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OPTIMUM ARRANGEMENT OF SECONDARY SOURCES AND ERROR SENSORS FOR ACTIVE NOISE BARRIER

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ABSTRACT
We have researched on the rational design method of active noise barrier based on the boundary surface control principle. This active noise barrier is composed of a conventional barrier, multiple secondary sources and multiple error sensors. The secondary sources and the error sensors are located on a surface in parallel with the barrier. By using this, we can control noise not only at the error sensor point but also at the other points in a wide area. In this paper, we study on the position of the secondary sources and the error sensors by calculating the control effect using the two-dimensional numerical method. The results show that: (1) the interval between the secondary sources should be less than the half of the wavelength at the frequency considered (2) increasing the distance between the error sensor and the secondary source improves effectiveness.

1 - INTRODUCTION

In many situations, undesired noise is radiated into the far field. If the noise source is fixed and well defined, it is possible to suppress the radiation scattered by the primary noise source by surrounding the noise source with the layer of secondary sources. An alternative is to use secondary sources spaced on a square grid to absorb or to reflect normally incident noise. This concept is known as an active noise barrier (ANB).

In recent years, the effectiveness of the ANB has been confirmed experimentally [1], [2]. However, in the same way as other applications of active noise control (ANC), the practical application of the ANB has its difficulties. In conventional studies of the ANB, the system has been focused on point control at an edge of a barrier or at a point around a barrier. Although this system is effective at the error sensor point, effectiveness in the area to be made quiet cannot be expected. This means that it is not possible to calculate the cost of the ANB that satisfies requirements of a client. In order to overcome these difficulties, it is necessary to construct a design method for the ANB that enables us to judge the scale of both the barrier and the ANC system [3].

In this paper, we propose a design method for the ANB based on the boundary surface control (BSC) principle. This design method can generalize the specification of the ANB. However, the investigation on optimum arrangement of secondary sources and sensors is required. Further, the basic principle of this method is discussed by numerical analysis based on the two-dimensional boundary element method (BEM).

2 - ACTIVE NOISE BARRIER

The ANB will have one of the compositions of (b) (c) and (d) in Fig. 1. This paper discusses the ANB (b) and (c) in Fig. 1. The barrier of Fig. 1 (a) is called a passive barrier. The ANB is equipped with multi secondary sources and multi energy sensors. The energy sensor senses both pressure and particle velocity. The amplitudes of the secondary sources are set to minimize the acoustic energy at the sensor

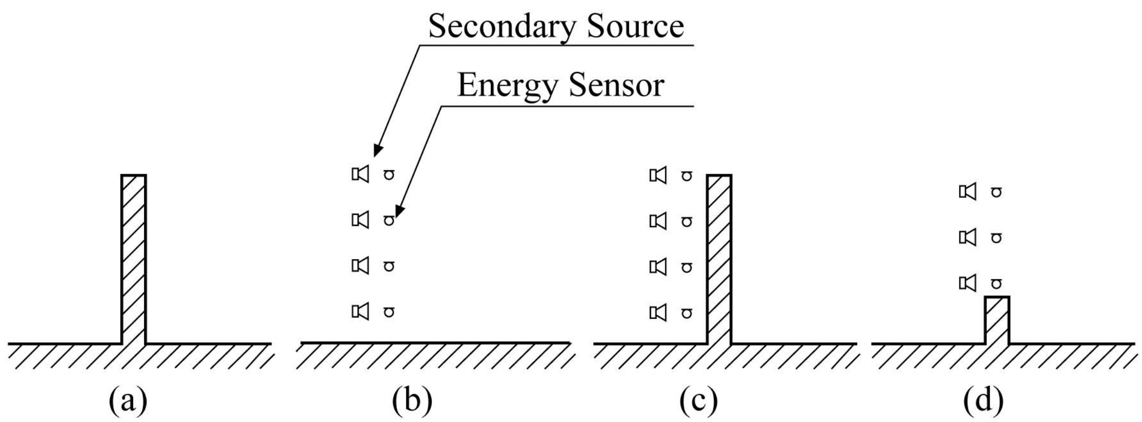


Figure 1: Models of active noise barrier; (a) a passive noise barrier, (b) the active noise barrier, (c), (d) combination of active barrier and passive barrier.

positions. Therefore, acoustic energy is reflected by the ANB at the position of sensor [4], [5]. The aims of this paper are (1) to examine the relationship between interval of energy sensors and the control effect (2) to examine the influence of passive barrier (3) to examine the relationship between secondary sources and energy sensors.

