

Estimating dose-response relationship of Shinkansen railway noise using noise mapping

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ABSTRACT

Up until now, in Japan, the dose-response relationship of Shinkansen railway noise has been estimated using measurement-based noise exposure levels as dose value. The noise exposure levels at the house of respondents were calculated by assuming a line sound source and a noise attenuation due to buildings was not considered. In this paper, we propose a noise mapping technique of Shinkansen-railway by using a point sound source model and re-estimate the dose-response relationship of Shinkansen railway noise.

Keywords: Noise mapping, Shinkansen railway noise, Dose-response relationship

1. INTRODUCTION

The dose-response relationship of traffic noise is key data to understand the total amount of traffic noise impact on residents and to develop the environmental noise standard in Japan. To estimate the dose-response relationship, the noise exposure levels at the house of respondents of the questionnaire survey have to be accurately estimated. Up until now, in Japan, the dose value has been estimated using measurement-based noise levels. There could be any number of reasons why they used measurement-based noise levels as dose value. It is thought that the main reason is the Environmental Quality Standards for Shinkansen Superexpress Railway Noise [1]. The noise levels are measured and evaluated using the peak noise level. The peak noise levels ($L_{A,Smax}$) of each of the Shinkansen trains passing in both directions for 20 successive trains are measured. After that, the Shinkansen railway noise is evaluated by the energy mean value of the higher half of the measured peak noise levels. Furthermore, the noise levels for dose value have not been considered the noise attenuation by houses because of the unestablished digital national base map. Recent years have seen rapid progress in establishing such detailed digital national base map on a scale of one to 2,500 by the Geospatial Information Authority of Japan and in establishing transportation noise mapping techniques. In this paper, we propose a noise mapping technique of Shinkansen-railway by using a point sound source model and re-estimate the dose-response relationship of Hokuriku Shinkansen Superexpress railway noise.

2. TARGET AREA

The social survey was conducted in November 2016 in Ishikawa and Toyama prefectures on detached houses along the Hokuriku Shinkansen railway [2]. The target houses were all detached houses within 150m from the centerline of upside and downside lines. In this paper, the target area to estimate the Shinkansen railway noise map is a residential district with detached houses and is located in Toyama Prefecture, Japan (Fig. 1). The area is with 1.2 km length and within 100 m from the

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centerline of upside and downside lines because of applicable limitation of the Shinkansen railway noise estimation model. In this area, the Hokuriku Shinkansen is operated 92 numbers of trains per day, and it is not operated from 24:00 to 6:00 due to restrictions (Table 1). The Hokuriku Shinkansen uses the E7 series of train type and it consists of a twelve-car train.

