Temporal change of train noise in underground stations

Ryota Shimokura*, Yoshiharu Soeta

National Institute of Advanced Industrial Science and Technology (AIST), Japan

*corresponding author: ryota.shimokura@aist.go.jp

(Received 30 November 2009; accepted 7 December 2009)

A covered underground station is a reverberant sound field. The acoustical characteristics of train noise in the station are determined by the noise source as well as the sound field. In a previous study, the A-weighted equivalent continuous sound pressure level (L_{Aeq}) of train noise in the island platform was higher than that in the side platform. The L_{Aeq} was the averaged value in the long duration (10 to 30 s). However, the acoustical characteristics of train noise changes dynamically in the duration, and the temporal change affects the comfort of passengers. The aim of this study was to evaluate the temporal change of train noise in underground stations. The train noise in underground stations (side and island platforms) were measured in five different lines (a total of 10 stations), and the increment and decrement of the L_{Aeq} were calculated when the train came into and left the station. The change of sound quality was evaluated by the standard deviation of the autocorrelation function (ACF) and interaural cross-correlation function (IACF) parameters (τ_1, ϕ_1, and IACC). The effect of the lines on the changes was significant, but the effect of the platform types was not significant. Since each line has a different train car, the changes in train noise were dependent mainly on the train cars (i.e. sound sources), not on the platform types (i.e. sound fields).

Key words: underground station, train noise, train car, side platform, island platform

1. INTRODUCTION

The train noise in a station indicates a series of train noises occurring while the train arrives, stops, and leaves a station. When the train arrives, the A-weighted equivalent continuous sound pressure level (L_{Aeq}) increases until the front end of the train passes a passenger. As the train decelerates, the L_{Aeq} decreases. During the train stop in the station, the L_{Aeq} remains low. When the train restarts, the L_{Aeq} increases as the train accelerates. Finally, the L_{Aeq} decreases after the rear end of the train passes the passengers. The train noise can annoy passengers and reduces the speech intelligibility of the public address (PA) system in a station [1-2]. Thus, the control of train noise is important for the comfort and convenience of the station.

The L_{Aeq} of train noise in underground stations is 5 dB higher than that in ground stations [3]. Because the walls and ceiling of an underground station are usually covered with reflective fire-resistant materials (e.g. steel or vitreous enamel panels), sound reflections and reverberations cause an increase in train noise. The L_{Aeq} of train noise has been changed by platform types [3]. Generally, underground stations have two types of platforms: side and island. The side platform type has a platform on each side and rail tracks in the center; the island platform type has one platform in the center and rail tracks on each side (Fig. 1). The L_{Aeq} of train noise in island platforms was 2.3 dB higher than that in side platforms [3].

The previous study reports that the L_{Aeq} was different according to the sound fields [3]. However, the acoustical characteristics of the train noise changes dynamically, and the temporal change also affects the comfort of the passengers [4, 5]. The aim of the present study was to clarify the change of acoustical characteristics of train noise in different platform types of underground stations. To evaluate temporal changes, noise measurements were conducted on the side and island platforms of 10 underground stations, and the increments and decrements of L_{Aeq} were calculated during the train coming and going. The standard deviations of the autocorrelation function (ACF) and the interaural cross-correlation function (IACF) parameters (τ_1, ϕ_1, and IACC) were calculated to evaluate the change in sound quality.

2. MEASUREMENTS

2.1. Measured stations

The measured stations were in five underground lines (A, B, C, D, and E). In each line, two types of platforms (side and island) were selected. In each platform, three receiver positions [near the entrance side (*r*1), the middle (*r*2), and the exit side (*r*3) of the tunnel] were distributed (Fig. 1).

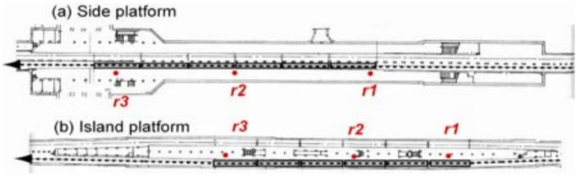

Fig. 1. Receiver positions on the platforms

2.2. Measurement setup

A dummy head microphone (KU100; Nuemann) was used. This microphone can simulate the frequency-dependent distortions of phase and amplitude on sound reaching the eardrums. Assuming a standing passenger, the height of the center of the ear entrance of the dummy head microphone was 1.6 m from the floor. Based on a passenger waiting for the train, the microphone was always facing perpendicular to the railway track.

