Reanalysis of dose-response curves of Shinkansen railway noise

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1 INTRODUCTION

The Shinkansen railway has increased its transportation capacity since its opening in 1964. This has led to increased levels of vibrations and noise (including low frequency noise caused by running trains), annoying people living along the railway corridor. For the purpose of helping to preserve living environments and for the protection of inhabitants' health against the adverse effect of noise, the "Environmental Quality Standards for Shinkansen Super-express Railway Noise" were introduced in 1975. Subsequently in 1976, the Director of the Environmental Agency recommended that "Shinkansen railway vibration countermeasures be taken urgently to ensure environmental preservation". The noise level is to be evaluated by the energy mean of the top 10 values among 20 peak measurements. The vibration index is determined by the arithmetic mean instead of the energy mean.

Several social surveys have been carried out so far in Japan on the community response to the Shinkansen noise issue. Sone et al. (1973) conducted social surveys on the Shinkansen noise in areas along the New Tokaido and Sanyo Lines. The results were compared with the results of aircrafts noise measurements. They discussed the application of several noise indices to evaluate Shinkansen noise annoyance levels. Subsequently, Tamura (1994) indicated that people along the Shinkansen railway rates more poorly than those along ordinary railways in the areas where railway noise is a major contributor to the total environmental noise.

From 2001 to 2003, Yokohama National University and the Kanagawa Environmental Research Center carried out social surveys in residential areas along the New Tokaido Line in the Kanagawa Prefecture. Yokoshima & Tamura (2003) indicated that the inhabitants had more severe attitudes to the Shinkansen railway noise than those exposed to noise from other forms of ground-based transportation. Furthermore, applying covariance structure analysis to the annoyance structure model of the noise and vibration, Yokoshima & Tamura (2005) revealed that there were synergetic effects between the Shinkansen noise and vibrations on annoyance.

In 2003, the Kumamoto and Hokkai Gakuen Universities carried out a joint social survey on the community response to Shinkansen railway noise in areas along the New Sanyo Line in the Fukuoka Prefecture. Yano et al. (2005) and Sato et al. (2004) suggested the presence of an interactive effect between the Shinkansen noise and vibration on annoyance.

Recently, the "Environmental Quality Standards" regarding other noises have been amended in Japan. The "Environmental Quality Standards for Noise" are defined by the environmental conditions related to noise in general living and roadside areas. The standards were revised in 1999. The new standards prescribe L_{Aeq} as the noise metric. In addition, in 2007, the Ministry of the Environment revised the "Environmental Quality Standards for Aircraft Noise". These require aircraft noise to be evaluated using L_{den} instead of WECPNL. On the other hand, environmental quality standards for conventional railway noise have yet to be legislated in Japan. However, the "Guidelines for Noise Measures with regard to Construction and/or Large-scale Improvement of Conventional Railways" in 1995 use L_{Aeq}. Therefore, it is indispensable to discuss the application of noise metrics in the evaluation of Shinkansen railway noise annoyance.

We discuss the dose-response curves of the Shinkansen railway noise using the results of two surveys: the Fukuoka and the Kanagawa Surveys. To find an appropriate metric for Shinkansen railway noise, we compare the relationships between the maximum-based and energy-based noise metrics and community responses to noise. Furthermore, we examine whether or not non-auditory effects, distance and vibration exposure, affect Shinkansen railway noise annoyance.

2 SOCIAL SURVEYS

Table 1: Details of the Shinkansen railway and the surveys used in this study

Prefecture	Kanagawa Survey	Fukuoka Survey
Railway line	New Tokaido Line	New Sanyo Line
Survey Range	100 meters from the track	150 meters from the track
Number of passing trains	287 trains	180 trains
Train series	Series 300，500，700	Series 0，100，300，500，700
Number of cars	16 cars	4-16 cars
Survey date	October 2001 September – October 2002 October 2003	April 2003
Sample Size	1,784	1,100
Respondents	986	724

2.1 Description of the Shinkansen railway lines

The operation of the Shinkansen train is prohibited from 12 midnight to 6 a.m. The total number of trains per day in the Kanagawa and Fukuoka Prefectures were 287 and 180, respectively. A maximum speed of above 250 km/h was observed at most sites for the Kanagawa Survey, in contrast to about 200 km/h for the Fukuoka Prefecture. In addition, the Sanyo Shinkansen trains have various numbers of cars ranging from 4 to 16, while 16 cars travelled on the New Tokaido Line (see Table 1).