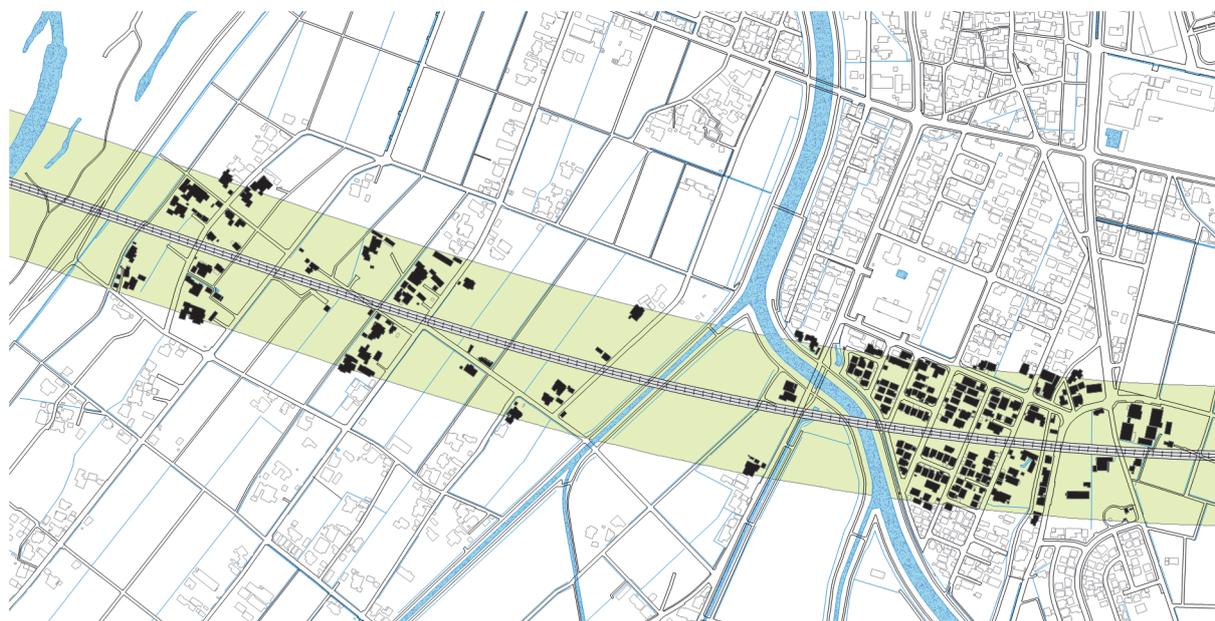


Figure 1 – Aerial view of the target area. The green buffer shows the estimation area within 100 meters from the center line of the Hokuriku Shinkansen rail track. The houses of respondent are a part of the black filled buildings.

Table 1 – Number of trains in operation per day

	Upside line	Downside line	Total
Day (7:00 – 17:00)	30	33	63
Evening (17:00 – 22:00)	9	8	17
Night (22:00 – 7:00)	5	7	12
Total	44	48	92

3. ESTIMATION OF NOISE EXPOSURE

3.1 Procedure of Estimating Shinkansen Railway Noise

As mentioned above, the evaluation value of the Environmental Quality Standard for Shinkansen Superexpress Railway Noise is generally used the $L_{A,Smax}$. Because of the comparison of the dose-response relationship with other countries in our future research, however, the L_{den} is used as evaluation value in this paper.

The Shinkansen railway noise consists of four noise sources; (a) two pantographs noise source per twelve-car train, (b) two rolling noise sources per car, (c) two structure-borne noise sources of viaduct per car and (d) one aerodynamic noise source per car. For each noise source, the A-weighted single-event sound exposure level (L_{AE}) is estimated from the unit pattern when one Shinkansen railway passes separately for the upside and downside lines using the Shinkansen railway noise estimation model [3]. After that, the L_{den} is calculated taking into account the number of operations by each time zone. However, since sound source data of the E7 series has not been published yet, so the data of the E2 series is adopted for estimation. The procedure for calculating noise propagation is as follows.

- 1) The SHAPEFILE formatted data of the center line of the Shinkansen railway and the outline of buildings are obtained through the web site of the Geospatial Information Authority of Japan [4].
- 2) The noise barrier of the viaduct is created by feature buffering based on the center line.
- 3) The height and width of viaduct are referred to the drawing sheets or survey results.
- 4) The feature of center line represents the position of the noise source of (c) structure-borne noise sources of viaduct.
- 5) The features of center lines of upside and downside line are created based on drawing sheets or survey results. These features represent the position of the noise source of (a) pantographs noise source and (b) rolling noise sources.
- 6) The discrete noise source points are created 1 m intervals on each feature and are given the A-weighted sound power level L_{WA} [dB] depending on the traveling speed as the property value. The values of traveling speed used in this paper are shown in Table 2.
- 7) The position of aerodynamic noise source changes depending on the spatial relationship between the position of noise source and receiver. Therefore, the relationship is judged in each case, and then the noise source is created on one side to the travel direction. The perpendicular distance from the noise source to the center line is half of the width of the track.
- 8) The features of receivers are created at the intervals of 2.5 m outer side of the buildings (Fig. 4 (a)).
- 9) The A-weighted sound pressure level $L_{A,i,j}$ [dB] for noise propagation from the i th noise source position of the j th noise source type to the receiver is calculated with following equations of One-path method. The diffraction is assumed double diffraction at the noise barrier and the edge of building as the knife-edge diffraction.

$$L_{A,i,j} = L_{WA,i,j} - 8 - 20 \log_{10} d_{i,j} + \Delta L_{db,i,j}, \quad (1)$$

$$\Delta L_{db,i,j} = \Delta L_{dif,i,j,1} + \Delta L_{dif,i,j,2} \quad (2)$$

$$\Delta L_{dif,i,j,k} = \begin{cases} -20 - 10 \log_{10}(c_{spec} \delta_{i,j,k}) & , c_{spec} \delta \geq 1 \\ -5 - 17 \cdot \sinh^{-1}(c_{spec} \delta_{i,j,k})^{0.36} & , 0 \leq c_{spec} \delta < 1, \\ \min [0, -5 + 17 \cdot \sinh^{-1}(c_{spec} \delta_{i,j,k})^{0.36}] & , c_{spec} \delta < 0 \end{cases} \quad (3)$$

where $L_{WA,i,j}$ is the A-weighted sound power level of a running train [dB], $d_{i,j}$ is the direct distance from the i th noise source position of the j th noise source type to the receiver, the coefficient c_{spec} is defined as 0.4 considering with the spectrum of the Shinkansen noise [5] and $\delta_{i,j,k}$ is the path difference. The function “min [a , b]” gives the smallest value of a and b .

