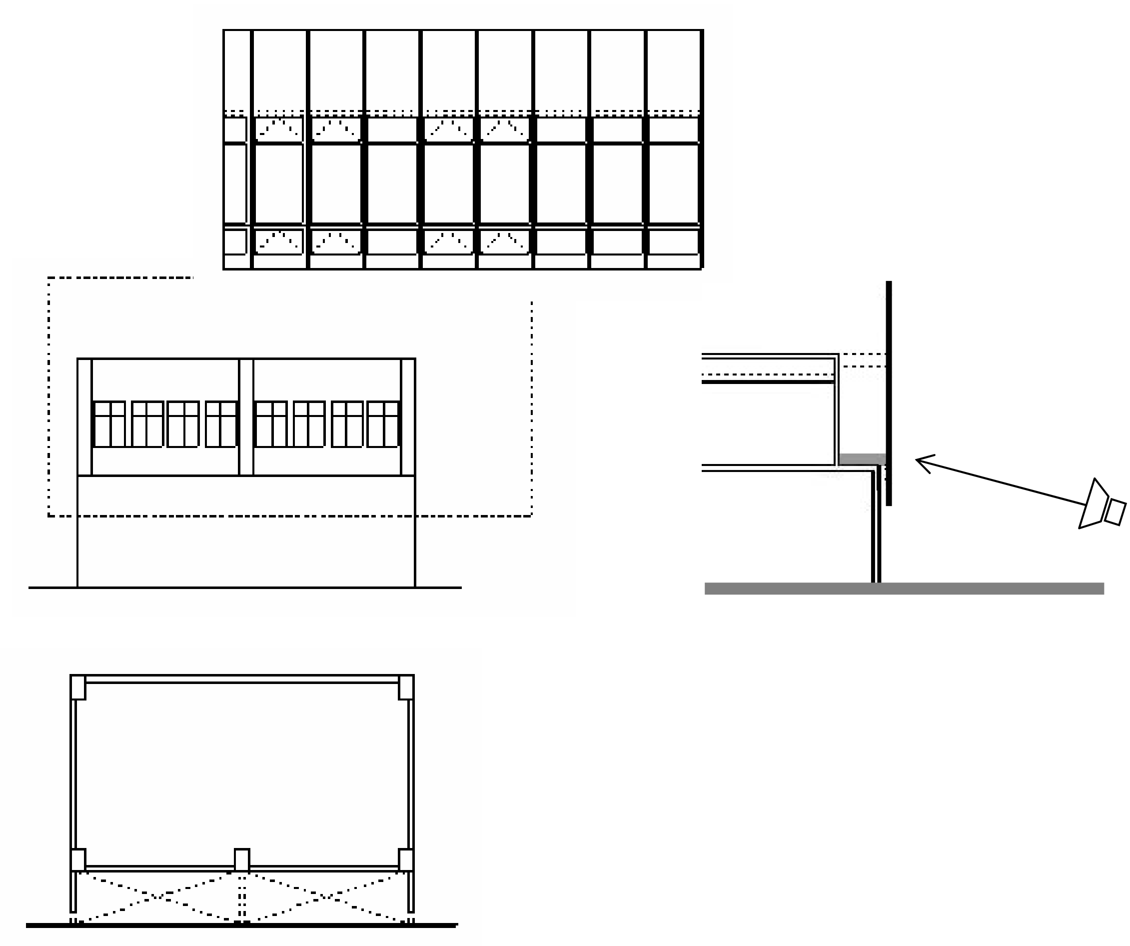

Figure 3. Model layout of the multi-story facade proposed for the International Building at National Taiwan University of Science and Technology.

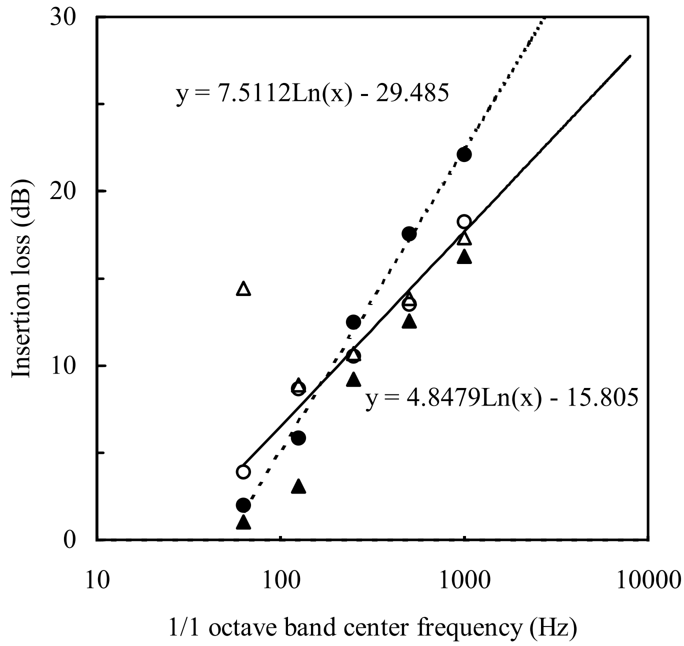

Figure 4. Insertion loss (IR) as a function of 1/1 octave band center frequency comparing opened (open) operable windows to closed (filled) conditions and with (circle) to without (triangle) absorbent treatment of the cavity. The solid line and the dashed line represent the regression models for window opened and closed conditions, respectively, with absorption treatment.

