Numerical analysis and experiment on noise shielding effects of eaves/louvers attached on building facade

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\textbf{ABSTRACT}

Some high-rise buildings located in urban areas of Japan have eaves on their façades for the aim of fireproofing in accordance with The Building Standard Law of Japan. From the environmental viewpoint, such eaves are regarded as an efficient measure for mitigating thermal loads on the buildings owing to solar shading. Besides that, the eaves can be an efficient countermeasure for noise shielding against road or railway traffic. The authors reported noise shielding effect of eaves/louvers attached to a building façade which were examined by a 1/20 scale model experiment. In this study, further experimental examination and numerical analysis using the finite-difference time-domain method on the noise shielding effects are presented.

\textbf{1. INTRODUCTION}

Several types of eaves/louvers are attached to building façade for the aim of mitigating thermal load by solar radiation. From the viewpoint of noise control, such eaves and louvers are expected to provide noise reduction effects. The authors have examined the noise reduction effects of the eaves/louvers by a 1/20 scale model experiments \cite{1}. In this study, the noise shielding effect is investigated using the finite-difference time-domain (FDTD) method, and the results are compared with experimental ones. As a further examination, a parametric study using the calculation method is performed.

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2. CONDITIONS IN THIS STUDY

Assuming a medium- or high rise building facing a road, noise shielding effect of eaves/louvers attached to a building façade was investigated. Variations of eaves/louvers attached to a building façade are shown in Figure 1. Three kinds of eaves/louvers are selected: flat eaves, incline eaves (inclination angle is 45 degrees) and louvers. Their noise shielding effects were evaluated by the insertion loss. As the heights of the receiving floor, 2 cases of 5th floor and 15th floor (angles of incidence were 61 degrees and 80 degrees) were assumed. In the experiment, conditions of the heights were controlled by varying the incident angle of the sound as shown in Figure 2, because of limitation of possible height of building scale model set in a hemi-anechoic chamber. Receiving points were set at the surface of the building boundary of each floor. Seven receiving points were assumed, but in the incline eaves, only five points were investigated because of the existence of the incline eaves as shown in Figure 1. As the position of the sound source, in this examination, two configurations of source position were assumed as shown in Figure 3 (S0_5F, S32 for 5F and S0_15F, S96 for 15F).

3. FINITE-DIFFERENCE TIME-DOMAIN ANALYSIS

Two-dimensional (2-D) solutions obtained from the FDTD method can be applied to the efficient calculation procedure proposed by Duhamel, in which the 2-D solutions are transformed into the three-dimensional (3-D) solution [2]. At first, the 2-D FDTD analysis was performed in 2-D cross-section shown in Figure 3 (a) and the impulse responses of the receiving points (from A to G) were obtained. Using the transformation from 2-D to 3-D solution by Duhamel’s theory expressed as Eq. (1), solutions in a 3-D sound field with constant geometry along the longitudinal direction can be obtained.

\[
\Phi_{3D}(x, y, z, k) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \Phi_{2D}(x, y, \sqrt{k^2 - \alpha^2}) e^{j\alpha d} d\alpha
\]

Where \( \Phi_{3D}(x, y, z, k) \) is a 3-D solution at position \((x, y, z)\) in Cartesian coordinates with \(k\) as the wave number (= \(\omega/c\), \(\omega\) is the angular frequency and \(c\) is the speed of sound), and \(\Phi_{2D}(x, y, k')\) is a 2-D solution with \(k'\) as the wave number.

The 3-D sound field solution in the time domain was obtained by the inverse Fourier transform.

![Figure 1: Variations of eaves/louvers](image1)

![Figure 2: Determination of source position for the two Lanes](image2)
4. SCALE MODEL EXPERIMENT

To compare with the calculation results, a 1/20 scale model experiment was performed. Setting of the model building, sound sources and a receiving point are shown in Figure 3. As a sound source, a dome tweeter was used to treat experimental signal in high frequency. Swept-sine method using a signal with a frequency range between 5kHz and 56kHz (250 Hz to 2800 Hz in real scale) was radiated from the tweeter and the signal was detected by a 1/4 inch condenser microphone located at the surface of the building and an impulse response was obtained by deconvolution technique [3]. Since the dome tweeter used in this experiment had sharp directionality, the source was settled directing toward the center point of the building surface.

