Psychoacoustic Analysis of Various Train Pass-by Noise Using Binaural Recording

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ABSTRACT

Due to the recent high speed of railway, noise and vibration generated during operation has emerged as a major social problem. Specially, the internal noise of railway varies depending on various operating conditions such as speed, vehicle crossings, and tunnel entry, and has a great effect on the riding comfort of passengers. In this study, an evaluation method for binaural noise of train pass-by noise and a simple wave field model which can reflect the Doppler effect are examined. To reflect the binaural characteristics of train pass-by noise, binaural measurements were conducted for several types of train, different measurement distances and various measurement angles. The annoyances of measured binaural noises were analyzed using conventional sound pressure level, psychoacoustic metrics, and their rate of change. Also, the noise emitted from high-speed railways was measured and characterized. By its analysis result, moving sounds were synthesized considering an initial frequency and a frequency shift. The synthesized sounds were convolved to reflect binaural condition. Auditory experiments were conducted using the synthesized moving sound stimuli, and the effects of the Doppler frequency shift on annoyance of moving sound sources were obtained.

1. Introduction

Traffic noise occupies the largest proportion in environmental noise. Especially for the residents near train tracks, noise emitted from railroad is the most serious. Tracks for high-speed trains are expanding rapidly as green transport systems in Korea. To satisfy the needs of both passengers and residents near tracks and to design high-quality acoustic comfort, sound environment must be characterized and evaluated accurately to reflect the annoyance perceived by both passengers and nearby residents.

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Especially, the noise level increases severely when two trains pass each other. These sudden changes in sound pressure influence the perception characteristics significantly and must be investigated to facilitate improved acoustic comfort. Unfortunately, most of the evaluation methods for train pass-by noise use monaural sound only but noise perception strategy of human is binaural. Because train pass-by noise is a kind of moving sound source, interaural level and time difference must be considered for evaluation. Also, since traffic noise sources generally do not stop but move at a high speed, pass-by noises are perceived by adjacent residents with frequency shift caused by the Doppler effect. The Doppler effect is a common phenomenon where the wavelength and the frequency of noise change due to the relative velocity between an observer and a noise source. In the case of high-speed railway noise, the frequency shift effect is very large by the proximity of the railway and at a high speed.

For pass-by noise, this study went beyond the limitations of the existing monaural evaluation method and proposed a new noise evaluation method through a binaural noise evaluation method considering a human noise perception model. And to figure out the influence that the Doppler effect of a high-speed running train has on annoyance, this study used a synthesized moving sound source where head-related transfer function was applied to reflect a binaural effect.

2. Evaluation of Pass-by Noise

Measurements of train pass-by noises were conducted at several locations. Pass-by noises caused by subways, freight trains, KTX trains, Mugunghwa trains, and Saemaeul and Nooriro trains whose running speed was below 140 km/h were measured in Seonghwan-eup, Cheonan. The pass-by noise caused by KTX and KTX-Sancheon whose running speed was 250~300 km/h was measured in Bongdam-eup, Hwaseong for different distances, and in Yongso-ri, Hwaseong for different measuring angles. Three binaural recorders (Headacoustics, MHS-II) were used for measurement at the same time. Measurement distances from rail were 13, 26 and 39 m perpendicularly for each binaural recorder and measurement angle θ was 0° in Seonghwan and Bongdam-eup. In Yongso-ri, measurement distances from rail were 50 m perpendicularly and measurement angle θ was 0, 45, 90° for each binaural recorder. Measurement height of each binaural recorder was 1 m. To minimize the effect of outdoor wind, wind shields were used for the binaural recorders. Running speed of trains was measured by speed radar (Pocket Radar, PR-1000).

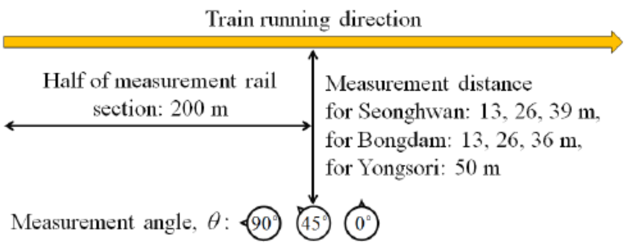

Figure 1: Measurement condition using binaural microphones.

Through the analysis, it was identified that there is a binaural effect on the annoyance. To reflect the binaural effect on the annoyance, two additional auditory experiments were conducted. As a result, the maximum change rates of difference between left and right channel of loudness and sharpness were proposed to evaluate the annoyance of pass-by noises.

3. Doppler Effect on the Perceived Noise

To examine the Doppler frequency shift of moving sound sources, pass-by noises of Korean high-speed train i.e. KTX were measured. The noise measurement was conducted at a distance of 13 m from the rail and a height of 1 m using a microphone installed with a windshield when a KTX train passed by at a speed of 300 km/h.

The measured noise was analyzed using a commercial program (Headacoustics, Artemis) in the time duration between the start and the end of a sound pressure level which was 30 dB lower from the maximum value. The noise level increased as a measuring point approached the railway. Especially when motive power cars at the very front and rear of train passed by, the noise level increased very rapidly.

Table 1. Stimuli used in the auditory experiment. The initial frequency is 250 Hz.

	f_0 (Hz)	Frequency shift, Δf (Hz)	L_{A0} (dBA)	$L_{A_{eq}}$ (dBA)	Scale value of annoyance
1	250	0	60	70.63	2.05
2		31.5	60	70.01	0.84
3		63	60	69.37	0.27
4		125	60	67.99	-0.43
5		125	54	61.99	-2.22
6		125	56	63.99	-1.79
7		125	58	65.99	-1.55
8		125	62	69.99	0.11
9		125	64	71.99	1.06
10		125	66	73.99	1.66

As a result, it was examined that intercoach spacing noise had a great contribution to the noise compared to measured noise frequency and predicted noise frequency using Rossiter equation. By means of the analyzed characteristics, moving wave fields with the same initial frequency and level but a different frequency shift was synthesized. The synthesized wave fields were convolved with a simple head related transfer function. Through an auditory experiment using the synthesized wave field as Table 1, it was determined that the Doppler effect made perceived annoyance decrease.

4. Conclusions

In this study, for binaural noise of train pass-by noise, an evaluation method was newly proposed. To complement the existing evaluation method which did not consider human perception of train passing-by noise as binaural hearing, binaural measurements were conducted for several train types, different measurement distances and various measurement angles using three binaural recorders. The annoyances were compared between measured monaural and binaural noises for the same pass-by noise. Similarly, the annoyances were compared for measurement distances and angles for the same binaural pass-by noise. With the two auditory experiments, it was identified that there was a binaural effect on the annoyance. To reflect the binaural effect on the annoyance, the maximum change rates of difference between left and right channels of loudness and sharpness were proposed to evaluate the annoyance of pass-by noises.

Furthermore, a fundamental study on the Doppler effect on human perception of pass-by noise was performed. The high-speed railway pass-by noise was characterized using time-frequency analysis and it was examined that noise from inter-coach spacing had a great contribution to the noise. The noise from inter-coach spacing showed repetitive frequency shifts. There was no study so far that determined the Doppler effect on human perception of pass-by noise. Considering the inter-coach spacing noise contribution to the pass-by noise, the Doppler effect on annoyance was determined through an auditory experiment using synthesized moving sound sources with a different Doppler shift. To reflect human hearing perception, a head-related transfer function was also applied to the synthesized moving sound sources. By conducting an auditory experiment, it was determined that the Doppler effect made perceived annoyance decrease.

5. Acknowledgements

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6. References

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