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Prediction method of insertion loss of detached houses against road traffic noise based on a point sound source model- Prediction formula considering the heights of buildings and a prediction point

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ABSTRACT

In the Environmental Quality Standards for Noise in Japan (EQS) revised in 1998, the problem of environmental noise at areas facing roads is evaluated by obtaining the numbers and the rates of buildings at which noise levels exceed the standard value. The Standards allow for the estimation of noise levels, instead of requiring actual measurements, in cases where taking the actual measurements would be difficult. In order to estimate noise levels, to grasp insertion loss of buildings in an evaluated area is needed. Based on the above background, the authors proposed F2012a which can predict insertion loss of detached houses against road traffic noise based on a point sound source model. However, F2012a confines the heights of buildings and a prediction point to 10m and 1.2m above the ground, respectively. To expand these heights, this paper propose an extension formula of F2012 which can be applied to the condition when the height of buildings is less than 10m and a prediction point is lower than buildings. The validity of the proposed formula is verified through the experiments. This extended F2012 is adapted into ASJ RTN-Model 2013, a new version of ASJ RTN-Model, and applicable to the evaluation of EQS.

Keywords: Road traffic noise, Insertion loss of buildings, Environmental Quality Standards for Noise
I-INCE Classification of Subjects Number: 51

1. INTRODUCTION

In the Environmental Quality Standards for Noise in Japan (EQS) (1) revised in 1998, the problem of environmental noise at areas facing roads is evaluated by obtaining the numbers and the rates of buildings at which noise levels exceed the standard value. EQS allow for the estimation of noise levels, instead of requiring actual measurements, in cases where taking the actual measurements would be difficult. In order to estimate noise levels, it is necessary to grasp insertion loss of buildings in an evaluated area. Considering the above information, the authors have proposed an original method to predict the insertion loss of detached houses against road traffic noise at an area facing a flat road, F2006 (2) and a bank road, F2006^{+} (3). They are adopted in ASJ RTN-Model 2008 (4), which is a standard prediction model of road traffic noise in Japan. However, F2006 and F2006^{+} are based on a line sound source model and they can be applied only to an area along a straight road. On the other hand, ASJ RTN-Model 2008 is in general based on a point sound source model, and consequently it can predict L_{Aeq} at areas along not only a straight road but also a curved road. Therefore, a method to predict the insertion loss of buildings against road traffic noise based on a point sound source model is needed for evaluating EQS at an area along a curved road. With these points as background, the authors proposed F2012a at inter-noise 2013 (5), which can predict the insertion loss of detached houses against road traffic noise based on a point sound source model. However, F2012a confines the heights of buildings and a prediction point to 10m and 1.2m above the ground, respectively.

To expand these heights, this paper proposes an extension formula of F2012a which can be applied to the condition when the height of buildings is less than 10m and a prediction point is lower than buildings.

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2. F2012a

First of all, F2012a, a prediction formula of insertion loss of detached houses against road traffic noise based on a point sound source model, which the authors proposes at inter-noise 2013, is presented. For more information, please refer to the authors' previous paper (5).

$$\Delta L_{\mathrm{B}} = 10\log_{10}\left\{a_0 + a_1\frac{\varphi}{\emptyset} + a_2\sum_i\left(\frac{\theta_i}{\emptyset}\frac{d_{\mathrm{road}}}{d_{\mathrm{ref},i}}\right) + a_3\frac{1}{n}\sum_{k=1}^{n}\left(\frac{0.251}{1+0.522\delta_k}\right) + a_4 10^{-0.0904\xi d_{\mathrm{SP}}}\right\} \qquad (1)$$

ΔL_{B}	:	Insertion loss of detached houses against road traffic noise, [dB]
φ	:	Perspective angle to a road from a prediction point when houses are placed, [rad]
$\emptyset$	:	Perspective angle to a road from a prediction point when house are not placed, [rad]
θ_i	:	Perspective angle to a road from an image prediction point, [rad]
d_{road}	:	Perpendicular distance from a prediction point to a road, [m]
$d_{\mathrm{ref},i}$	:	Perpendicular distance from an image prediction point to a road, [m]
δ_k	:	Diffraction path difference of the first diffraction, [m]
ξ	:	House density in a rectangle, [-]
d_{SP}	:	Horizontal distance from a sound source point (S) to a prediction point (P), [m]

Here, a_0=0.0390, a_1=1.16, a_2=0.201, a_3=0.340, and a_4=0.288.

