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Architectural treatments for improving sound fields for public address announcements in underground station platforms

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A B S T R A C T

This study investigates the effects of subway platform design elements, such as finishing materials, on the temporal and spectral characteristics of public address (PA) announcements. To reproduce the acoustic conditions of the simulation model, acoustic-fitting using ray-tracing models was performed for two existing subway stations with island platforms using field measurement data. A systematic investigation using a computer station model was then carried out to clarify variations in the sound field characteristics when modifying station dimension and replacing finishing materials. It was found that smaller station dimensions yielded a higher speech transmission index (*STI*) and sound pressure level (*SPL*) with low early decay time (*EDT*), whereas higher absorption materials yielded a higher *STI* with lower *SPL* and *EDT* in the platform sound fields. In particular, a smaller station cross-sectional area obtained by modifying the station width and corridor height was the most effective for improving *STI*. More absorption on the floor and ceiling surfaces in the platform area had a marked influence on improving *STI*. In addition the auralized PA sounds with anechoic male and female announcements were analyzed using spectrogram and auto-correlation/interaural cross-correlation factors. It was found that the absorptive treatments contributed to clearer temporal characteristics of the PA sounds with decreased binaural dissimilarity and without any changes in spectral components.

1. Introduction

Public address (PA) systems for speech in railway stations have an important role in providing passengers with proper travel information including the arrivals and destinations of trains, and emergency instructions such as in the event of an accident [1,2]. Acoustic environments according to the various platform designs in terms of station dimensions or finishing materials have a direct impact on the propagation and perception of PA announcements [3]. In particular, underground stations have worse acoustic environments in terms of speech intelligibility than above-ground stations, with higher train noise levels [4], lower speech transmission indices (*STIs*) and longer reverberation time (*RT*) [5], because of their long enclosures with reflective surfaces. Thus, improving speech intelligibility of PA system has been one of the important issues in the design of acoustic environments in underground railway stations [1,2,5–7].

From field measurements in underground stations [8,9], diverse distributions of sound field characteristics are apparent depending on station arrangements, shapes, and/or materials. For example, the *RT* in underground station platforms ranged from 0.96 to 4.00 s at 500 Hz [9]. Since these acoustic properties are closely related to speech intelligibility performance, architectural treatment such as the design of enclosure dimensions or the application of absorptive material, have been investigated as effective approaches to improving sound fields in stations [3,10–12]. Kang [3] reported that the speech intelligibility of a PA system could be improved by installing diffusers and absorbers through scale model testing. Chew [10], using numerical calculations, investigated an acoustic design approach for an integrated bus/rail station which decreased background noise levels by increasing the ceiling height or reducing the concourse width. Haan [11] investigated several design elements, such as noise barrier heights or materials in a high-speed train station, using ray-tracing simulation. Recently, the effects of interior materials on sound fields in an underground station were investigated through field measurements in two different stations [13]. Generally, room volume and absorption in relation to reverberation and sound propagation can be controlled by changing the sectional dimensions or finishing materials of stations. However, we still have little understanding on how to identify which dimension or location is more influential on improving the acoustic quality of underground stations. Therefore, a systematic approach using various architectural treatments in underground stations is required using acoustically reliable prediction models.

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Many previous studies [1,2,6,7,14] have suggested prediction methods for sound fields in underground stations because the theory of classical room acoustics is not applicable to long enclosures [15]. In evaluating speech intelligibility of PA systems, various prediction methods have been adopted such as numerical calculation [6,14], ray-tracing simulation [1,2,6,10–12], and scale model testing [7]. Currently, ray-tracing simulation is the most frequently used method for investigating station acoustics in the design process because of its ease of use and practicality [3,6,10–12]. However, consideration of the actual details, such as columns or stairs, and acoustic validation with the field measurements, are lacking in previous studies. Therefore, acoustic models using ray-tracing simulation for underground stations need to be developed based on actual conditions.

The architectural treatments also affect propagation and perception of PA announcements. Sato et al. [16] reported some temporal characteristics of PA announcements through field measurements. However, studies on temporal and spectral characteristics of spoken announcements over PA systems taking into account various architectural treatments are rare. The temporal and spectral attributes of PA announcements can be characterized by spectrogram and psycho-acoustical analysis methods such as auto-correlation and interaural cross-correlation functions (ACFs/IACFs) [4].

In this study, therefore, architectural design elements for improving platform sound fields and acoustic characteristics of PA announcements are investigated using a ray-tracing simulation model. First, two simulation models of the underground station platform were constructed based on field measurement data to derive accurate simulation configurations. The effects of dimensional alteration and finishing materials on sound fields in a platform were investigated using a station model. Finally, temporal and spectral characteristics of PA announcements were analyzed using simulated impulse responses in comparison with the acoustic properties of the collected PA sources.