2.2 The Kanagawa Survey

The Kanagawa Survey was conducted in residential areas along the New Tokaido Line in the Kanagawa Prefecture, from 2001 to 2003. Questionnaires were distributed to inhabitants 18 years of age and over at 98 survey sites. Each site, covering 100 square meters, was extracted at random from the areas within 100 meters of the railway. The survey used a distribution-by-mail method. However, the survey covered 10 survey sites in the vicinity of the Atsugi Naval Air Facility. Since noise generated by training flights may also have adversely affect people's daily life in the areas surrounding the Atsugi Base, there is a possibility that their responses are biased by the aircraft noises. Consequently, 114 respondents in the 10 sites were eliminated from the sample. The sample size for people living in detached houses amounted to 872, and the response rate was about 55 %.

The contents of the questionnaire used in the Kanagawa Survey are as follows. Q1, satisfaction of residential environments included the degree of “outdoor quietness” and “house vibration”. These items were rated on a 5-point verbal scale. Q6, daily activity disturbances, including the following items related to noise and vibration: the rattling of fittings, listening disturbance, sleep disturbance, reading/thinking disturbance and degree of restriction in opening windows. The answer format of Q6 was multiple choice. In Q7, the annoyance level of each of nine sources of noise, including the Shinkansen railway, was evaluated based on the ICBEN scale: not at all, slightly, moderately, very and extremely “bothered” by the noise.

After the social survey was completed, noise and vibration measurements were made to estimate the actual noise exposures associated with each of the respondents’ dwellings at each site. The sound exposure level (L_{AE}) and SLOW-peak sound level (L_{ASmax}) of each passing train was measured at several points at different distances from the track. At each point, the 24-hour L_{Aeq} was determined based on the mean energy value of the L_{AE} and the number of trains per day. Likewise, the energy mean value of the upper half of the measured SLOW-peak noise levels (L_{Amax}) was also calculated. According to the noise metrics, one or more distance reduction equations, logarithmic regression equations between distance and noise levels, were formulated. Noise exposures to each dwelling were estimated in every survey site by the corresponding formula. For L_{dn} and L_{den}, the exposures were estimated using the train schedule and the 24-hour L_{Aeq} values at each dwelling.

Similarly, the peak vibration level in the vertical direction was measured at the same point as the noise measurement was taken. The vibration level was recorded on the ground using a vibration level meter. The vibration exposure (L_{Vmax}) was calculated from the arithmetic mean value of the upper half of the measurements (re 10^{-5} m/s^2) at each point. The distance reduction equations were formulated based on the L_{Vmax} values, and the vibration exposure to each house was estimated from the equations.

2.3 Fukuoka Survey

The Fukuoka Survey was conducted in 2003 in residential areas along the New Sanyo Line in the Fukuoka Prefecture. Since the Shinkansen line is elevated and noise barriers have been constructed along the line in almost all areas, essentially all of the detached houses within 150 m of the track were selected for the survey. When there was no house within the 150 m range, detached houses directly facing the railway were also included, up to a maximum distance of 680 m from the railway. Respondents aged between 20 and 75 years were randomly selected from a list of voters on a one-person-per-family basis. The questionnaires were distributed and collected either by the staff or by mail. In total, 724 responses were obtained and the response rate was 66 %.

The contents of the questionnaire, which were significantly different from those for the Kanagawa Survey, were as follows: housing factors, evaluation of the residential environment, annoyance caused by environmental factors including noise from the Shinkansen railway, interference in activities as a result of the Shinkansen trains, and personal factors. The annoyance and activity interferences in this case were also measured using the ICBEN scale.

After the social survey was carried out, noise measurements were made. Shinkansen noise levels, L_{AE} and L_{ASmax}, were recorded at least five times for each train type and for both near and far tracks at a reference point close to the Shinkansen line and points 5, 10, 20, 40 and 80 m apart from the reference point. Concurrent measurements were made using integral sound level meters. Distance reduction equations, logarithmic regression equations between distance and noise reduction, were formulated separately for the near and far tracks based on the L_{AE} and L_{ASmax} values. Noise exposures to each house were obtained from the $L_{Aeq,24h}$ at the reference point and the noise reduction calculated using the formula. The values of L_{dn} and L_{den}, were estimated by the same method as used in the Kanagawa Survey.

The peak vibration levels in the vertical direction were measured at points 12.5, 25, 50, 75, 100 and 150 m from the near track. The measurements were made at five sites along the line. The vibration level on the ground was recorded and the L_{Vmax} value was calculated from the measurements. The distance reduction equations of L_{Vmax} were formulated and the vibration exposure to each house was estimated. However, the number of the houses for which L_{Vmax} values were determined was only 358.

