Exposure-response relationship due to ground transportation vibration in Japan

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ABSTRACT

Many socio-acoustic surveys on community response to noise have been carried out in Japan. Accumulating micro data (exposures, responses, demographic factors, etc.) derived from the surveys, a technical subcommittee established in the Institute of Noise Control Engineering/Japan has managed Socio-Acoustic Survey Data Archive, SASDA since 2011. In contrast, less surveys on community response to vibration have conducted compared to noise. Japanese government established “Vibration Regulation Law” in 1976. And then, the Director of Environmental Agency has recommended “Shinkansen railway vibration countermeasures to be urgently taken for environmental preservation” in that year. The law and recommendation were never revised since the enforcement. In recent years, most complaints against transportation vibrations are generated at sites below the regulatory standard and guideline values. Thus the government is currently in a period of reviewing the values. Examination of the values requires for dose-response relationships for each vibration source. However, the micro data necessary for determining the relationships has not managed in a unified manner for re-analysis. The authors managed micro data from eleven surveys conducted for the last twenty years in Japan and presented exposure-response relationship for each ground vibration source: road traffic, conventional railway and Shinkansen railway. Furthermore, we clarified the effect of noise on dose-response relationship of vibration.

INTRODUCTION

In Japan, vibration problems, one of “Seven Major Types of Pollution”, has affected many people. Japanese government, for the purpose of preserving living environment and contributing to protection of the people's health, established “Vibration Regulation Law” in 1976. The purpose of this law is to regulate the emission from the following sources: specified factories, specified construction work and road traffic vibrations. In addition, the Director of the Environmental Agency recommended “Shinkansen railway vibration countermeasures to be urgently taken for environmental preservation” in the same year. The law and recommendation are intended for only vertical vibration at the surface on the ground. The law establishes regulatory standards for specified factory or specified construction work vibration, and limits for road traffic vibration. Likewise, the recommendation stipulates a guideline for countermeasures. However, no regulation or standard on conventional railway vibration is covered by any statute.

Enforcement of the law and recommendation has produced significant effect reducing vibrations. However, around 40 years has passed since the enforcement; the law and recommendation have never been revised. In recent years, most of complaints against vibrations from ground transportations are generated at sites below the values of the regulatory standards, limits or guideline. This means that the values don't work as criterion for preserving living environment and protecting people's health. Therefore, discussions on the revision, including evaluation of horizontal vibrations in buildings, review of the regulatory standard and guideline values, etc. should be started.

To examine criterion value for vibration induced by ground transportation, dose-response relationship for each mode forms the basis for the discussion. For noise, many socio-acoustic surveys on community response to noise have been carried out in Japan. Accumulating micro data (exposures, responses, demographic factors, etc.) derived from the surveys, a sub-technical committee at the Institute of Noise Control Engineering/Japan has managed Socio-Acoustic Survey Data Archive, SASDA since 2011 (Yokoshima et al. 2011). Using the SASDA, the committee released dose-response relationships for transportation noises in Japan (Yokoshima et al. 2012; Ota et al. 2013). However, micro data regarding vibration exposures and responses have not been managed in a unified manner for re-analysis. Thus the accumulation and management is the first step toward preparing the revision.

Datasets derived from 11 surveys which the authors conducted for the last 20 years were reviewed. Based on the micro data, we presented exposure-response relationship due to each of ground transportation vibrations: road traffic, conventional railway and Shinkansen railway (high speed railway) vibrations. Furthermore, we examined the effect of noise on dose-response relationship of vibration.

SURVEYS

Table 1 indicates the outline of the datasets. In the ID column, prefixes of RT, CR and SR denote respective sources of road traffic, conventional railway and Shinkansen railway. 13 datasets are derived from 11 surveys. The surveys were conducted in residential sites along the ground transportation.