3. PREDICTION FORMULA TAKING THE HEIGHTS OF BUILDINGS AND PREDICTION POINT INTO CONSIDERATION

F2012a confines the heights of buildings and a prediction point to 10m and 1.2m above the ground, respectively. However, there are many detached houses the height of which are lower than 10m, and to predict L_{Aeq} at points with the height of other than 1.2m is needed for evaluating EQS. Therefore, the authors try to expand F2012a to be applicable when the height of buildings is less than 10m and a prediction point is lower than buildings. For this purpose, Experiment II is performed.

3.1 Experiment II

Since the outline of Experiment II is almost the same with that of Experiment I, which was carried out in the previous paper (5), except the heights of detached houses and receiving points, the detailed description is omitted here. The experimental conditions of Experiment II are shown in Table 1. The ω (the ratio of the area of the houses to the entire residential area) are 16.8%, 21.6%, 28.0%, and 34.4%, and the d (the smallest horizontal distance between the receiving point and a road) are 20m, 30m, 40m, and 50m. By combining them, the number of arrangement of houses are 16 patters. And the H (the height of buildings) are 10m, 7m, and 4m, and the H is constant in each arrangement of houses. The h_{p} (the height of a receiving point) are 1.2m, 2.2m, 3.2m, 5.2m, 6.2m, 8.2m, and 9.2m when the H is 10m, and 1.2m, 2.2m, 3.2m, and 5.2m when the H is 7m, and 1.2m, 2.2m, and 3.2m when the H is 4m. Thus, the number of combinations of the H and the h_{p} is 14. Examples of arrangement of houses are shown in Figure 1.

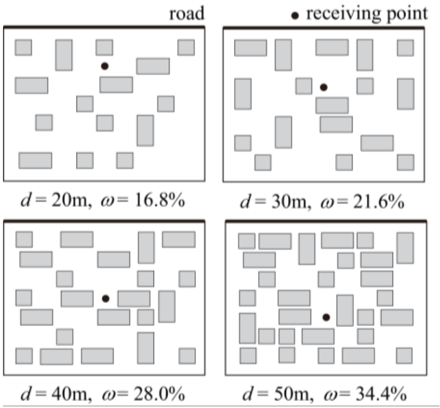

Figure 1– Examples of arrangement of houses.

Table 1– Experimental conditions (Exp.II).

d	ω	Number of arrangements	House
20m	16.8%	1	Plan 8m×8m, 8m×16m
30m	21.6%	1	
40m	28.0%	1	Height H=10m
50m	34.4%	1	

The experimental results are analyzed in the same way in the previous paper (5), and 1,936 data of ΔL_B are obtained in each combination of the H and the h_p (14 patterns).

3.2 Construction of prediction formula

All data of ΔL_B for each H and h_p are compared with the ΔL_B when H=10 and h_p=1.2 in Figure 2. It is found that the ΔL_B increase as the height of houses (H) become lower and the height of a prediction point (h_p) become higher. Since this could be caused by the sound energy propagating over the houses, the difference between H and h_p, (H-h_p) is examined to grasp the difference of ΔL_B for each H and h_p from ΔL_B when H=10 and h_p=1.2. As linear relationships are found in all figures in Figure 2, a regression analysis is applied. As a result, regression coefficients (p and q) are obtained. The relations between p, q and the (H-h_p) are shown in Figure 3. As a linear relationship is found in both p and q with (H-h_p), a regression analysis is applied again.

Thus, the prediction formula of ΔL_B taking the heights of houses and a prediction point into consideration is obtained by Eq.(2). Both Eq.(1) and Eq.(2) are all together called as F2012 hereafter.

$$\begin{gathered}\Delta L_{\mathrm{B}} = p \cdot \Delta L_{\mathrm{B},H=10,h_{\mathrm{p}}=1.2} + q \\ p = 0.017(H - h_{\mathrm{P}} - 8.8) + 1.0 \\ q = -0.063(H - h_{\mathrm{P}} - 8.8)\end{gathered} \tag{2}$$

