PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Community response to high-speed railway noise in Tianjin, China

Lan ZHANG[1]; Hui MA[1]

[1] Tianjin University, China

ABSTRACT

Adverse effects of noise from high-speed railway have become more and more serious and widespread with the rapid development of high-speed rail in China. A social survey on community response to high-speed railway noise was carried out in Tianjin, China from March to July, 2018 along the Beijing-Tianjin intercity high-speed rail line and Beijing-Shanghai high-speed rail line. 674 residents were interviewed by questionnaires to explore their noise annoyance, activity interference caused by high-speed railway noise, sensitivity to noise, and satisfaction with living environment. The exposure of high-speed railway noise was measured for 24h at each site, and standardized questions and scales suggested by ICBEN Team 6 were used in the social survey. As a result, the dose-response relationship curve for high-speed railway noise of Chinese residents was established, and it showed that with the increasing of noise level ($\boldsymbol{L}_{\mathrm{dn}}$), annoyance increased exponentially. Compared with Japanese and French people, Chinese residents showed more annoyed to high-speed railway noise. It also suggested background noise had important impact on noise annoyance evaluation to high-speed railway. Furthermore, annoyance caused by high-speed railway noise was also greatly influenced by subjective characteristics such as noise sensitivity, satisfaction of living environment and attitudes towards high-speed rail.

Keywords: Community response, High-speed rail noise, Annoyance

1. INTRODUCTION

Since the opening of the Tokaido Shinkansen Line in 1964, rapid transit railway networks had been constructed in European countries such as France, Spain, and Germany and in Asian countries such as China and Korea. The high-speed rail emitted much noise because of its high speed (1). Noise problems caused by high-speed rail had grown from a local to a global issue.

The research on conventional railway noise was relatively mature (2-5), but the research on high-speed railway noise was still in its infancy (6-8). Japanese scholars conducted a series of social surveys on impact of Shinkansen noise. Sato T (9) carried out a social survey on community responses to Shinkansen noise in Kyushu. The result indicated that people living along the Shinkansen were more annoyed by the same amount of noise than those living along the ordinary railways. Yokoshima S et al. (10) compared the exposure-response relationships for transportation noise using datasets accumulated in Japan and showed that Shinkansen railway noise was equally as annoying as commercial aircraft noise and more annoying than conventional railway and road traffic noise. The research on community response to high-speed railway noise was mainly concentrated in developed countries such as Japan and France(11). In the research comparing community response to road traffic noise between Japan and Sweden, Sato T et al. (12) found the difference in lifestyles might result in the different response. Hence, a question arose as to whether the findings of previous studies, which were obtained mainly for developed countries, were applicable to the rest of the word, especially developing countries. China, as a populous country, had the highest amount of high-speed rail construction. The involvement of China would contribute to the knowledge of the situation of developing countries in terms of environmental noise in the word.

Even in a country with the same cultural background, the percentage of highly annoyed residents was found to vary greatly among different regions. In the research on community response to road traffic noise in Vietnam, Phan HYT(13) found inhabitants lived in residential areas with relatively narrow roads and high levels of traffic density would initiate higher annoyance. Gjestland T (14)

[1] zhanglan@tju.edu.cn
[1] muhui@tju.edu.cn

conducted a second analysis of data from previous community response social survey. He found that residents in detached house were more annoyed to Shinkansen noise than residents in apartments. However, different settlements in China had their own characteristics. It remained to be explored what features of sites in Tianjin of China would cause differences in annoyance.

In previous studies, noise annoyance was not only affected by acoustic factors, but non-acoustic factors also played an important role. In the investigation of community response to aircraft noise in Vietnam (15), it found that the frequency of use of airplanes and time to go to bed seemed to affect annoyance. To assess the factors on road traffic annoyance in Vietnam, Nguyen T (16) developed five structural equation models for five cities. The result showed that sensitivity would become greater modifier of road traffic noise annoyance if residents didn't satisfy with their living area. Different non-acoustics factors might be involved in different noise sources. The impact of non-acoustic factors on high-speed railway noise needed further research.