- 10) The sound exposure level L_{AE} is calculated with the following equation considering the correction value ΔL_{AE} . The values used in this paper are shown in Table 2.

$$L_{AE} = 10 \log_{10} \sum_i \sum_j \left(n_j \cdot 10^{\frac{L_{A,i,j}}{10}} \right) + \Delta L_{AE}, \quad (4)$$

where n_j is defined as the number of noise source per twelve-car train, for instance, the number of the rolling noise sources is 24 per twelve-car train.

- 11) The L_{den} is calculated in consideration of the number of trains in operation per day (Table 1).

3.2 Result of Measurement and Estimation of Noise Exposure Levels

To calculate the ΔL_{AE} , the measurement was conducted at 25m distance from the centerline of the upside and downside line by using the sound level meter (RION NL-31, 32, 42 and 62). The height of the receiver was 1.2m from the ground. In the measurement, the instantaneous values of the sound pressure level at intervals of 100 milliseconds were recorded in the SLM's memory. The recordings were carried out against six trains passing through upside line and seven trains passing through downside line. To estimate the traveling speed of trains, at the same time, the trains passing through were recorded with a video camera. After the measurements, the traveling speed and the L_{AE} were calculated in our laboratory.

Relationship between the measured L_{AE} and the traveling speed (left figure) and between the

measured L_{AE} and the estimated L_{AE} (right figure) are illustrated in Fig. 2. It is understood from the figure that the trends of the upside and downside are different. When the trains passed through the upside line, the L_{AE} becomes higher with faster running speed of the train, but when the trains passed through the downside line, the L_{AE} becomes lower with faster running speed of the train. At the time of writing this paper, we cannot understand the reason why the trends of L_{AE} are different between lines, therefore, a more detailed measurement will be carried out in our future studies. The estimated L_{AE} when the trains pass through the upside line is approximately 2 dB less than the measured values. On the other hand, when the trains pass through the downside line with faster than 180 km/h, the estimated and measured L_{AE} has good correlation. As a result, to estimate the noise exposure levels at each respondent's house, the average running speed and the difference of energy based average of L_{AE} between the estimation value and measurement value at each line are defined as in table 2. An example of the noise exposure level mapping is illustrated in Fig. 3. The state of the noise attenuation caused by buildings and the incursion of noise in the residential area along the roads is confirmed visually.