3 RESULTS

Figure 1 indicates the averaged exposures (L_{Aeq}, L_{Amax}, and L_{Vmax}) according to the distance categories. Analyses were done with L_{Aeq} as an energy-based noise index. This figure shows the results for respondents living within 100 m of the track. While the L_{Aeq} values for the Kanagawa Survey were higher within 25 m of the track, those for the Fukuoka Survey indicated the same or higher levels at distances over 25 m. For the L_{Amax}, the Fukuoka Survey shows higher levels than found in the Kanagawa Survey for distances over 25 m. Since the number of and each duration time of the noise events and per day differed between the New Tokaido and Sanyo Lines, the L_{Aeq} value of the Kanagawa Survey was 5 dB larger than that of the Fukuoka Survey, even when the L_{Amax} value was at the same level for both surveys. The L_{den} and L_{dn} values were about 4 dB and 3 dB higher than the L_{Aeq} value for both surveys, respectively.

In contrast, the vibration level from the New Tokaido Line was higher compared with the New Sanyo Line.

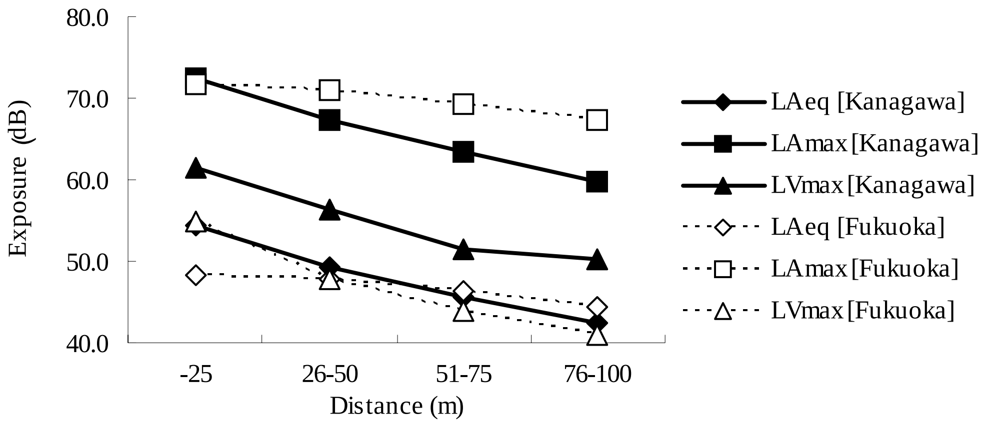

Figure 1: Averaged exposures according to the distance categories

Figure 2 compares the dose-response relationships for the Shinkansen noise annoyance between the two surveys. The “%HA” was defined here as the rate of respondents who answered in the top category (“extremely”) in each exposure range. For the L_{Aeq}, it was found that the difference in the %HA was significant at the 5 % level in the range of 46-50 dB using Fisher’s exact test. In contrast, there was a significant difference in %HA at the 5 % level in the L_{Amax} range of 61-65 dB. These figures suggest that the dose-response relationships between the surveys didn't agree, especially for L_{Aeq}.

Likewise, Figure 3 compares the dose-response relationships for listening disturbance between the two surveys. The "%LD" was defined here as the following: the rates of the respondents who answered the presence in listening disturbance. However, the answer formats of listening disturbance differed between the surveys. Therefore, this paper regarded the responses in the top two categories, "very" and "extremely", for the Fukuoka Survey as the presence of disturbance. For the L_{Aeq}, the Fukuoka Survey indicated a tendency towards a higher disturbance response rate than the Kanagawa Survey. A significant difference for the L_{Aeq} values was observed at the 5 % level in the range of 46-50 dB. However, no significant difference in the L_{Amax} was found.