This paper conducted a social survey on the response of Chinese residents to high-speed railway noise. The objectives of this study were to propose a representative dose-response relationship curve for high-speed rail noise in China and to assess how acoustic and non-acoustic factors moderated response differences among different sites.

2. METHOD

2.1 Survey Sites

A social survey on community response to high-speed railway noise was carried out in Tianjin, China from March to July, 2018 along the Beijing-Tianjin intercity high-speed rail line (BTL) and Beijing-Shanghai high-speed rail line (BSL). The two lines represented the form of short-distance and long-distance lines in China, respectively. The BTL is the first intercity high-speed railway in mainland of China with a line length of 120 kilometers which opened in 2008. The BSL from Beijing to Shanghai with a total length of 1318 kilometers went into service in 2011. The total number of trains per day running on BTL was 200-230, and there were 229-239 trains a day on BSL (see Figure 1).

In our investigation, the sites with only high-speed trains passing though were selected in order to eliminate the interference of conventional railway noise. The high-speed trains passed through both rural and urban areas in China. Therefore, four rural residential areas and three urban residential areas along BSL, as well as three rural residential areas and three urban residential areas along BTL were selected in this survey. According to the type of settlements and railway lines, investigation sites were divided into four sub-areas: four rural residential areas along BSL in sub-area 1, three urban residential areas along BSL in sub-area 2, three urban residential areas along BTL in sub-area 3 and three rural residential areas along BTL in sub-area 4, as shown in Figure 2.

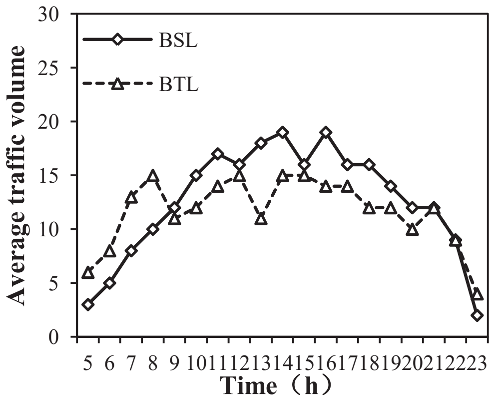

Figure 1 – Average traffic volume in BSL and BTL

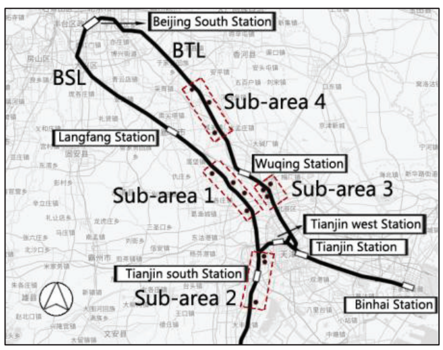

Figure 2 – Map of survey sites in Tianjin.

2.2 Questionnaire Design

The questionnaire was labeled as "Survey on living environment". It was not only on noise but also on various components of living environment. There were 33 questions in five aspects: annoyance, activities disturbance caused by high-speed railway noises, living environment evaluations, housing factors and demographic variables, as summarized in Table 1.General annoyance and activity interferences were measured with an 11-point numeric scale constructed by ICBEN Team 6 (17) ,with end points of 10= “extremely annoyed” and 0= “not at all annoyed”. Other items such as self-reported noise sensitivity to noise source were gauged using five-point verbal scale.

Table 1 – Questionnaire item of surveys

Residential environment	Quiet, comfort, preference
Housing factors and details of the house	Quality of residential environment (soundproof, ventilation, sunshine, insulation, area of house), Housing type, the number of glass layers, frame type of windows, direction of facing or not facing railways
Annoyance	Annoyance due to high-speed railway noise, Annoyance due to vibration caused by high-speed railway, the influence time
Interference on daily activities	Sleeping disturbance, listening to TV or radio, talking, disturbance in outdoor or balcony, reading or working, opening windows, emotion or mood
Sensitivities, attitudes, etc	Noise sensitivity, attitudes to the transportation (using frequency, comments on safety, support for its construction)
Life style	The time of getting up and going to sleep, length of period to stay at home, the frequency of opening widows in summer
Socio-demographic variables	Occupation, age, gender, education, the number of family, income, health states(whether heart disease and headache occur）