3 - NUMERICAL CALCULATION

3.1 - Calculation model

The numerical calculations were carried out using the two-dimensional BEM to confirm the effectiveness of this technique. The primary source, the secondary sources and the energy sensors were arranged in the two-dimensional sound field shown in Fig. 2. The origin of the X-coordinate was located as the position of the passive barrier and the origin of the Y-coordinate as the ground. The primary source was installed 7.5 m in front of the X-coordinate position of the passive barrier, and the secondary sources were installed 1.0 m in front of the passive barrier. The ground and passive barrier are assumed perfectly rigid. Therefore, "Image method" was used in the numeric calculations. The input signal of the secondary source was determined to minimize the acoustic energy at the sensor position, and then the sound pressure level was calculated. The element size for the calculation was set to 5 cm to satisfy the accuracy requirements at the frequency considered. The evaluation area was set to 2 m high and 10 m wide. The sound pressure level was calculated every 20 Hz in the range from 100 Hz to 1000 Hz.

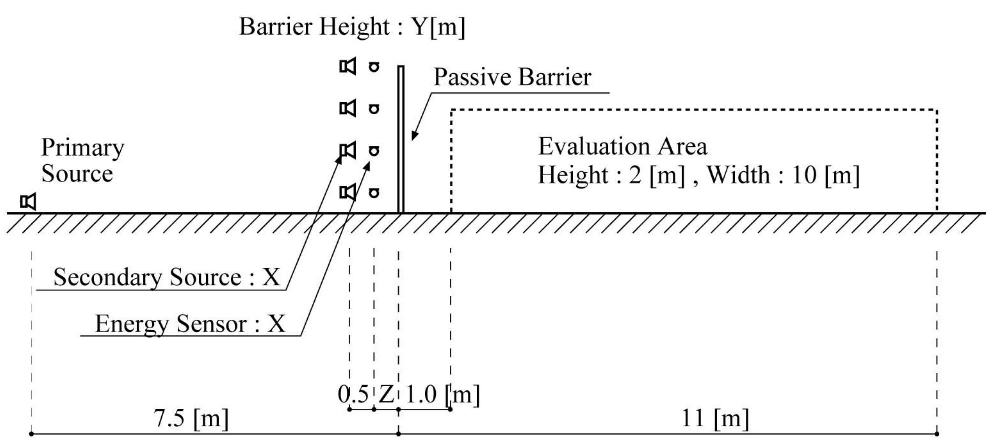


Figure 2: Two-dimensional model of numerical calculation.

3.2 - Calculation conditions

The sound pressure level was calculated under the conditions with 2, 4, 8, and 16 sensors attached at heights of 1, 2, and 3 m to the active and passive noise barriers (see (b) and (c) in Fig. 1). The energy sensors were set to Z m behind with the secondary sources. In the condition of Fig. 1 (c), the heights of the passive barrier and top sensor are equal. The format of the condition name is shown by "X + number of sensors (secondary sources) + Y + top sensor height + passive barrier height". "X16Y30" means that the number of sensors is 16, the top sensor height is 3 m, and the passive barrier height is 0 m (in other words, no barrier). The same number of sensors and secondary sources was installed on the X-coordinate axis at equal height intervals. The interval between the first sensor and ground was made to be a half in other sensor interval to do equal the interval of the sensor in the calculation.

Number of sensors: X	2, 4, 8, 16
Top sensor height: Y	1 m, 2 m, 3 m
Distance between secondary sources and sensors: Z	0.125 m, 0.25 m, 0.5 m, 1 m, 2 m
Calculate frequency	100 Hz ∼ 1 kHz, 20 Hz step
Element size	0.05 m
Evaluation area	2 m high and 10 m wide, 105 points

Table 1: Calculation conditions.

3.3 - Insertion loss

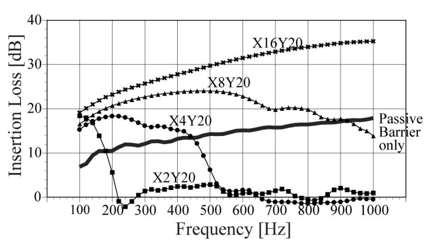
The insertion-loss which is the difference of the sound pressure level between with the barriers and without any barrier calculated in the evaluation area (105 calculation points in an area 10 m wide and 2 m high) of Fig. 2.

4 - RESULTS AND DISCUSSION

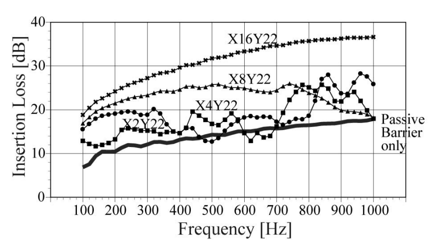
4.1 - Frequency and insertion loss

Fig. 3 shows the sample of insertion-loss. In Fig. 3 (a), there are no passive barriers and the height of the top sensor is 2 m, respectively. The condition of Fig. 3 (b) has been inserted in the passive barrier of 2 m height as well as Fig. 3 (a). Fig. 3 shows insertion losses calculated at every 20 Hz in the range from 100 Hz to 1000 Hz when the number of sensors (secondary sources) is 2, 4, 8, and 16. For the comparison, the figures also show insertion-losses in using only the passive barrier.

