Acoustic effects of platform screen doors in underground stations

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ABSTRACT

This study investigates acoustic effects of platform screen doors (PSDs) in underground stations using computer simulation and scale model testing. Dimension of underground stations with island and side platforms was determined based on the field survey. Ray-tracing computer models and 1/25 scale-down physical models of underground stations were employed to simulate sound field characteristics. In experiments, four types of PSDs were tests: mobile closed full-height (MCFH), mobile open full-height (MOFH), mobile half-height (MHH), and fixed half-height (FHH). Acoustic parameters of speech intelligibility, sound pressure level, reverberation time and Interaural cross-correlation coefficient were employed for understanding sound field characteristics from sound source of public address announcements. As results, speech intelligibility and sound pressure level were increased by most types of PSDs except for MCFH. MOFH showed the highest speech intelligibility and spatial diffusivity. In addition, noise reduction effects of PSDs for train noises were discussed. PSDs in side platform showed higher noise reduction performances around than PSDs in island platform. In particular, noise reduction level by MOFH was 4.3 dB in side platform and 5.0 dB in island platform.

INTRODUCTION

Recently, platform screen doors (PSDs) are widely applied to platform area in rapid transit systems for passengers' safety and smoke containment (Kim et al. 2004; Oldfield 2012). After installation of PSDs, acoustic environments in underground station were also improved by isolating train noises (Lee et al. 2009; Kim et al. 2009; Nam et al. 2010; Lee et al. 2011, Soeta & Shimokura 2012). The most dominating effects of PSDs are reduction of train noise level, but reinforcement of early reflections for public address sounds was also found (Oldfield 2012). Reported noise reduction levels by presence of PSDs in underground stations were ranged from 9 to 18 dB from the field measurements (Lee et al. 2009; Kim et al. 2009; Nam et al. 2010; Lee et al. 2011, Soeta & Shimokura 2012).

However, sound field characteristics changed by PSDs were rarely studied. In particular, contribution of PSDs to improve speech intelligibility was not yet known. Moreover, noise reduction effects of PSDs in the previous study (Soeta & Shimokura 2012) were derived through field measurements in different venues because it was impossible to change PSDs, which have been once installed. Therefore, noise reduction performances of PSDs can be more accurately predicted through simulation approach with reliable acoustic models with different platform styles.

Therefore, this study investigated changes of sound field characteristics including its noise reduction effect according to different types of PSDs using computer simulation and acoustic scale modeling. It was hypothesized that speech intelligibility and noise reduction performances would be improved by the presence of PSDs according to type of platform shape.

METHODS

Target underground stations

As shown in Figure 1, two simplified underground stations with island and side platforms, respectively, were selected for the investigations. Details of the target stations including acoustic fitting to the real stations had been described in the previous studies (Shimokura & Soeta 2011; Soeta & Shimokura 2012; Kim & Soeta 2013). Both stations were simulated without passengers and background noises.

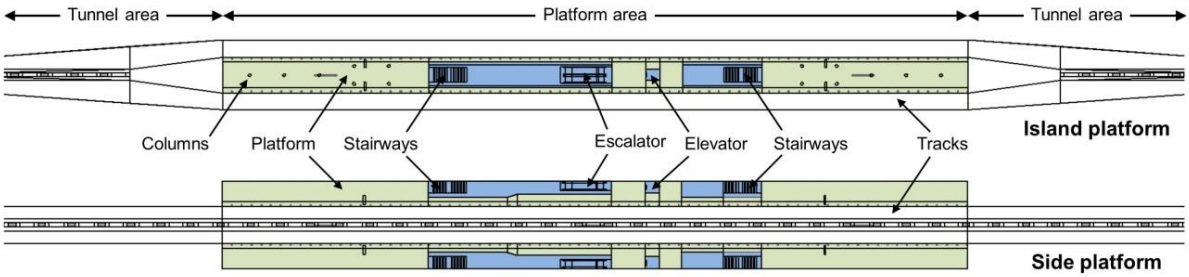
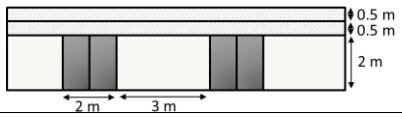
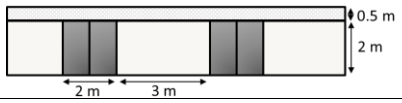
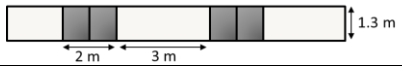
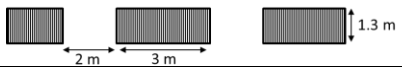
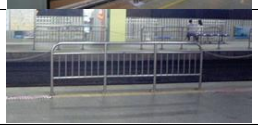


Figure 1: Floor plan of the target underground stations with island (above) and side (below) platforms.