3.3 Precision of Eq.(2)

All experimental data of ΔL_B are compared with the calculated ones by Eq.(2) (6); however, they are omitted in this paper on account of limited space. RMS of differences and the maximum difference are 1.9dB and 6.4dB, respectively. They are nearly equal to the values of F2012a (1.6dB, 6.0dB, respectively). Then, 14 data of $\Delta L_{\mathrm{bldgs}}$, which is an averaged energy level of ΔL_B when a vehicle runs from R_1 to R_2 shown in Figure 1 of the previous paper (5), compared with the calculated ones by Eq.(2). RMS of differences and the maximum difference are 0.8dB and 1.9dB, respectively, and they are nearly equal to the values of F2012a (0.7dB, 1.7dB, respectively). The above shows Eq.(2) has almost the same accuracy of F2012a.

3.4 Comparison of F2012 with F2006

When a road is straight, $\Delta L_{\mathrm{bldgs}}$ can be also predicted by F2006 (2) based on a line sound source model. To compare the accuracy of F2012 with F2006 for a straight road, the experimental $\Delta L_{\mathrm{bldgs}}$ (“circle”) are compared with the predicted ones by F2012 (“black triangle”) and F2006 (“cross”) in Figure 4, in which only 9 patterns are shown among 14 patterns. The results show 52% of the predicted $\Delta L_{\mathrm{bldgs}}$ by F2012 have better agreement with the experimental ones than those by F2006, and RMS and the maximum difference between the experimental values and predicted ones are 0.6dB and 0.8dB while 0.7dB and 1.2dB for F2006, respectively. This shows F2012 has better accuracy than F2006 for a straight road.

3.5 Examination of the validity of F2012

To verify F2012 is effective for a curved road, an additional model experiment (Experiment IIa) is performed. Examples of arrangement of houses are shown in Figure 5 and the experimental conditions of Experiment IIa are shown in Table 4. A road is an arc of a circle whose radius is 100m. The d are 20m, 30m, 40m, and 50m, and the ω are 16.6% and 21.5% when the d are 20m and 40m, 28.3% and 34.2% when the d are 30m and 50m. Thus, the number of the arrangements of houses is 8. The H are 10m, 7m, and 4m, where the H is constant in each arrangement of houses. The h_p are 1.2m, 4.0m, and 7.0m when the H is 10m, and 1.2m, 3.0m, and 5.0m when the H is 7m, and 1.2m and 3.0m when the H is 4m. The experimental results are analyzed and 1,128 data of ΔL_B are obtained in each combination of the H and the h_p (8 patterns).

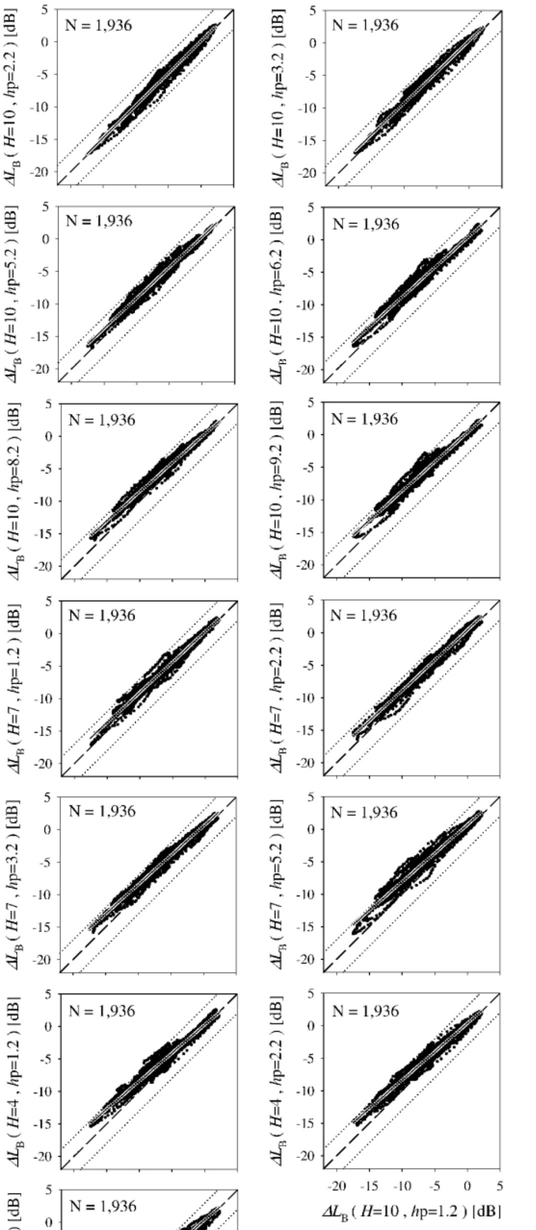

Figure 2– Comparison of ΔL_{B} with $\Delta L_{\mathrm{B},H=10,h\mathrm{p}=1.2}$.

