An investigation of exposure-response relationships for vibrations induced by ground transportation

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ABSTRACT

Vibrations, along with noises, caused by ground transportation could degrade residential environment. It would be useful to understand the community response to those ground-borne vibrations so as to assess and improve residential environment. Although there have been a number of studies of community response to noise worldwide, the number of previous studies of community response to vibration has been limited. In the present investigation, a questionnaire survey was conducted in residential areas along roads and railways in Saitama City, Japan. The questions in the survey included those about the perception of vibration and noise, and annoyance caused by vibration and noise. The questionnaire was distributed to each single-family house, typically two-story wooden building, in the areas, and answers to the questionnaire were returned by post. A total of 453 responses were obtained with a response rate of 27.9%. The exposure-response relationships were investigated for the community response about vibration perception and annoyance. There was no metric that had been accepted worldwide for the evaluation of the community response to vibration, and, therefore, exposure-response relationships were determined with different metrics based on the current standardized methods. The exposure-response relationships determined in the present investigation were compared with the results of a recent study in UK. Additionally, relation between vibration and noise annoyances was discussed.

INTRODUCTION

Vibrations in residential environments have been designated as one of the seven causes of “environmental pollution” by the Basic Environmental Law in Japan. Community response to environmental vibration is relevant information to understand the trend of opinions of people on vibration. Such information can be considered in the decision of a policy on environmental vibration, the establishment of criteria to control them, and so on. Although there have been a number of previous studies of community response to environmental noise worldwide, a limited number of previous studies of community response to vibration have been conducted. The criteria for the control of vibrations induced by industries, construction works and road traffic defined in the Vibration Regulation Law in Japan, were determined partly based on various scientific evidences including those of community response to vibration from limited studies. It was reported in recent years that, in most of the cases in which a complaint against vibration was raised from a resident to a local government and the vibration was measured for the assessment, the evaluation of vibration did not

exceed the limit values set by the law (Ministry of the Environment, Japan 2012). This implies that those limit values determined in 1976 when the law was enforced may not be reasonable to assess vibration in the current residential environments. Knowledge about the current community response to vibration could be informative to investigate the appropriateness of those vibration limit values.

The objective of the present investigation was to obtain information about the current community response to vibration in residential environments in Japan. A questionnaire survey and associated vibration and noise measurements were conducted in areas along roads and railways. Exposure-response relationships for community responses to vibration and noise induced by road traffic and railway were investigated. There was no metric that had been accepted worldwide for the evaluation of the community response to vibration. Therefore, exposure-response relationships were determined with different metrics based on the current different standardized methods.

QUESTIONNAIRE SURVEY

A questionnaire survey was conducted in residential areas along roads and railways in Saitama City, Japan. A total of 1794 questionnaire sheets were distributed to single-family detached houses, typically two-story wooden building, at a distance within about 100 m from the source of vibration, i.e., either road or railway. A resident who usually stayed at home for the longest time was asked to answer the questions. It was asked to return the questionnaire sheet by post within two weeks from the distribution. Table 1 shows a summary of the questionnaire survey described in this paper, including the number of responses and the response rate in each area. The survey included one more area which is not described in this paper because estimates of vibration and noise exposures, described later in this paper, were not able to be estimated reasonably.

Table 1: Summary of questionnaire survey

Source	Road traffic		Railway	
Configuration	Surface	Surface Elevated	Surface	Elevated
Size	2 Lanes	6 Lanes (S) 4 Lanes (E)	8 tracks	4 tracks
Approximate traffic volume	17000 [vehicle/day]	120000 [vehicle/day]	980 [trains/day]	600 [trains/day]
Survey period	May to July in 2011			
Measurement period	November to December in 2011			
Building type	Single-family detached house			
Number of Responses	144	61	110	61
Response rate	26.2%	27.0%	30.8%	25.0%

The questionnaire was prepared based on the recommendation given in Namba et al. (2006). The questions in the questionnaire included those about vibration and noise perceived in the house. The verbal scale used in the questionnaire was in accordance with the scale recommended by the International Commission on Biological Effects of Noise (Fields et al. 2001). The degrees of annoyance in the last 12 months caused by vibration and noise from each of five different designated

sources, including road traffic and railway, and an additional source selected by the respondent were asked in Q6 and Q8, respectively, by selecting among from “Extremely”, “Very”, “Moderately”, “Slightly” or “Not at all”. The Japanese translation of this verbal scale used in the questionnaire has been developed by Yano et al. (2002). In addition to the five-point verbal scale, the respondent was able to select “Do not perceive” or “Do not know”.