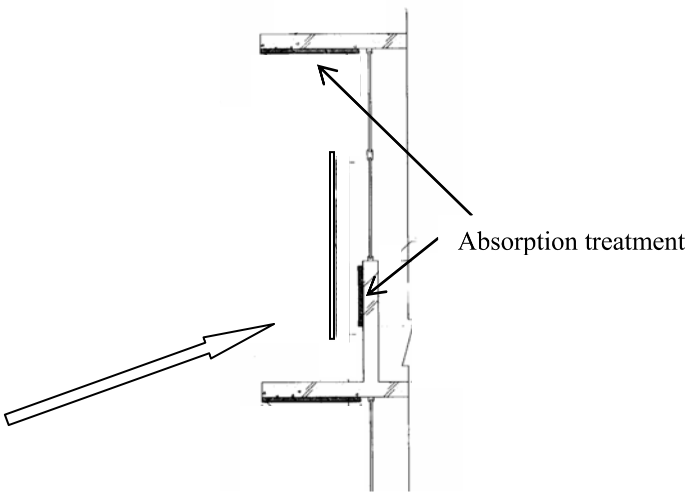

Figure 5. Sectional drawings showing the sound direction and classroom facade at Yunshulin Elementary School.

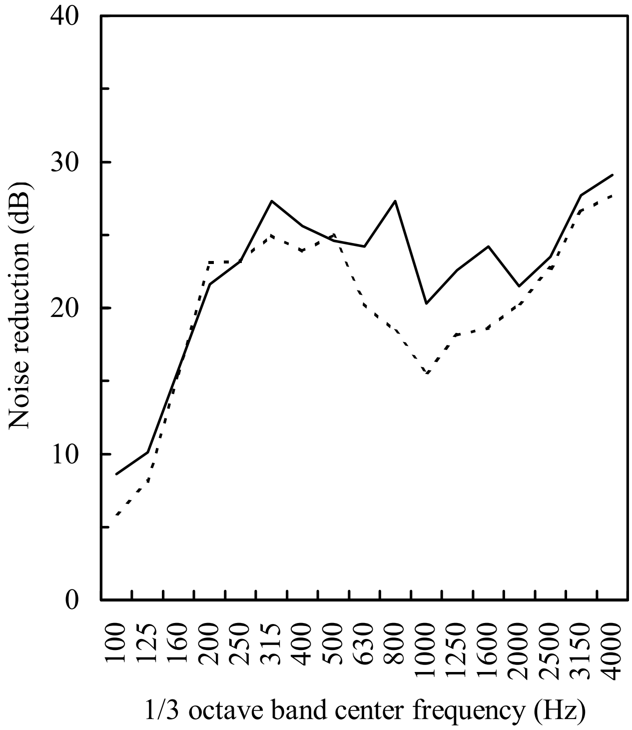

Figure 6. Noise reduction (NR) as a function of 1/3 octave band center for two classrooms equipped with box-window at Yunshulin Elementary School.

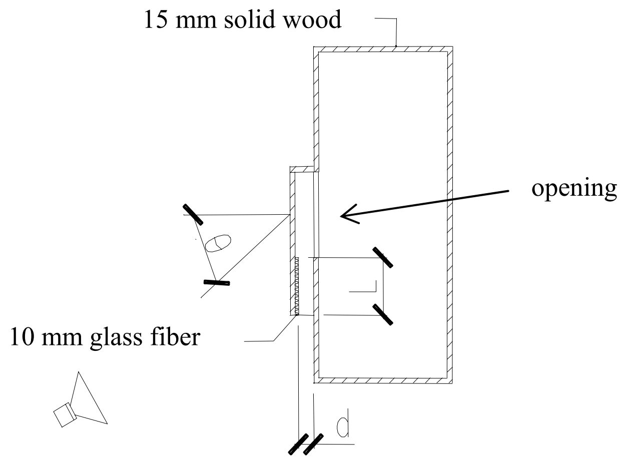

Figure 7. Sectional drawings showing the layout of the experimental setup with various cavity depths and incident angles for a box-window type facade.