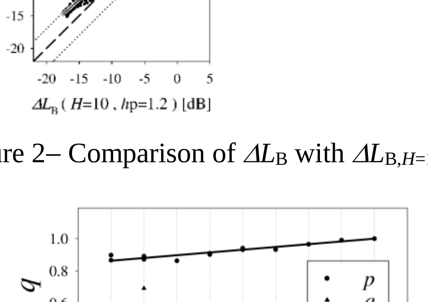

Figure 3– Relations between p, q and (H-h_{p}).

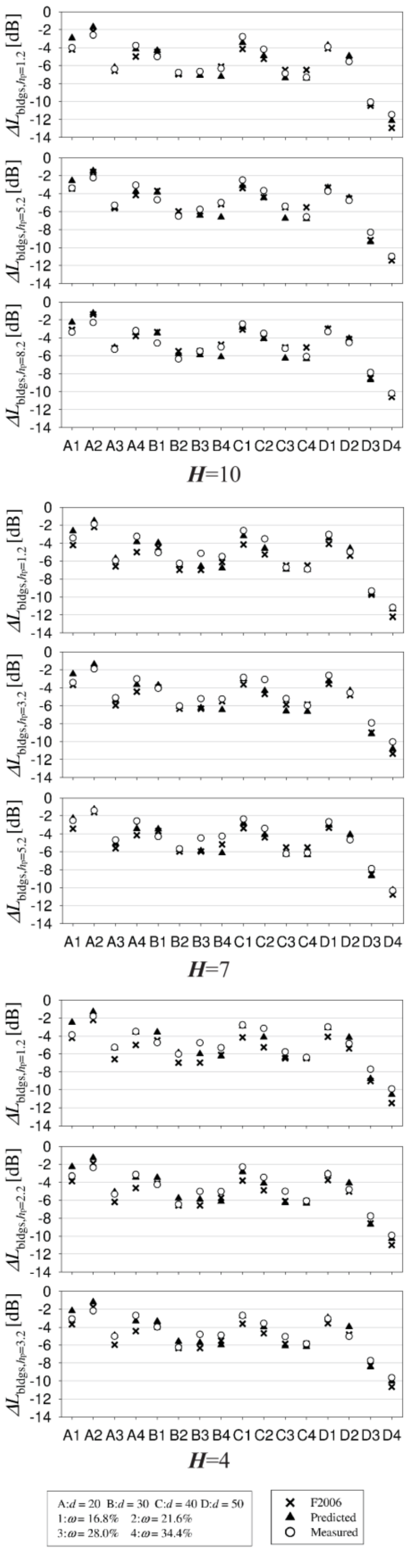

Figure 4– Comparison betweenF2012 and F2006.

Figure 6 shows two examples of unit patterns among 8 arrangements. Good agreement between experimental values and predicted ones is found. A comparison of the experimental ΔL_{B} and $\Delta L_{\mathrm{bldgs}}$ with the predicted ones is shown in Figure 7. RMS and the maximum difference are 1.6dB and 4.0dB, respectively. They are nearly equal to the values for a straight road (1.9dB, 6.4dB, respectively). Then, 8 data of $\Delta L_{\mathrm{bldgs}}$ are compared with the calculated ones. RMS and the maximum difference are 1.0dB and 1.4dB, respectively, and they are nearly equal to the values for a straight road (0.8dB, 1.9dB, respectively).The above shows F2012 can predict the insertion loss of detached houses against road traffic noise with almost the same accuracy with a straight road.