RT96, CR02 and SR03 are derived from the surveys carried out by Kumamoto University (Yano et al. 2006). RT11 and CR11 are derived from the survey conducted by Saitama University (Yokoshima et al. 2013). SR05 is derived from the survey conducted through collaboration between industry, educational institutions and the administration (Yokoshima et al 2011). Other datasets are derived from surveys jointly conducted by Yokohama National University and Kanagawa Environmental Research Center. RT98, CR97 and SR95 are originated from the surveys for comparing community response to noise and vibration among the sources in Kanagawa Prefecture (Yokoshima & Tamura 2003). RT04 and CR04 were originated from the survey, covering mixed exposure to noise and vibration induced-by road traffic and conventional railway (Ota et al. 2006). SR01 is derived from the survey to clarify combined annoyance due to noise and vibration (Yokoshima & Tamura 2006).

Please note that "Question wording of annoyance" is somewhat different from original one printed in the questionnaire. For the scale, although there is no consistent rule for annoyance descriptor, most of recent surveys use the modifier similar to the ICBEN verbal scale. Regarding survey methods, SR-05 used interview method; others use self-administered questionnaire. This paper focuses on micro data not with apartment buildings but with detached houses.

Noise and Vibration Exposures

Measurement of noise and ground vibration, in principle, was carried out on a site-by-site basis for each survey after the survey had been completed; for SR-05, conversely, the city government carried out the measurement prior to the survey.

Vertical vibration level on the surface of the ground was measured. Measuring points were allocated according to the distance from each source. As the measuring unit of vibration, Japanese Industrial Standard (JIS) Z 8735, "Methods of Measurement for Vibration Level," defines "vibration level", different from the indices given in ISO2631-1. Vibration level is defined as twenty times the logarithm to the base 10 of the ratio of the root-mean-square vibration acceleration, to the reference (10^{-5} m/s^2). This paper regards a maximum-based index of vibration level (L_{vmax}) as vibration exposure. The method of calculation for L_{vmax} with each dataset is indicated in the Table 1. Similarly for vibration level, sound pressure level was measured at the same points as vibration measuring. For road traffic noise, based on equivalent sound pressure level measured for a short time (from 10 minutes to around 4 hours), 24 hour value (L_{Aeq}) was estimated. For railway noises, both conventional and Shinkansen railways, equivalent sound pressure level was calculated from sound exposure during a train passing and the number of trains in operation. On the basis of measurements, all the surveys estimated L_{vmax} and L_{Aeq} for each respondent, using logarithmic distance attenuation formula; values were rounded off to decimal place.

Here, we present the relationship of L_{vmax} and *MTVV* [m/s^2] per mode of ground transportation for reference (Yokoshima et al. 2013). Based on the measurements of L_{vmax} and *MTVV* in Saitama City, where a survey deriving the datasets of RT11 and CR11 was conducted, approximate expressions on road traffic and conventional vibrations are as below. For Shinkansen railway vibration, a previous study indicated the following approximate expression (Yokoshima et al. 2013).

Road traffic vibration: $10\log_{10}(MTVV/10^{-5})^2 = L_{vmax} + 2.7$

Conventional railway vibration: $10\log_{10}(MTVV/10^{-5})^2 = L_{vmax} + 3.3$

Shinkansen railway vibration: $10\log_{10}(MTVV/10^{-5})^2 = L_{vmax} + 2.5$

Results

This paper analyzes micro data with L_{vmax} from 36 dB to 65 dB. The sample size amounts to be 4,143.

Using 13 datasets, Figures 1 to 3 indicate relationships between exposure and annoyance, associated with vibration induced-by ground transportation. L_{vmax}, vibration exposure, is divided into the interval of 5 dB. Annoyance is measured by %HA, percent highly annoyed person. This index is defined as the percentage of "highly annoyed person": the respondent answering in the top category of annoyance scale in each L_{vmax} interval. Figure 1, for road traffic (RT), indicates that RT99 has the highest %HA, because bipolar scale of "satisfied" and "dissatisfied" are used as a base descriptor for annoyance. In addition, "dissatisfied" with no modifier may be a contributor to high response. Although RT04 indicates slightly higher annoyance, there is no significant difference among the other datasets. For conventional railway (CR), %HA of CR11 rises rapidly at the ranges of 51-55 dB and over; others indicate similar dose response relationship. For Shinkansen railway (SR), SR03 has the steepest slope, followed by SR01. In common with each mode of transportation, response with "can't bear at all" has relatively low response.