2.3 Social Surveys

Since the most high-speed railway lines passing though residential areas were in the form of viaducts and most of the residential buildings were perpendicular to the railway lines, the high-speed railway noise spread far. Thus, questionnaires were delivered to people living in houses within 500 meters of the railway, as an investigation rule. Respondents were interviewed face to face on a one-person-per-family basis. Totally, 674 responses were obtained and the response rate was 85% shown in Table 2. The socio-demographic factors of this survey were presented in Table 3. Employed respondents constituted 45% in the surveys. 65.9% respondents were in the age from 20 to 60. The proportions of these demographic characteristics were balanced, except that the ratio of females was a higher than that of males. Because housewives who spent the longest time at home in settlements accounted for a large proportion of respondents.

Table 2 – Outlines of social surveys

	Sub-areas 1	Sub-areas 2	Sub-areas 3	Sub-areas 4	Total
Type of rail [a]	BSL	BSL	BTL	BTL	
Residential type	Rural areas	Urban areas	Urban areas	Rural areas	
Type of house [b]	DH	AH	AH	DH	
Survey sites	4	3	3	3	
Sample	190	265	120	210	785
Respondents	164	252	99	159	674
Response rate	86%	95%	82.5%	75%	85%

[a] Beijing-Tianjin intercity high-speed rail line (BTL) ;Beijing-Shanghai high-speed rail line (BSL);

[b] Detached house(DH); Apartment house(AH);

Table 3 – Demographic factors of the survey.

Items	Category	Proportion
Gender	Male	37.5%
	Female	62.5%
Age	Under 20s	3.9%
	20-39s	31.8%
	40-59s	34.1%
	Older than 60s	29.6%
Occupation	Employed	45%
	Students, housewives, retired, and unemployed	55%

2.4 Noise Measurements

After the social survey, noise measurements were made. The specific measurement method was as follows. At reference points close to the railway, noise levels were measured with an integrating sound level meter for 24 hours. $L_{Aeq.24h}$ and L_{dn} were both calculated from these noise measurement data. Then the distance reduction measurements were conducted at each site. The noise levels of at least three pass-by trains were measured at points 0, 10, 20, 40, 80 and 160m from the reference points simultaneously. L_{AE} values were calculated from noise level data recorded every 20 ms within 10 dB from the maximum noise levels of noise events. Equations for estimating the distance reductions of L_{AE} were formulated. The noise exposure to each house was calculated using $L_{Aeq.24h}$ and L_{dn} at the reference point and the distance reduction equations.

3. RESULTS AND DISCUSSION

3.1 Dose-response Relationships

Dose-response relationships were established with the indicators of L_{dn} and $L_{Aeq.24h}$, commonly used in noise evaluation. And the percentage of highly annoyed respondents was taken from the top three points of the 11-point numeric scale. Figure 3 showed that with the increase of L_{dn}, the proportion of residents with high annoyance increased exponentially. And an approximate linear relationship was found between $L_{Aeq.24h}$ and annoyance.