2.3. Analysis

The recorded train noises were analyzed by the ACF and IACF. The normalized running correlation function was defined by

$$\phi_{lr}(\tau;t,T)=\frac{\Phi_{lr}(\tau;t,T)}{\sqrt{\Phi_{ll}(0;t,T)\Phi_{rr}(0;t,T)}} \qquad (1)$$

where

$$\Phi_{lr}(\tau;t,T)=\frac{1}{2T}\int_{t-T}^{t+T} p_l'(s)p_r'(s+\tau)ds \qquad (2)$$

in which $p_l'(t)$ and $p_r'(t)$ are the left and right signals after passing through the A-weighting filter. The $\Phi_{ll}(\tau, t, T)$ and $\Phi_{rr}(\tau, t, T)$ are the ACFs of the left and right signals, respectively. The $\Phi_{lr}(\tau, t, T)$ is the IACF. The $2T$ is the integral interval, and τ is the time delay.

The L_{Aeq} as a function of time, t, was calculated by

$$L_{Aeq}(t,T)=10\log\sqrt{\Phi_{ll}(t,T)\Phi_{rr}(t,T)} \qquad (3)$$

where Φ_{ll} and Φ_{rr} have $\tau = 0$. The train intervals were defined as “come”, “stop”, and “go” (Fig. 2). The interval “come” was started when the L_{Aeq} of the train noise increased to 60 dB and ended when the door of the train was opened. The interval “stop” was the duration the door was open. The interval “go” was started when the door was closed and ended when the L_{Aeq} decreased to 60 dB. In the interval “come”, the regression line was calculated until the peak of L_{Aeq}, and then the slope of the line was defined as increment_{come} (Fig. 2). The regression line was calculated from the peak to the end of the interval, then the slope of the line was defined as decrement_{come}. For the interval “go”, the increment_{go} and decrement_{go} were calculated in the same manner.

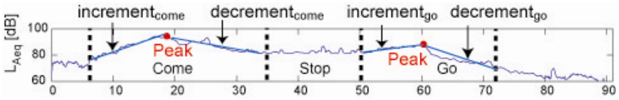

Fig. 2. Definitions of the intervals such as “come”, “stop”, and “go”and the slopes such as increment_{come}, decrement_{come}, increment_{go}, and decrement_{go}

The IACC is the maximum peak of the normalized IACF within the τ of 1 ms (Fig. 3a). When IACC is 1, the passenger can perceive a clear direction of incoming train noise. When IACC approaches 0, passengers can hear the train noise, but it is diffuse.

The τ_1 and ϕ_1 were calculated from the left channel of the ACF. The τ_1 and ϕ_1 are the time delay and amplitude of the first peak, respectively, of the normalized ACF (Fig. 3b). The motor noise propagated from the train vehicle often contains complex sounds. The perceived pitch and strength (i.e. tonality) of complex sounds can be expressed by the τ_1 and ϕ_1, respectively.

To observe the change of these parameters, the integration interval (2T) was 0.5 s, and the running step was 0.1 s in all calculations (Fig. 4).