5. COMPARISON BETWEEN CALCULATION AND EXPERIMENT

A. Analysis of the Calculated and Measured Impulse Responses

Calculated and Measured impulse responses for all points were filtered in 1/3 octave bands in the frequency range from 315 Hz to 2kHz for calculation and from 6.3kHz to 40kHz for the experiment. The filtered responses were squared and integrated in time domain to obtain single event sound exposure levels. After that, effects of eaves/louvers were evaluated by an insertion
loss, which was a level difference between sound exposure levels for two cases without and with eaves/louvers.

Figure 4: Comparison of the insertion loss between calculation and experiment
B. Results and Discussions
Some results of insertion loss at the three receiving points on 5th floor are shown in Figure 4 (a) and those on 15th floor are shown in Figure 4 (b). Horizontal axes indicate frequency and vertical axes indicate insertion loss. Full lines and dotted lines indicate calculation results and experimental ones, respectively.

It is observed that calculated and measured values agree approximately in cases of flat and incline eaves for both floors. In the case of louvers, although discrepancy is observed at the peak frequency, both results from calculations and experiments show that the noise shielding effect ranges from 0 dB to 5 dB for the 5th floor. On 15th floor, a discrepancy in the high frequency is observed between calculation and experiment.

6. PARAMETRIC STUDY USING NUMERICAL ANALYSIS
A. Height of Receiving Floor
Calculation Condition
Using the calculation method presented in chapter 3, differences of the effects of eaves/louvers by varying the heights of receiving floors were investigated. Variations of eaves/louvers were the same as previous chapter and the heights of the receiving floors were varied as 2nd, 5th, 10th, 15th and 20th floors. The sound source was located at S0 and at S96 (see Figure 3 (a)). As the source, road traffic noise was assumed, and A-weighted sound exposure levels were obtained through a correction of sound power spectrum of running vehicle noise given in the ASJ RTN-Model 2008.

Results and Discussions
Calculation results of insertion loss for S0 and S96 are shown in Figure 5 (a) and Figure 5 (b), respectively. Horizontal axes indicate insertion loss and vertical axes indicate receiving points. In the incline eaves, the insertion loss has positive values for all floors except 2nd floor. The fact indicates that the incline eaves are effective for reduction of road traffic noise. The noise reduction effect by incline eaves becomes higher as the receiving floor is higher. On the other hand, in cases of the flat eaves and louvers, values of the insertion loss take both positive and negative. Figure 6 shows impulse responses between S0 and a receiving point D for 15th floor. Whereas multiple reflections occur in the case of the flat eaves, only a few reflections with small amplitude are seen in the case of the incline eaves. By the incline eave, an incident sound reflects outward from the façade of the building.

B. Angle of inclination of eaves
Calculation Condition
As the second investigation, influence of an inclination angle of the incline eave was studied. The inclination angles were varied from 0 degrees (same as the flat eaves) to 45 degrees at 5 degrees interval as shown in Figure 7.

Results and Discussions
Calculation results are shown in Figure 8. For the 5th floor, spatial characteristics of the insertion loss are a bit complicated. The noise shielding effect is negative at high receiving points and the effect becomes higher as the receiving position is lower. The difference of the noise shielding effect by varying the inclination angle is relatively small. On the other hand, for higher floor of 15th, the noise shielding effects are positive at all receiving points and the difference of the noise shielding effect by varying the inclination angle is obvious. By making the inclination angle 15
degrees or more, the noise shielding effects becomes almost maximum, and the value ranges between 10 dB and 15 dB.

Figure 5: Change of insertion loss by varying heights of receiving floors
Figure 6: Comparison of the transient waveforms
Figure 7: Inclination angles

(a) 5th floor

(b) 15th floor

Figure 8: Change of insertion loss by varying inclination angles
7. CONCLUSIONS
Effects of eaves/louvers attached on a building façade were investigated by a numerical analysis and a 1/20 scale model experiment. The calculation and experimental results were approximately in agreement and the applicability of the numerical analysis method was confirmed. Using the numerical analysis method, some parametric studies were performed and the following tendencies regarding noise shielding effects of eaves/louvers were indicated.

- Eaves attached on upper and lower position of the floor give both positive and negative influences from a viewpoint of reduction of outdoor noise: shading effect by a lower eave (positive) and reflection effect by an upper eave (negative).
- Making an upper eave inclined is effective countermeasure for noise reduction because the inclined eave reflects an incident sound outward from the façade of the building. The noise reduction effect is higher as the receiving floor is higher.
- When the receiving floor is at around 15th or more, incline eaves with their inclination angle of 15 degrees or more give the almost highest noise reduction effect over 10 dB.

REFERENCES