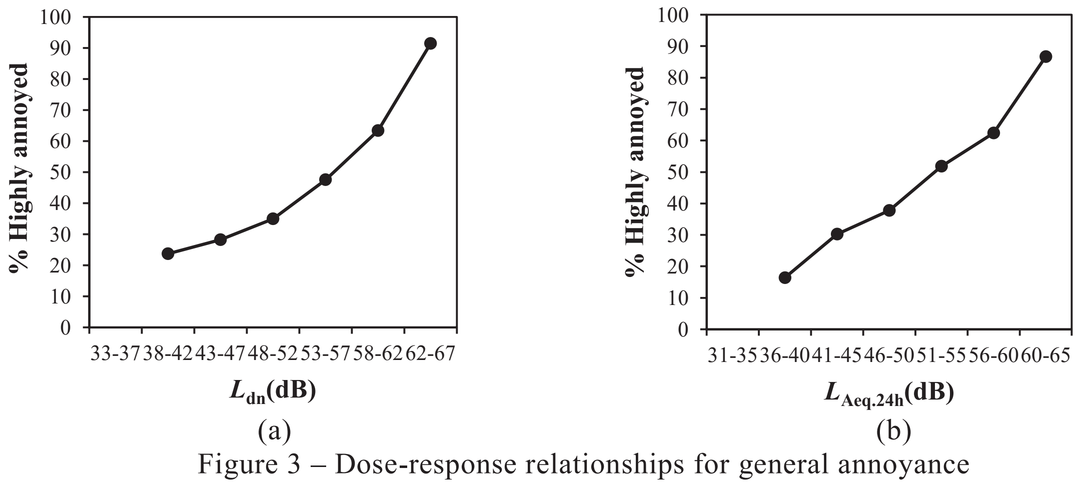

Figure 3 – Dose-response relationships for general annoyance

Figure 4 showed the comparison of dose-response curves among China, Japan and France. The individual datasets of Japan analyzed in this paper were derived from five social surveys: Kanagawa (KNG01), Fukuoka (FKO), Nagoya (NGY), Kumamoto (KMM), and Nagano surveys (NGN) (10). The dataset of France came from a social survey on annoyance from TGV traffic noise in 1996(11). The result indicated that respondents in China were more annoyed by high-speed rail noise than those in

Japan and France at the same noise level. Such differences might be attributed to the differences in acoustic characteristics of high-speed railway noise among countries. The maximum operating speeds of high-speed trains in China, Japan and France were 350km/h, 200-250km/h and 300km/h respectively, resulting in a different perception of suddenness of noise.

This hypothesis could be supported by a previous laboratory study on exploration of high-speed rail noise indicators (18). It suggested that "shock-effects" caused by the sudden increasing of noise level of the aerodynamic noise might lead to higher degree of noise annoyance. The noise of high-speed train caused much more annoyance than that of conventional train at the same L_{Aeq}, partially was a result of the "shock-effects" value. According to this explanation, it could be inferred why the annoyance of high-speed rail noise in China was higher than those of Japan and France might be the different "shock-effects" caused by high-speed trains with different maximum speeds.

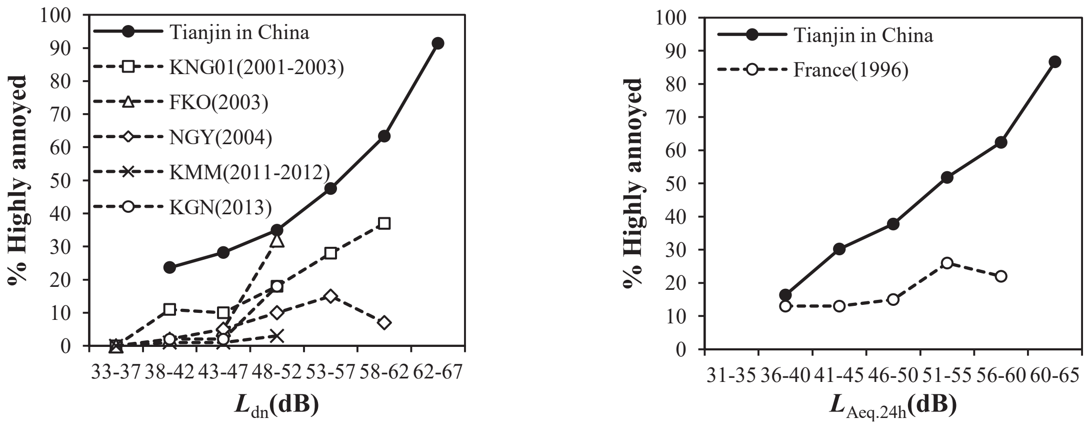

Figure 4 – Comparison of dose-response relationships between China and Japan or France

3.2 Differences in Response among Sites

L_{dn} and L_{Aeq} were highly correlated variables, thus, the differences in annoyance among different sites obtained by using these two variables as indicators were similar. Since the correlation between L_{dn} and annoyance score was slightly higher than L_{Aeq}, L_{dn} was used in the next analysis. Residential type and railway line were the main different factors in these sites. The dose-response relationship curves in each sub-area were plotted, shown in Figure 5. Because the residents in sub-area 3 were also affected by military aircraft noise, the result in this area was excluded in next analysis in order to avoid the bias on the response to high-speed rail noise. Table 4 compared the percentage of highly annoyed respondents between sub-areas at each range of L_{dn} by Chi-square test. It showed that there was no difference between sub-area 1 and sub-area 4 at the range of 48-62dBA. And there was significant difference in annoyance between sub-area 1 and sub-area 2 at each range of L_{dn}. The result suggested that respondents in rural areas were more annoyed by high-speed railway noise than those in urban areas at the same noise levels.