ESTIMATION OF VIBRATION AND NOISE EXPOSURE

Vibration and noise exposures at the locations of each respondent’s house were estimated by the method used by Yokoshima (2006), which was based on measurements of selected locations and an assumption on the decay of vibration and noise by distance.

Road traffic

The measurement of vibration and noise induced by road traffic was made at three locations simultaneously. One of the three locations was designated as a reference point, while the other two locations were moving points. The locations of moving points were determined based on the spatial distribution of the respondents of the questionnaires. The measurement at moving points was repeated with changing the measurement locations until it covered an area selected for a measurement set on a single day. The duration of the measurement at a set of two moving points was about 10 minutes. The measurement at a reference point located at the side of the road was continued until a measurement set on a single day was completed: its duration was longer than 4 hours within the period from 10am to 4pm. At each measurement point, vibration and noise were measured with a Vibration Level Meter, RION VM-53, and a Sound Level Meter, RION NL-32. Vibration accelerations in three orthogonal axes and A-weighted sound pressure level with the time weighting F were recorded with a data recorder, RION DA-20.

Different metrics were used to represent vibration exposure in the present study. The vibration and noise exposures at a reference point for the whole measurement duration, i.e., at least 4 hours, were calculated from the data recorded. The exposures for 24 hours were then estimated by using the data of traffic volume published by the Ministry of Land, Infrastructure, Transport and Tourism. The vibration and noise exposures at moving points were determined as follows. The vibration exposure at each moving point was first calculated from the data for 10 minutes. The vibration exposure at the reference point was also calculated for the same 10 minutes. The differences in those values between the moving and reference points were then used to estimate the vibration exposures at moving points from the vibration exposure at the reference point.

Linear regression was applied to establish a relation between logarithmic distance and vibration and noise exposures (either logarithmic quantity or level in dB) for each set of measurement. The relations obtained were then used to estimate the vibration and noise exposures at each respondent house by substituting the distance between the center of the closest traffic lane and the house into those relations.

Railway

The measurement of vibration and noise induced by railway was made along measurement lines perpendicular to the rail tracks. Each measurement line consisted of three measurement points: a reference point located at a distance of 3 m to 12.5 m from the center of the closest track and two points from distances of either 25 m, 50

m or 100m. The location of measurement line was determined based on the spatial distribution of the respondents of the questionnaire survey. The duration of the measurement with each measurement line was determined so that it covered passes of more than five trains on every track. The measurement set-up for railway was the same as that for road traffic described above, although the time-weighting S was used for railway noise.

Different metrics were used to represent vibration exposure in the present investigation. The vibration and noise exposures were calculated at each measurement point and the exposures for 24 hours were estimated based on the train time tables. The vibration exposure at each respondent house was estimated in the same manner as that used for road traffic.

ATTRIBUTE OF RESPONDENTS

Table 2 summarizes the attributes of respondents in the questionnaire survey. Similar trends were observed in the attributes of respondents for road traffic and railway: there were slightly more female respondents than male respondents, about two thirds of respondents were age 60 or older, and majority of respondents were housewife or out of work.

Table 2: Summary of questions

Item	Attribute	Road [%]	Rail [%]
Gender	Male	44.1	45.8
	Female	55.9	54.2
Age	Under 40	7.8	4.1
	40's	10.3	9.5
	50's	13.7	21.3
	60's	35.3	27.8
	70 or older	32.9	37.3

Item	Attribute	Road [%]	Rail [%]
Occupation	Self-employed	8.3	10.1
	Employee	9.3	10.7
	Housewife	28.4	30.2
	Part-time jobber	12.3	12.4
	Our of work	35.3	33.1
	Others	6.4	3.5

VIBRATION AND NOISE ANNOYANCES

Figure 1 shows the relation between vibration and noise annoyances for road traffic and railway. In the figure, the responses to Q6 for vibration and Q8 for noise are represented by using numbers as 0 for "Do not perceive", 1 for "Not at all", 2 for "Slightly", 3 for "Moderately", 4 for "Very", and 5 for "Extremely".