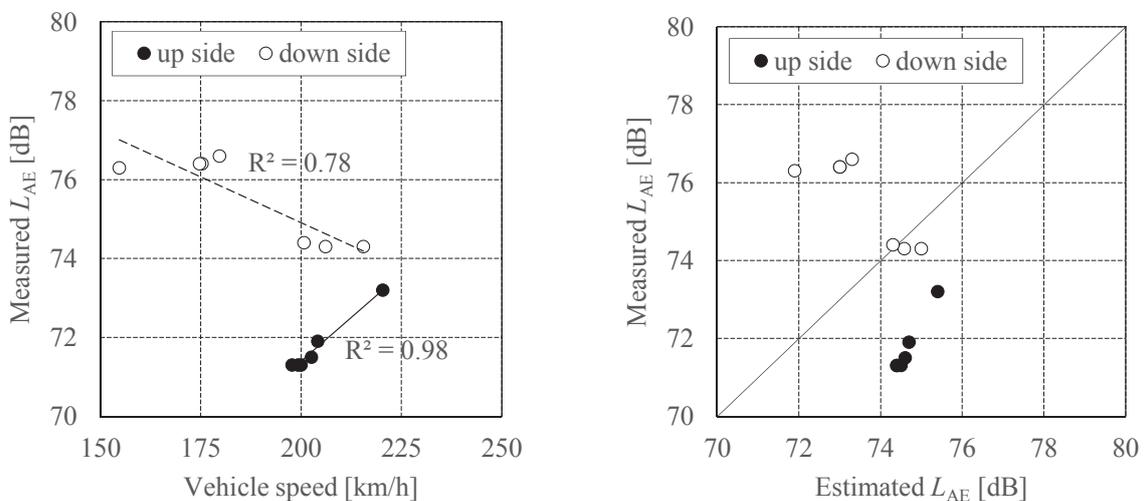


Figure 2 – Relationship between the measured L_{AE} and the traveling speed (left figure) and between the measured L_{AE} and the estimated L_{AE} . The location of the measurement and estimation point are 25 m distance from the centerline and the height is 1.2m from the ground.

Table 2 – Traveling speed of Shinkansen and the correction value of L_{AE} at each line.

	Upside line	Downside line
Average running speed of train [km/h]	204.0	186.7
ΔL_{AE} [dB]	-2.9	2.0



Figure 3 –Noise exposure level map when a train passes through upside line.

3.3 Influence of Interval of Receiver Points on Estimation Accuracy

The representative noise exposure level at the residential buildings is assigned to evaluate dose-response relationship or to assess the population exposure to noise. Generally, the maximum noise level in front of the building façades of the residential buildings is calculated [6]. The noise level at receiver points in front of the building façades can be calculated directly from the noise source points without using the noise map. Considering the profit of estimating noise map of the whole urban area while the high computational load, however, it is useful that the noise level at receiver points is calculated indirectly by over-layering with a noise map. Accordingly, in this section, we discuss the optimal interval of the receiver points in the view of the maximum noise level in front of the façades at each building.

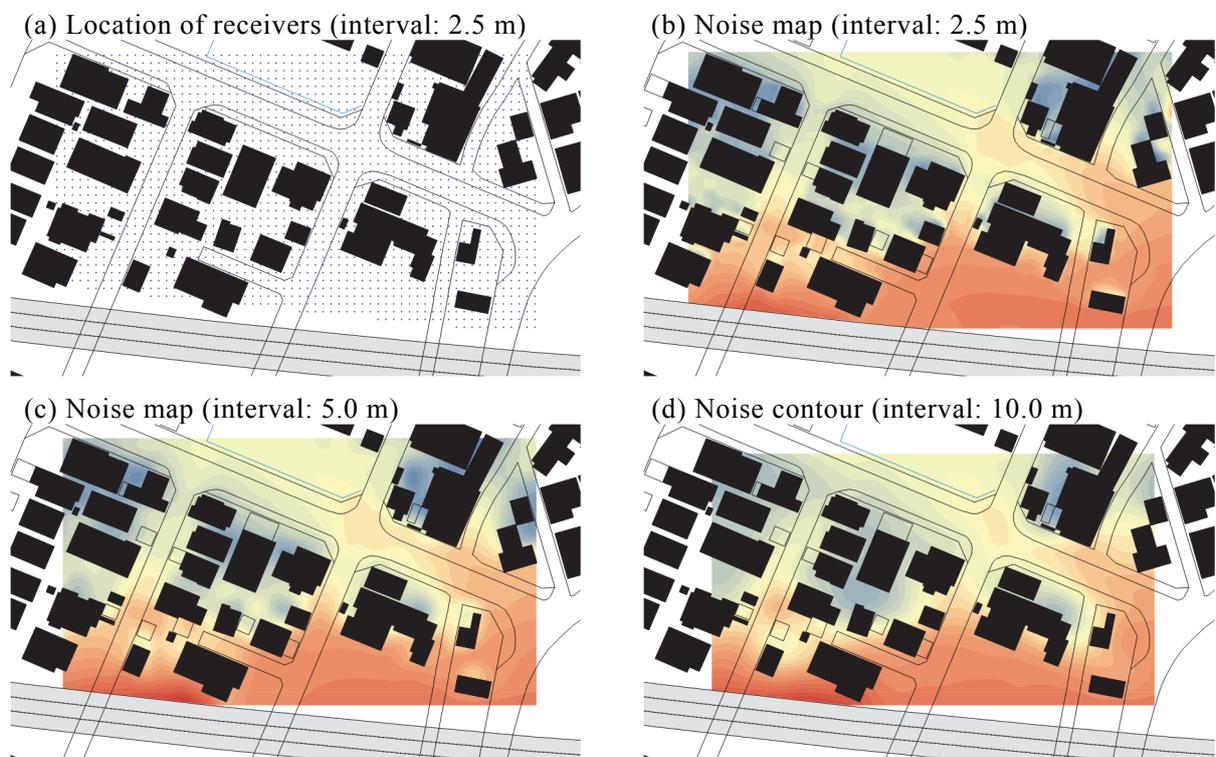


Figure 4 – Receiving points and noise map.