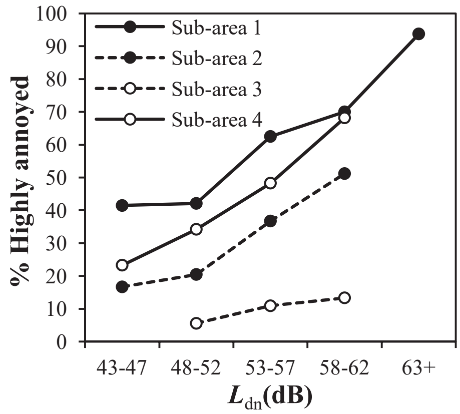

Figure 5 – Comparison of dose-response relationships among sub-areas in Tianjin, China (sub-area 1: rural areas along BSL; sub-area 2: urban areas along BSL; sub-area 3: urban areas along BTL; sub-area 4: rural areas along BTL)

Table 4 – Chi-square test of the percentage of highly annoyed respondents between urban-rural areas and between BTL-BSL at each range of $\boldsymbol{L}_{dn}$.

Type 1	Type 2	43-47	48-52	53-57	58-62
Sub-area 1 (rural areas)	Sub-area 2 (urban areas)	0.042	0.013	0.002	0.033
Sub-area 1 (BSL)	Sub-area 4 (BTL)	0.039	0.292	0.127	0.877

On average, the background noise levels in urban areas were approximately 5dB higher than those in rural areas. The background noise level defined as the 95th percentile level ($\boldsymbol{L}_{95}$) in this study. Multiple regression analysis were conducted to examine the effect of background noise level($\boldsymbol{L}_{95}$).The results indicated that there was a significant effect of background noise level($p < 0.01$) on annoyance. When the difference value between $\boldsymbol{L}_{dn}$ and $\boldsymbol{L}_{95}$ was used as an indicator of exposure, the percentage of highly annoyed respondents was raised with the increase of this indicator value, and the difference of community response between rural and urban residents didn't exist at the range of 10-20, as seen in Figure 6 and Table 5. It could be speculated that noise of high-speed railway events might be generally more noticeable in rural areas because of the lower noise level in those areas. This finding was consistent with the result of another study on community response to aircraft noise in Vietnam(15),which also proved that the areas affected by a single aircraft noise with a lower background noise level yielded more annoyance.

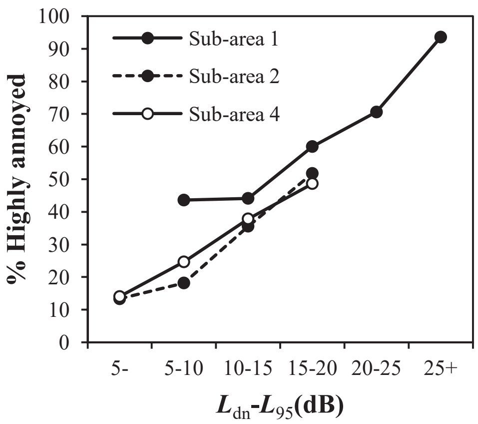

Figure 6 – Comparison of dose-response relationships among sub-areas at each range of $\boldsymbol{L}_{dn}$-$\boldsymbol{L}_{95}$ in Tianjin, China

Table 5 – Chi-square test of the percentage of highly annoyed respondents between urban-rural areas and between BTL-BSL at each range of $\boldsymbol{L}_{dn}$-$\boldsymbol{L}_{95}$

Type 1	Type 2	5-10	10-15	15-20
Sub-area 1 (rural areas)	Sub-area 2 (urban areas)	0.012	0.211	0.353
Sub-area 1 (BSL)	Sub-area 4 (BTL)	0.039	0.404	0.116

It remained significant difference between rural and urban areas at range of 5-10 for the $\boldsymbol{L}_{dn}$-$\boldsymbol{L}_{95}$ value. It seemed that background noise didn't work when high-speed rail noise events were not prominent. In this case, such difference might be result from the difference in the type of house. Residential buildings in rural areas were dominated by detached house with single-story windows, while residential buildings in urban areas were mainly apartments with double glazed windows. Compared to rural residents, urban residents had more opportunities to choose a quiet environment when closing the windows at home.