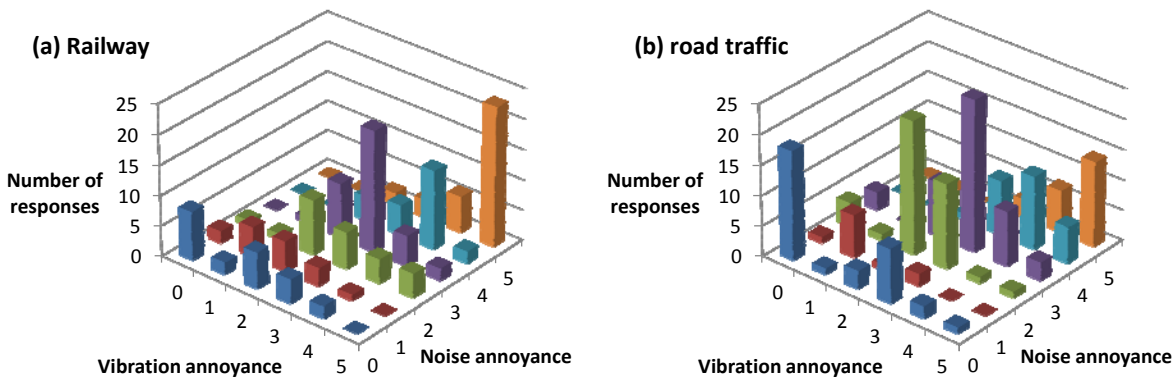


Figure 1: Vibration and noise annoyances

It can be observed in the figure that many respondents assigned the same degree of annoyance for vibration and noise. The Spearman rank-order correlation coefficient between vibration and noise annoyance responses was 0.685 for road traffic and 0.654 for railway. For railway, the number of responses for “Extremely” was relatively large for both vibration and noise, as observed in Figure 1(a).