The intervals of receiver points were varied 2.5 m, 5.0 m, and 10.0 m. The noise levels at every receiver points were estimated and then the noise maps were calculated using the spline interpolation method (the resolution after interpolation was 1.0 x 1.0 m). The results of calculating the noise maps are illustrated in Fig. 4. The noise levels in the case when the intervals are 5.0 m and 10.0 m do not look like correct in the case of behind the buildings or the narrow space between the buildings comparing with when the intervals of 2.5 m. The reason of difference is mainly due to the case of few receiving points. The receiver points are less likely to be located at such places, and the noise levels at the places are lower than other places. Therefore, the interpolated noise levels based on higher noise levels around such places tend to become higher than the real situation. Figure 5 shows the difference of noise levels from the case of 2.5 m of intervals. As mentioned above, the noise levels behind the buildings tend to become lower than in other places. From the viewpoint of the maximum noise level of each building, however, the noise levels may not be different between the case of the intervals of 2.5 m and 5.0 m.

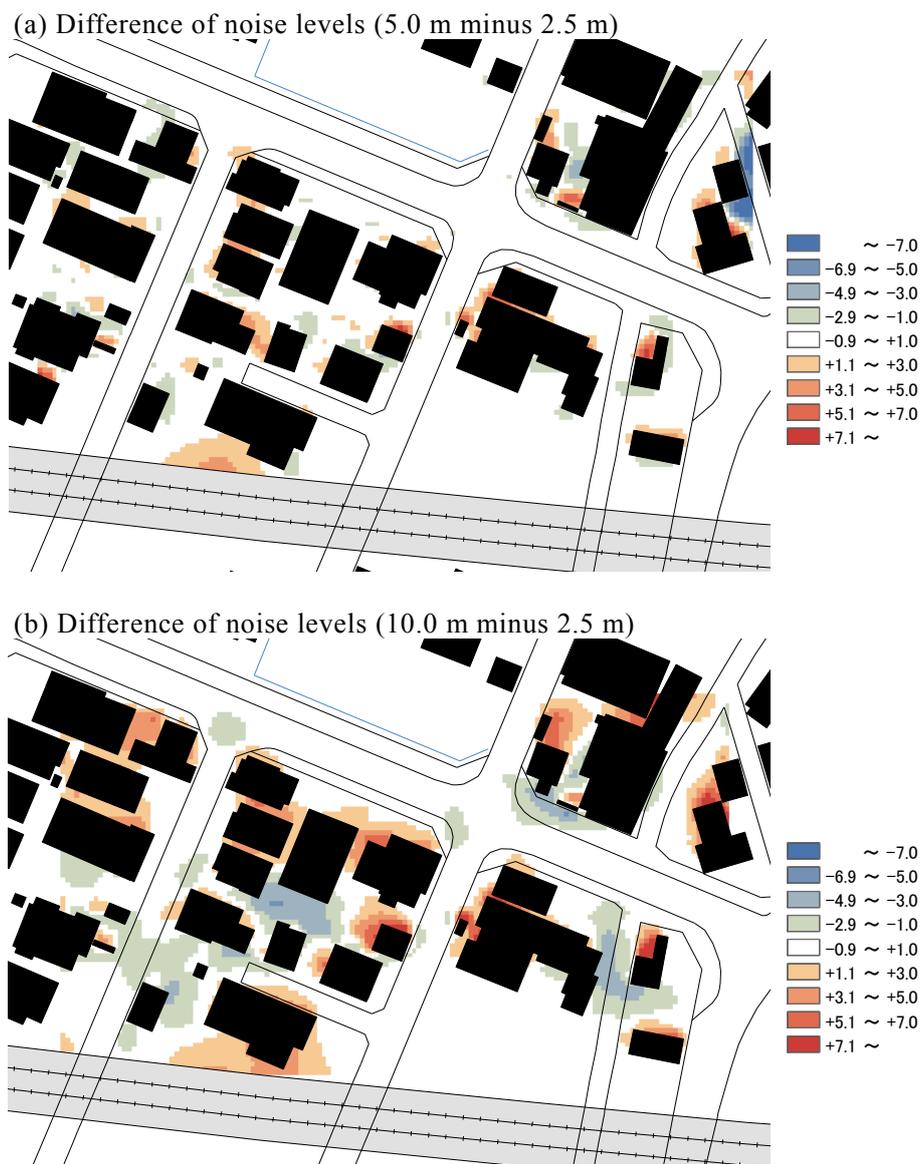


Figure 5 – Difference of noise levels from the case of 2.5 m of intervals.