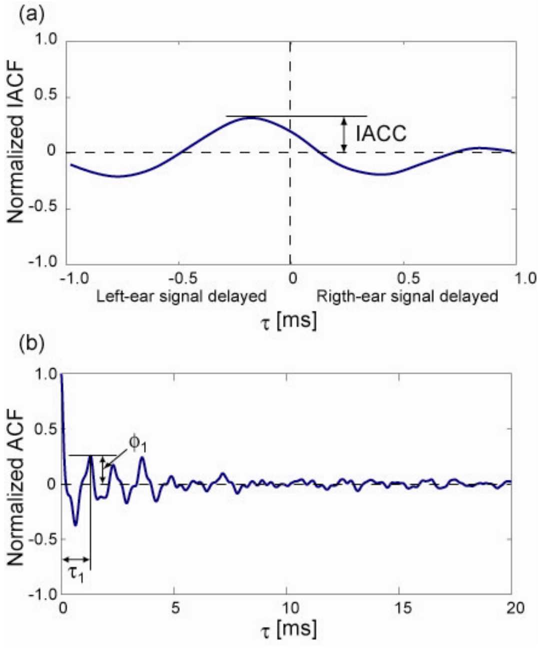

Fig. 3. Definitions of factors extracted from (a) IACF and (b) ACF

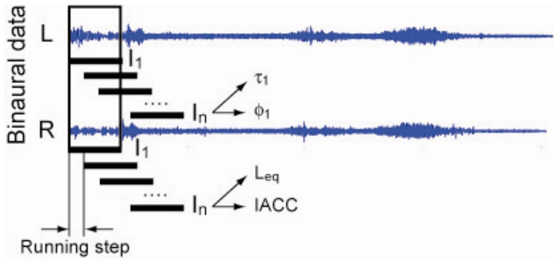

Fig. 4. Concept of short-time moving IACF and ACF analysis along the train noise

3. RESUTLS

Figs. 5 and 6 show the L_{Aeq}, IACC, τ_1, and ϕ_1 as a function of time in the side and island platforms on line B. The changes of these parameters in these platforms were similar. The L_{Aeq} increased and decreased when the train left from and went into the station. When the train stopped in the station, L_{Aeq} remained low, but was increased by the bells and the announcement to inform the train arrival and departure. The IACC increased while the train was coming and going in the tunnels. Then, the directional train noise arrived from the tunnel to the receiver. Except for the intervals of the announcement, the τ_1 was relatively stable, and the ϕ_1 became higher while the train was coming and going in the tunnels.

Fig. 7 shows the $\text{increment}_{\text{come}}$ and $\text{decrement}_{\text{come}}$. A three-way ANOVA was calculated to observe the effects of different lines (A to E), platform types (side and island), and receiver positions (r1, r2, and r3). The effects of lines ($F_{4,8} = 5.61$, $p < 0.05$) and receiver positions ($F_{2,8} = 12.05$, $p < 0.01$) on the $\text{increment}_{\text{come}}$ were significant, but the effect of platform type was not significant ($F_{1,8} = 0.02$). The $\text{increment}_{\text{come}}$ values were changed according to the railway lines, and it was large at the receiver position near the entrance side of the tunnel (*r*1). For the $\text{decrement}_{\text{come}}$, only the effect of receiver position was significant ($F_{2,8} = 4.78$, $p < 0.05$). The $\text{decrement}_{\text{come}}$ was large at the receiver position near the exit side of the tunnel (*r*3).

Fig. 8 shows the $\text{increment}_{\text{go}}$ and $\text{decrement}_{\text{go}}$. Only the effect of the line on $\text{increment}_{\text{go}}$ was significant ($F_{4,8} = 13.74$, $p < 0.01$). The increments of the accelerating noise were different according to the railway lines. No significant effects on the $\text{decrement}_{\text{go}}$ were found.

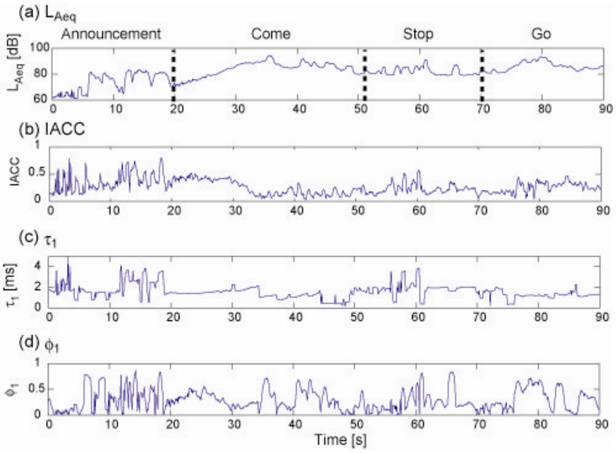

Fig. 5. (a) L_{Aeq}, (b) IACC, (c) τ_1, and (d) ϕ_1 as a function of time at the side platform on line B (Receiver: *r*1)

