Applied Acoustics 73 (2012) 1150–1158

Contents lists available at SciVerse ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Sound field characteristics of underground railway stations – Effect of interior materials and noise source positions

Ryota Shimokura, Yoshiharu Soeta *

Health Research Institute, National Institute of Advanced Industrial Science and Technology, 1-8-31 Midorigaoka, Ikeda, Osaka 563-8577, Japan

ARTICLE INFO

Article history:
Received 25 June 2011
Received in revised form 25 May 2012
Accepted 29 May 2012
Available online 25 June 2012

Keywords:
Underground station
Tunnel
Sound field
Strength
Reverberation time

ABSTRACT

In the case of most underground railway stations, no acoustical solutions are used to reduce train noise. Because the reflecting features of train noise in an underground station are not known, appropriate methods for controlling these features have yet to be established. The aim of this study was to clarify the sound field characteristics of underground stations by putting a sound source and receiver on the railway track and platform, respectively. The impulse responses for two vacant underground stations were measured to clarify the effects of the interior materials of the station (Comparison I), and the sound source was put in each station and tunnel to clarify the effect of the noise source positions (Comparison II). Results showed that the sound fields were similar between the stations whose lateral walls were covered with either metallic or fire-resistant wooden panels (Comparison I), and that the sound field for the sound sources near or in the tunnel presented a higher strength (G) by 5.1 dB and longer reverberation time (EDT) by 0.7 s compared to the sound source in the station (Comparison II). The sound sources in the tunnel presented strong and long reverberations at around 500 Hz due to the convergence effect of the tunnel. Therefore, this study proposes a platform screen with doors to limit noise transmission into the platform.

1. Introduction

An underground railway station can be a highly reverberant sound field. The walls and ceiling of an underground station are usually covered with fire-resistant materials (e.g., steel or vitreous enamel panels). As a result the sound reflections and reverberations cause an increase in train noise in stations (TNIS) [1,2] and decrease the speech intelligibility of public address (PA) systems [3,4]. Consequently, passengers using underground railway lines on a daily basis may be exposed to such high-pressure TNIS, and cumulative daily noise exposure may lead to noise-induced hearing loss [5–7]. Older people in particular may have difficulty listening to PA announcements in the reverberant sound field [8]. In the Tenjin–Minami subway station in the city of Fukuoka, Japan, sound-absorbing ceramic panels were installed on the lateral walls of the platform level, resulting in the station being considered a relatively quiet environment by subjective evaluations. However, it is rare for practical acoustical solutions to be introduced into underground railway stations. Effective control of sound reflections and reverberations is required to produce satisfactory acoustics.

It is necessary to examine the acoustical characteristics of underground stations to provide effective acoustical treatment where necessary. Some previous studies have investigated the acoustic characteristics of underground stations and road tunnels, the results of which showed that early decay time (EDT) is from 2 to 4 s in the 1-kHz octave band, and that the speech transmission index (STI) ranges from 0.4 to 0.6 [3,9–11]. In the examined underground stations and tunnels, the EDT was found to be longer than that in a concert hall, and the speech intelligibility rating based on STI was "fair" to "poor" [12]. The aim of these previous studies was to improve the speech intelligibility of PA system, and for this reason both the sound source and receiver were located on the platform, simulating a PA system and passenger, respectively. However, there have been no studies to examine the sound fields of underground stations by simulating TNIS. The TNIS in underground stations is approximately 6 dB larger than that in above-ground stations [2]. Although the increase of TNIS is mainly due to reflections in the underground station and its tunnels, it is not clear how the TNIS arrives to passengers in such situations.

The aim of our study was to examine the sound field characteristics of underground stations to consider possible acoustical solutions for TNIS. In particular, we hypothesized that insulators on reflection pathways or absorbers for reflection walls may weaken TNIS. We therefore measured impulse responses by locating a sound source and receiver on both the train track and the platform

* Corresponding author. Tel.: +81 72 7519496; fax: +81 72 7519517.
E-mail address: y.soeta@aist.go.jp (Y. Soeta).

0003-682X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apacoust.2012.05.012

to simulate a train and passenger, respectively. Because sound fields are different according to the interior material and noise source position, measurements were carried out in two stations whose lateral walls were covered by metallic and wooden panels, respectively, to verify the effect of different interior materials (Comparison I). Then, to verify the effect of the noise source position, we placed a sound source both in the station and in the tunnel (Comparison II). A previous study reported that TNIS was modified by different sound fields in the station and tunnel; specifically, the TNIS from the tunnel was directional and less attenuated, while the TNIS when a train was approaching in the tunnel caused the noise level to be particularly higher [2]. The characteristics of the TNIS in the interval in which a train is approaching may thus be explained by examining the impulse responses obtained when the sound source is placed in the tunnel.