3.3 Non-acoustic Factors Affecting Response

In order to find out the factor that affected annoyance of high-speed railway noise, a logistic regression model was fitted with high annoyance as the dependent variable and various factors displayed in Table 6 as independent variables. The result showed that non-acoustic factor contained noise sensitivity, health state (whether suffering from heart disease), house satisfaction, satisfaction of living environment and attitudes towards high-speed rails. As the levels of the first two factors increased, the proportion of residents with high annoyance would raise. It indicated that residents who were sensitive to noise or suffered from heart diseases were more susceptible to high-speed rail noise. And noise sensitive had the greatest effect on annoyance cause by high-speed rail noise among non-acoustic factors. Furthermore, with increasing of the last three factors, the percentage of highly annoyed respondents would reduce. The annoyance caused by high-speed rail noise would be decreased by improving the satisfaction of living environment and house. And residents who considered high-speed railway more safety had relatively lower annoyance of high-speed rail noise. These factors were somewhat consistent with previous research on community response to road traffic noise in Vietnam (16). However, the result was different from the research on community response to Shinkansen noise (19), a second analysis of data from social surveys in Kanagawa and Fukuoka. It found that only gender provided a significant effect on noise annoyance among demographic factors and the responses to living environments had no significant effects on the annoyance reaction.

It should be emphasized was that there might be an interaction between palpitations and annoyance. Not only residents with heart diseases were more annoyed by high-speed rail noise, but high-speed rail noise could also cause heart palpitations to some extent though this conclusion needs more support of further research.

Table 6 – Results of logistic regression analysis for general noise annoyance [a].

Items	B	Odds radio	95% CI	p
L_{dn}	0.375	1.455[b]	1.170-1.810	0.001
L_{95}	-0.155	0.856[c]	0.774-0.947	0.003
Satisfaction of living environment	-0.510	0.600[d]	0.478-0.755	0.000
House satisfaction	-0.336	0.714[d]	0.574-0.889	0.003
Attitudes towards high-speed rails	-0.570	0.565[d]	0.410-0.780	0.001
Noise sensitivity	0.863	2.369[d]	1.855-3.026	0.000
Heart disease	0.665	1.945[d]	1.169-3.235	0.010
Constant	3.454	-		0.092

[a] Dependent variable: high level of noise annoyance, represented by the top three points of the 11-point numeric scale; [b] Increase of risk per 5dBA; [c] Increase of risk per 1dBA; [d] Increase of risk per unit scale.

4. CONCLUSIONS

The results from the social survey on community response to high-speed railway noise conducted in Tianjin provided a broader knowledge on high-speed railway noise situation in China. The dose-response relationship curve between noise levels and % highly annoyed was established in Tianjin, China. With the increasing of noise level (L_{dn}), annoyance of high-speed rail noise increased exponentially. Compared to Japan and France, Chinese residents were more annoyed by high-speed railway noise at the same equivalent sound pressure levels probably due to different maximum speed of high-speed train. The response to high-speed railway noise of rural residents was significantly more serious than that of urban residents at the same noise levels, possibly because of the different background noise level in urban and rural areas. It was also recommended that background noise had important impact on noise annoyance evaluation of high-speed railway noise. In addition to acoustic factors, non-acoustic factors such as noise sensitivity, satisfaction of living environment, attitudes towards high-speed rails, and health status should be considered when evaluating annoyance caused by high-speed railway noise.

ACKNOWLEDGEMENTS

This study was supported by the National Natural Science Foundation of China (Project

No.51678401). The authors would like to thank every member of Acoustics team at Tianjin University for conducting noise measurement. We would also like to express our appreciation to each respondent for completing the questionnaire.