Table 1 indicates outline of datasets used for this analysis.

ID (Survey year)	Site location	Question wordings of annoyance	Verbal scale of annoyance	Calculation for L_{vmax}
RT96 (1996)	Kumamoto city	There are many annoying factors due to road traffic noise and vibrations in living environments. Have you ever disturbed by house vibration from motor vehicles?	1. not disturbed 2. somewhat disturbed 3. significantly disturbed 4. extremely	Mean value of maximum vibration levels for 10 minutes (measuring time: continuous 100 minutes)
RT98 (1998)	Kanagawa Prefecture	Can you put up with vibrations from motor vehicles, or can't you bear?	1. I don't disturb it. 2. I can put up with it. 3. If anything, I can put up with it 4. If anything, I can't put up with it 5. I can't bear it at all	Mean value of maximum vibration levels for 10 minutes (Number of measuring times: 4 or more)
RT99 (1999-2000)	Kanagawa Prefecture	We will ask you questions about the community or residence where you live. Are you satisfied or dissatisfied with vibrations from motor vehicles?	1. satisfied 2. somewhat satisfied 3. cannot say either way 4. somewhat dissatisfied 5. dissatisfied	Mean value of maximum vibration levels for 10 minutes (measuring time: 1 hour or more)
RT04 (2004-2006)	Kanagawa Prefecture	When you are here at home, are you bothered or not bothered by vibrations from motor vehicles?	1. not bothered at all 2. slightly bothered 3. moderately bothered 4. very bothered 5. extremely bothered	Mean value of maximum vibration levels for 10 minutes (measuring time: 1 hour or more)
RT11 (2011)	Saitama City	Thinking about 1 year or so, when you are here at home, how much are you bothered or annoyed by vibrations from motor vehicles ?	1. not at all 2. slightly 3. moderately 4. very 5. extremely	Energy mean value of top 10 among peak vibration levels (Measuring time: continuous 4 hours)
CR97 (1997)	Kanagawa Prefecture	Can you put up with vibrations from motor vehicles, or can't you bear?	1. I don't disturb it. 2. I can put up with it. 3. If anything, I can put up with it 4. If anything, I can't put up with it 5. I can't bear it at all	Energy mean value of top half among maximum vibration levels during trains passing
CR02 (2002)	Fukuoka Prefecture	There are many annoying factors due to the passage of trains. How much are you disturbed by house vibrations from trains?	1. not at all 2. slightly 3. moderately 4. very 5. extremely	Mean value of top 10 among 20 maximum vibration levels during passing trains
CR04 (2004-2006)	Kanagawa Prefecture	When you are here at home, are you bothered or not bothered by vibrations from trains?	1. not bothered at all 2. slightly bothered 3. moderately bothered 4. very bothered 5. extremely bothered	Energy mean value of top half among maximum vibration levels during trains passing
CR11 (2011)	Saitama City	Thinking about 1 year or so, when you are here at home, how much are you bothered or annoyed by vibrations from passing trains?	1. not at all 2. slightly 3. moderately 4. very 5. extremely	Energy mean value of top half among maximum vibration levels during trains passing on the closet lines
SR95 (1995-1996)	Kanagawa Prefecture	When you are here at home, how do you feel the vibration from Shinkansen bullet train affects you?	1. I don't disturb it. 2. I can put up with it. 3. if anything, I can put up with it 4. if anything, I can't put up with it 5. I can't bear it at all	Mean value of top half among maximum vibration levels during trains passing
SR01 (2001-2003)	Kanagawa Prefecture	When you are here at home, are you bothered or not bothered by vibrations due to from Shinkansen bullet trains?	1. not bothered at all 2. slightly bothered 3. moderately bothered 4. very bothered 5. extremely bothered	Mean value of top half among maximum vibration levels during trains passing
SR03 (2003)	Fukuoka Prefecture	There are many annoying factors due to the passage of Shinkansen bullet train in living environments. How much are you disturbed by house vibrations from Shinkansen trains?	1. not at all 2. slightly 3. moderately 4. very 5. extremely	Energy mean value of top half among maximum vibration levels during trains passing
SR05 (2005)	Nagoya City	How do you feel vibrations except for earthquake when you are here at home	1. not disturbed at all 2. slightly disturbed 3. moderately disturbed 4. very disturbed 5. extremely disturbed	Mean value of top 10 among 20 maximum vibration levels during passing trains