To evaluate the sound field characteristics, the acoustical parameters, such as strength (G), reverberation time (EDT), interaural cross-correlation coefficient (IACC), and direction of arrival (DOA) were calculated from binaural and three-dimensional (3D) impulse responses. In most surveys of noise, a sound level meter is usually used to evaluate the sound pressure level of a noise source. However, when the environmental noise is affected by sound reflections and reverberation, such room-acoustical techniques can also be used to better understand how the noise is amplified to the extent of causing discomfort to passengers [3,13]. The G and EDT parameters indicate the strength and length of reverberation, and thus the amplification of TNIS can be assumed to be related to these parameters. Further, the EDT is sensitive to the absorption coefficient of the boundaries [9], and thus it may show different acoustical characteristics in stations with different interior materials. The DOA parameter represents the position of the reflective walls, and thus it can guide us to where sound absorbers should be introduced. The IACC parameter represents the diffuseness of incoming sound, and thus the DOA and IACC can together serve as a guide to where sound diffusers should be introduced. Some previous studies reported that sound in a long, rectangular enclosure such as an underground station is not well diffused [9–11]. Such a sound field causes a standing wave, and therefore it is possible to amplify particular frequency ranges of the TNIS. In fact, the TNIS in an underground station includes stronger tonal components than that in an above-ground station. In addition, a previous study has pointed out the danger that the clear pitches of TNIS may also annoy passengers [2].

Table 1
Dimensions of stations A and B [m].

Station	W_s	H_s	W_p	H_p	L_p	H_c
A	14.8	5.8	7.3	1.1	162	3.0
B	14.7	5.3	8.0	1.1	332	3.0

2. Methods

2.1. Target stations

The underground railway line used for our measurements had not yet begun operation by the time of the study. Therefore there were no passengers or trains in the station. The target stations (hereafter denoted as "A" and "B") of the underground railway line had island-type platforms (one platform at the center and railway tracks on both sides). The dimensions of these stations are shown in Fig. 1c and Table 1. The length of the platform (L_p) in station B was longer than that in station A. The columns and ceiling were covered by metallic panels, and the platform and railway floors were covered by stone panels and concrete, respectively. The lateral walls of the platform were covered by metallic panels in station A and wooden panels in station B (Fig. 1a and b).

2.2. Sound source and receiver positions

In Comparison I, the three sound sources (s1, s2, and s3) and one receiver (r1) were positioned at the center of the platform in both stations A and B, simulating a train stopping in the station (Fig. 2a and c). In Comparison II, the sources were positioned near (s4) and in the tunnel (s5 and s6), simulating a train entering or leaving the station; the receiver (r2) was positioned at the end of the platform in station A (Fig. 2b and d). Because the tunnel was

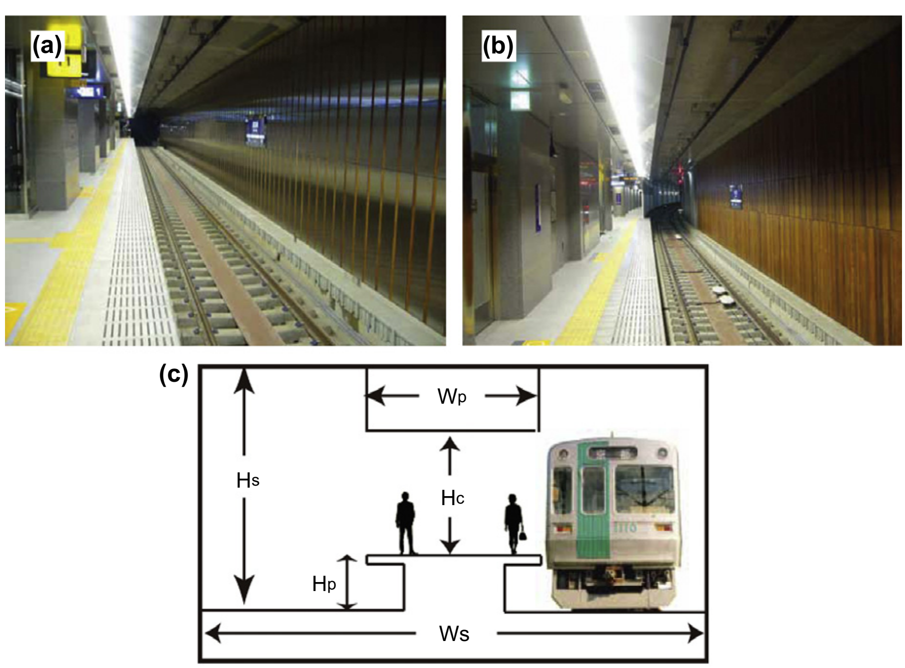

Fig. 1. Lateral walls of the platforms in (a) station A (metallic panels) and (b) station B (wooden panels).