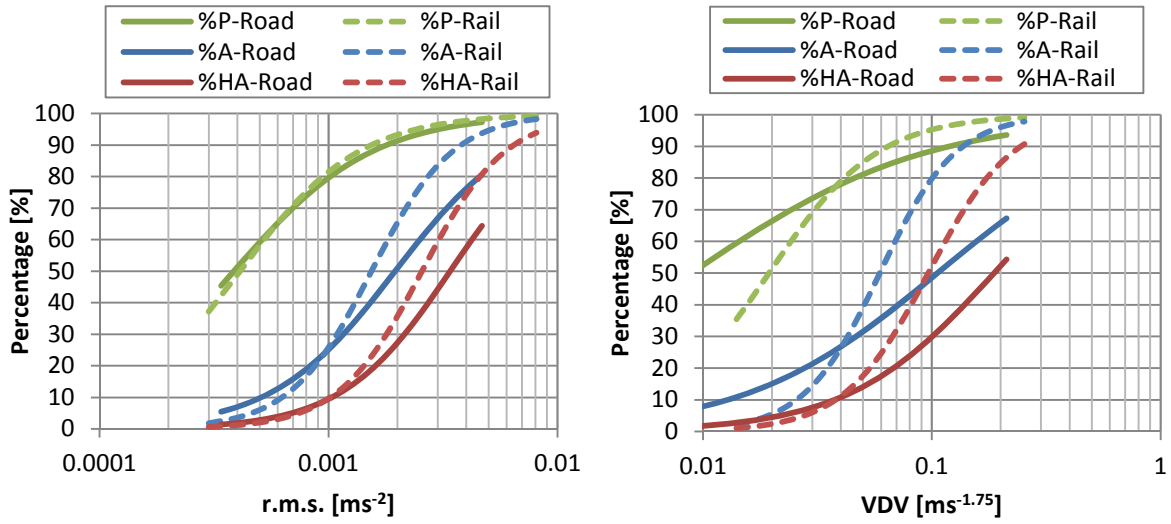
EXPOSURE-RESPONSE RELATIONSHIP FOR VIBRATION ANNOYANCE

In the discussion of exposure-response relationship for vibration in the present paper, the responses to Q6, the evaluation of the degree of vibration annoyance, were used. The percentage of the responses of “Very” and “Extremely” was regarded as “%A (%annoyed)”, and the percentage of “Extremely” was regarded as “%HA (%highly annoyed)”. Additionally, the percentage of all responses except for “Not at all”, “Do not perceive” and “Do not know” was regarded as “%P (%perceived)”. Vibration exposures were determined by using vertical vibration only, because the vertical vibration was dominant in all measurement locations in the present investigation. The logistic regression was applied to derive exposure-response relationships with exposures represented by either logarithmic quantity or level in dB.

Figure 2 shows exposure-response relationships for vibrations induced by road traffic and railway. The metrics defined in ISO 2631-1 (1997), i.e., the weighted root-mean-square (r.m.s.) acceleration and the Vibration Dose Value (VDV) are used to present the results in this paper. The results are presented in the ranges of exposures estimated for the responses obtained in the questionnaire survey. Both weighted r.m.s. acceleration and VDV took into account vibrations for 24 hours. In the r.m.s. acceleration, the squared weighted acceleration was integrated with time, compared to the fourth power of the weighted acceleration in the VDV to increase the effect of vibration events at greater magnitudes on the metric representing exposure.

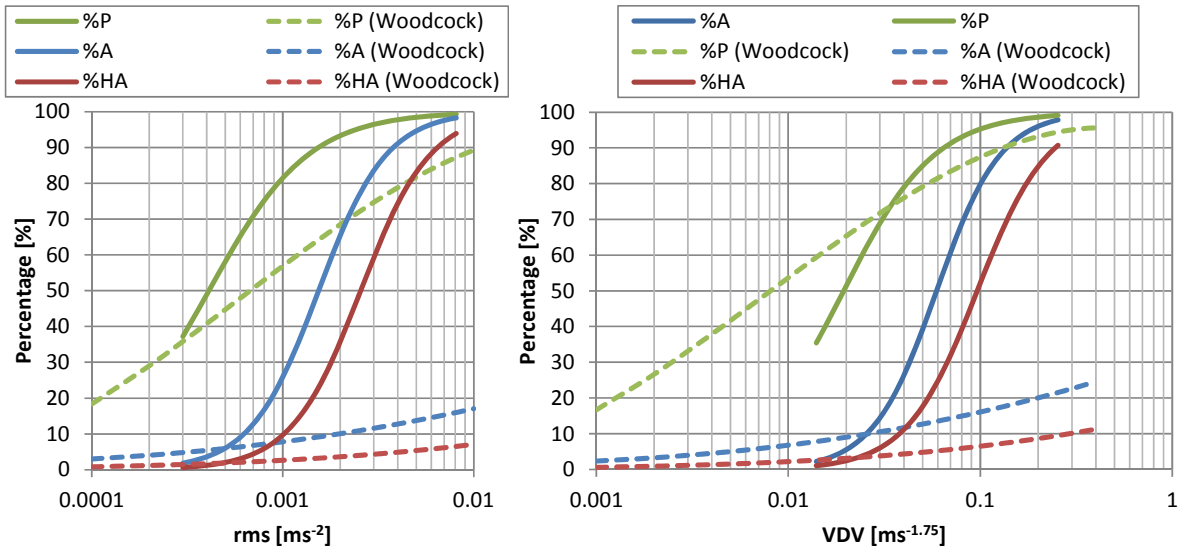
As observed in Figure 2, there were differences in exposure-response relationship between road traffic and railway, irrespective of metrics used to represent vibration exposure. The annoyance caused by railway vibration tended to increase with increases in vibration exposure more sharply, compared to the annoyance caused by road traffic vibration. This trend was more clearly observed with the VDV (Figure 2(b)), which were defined as an additional evaluation method in ISO 2631-1 (1997). The weighted r.m.s. acceleration might be regarded as a better metric to represent exposure-response relationship for both road traffic and railway vibrations in the present investigation because the differences in exposure-response relationship between road traffic and railway were less with the r.m.s. acceleration than the VDV.