Figure 4 compares relationship between exposure and annoyance associated with vibration per mode of ground transportation. It is not observed to be significant difference among the modes. Then, Figure 5 indicates %HA as the nominal logistic regression model of L_{vmax} for each mode. Since it in not clear that the rise in %HA of RT99 is associated with the increase in L_{vmax}, we work out the relationship of annoyance to exposure for road traffic vibration without RT99 (n = 3,507). Generally speaking, the threshold of whole body vibrations is estimated to be around 55 dB. At vibration exposure under 55 dB, annoyance due to vibrations induced-by road traffic and Shinkansen railway is higher than that induced-by conventional railway; in contrast, at higher ranges over 60 dB, conventional railway indicates the highest annoyance.

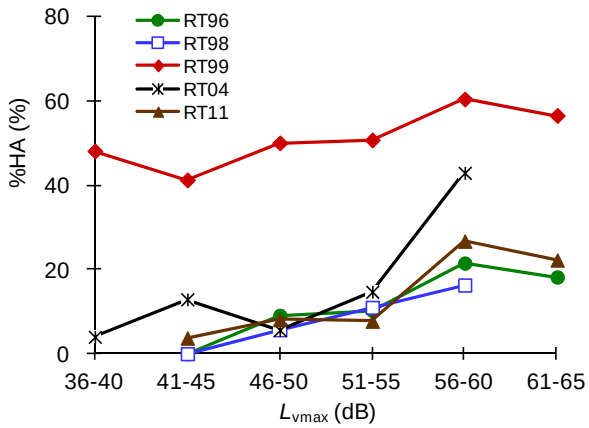

Figure 1: Relationship betweenexposure and annoyance for road traffic vibration.

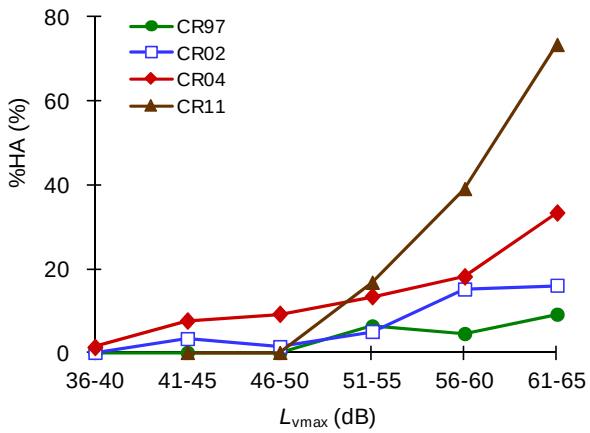

Figure 2: Relationship between exposure and annoyance for conventional railway vibration.

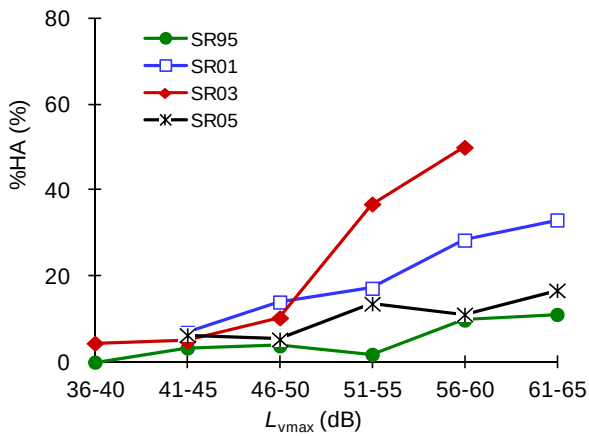

Figure 3: Relationship between exposure and annoyance for Shinkansen railway vibration.