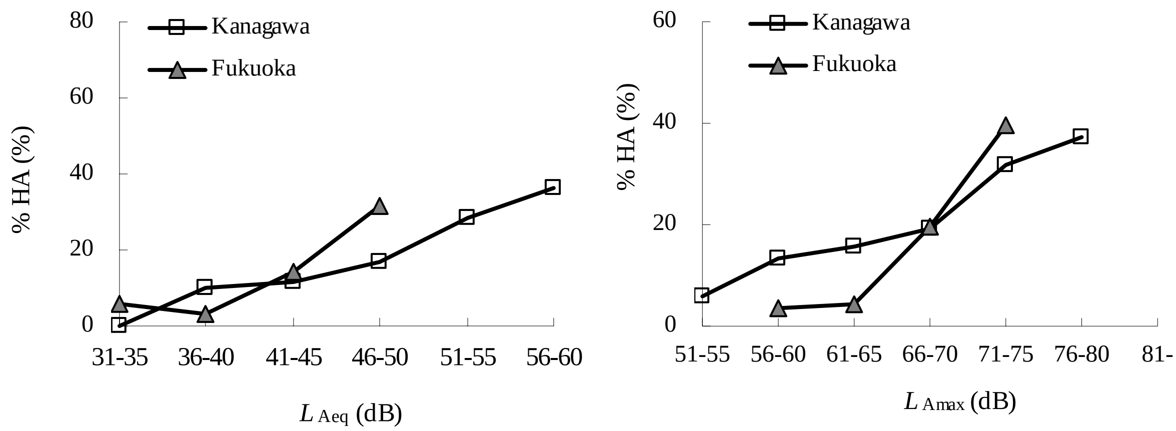

Figure 2: Comparison of noise exposure –annoyance relationships between the surveys

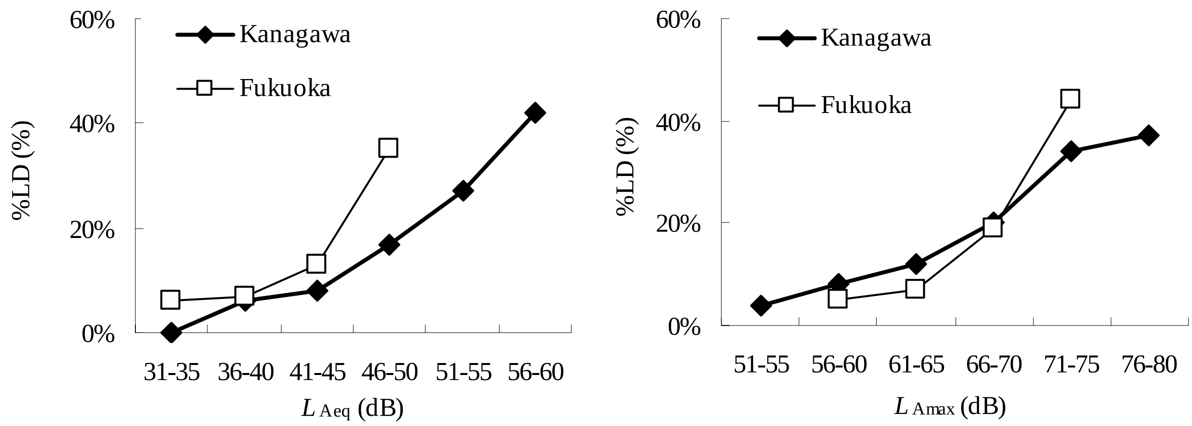

Figure 3: Comparison of noise exposure –disturbance relationships between the surveys

Figure 4 shows the mean values of the L_{Aeq} and LAmax using a 5-point scale of noise annoyance according to the surveys. The X and Y axes are the noise exposure and annoyance scale (1=not at all, 2=slightly, 3=moderately, 4=very, 5=extremely), respectively. The L_{Amax} values of the Kanagawa Survey were about 4 dB higher than those found in the Fukuoka Survey on every scale level from the "slightly" to the "extremely" levels. For the "not at all" level, no difference was found between averaged L_{Aeq} values. In contrast, there was no difference in the L_{Aeq} between the two surveys except at the "not at all" level of the scale.

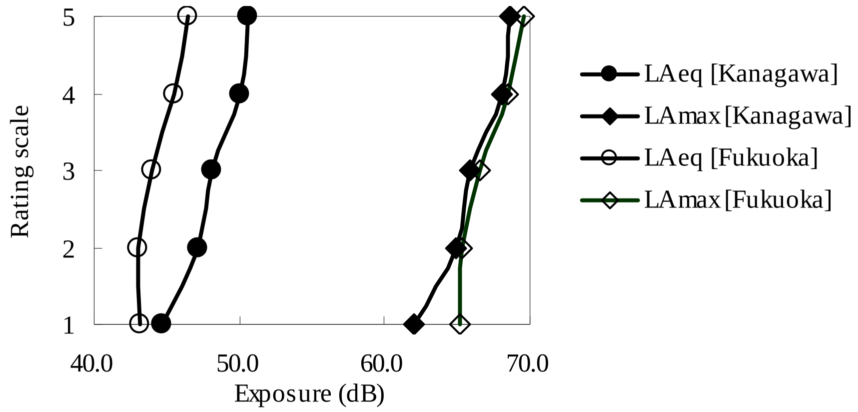

Figure 4: Averaged L_{Aeq} and L_{Amax} values according to the rating scales of noise annoyance