Figure 3 compares the exposure-response relationships obtained for railway vibration in the present investigation with those reported in Woodcock et al. (2011) for the weighted r.m.s. acceleration and VDV. As observed in the figure, there were significant differences in the exposure-response relationships between the two studies: the degree of annoyance at a particular exposure level tended to be much higher in the present investigation. A factor affecting this difference may be that the exposures inside of buildings were estimated in Woodcock et al. (2011), whereas the exposures outside of buildings were used in the present investigation. However, additional vibration measurements made in houses of some respondents and knowledge in literature implied that possible differences in vibration exposure between inside and outside of buildings may not fully explain the differences observed in the exposure-response relationships between the two studies. Figure 4



(a) (b)

Figure 2: Exposure-response relationships for vibration. (a) weighted r.m.s. acceleration, (b) VDV.



(a) (b)

Figure 3: Comparison of exposure-response relationships for railway vibration with a previous study. (a) weighted r.m.s. acceleration, (b) VDV.

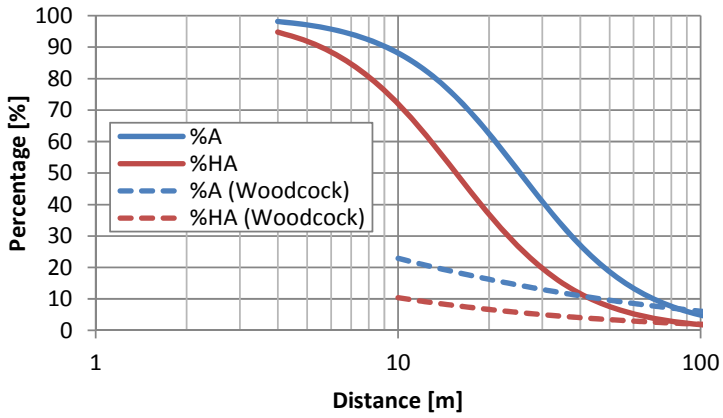
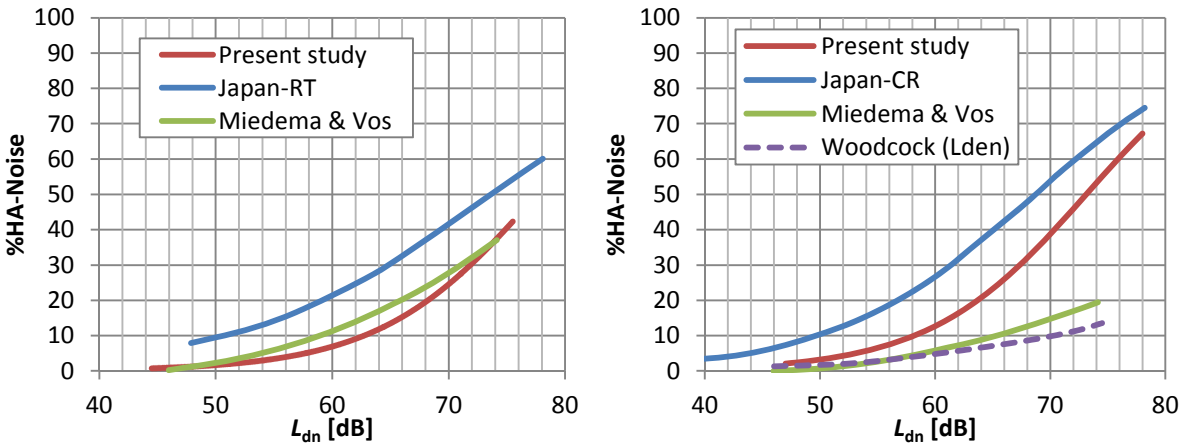


Figure 4: Distance-response relationships for railway vibration

shows the relationships between the distances from vibration source to respondents' house and the degree of annoyance in the two studies. The degree of annoyance at a particular distance appeared to be much higher in the present investigation, compared to the previous study. The results shown in this section may imply that the respondents in the present investigation tended to be more sensitive to railway vibration than those in Woodcock et al. (2011).