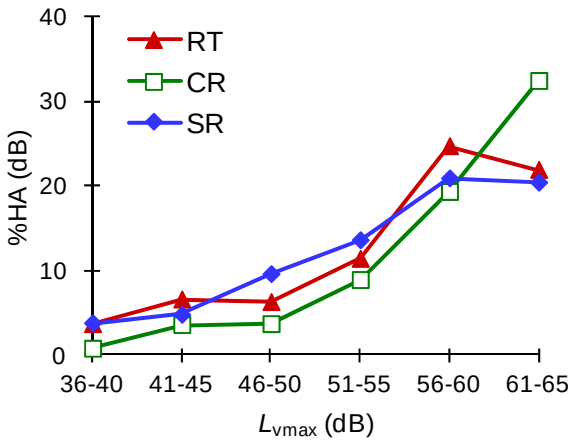

Figure 4: Relationship between expsure and annoyance for each vibration source.

Effect of noise on annoyance due to vibration

Then we focus on examining the effect of noise on exposure-annoyance relationship due to vibration. Figures 6 to 8 indicate %HA as the logistic regression model of L_{vmax} per mode of transportation according to low and high sound pressure levels. The division of lower and higher sound pressure levels is carried based on the following procedure. First, we determine linear regression model, L_{Aeq} and L_{vmax} as objective and explanatory variables respectively according to the mode. Comparing the exposure with estimate by the linear regression model for L_{Aeq}, we divide

respondents into low and high sound pressure level groups. Respondents with the exposure being lower than the estimate are categorized into the low group.

For road traffic vibration, the %HA with high_spl in relation to L_{vmax} is higher than that with low-spl at the 1% level. For example, the difference in %HA is around 5% at L_{vmax} of 55 dB: the difference is around 7% at 60dB. Likewise, for railway vibrations, the %HA with high-spl is significantly higher at the 1% level than that with low-spl. At L_{vmax} of 60 dB, the differences in %HA are 10% and 5% for conventional and Shinkansen railway vibration, respectively. At the same %HA, for both 15% and 20%, the difference in L_{vmax} between high and low sound pressure levels is around 7 dB regardless of vibration sources.

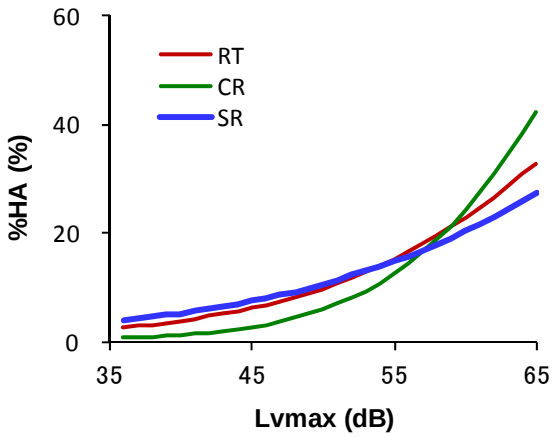

Figure 5: %HA as the logistic regression model of L_{vmax} for each mode of ground transportation.

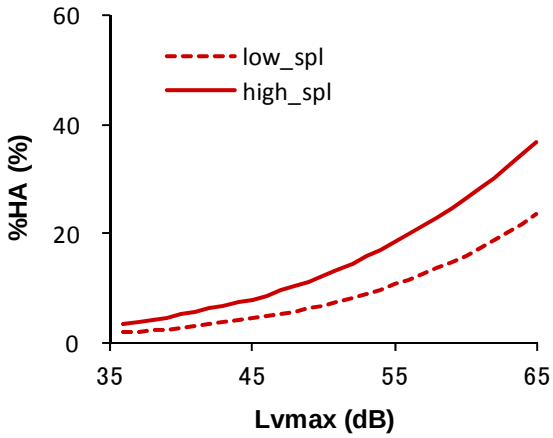

Figure 6: %HA as the logistic regression model of L_{vmax} for road.