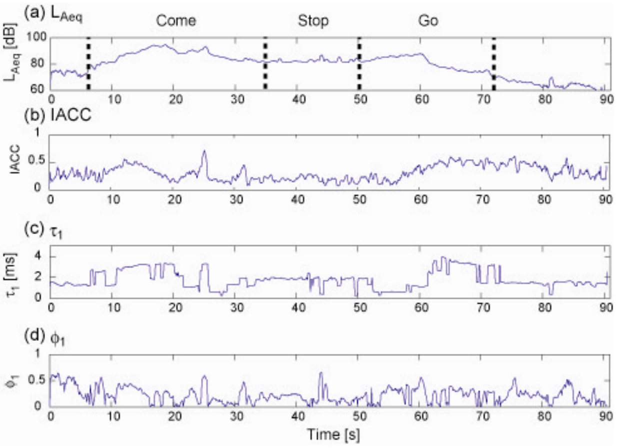

Fig. 6. (a) L_{Aeq}, (b) IACC, (c) τ_1, and (d) ϕ_1 as a function of time at the island platform on line B (Receiver: *r*1)

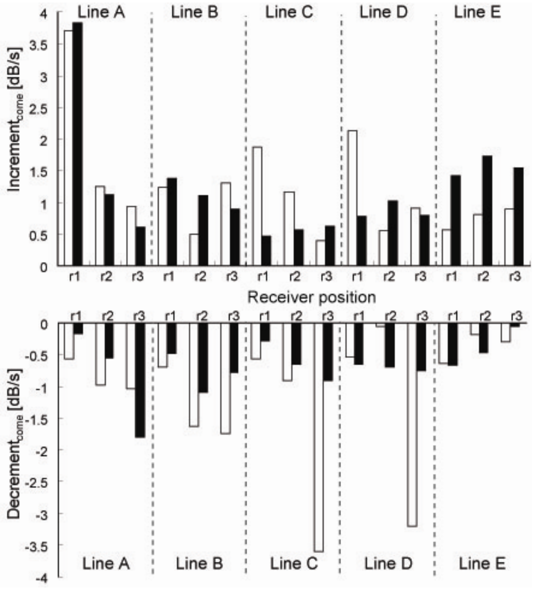

Fig. 7. $\text{Increment}_{\text{come}}$ and $\text{decrement}_{\text{come}}$ in each line and receiver position (■: side platform, □: island platform)

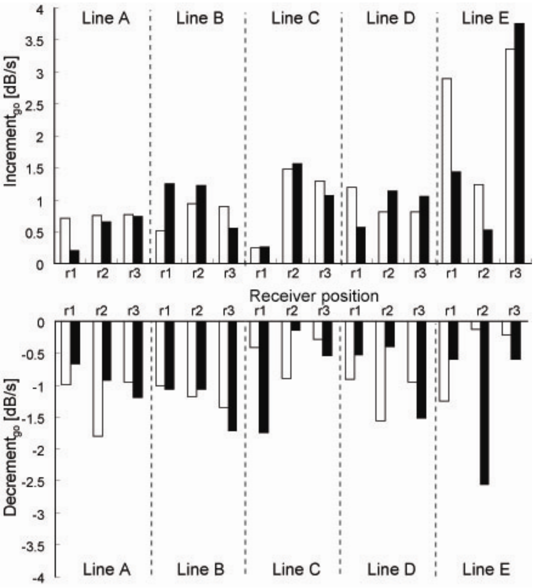

Fig. 8. $\text{Increment}_{\text{go}}$ and $\text{decrement}_{\text{go}}$ in each line and receiver position (■: side platform, □: island platform)

Fig. 9 shows the standard deviation of τ_1, ϕ_1, and IACC (SD_τ_1, SD_ϕ_1, and SD_IACC) in each time interval (come, stop, and go). Because an effect of receiver position was not found, the bars in these figures indicate the averaged values in all receiver positions. Results of a four-way ANOVA (i.e. lines, platform types, receiver positions, and time intervals) showed that the effect of lines on the SD_τ_1 was significant ($F_{4, 52}$ = 6.82, $p < 0.01$), but no other effects on the SD_τ_1 were found. For the SD_ϕ_1, the effects of line ($F_{4, 52}$ = 4.74, $p < 0.01$) and time interval ($F_{2, 52}$ = 9.08, $p < 0.01$) were significant. The SD_ϕ_1 was small when the train left. For the SD_IACC, the effects of line ($F_{4, 52}$ = 3.95, $p < 0.01$) and time interval ($F_{2, 52}$ = 6.14, $p < 0.01$) were significant. The SD_IACC was large when the train stopped.