2. Methods

2.1. 3D modeling of the target stations

Two underground stations in Japan were selected for the experiments to improve the acoustic reliability of the simulation model. The field measurements in these stations have been taken and are described in previous studies [8,13].

Station A has two tracks and circular sectional tunnels, while Station B has three tracks and rectangular sectional tunnels as shown in Fig. 1a. Both stations have a single island platform positioned between two parallel tracks.

Based on architectural drawings, 3D models of Stations A and B were built using computer-aided design software (AutoCAD). In the 3D model, all elements of the floors, walls, and ceilings were considered including the lifts, columns, bulletin boards and stairways. The lengths of the platforms were 162 m and 332 m for Stations A and B. In the 3D model, the modeled tunnel length was determined to be a third of the platform length taking into account reflections from the tunnel areas [7] (Station A: 112 m for both sides, Station B: 101 m). The cross-sectional dimensions of Stations A and B are described in Table 1. The simulation situation was to have no passengers on the platform to match the field measurement conditions.

2.2. Source and receiver positions

As shown in Fig. 2, the source and receiver positions in the simulation model were determined in the same manner as the field measurements, and S1 was the same sound source. In the field measurements, an omni-directional loudspeaker was used as a sound source, which represented a PA loudspeaker at the longitudinal center of the platform [13]. Therefore, the height of the sources was 2.2 m above the platform floor. The other source positions (S2 and S3) were also employed in investigating the effects of source locations. In the field measurements, four receivers were placed at R1, R3, R5 and R7 positions with 5 m spacing, and the first receiver (R1) was 5 m away from source position (S1). In the simulation, a total of 16 receiver positions with 2.5 m spacing were considered including field measurement positions. In addition, the frequency response of the actual loudspeaker installed in Station A (TOA CM-1801) was measured to set up the power level of the sound source in the ray-tracing simulation. Table 2 shows the measured sound power levels of the PA loudspeakers for deriving the room impulse responses.

2.3. Acoustic measures

Acoustic parameters specified in ISO 3382-1 [17] were used for simulation fitting of the sound field characteristics of underground stations: early decay time (*EDT*), *RT* (T_{30}), definition (D_{50}), clarity (C_{50}) and the interaural cross-correlation coefficient ($1\text{–}IACC_{E3}$). For the acoustic fitting process, the averaged values from the same receivers as used in the field measurements were used with the sound source of S1. However, for plotting the simulation results, the averaged values of all 16 receivers with the sound source S1 were used for greater understanding of the sound field characteristics. For the frequency averaging methods, C_{50} and *IACC* were averaged from 0.5 to 2 kHz. *RT* and *EDT* were averaged from 0.5 to 1 kHz. The *IACC* was analyzed in two parts: early reflections (0–80 ms; $1-IACC_{E3}$) and late reflections (80 ms to the end; $1-IACC_{L3}$). For the acoustic evaluation of architectural treatments, the sound pressure level (*SPL*) and *STI* were also derived. Two types of *relative SPL*s were calculated with reference to the current condition of Station A and the source power levels to estimate the energy attenuation as a function of source-receiver distances [18]. Values of the *relative SPL* were averaged from 0.5 to 1 kHz. The *STI* [19] was calculated with a condition of no-background-noise.

2.4. Acoustic fitting

For the acoustic fitting, ray-tracing simulation software (Odeon v.11.20) was used. This software has been widely used to predict acoustic environments of train stations as well as auditoria [2,10–12]. The details of the calculation parameters are listed in Table 3. Air absorption was included with its temperature of 20 °C and relative humidity of 50%. The binaural impulse responses were derived from the simulation. Acoustic fitting was carried out by changing the absorption and scattering coefficients of the finishing materials. Acoustical agreement between field measurements and simulations was determined in terms of acoustic parameters. Judgment on whether the model was acoustically fitted or not was made based on just noticeable difference (*JND*) values [17].

Table 4 describes the results of the acoustic fitting processes in Stations A and B. The differences in all five parameters between measurements and simulations were within *JND* values. The final acoustic input for each surface of the fitted model was derived taking into consideration both station models (A and B), as shown in Table 5. The tunnel ends were assumed to be highly absorbent [7]. In this study, two architectural treatments were considered for the model of Station A: dimensional alterations and changes in finishing materials. The simulation configurations and results are described in terms of the architectural treatment methods in the following sections.