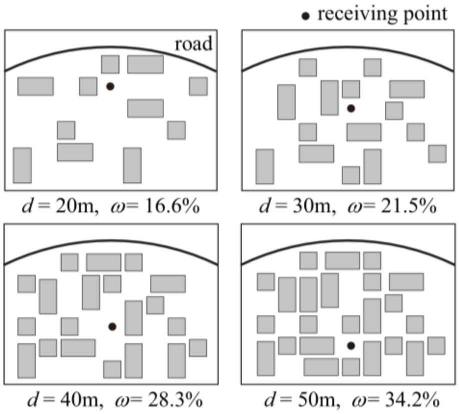

Figure 5– Examples of arrangement of houses.

Table 4– Experimental conditions (Exp.IIa).

d	ω	Number of arrangements	House	
20m	16.8%	1	Plan	8m×8m 8m×16m
30m	21.5%	1		
40m	28.3%	1	Height	H=10,7, 4m
50m	34.2%	1		

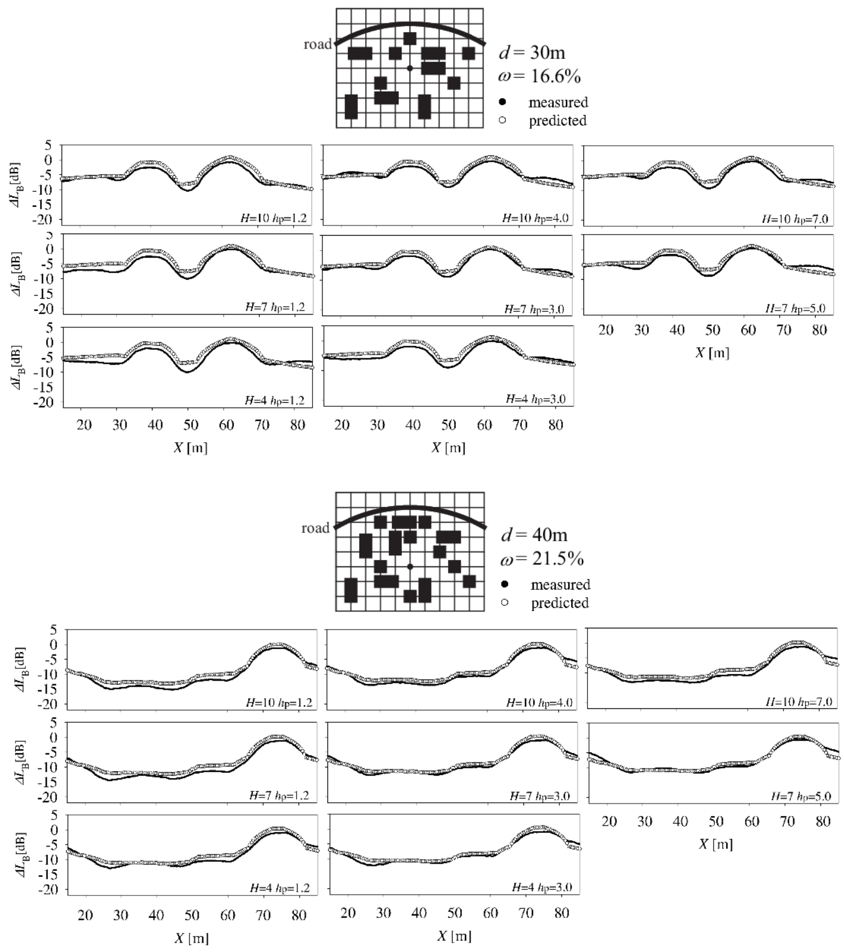

Figure 6– Comparison between experimental unit patters and predicted ones (Exp.IIa).