REFERENCES

1. Lee PJ, Griffin MJ. Combined effect of noise and vibration produced by high-speed trains on annoyance in buildings. J Acoust Soc Am. 2013;133(4):2126-2135.
2. Di G, Liu X, Lin Q, Zheng Y, He L. The relationship between urban combined traffic noise and annoyance: an investigation in Dalian, north of China. Sci Total Environ. 2012;432:189-194.
3. Gidlof-Gunnarsson A, Ogren M, Jerson T, Ohrstrom E. Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise Health. 2012;14(59):190-201.
4. Licitra G, Fredianelli L, Petri D, Vigotti MA. Annoyance evaluation due to overall railway noise and vibration in Pisa urban areas. Sci Total Environ. 2016;568:1315-1325.
5. Peris E, Woodcock J, Sica G, Sharp C, Moorhouse AT, Waddington DC. Effect of situational, attitudinal and demographic factors on railway vibration annoyance in residential areas. J Acoust Soc Am. 2014;135(1):194-204.
6. Chen X, Tang F, Huang Z, Wang G. High-speed maglev noise impacts on residents: A case study in Shanghai. Transportation Research Part D: Transport and Environment. 2007;12(6):437-448.
7. Mellet C, Létourneaux F, Poisson F, Talotte C. High speed train noise emission: Latest investigation of the aerodynamic/rolling noise contribution. Journal of Sound and Vibration. 2006;293(3-5):535-546.
8. Park B, Jeon J-Y, Choi S, Park J. Short-term noise annoyance assessment in passenger compartments of high-speed trains under sudden variation. Applied Acoustics. 2015;97:46-53.
9. Sato T, Yano T, Morihara T. Community response to noise from Shinkansen in comparison with ordinary railways: a survey in Kyushu, Japan. Proceedings. 18th International Congress on Acoustics (ICA 2004), Kyoto, Japan. 2004: 4-9.
10. Yokoshima S, Morihara T, Sato T, Yano T. Combined Effects of High-Speed Railway Noise and Ground Vibrations on Annoyance. Int J Environ Res Public Health. 2017;14(8).
11. Lambert J, Champelovier P, Vernet I. Annoyance from high speed train noise: a social survey. Journal of sound and vibration, 1996; 193(1): 21-28.
12. Sato T, Yano T, BjÖRkman M, Rylander R. Comparison of Community Response to Road Traffic Noise in Japan and Sweden—Part I: Outline of Surveys and Dose–Response Relationships. Journal of Sound and Vibration. 2002; 250(1):161-167.
13. Phan HYT, Yano T, Phan HAT, Nishimura T, Sato T, Hashimoto Y. Community responses to road traffic noise in Hanoi and Ho Chi Minh City. Applied Acoustics. 2010;71(2):107-114.
14. Gjestland T. Research on community response to noise–in the last five years. 9th International Congress on Noise as a Public Health Problem (ICBEN). 2008.
15. Nguyen TL, Yano T, Nguyen HQ, Nishimura T, Fukushima H, Sato T, et al. Community response to aircraft noise in Ho Chi Minh City and Hanoi. Applied Acoustics. 2011; 72 (11):814-822.
16. Nguyen T, Yano T, Yokoshima S, et al. Structural equation model of road traffic noise annoyance in Vietnam. INTER-NOISE and NOISE-CON Congress and Conference Proceedings. Institute of Noise Control Engineering, 2014;249(7): 709-717.
17. Yano T, Ma H. Standardized noise annoyance scales in Chinese, Korean and Vietnamese. Journal of Sound and Vibration. 2004;277(3):583-588.
18. Hu X, Wu X, Lu L. Discuss on the Noise Metrics for High-Speed Train Noise Assessment. INTER-NOISE and NOISE-CON Congress and Conference Proceedings. Institute of Noise Control Engineering, 2016; 253(3): 4961-4964
19. Yokoshima S, Morihara T, Ota A, et al. Analysis of non-acoustic effects on noise annoyance caused by the Shinkansen Railway. Journal of Temporal design in architecture and the environment, 2009;9(1): 133-136.