4. DISCUSSION AND REMARKS

When the train came into and left the station, the increments of L_{Aeq} were different according to the line. Each line has different train cars. Thus, the change of L_{Aeq} is dependent largely on the kind of train car (i.e. sound source), not the platform type (i.e. sound field). It is interesting that the L_{Aeq} increased suddenly at the receiver position near the entrance side of the tunnel (r1). Therefore, the annoyance of passengers standing at this position may be greater [4, 5].

The standard deviations of τ_1, ϕ_1, and IACC changed according to the line. Changes in these parameters were dependent mainly on the train cars. In addition, effects of time interval were found in the change of ϕ_1 and IACC. The change of ϕ_1 was small when the train left the station. This means that the pitch strength of the motor noise was stable while the train was accelerating. The change of IACC was large when the train stopped, indicating that the announcement and bells changed the IACC dynamically. These results suggest that the changes in sound quality could be controlled by the train car or the announcements.

ACKNOWLEDGEMENTS

This work was supported by an academic grant from a Grant-in-Aid for Young Scientists (A) from the Japan Society for the Promotion of Science (18680025), an Ono Acoustics Research Fund, and a Sasagawa Scientific Research Grant.

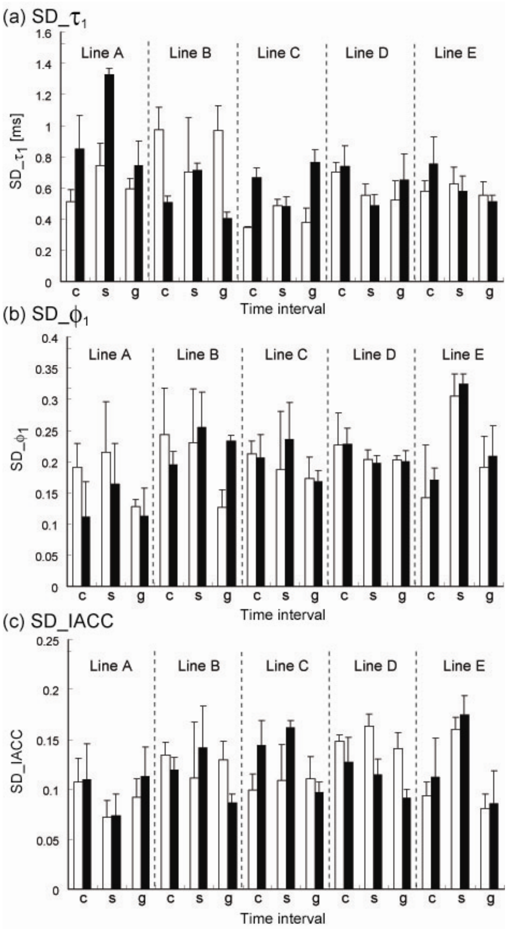

Fig. 9. Standard deviation of (a) τ_1, (b) ϕ_1, and (c) IACC in each time interval (c: come, s: stop, g: go). (■: side platform, □: island platform)

REFERENCES

[1] Endoh, H., Suzuki, H., Izumi, Y., and Hio, Y. (2007). Appropriate sound level of broadcasting on station platforms under noisy environment. RTRI REPORT 21, 41-46 (In Japanese).

[2] Izumi Y., and Fujii, K. (2007). An investigation the actual condition and subjective evaluation test of acoustical environment in railway station. RTRI REPORT 21, 47-52 (In Japanese).

[3] Shimokura, R., and Soeta, Y. (2008). Spatial characteristics of noises in platforms and vehicles of train. Proceedings of the 37th Inter Noise, N432.

[4] Fujii, K., Atagi, J., and Ando, Y. (2002) Temporal and spatial factors of traffic noise and its annoyance. Journal of Temporal Design in Architecture and the Environment 2, 33-41.

[5] Sato, S., You, J., and Jeon, J. Y. (2007) Sound quality characteristics of refrigerator noise in real living environments with relation to psychoacoustical and autocorrelation function parameters. Journal of the Acoustical Society of America 122, 314-325.