4 DISCUSSION

As shown in Figures 2 and 3, there is a tendency for the Kanagawa Survey to indicate higher annoyance and listening disturbance response rates compared with the Kanagawa Survey, even at the same L_{Aeq} level. With regard to the L_{Amax}, on the other hand, the difference in the response rate is less. In addition, Figure 4 indicates less of a difference in the L_{Amax} than in the L_{Aeq}. These results confirm that the maximum-based noise metric is universal as the metric for the Shinkansen railway noise. Its adequacy as a maximum-based metric is attributed to the following factors: long-term evaluation, long-term residence, assessment of specific (and not general) noises, the synergetic effect of vibration, etc. The assessment of the universality of the metric would benefit from an extension of the database to other areas.

Non-auditory factors (such as the vibration level to which the respondents were exposed and the distance from the railway) were also examined to determine whether or not these contributed to their annoyance rating. Figure 5 compares the annoyance response to the Shinkansen railway noise according to the categories of L_{Vmax} and the distance for both sets of survey data. For this purpose, the L_{Amax} is used as the measure of noise exposure. At the lower levels of L_{Amax}, the difference in the %HA was significant at the 5 % level for both the vibration level and distance. Figure 5 confirms that distance has a synergetic effect on noise annoyance. The vibration level is related to distance, and also has a similar effect, as noted by other studies.

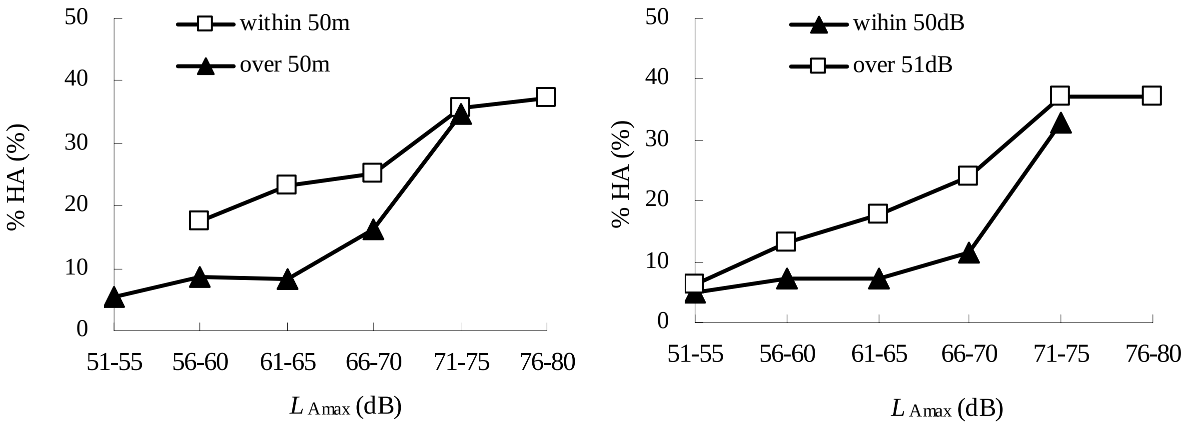

Figure 5: Comparison of the relationship between noise exposure and annoyance level sorted by distance categories and vibration level categories

Figures 2 and 3 indicate that the slopes of the dose-response curves for the Fukuoka Survey are higher than those for the Kanagawa Survey. The difference can probably be attributed to the differences in distances between the track and the dwellings between the surveys. While the level of noise annoyance in the vicinity of the railway is likely to have been affected by the distance, there is no synergetic effect on the annoyance in the area distant from the source. Therefore, the difference in the distance brings about the steeper slope for the Fukuoka Survey.

5 CONCLUSION

Using two social surveys of community responses, the Kanagawa and the Fukuoka Surveys, we reanalyzed the dose-response relationships for Shinkansen railway noise. For the noise metric L_{Amax}, a maximum-based noise metric rather than L_{Aeq} has been found to be universal for assessing noise annoyance. In addition, we examined whether non-auditory effects affect annoyance or not. In particular, the distance from the source to the dwelling and the respondents' vibration level of exposure showed significant effects on individual annoyance levels.

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