EXPOSURE-RESPONSE RELATIONSHIP FOR NOISE ANNOYANCE

Figure 5 compares the exposure-response relationship obtained for %HA for noise in the present study and those presented in the previous studies (Ota et al. 2013; Woodcock 2011). As shown in the figure, the exposure-response relationships for noise in the present investigation were comparable to those in the previous studies, which may imply that the results of the questionnaire survey and the estimation of exposure in the present investigation were reasonable.



(a) Road traffic (b) Railway

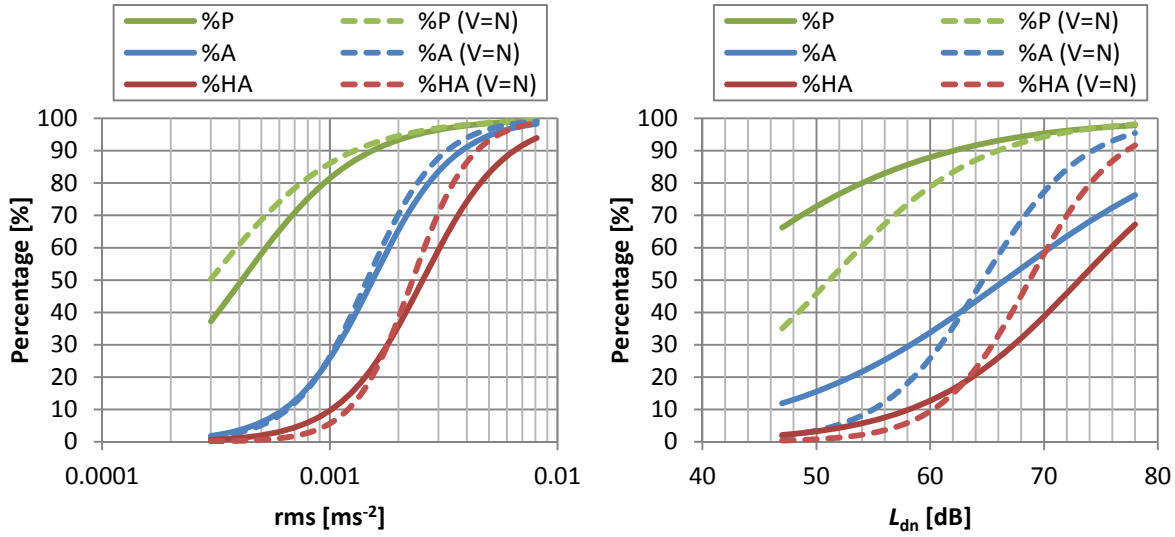
Figure 5: Exposure-response relationships for noise annoyance

POSSIBLE INTERACTION BETWEEN VIBRATION AND NOISE ANNOYANCES

Figure 6 shows the exposure-response relationships for railway vibration and noise obtained with the data of respondents with an equal category of vibration and noise annoyances, together with the exposure-response relationships with all data. As observed in the figure, the degree of annoyance tended to be higher at a particular vibration or noise exposure level when vibration and noise annoyance were at a similar degree. This may imply that there could be interaction between vibration and noise annoyances when they were at a comparable degree. This possible interaction appeared to have more effect in noise annoyance in the data shown in Figure 6: noise annoyance might have increased with a comparable annoyance from vibration.

CONCLUSIONS

The exposure-response relationships for community response to vibration induced by road traffic and railway were investigated based on the questionnaire survey and the corresponding vibration measurements. The results shown in the present paper were obtained from a limited number of responses to the questionnaire compared to more comprehensive questionnaire survey, which has been conducted for environmental noise. However, there have been a limited number of studies of exposure-response relationships for vibration in residential environments available and the results shown



(a) Vibration (b) Noise

Figure 6: Exposure-response relationships obtained from all data (solid line) and from data with equal vibration and noise annoyance only (dotted line) for railway vibration and noise

in this paper could provide relevant information about community response to vibration. Railway vibration tended to cause higher degree of annoyance than road traffic vibration at an equivalent level of exposure in the present investigation. This trend was similar to that reported for noise annoyance in Japan, although the opposite trend was reported in Europe. There were signs of interaction between vibration and noise annoyance when they were at a similar degree, in which vibration and noise annoyances appeared to enhance each other.

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