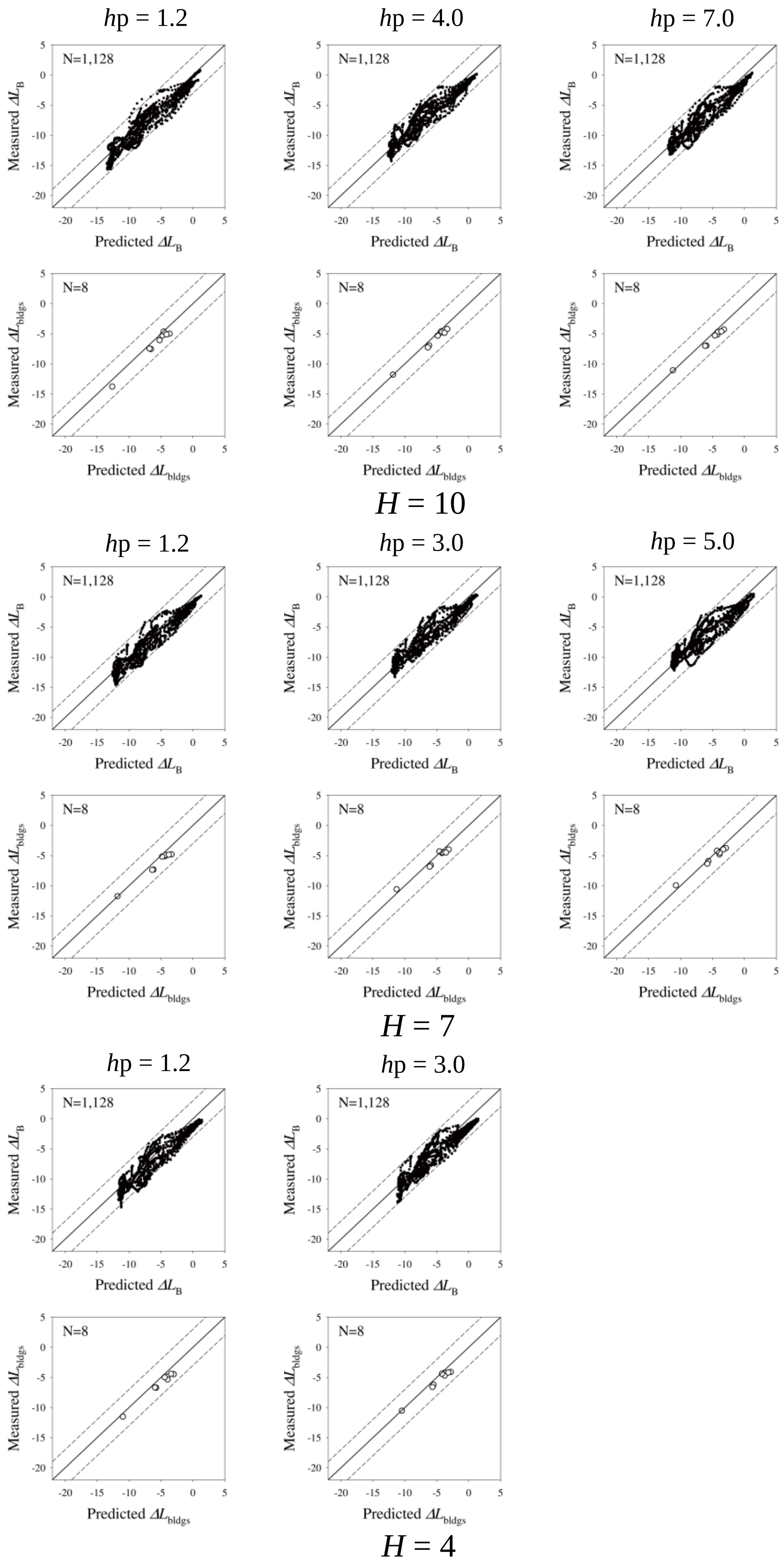

Figure 7– Comparison of the experimental ΔL_{B} and $\Delta L_{\mathrm{bldgs}}$ with the predicted ones (Exp.IIa).

4. CONCLUSIONS

Since a method to predict the insertion loss of buildings against road traffic noise based on a point sound source model is needed for evaluating EQS at an area along a curved road, the authors proposed F2012a at inter-noise 2013, which can predict the insertion loss of detached houses against road traffic noise based on a point sound source model. However, F2012a confines the heights of buildings and a prediction point to 10m and 1.2m above the ground, respectively. To expand these heights, this paper performs the experiment in which the height of houses and prediction points are varied and presents an extension formula of F2012a which can be applied to the condition when the height of buildings is less than 10m and a prediction point is lower than buildings through a scale model experiment. And the validity of the proposed formula F2012 is verified through the experiment.

F2012 proposed in this paper was adapted into ASJ RTN-Model 2013 (7), the latest version of ASJ RTN-Model presented by the Acoustical Society of Japan, and it is applicable to the evaluation of Environmental Quality Standards for Noise in Japan at the area along not only a straight road but also a curved road.

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