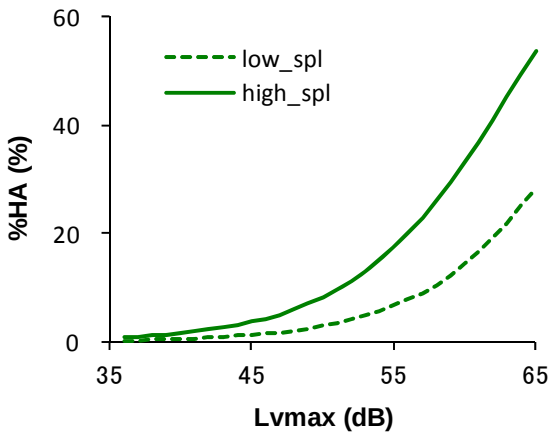

Figure 7: %HA as the logistic regression model of L_{vmax} for conventinal railway.

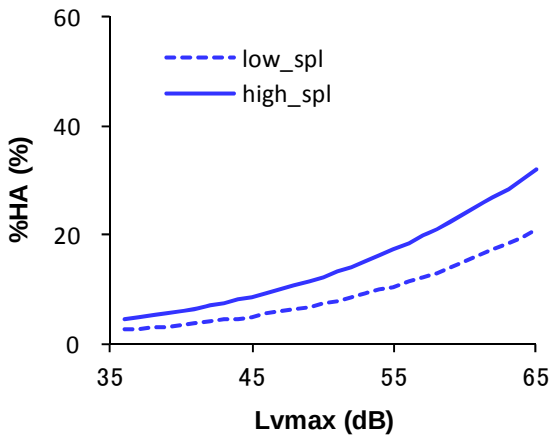

Figure 8: %HA as the logistic regression model of L_{vmax} for Shinkansen railway.

Discussion

Using 13 datasets, derived from 11 surveys associated with ground transportation, we examined the relationship between maximum-based exposure and annoyance due to vibration. At high vibration exposures, %HA of conventional railway is slightly higher than that with other modes: road traffic and Shinkansen railway. Thus, the order of %HA due to vibration among the modes of ground transportation differs from that due to noise: annoyance due to noise from Shinkansen railway is highest, followed by conventional railway, road traffic (Yokoshima et al. 2012).

Here we'd like to move to the discussion about the difference in the annoyance. There is significant difference in annoyance by high and low sound pressure levels as shown in Figures 6 to 8. Therefore we focus on the comparison of L_{Aeq} value at the same L_{vmax} range. At L_{vmax} range under 50dB, L_{Aeq} values of road traffic, conventional railway and Shinkansen railway are 56 dB, 46 dB and 42 dB, respectively. At L_{vmax} range over 50 dB, road traffic and conventional railway indicated the same L_{Aeq} value, around 62 dB: 10 dB higher than Shinkansen railway. This means effect of noise from road traffic and conventional railway can bring about higher vibration annoyance than that for Shinkansen railway. In addition, by examining the relationship between L_{vmax} and response to rattling due to vibration, it is found that more inhabitants along both conventional and Shinkansen railway, perceived rattling than those along an arterial road. It is likely that the effect of rattling induced-by conventional railway provokes higher vibration annoyance than road.

Conclusion

We made re-analysis on micro data from 11 surveys conducted in residential areas along the traffic facility, road, conventional and Shinkansen railways, for the last 20 years. Based on the micro data, we presented relationship between exposure and annoyance due to vibration induced by each traffic facility on the ground. Furthermore, we clarified the effect of noise on exposure-annoyance relationship of vibration. For the future, we'd like to investigate the effect of noise on annoyance due to vibration in more detail.

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