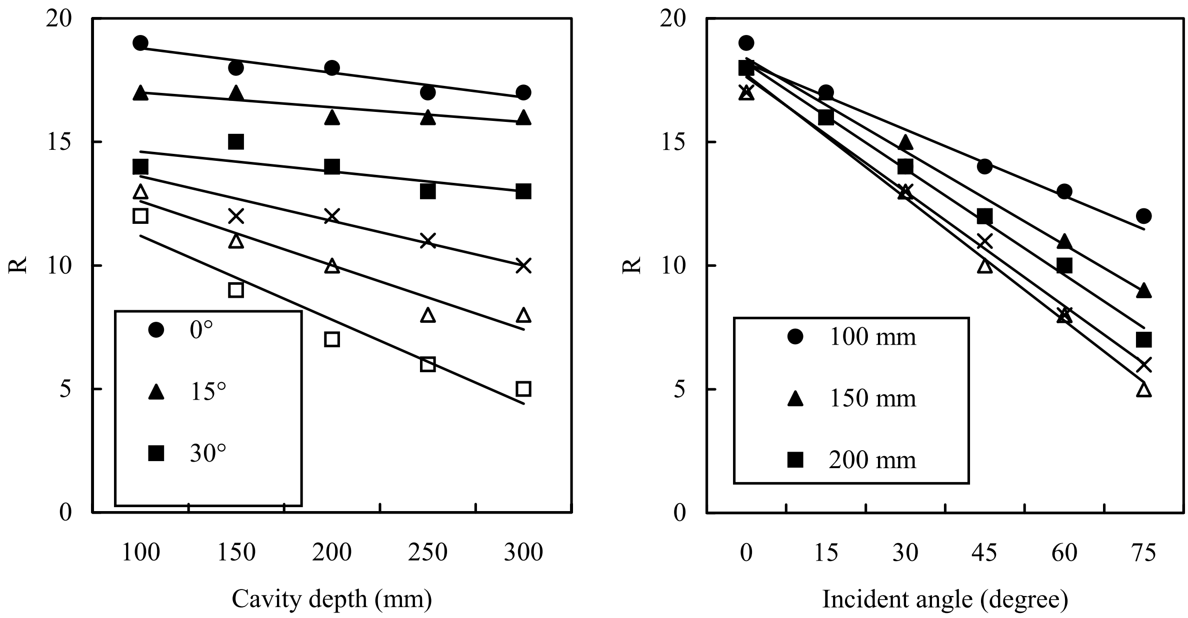

Figure 8. STC as a function of cavity depth (left) and incident angle (right) with liner fit shown for individual data subgroups.

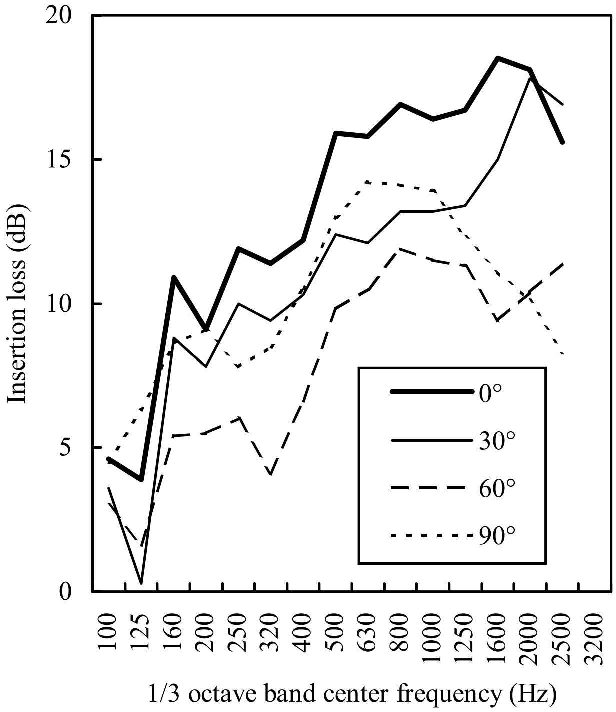

Figure 9. Insertion loss (IR) as a function of 1/3 octave band center frequency averaged over 5 cavity depths for 4 incident angles.

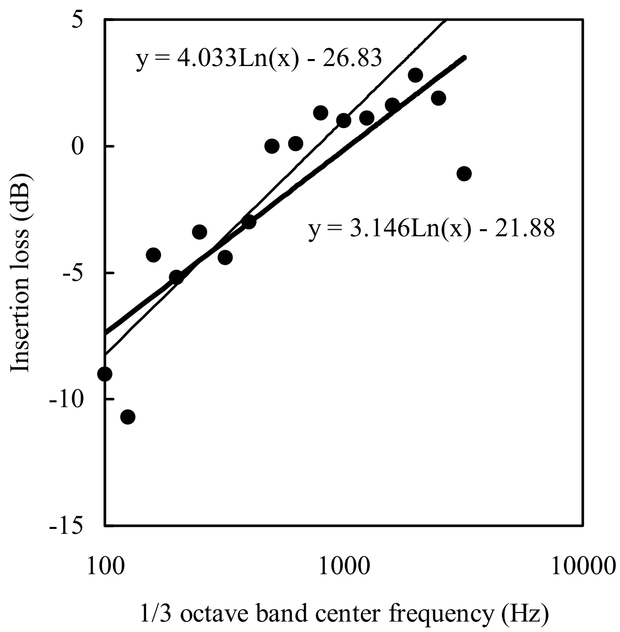

Figure 10. Insertion loss (IR) averaged 0° to 60° as a function of 1/3 octave band center frequency (mark). The thick line represents the linear regression model for all data points and the thin line represents the regression model with frequency band up to 1000 Hz only.