3.4 Result of Estimating Noise Exposure Levels of Respondent's houses

The noise levels L_{den} were estimated for 52 respondents of the social survey by using the noise map. Figure 6 shows the comparison between L_{den} of respondents estimating based on measurement

values and the noise map. The noise levels based on measurement are varied only from 47 dB to 50 dB because the values do not consider the attenuation caused by the buildings. On the other hand, the noise levels based on the noise map are varied from 39 dB to 54 dB.

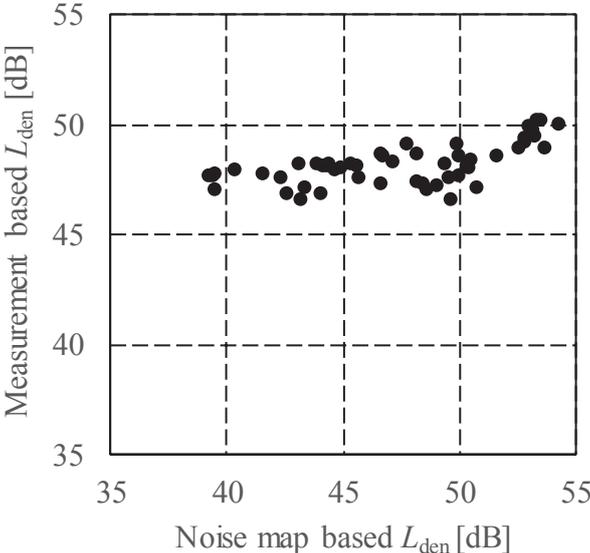


Figure 6 – Comparison of the noise levels between the measurement-based L_{den} and the noise map-based L_{den} .

4. COMPARISON OF DOSE-RESPONSE RELATIONSHIP

Figure 7 shows the relationship between community response and noise exposure level. In this paper, the ratio of respondents who chose either the top 2 categories in the 5-point verbal scale is defined as % highly annoyed [7]. Although the dose-response relationship is generally described with the logistic regression curve, it is not adopted in this paper because of the few samples. Both of them tend to become higher with higher noise levels.

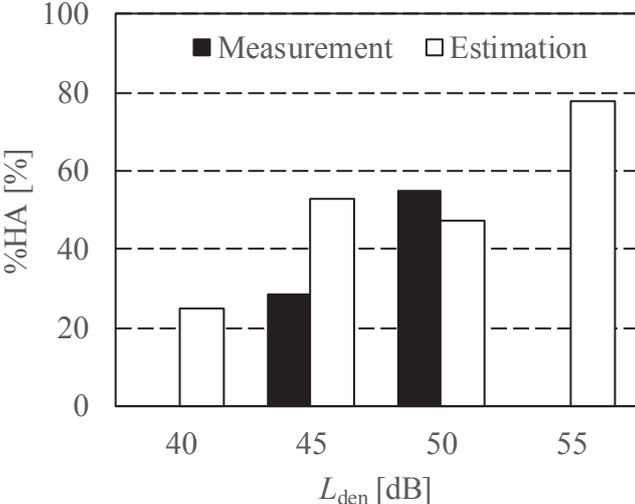


Figure 7 – Dose-response relationship due to noise annoyance.

5. CONCLUSIONS

In this paper, we proposed a noise mapping technique of Shinkansen-railway by using a point sound source model and re-estimate the dose-response relationship of Hokuriku Shinkansen Superexpress railway noise. The interval of receiver points may set less than 5.0 m from the viewpoint of the maximum noise level as the representative value of buildings. The noise level estimated with the noise map was much more widely varied than those estimated based on the measurement. In future research, we have to confirm the accuracy of the result of the noise map by conducting more detailed noise measurements. Furthermore, we will evaluate the dose-response relationship against all of the respondents of the social survey along the Hokuriku Shinkansen Superexpress railway.

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