According to Fig. 3 (a), the insertion loss becomes larger as the number of sensors augments (and the interval of the sensor decreases). X4Y20 in Fig. 3 (a) produces no control effects over 550 Hz, because the sensor interval is 57 cm, and it is not enough small interval for 550 Hz (wavelength: 62 cm) and higher frequency. Contemplating these results, the ANB that is more effective than a passive barrier of the same height can be realized by placing sensors at an interval small enough for the wavelength. In X16Y20 of Fig. 3 (a), the active noise barrier is more effective over 12 dB than the 2-meter-high passive barrier. In X4Y22 of Fig. 3 (b), using a passive barrier as well ensures a barrier insertion loss even at 550 Hz and higher frequency, while X4Y20 in Fig. 6 (a) produces no control effect. Thus, the control effect does not decrease even at lower frequencies.



(a): No passive barrier.



(b): With passive barrier.

Figure 3: Sample of insertion loss; a height of barrier = 2 m.

4.2 - Sensor interval and wavelength

The calculation results summarized from the viewpoint of the relationship between interval of the sensor and wavelength as shown in Fig. 4 and Fig. 5. The insertion loss when no passive barrier is installed as shown in Fig. 4. The insertion loss, which is the effect of improvement when a passive barrier is used as, well under the conditions of Fig. 4 and compared the loss to that when the ANB is used alone as shown in Fig. 5.

These results clearly indicate that: (1) If the interval of the sensor is greater than the object wavelength, the insertion loss becomes zero. (2) Setting the sensor interval smaller than half of the wavelength permits sound control. (3) In the controllable sensor interval, there is no improvement by the combined use of the passive barrier, when simultaneously passive barrier and active barrier are used. For this, it is proven that the insertion loss is gotten by the passive barrier in impossible controlling sensor interval.

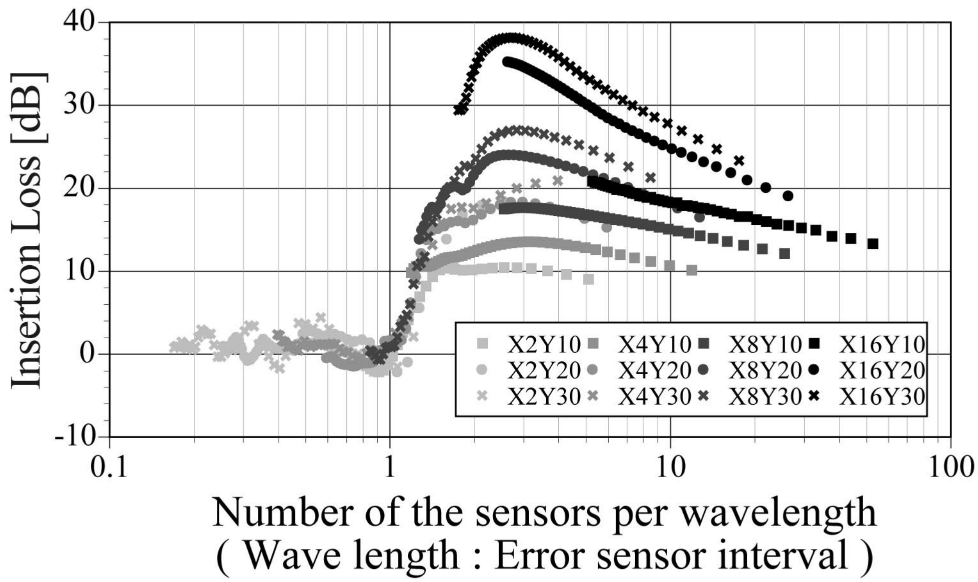


Figure 4: Relationship between sensor interval and wavelength (no passive barrier).

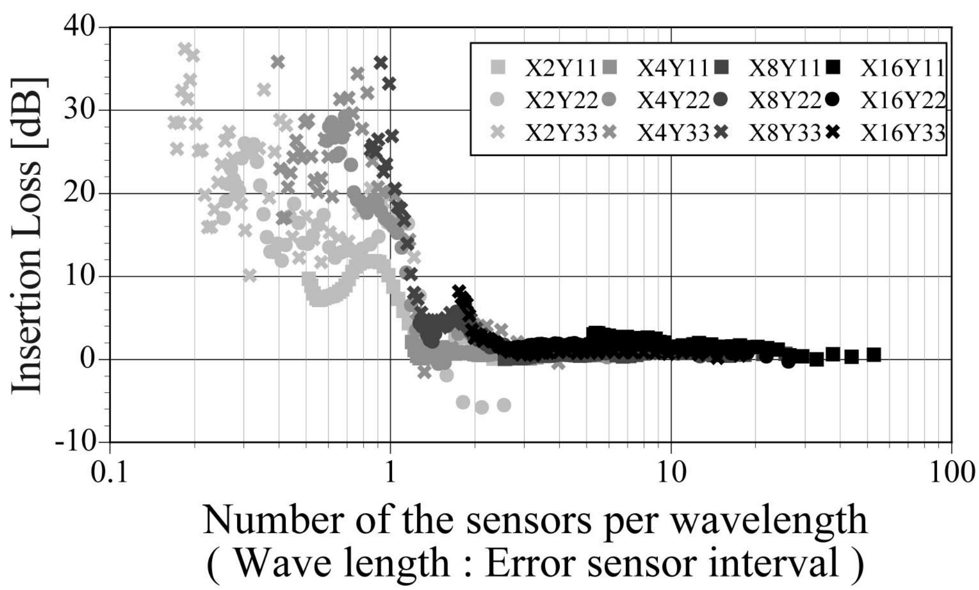


Figure 5: Relationship between sensor interval and wavelength (with passive barrier).

4.3 - Influence of distance between secondary source and sensor

Fig. 6 shows the insertion losses where the secondary sources of X8Y30 are fixed, and the energy sensors are moved horizontally in parallel. The distances between secondary sources and sensors are 0.125, 0.25, 0.5, 0.75, 1, and 2 m. According to this figure, the value of the insertion loss increases, as the distance between energy sensor and secondary source extends.

5 - CONCLUSION

If the ANB is used according to the design rules explained in this paper, its performance can be designed independent of passive noise barrier. It is necessary to shorten the installation interval of the sensors

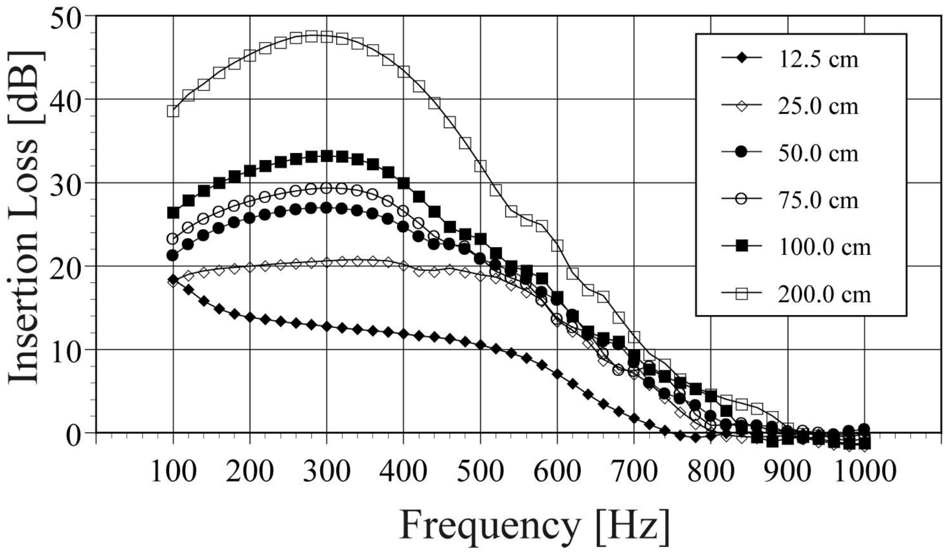


Figure 6: Influence of distance between secondary sources and sensors.

to obtain the effect of decreasing the sound pressure level. For ANC control, the interval of the sensor should be smaller than half the wavelength of the targeted noise. If the ANB produces a control effect, the sound pressure level improves over 10 dB in comparison with the case in which only the passive barrier is used. When the installation interval of the sensors is longer than the wavelength of the noise, it is to use the passive barrier simultaneously. The combination of passive barrier ensures the soundproofing effect. In this case, soundproofing effect in the high frequency is fully guaranteed the soundproofing effect by the passive barrier. In addition, the soundproofing effect by the active barrier is obtained in the low frequency. Moreover, the passive barrier does not affect the control effect of the active noise barrier at the low frequency. Lastly, if there were no limitation on installation of the ANB, it would be preferable to extend the distance between secondary source and error sensor.

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