Platform screen doors

Table 1 shows the five types of PSDs used in this study: three mobile (MCFH: closed full-height, MOFH: open full-height, MHH: half-height) and two fixed (FHH: half-height, FB: barrier) types. Dimension was determined based on the practical designs. Doors and lower walls of PSDs were made of tempered glass. Upper wall of PSDs were made of metal sheet.

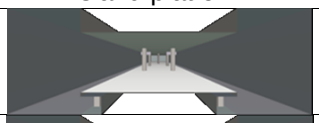
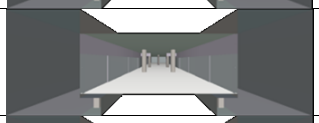
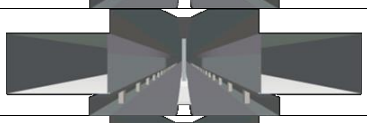
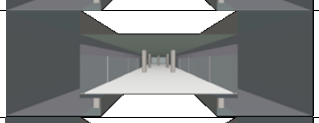
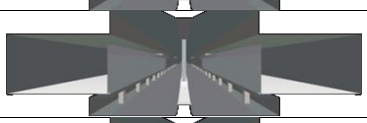
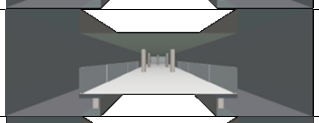
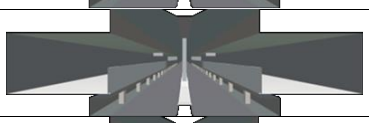
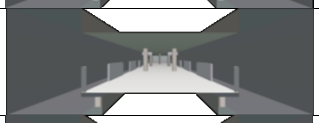
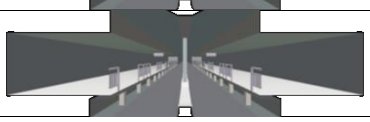
Table 1: Module of the five types of PSDs with its dimension.

Type	Module dimension	Examples
MCFH		
MOFH		
MHH		
FHH		
FB		

Simulation models using ray-tracing method

Ray-tracing software (B&K Odeon 11.23) was employed to derive acoustic parameters and binaural impulse responses. As shown in Table 2, twelve cases in total were simulated according to various PSDs configurations including no-PSDs condition (NSD). As simulation parameters, transition order was 1 with rays of 120,000. Environmental condition was 20 ºC and 50%RH.

Table 2: Simulation configurations according to type of PSDs.

Cases	Island platform	Side platform
NSD		
MCFH		
MOFH		
MHH		
FHH		
FB		

Physical models in 1/25 scale

A 1/25 scale model station with island platform was built for validation of computer simulation results. Main body of the scale model was made of 9 mm thick medium-density fiberboard (MDF) with varnish coating. PSDs were made of 1 mm thick Foamex plastic board (a type of polyvinyl chloride plastic). Figure 2 shows the model testing configurations according to types of PSDs.

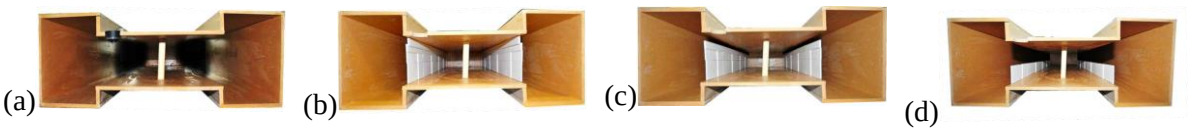


Figure 2: Section of the scale model stations with PSDs (a) NSD (b) MCFH, (c) MOFH and (d) MHH.

Source and receiver position

In this study, two measurement configurations were applied to investigate. As Configuration 1, Figure 3 shows source and receiver positions in both simulation and scale models for evaluation of sound field characteristics in order to determine speech intelligibility of PA sounds. Sound source at a height of 2.8 m (0.112 m in scale model) was located 22.5 m (0.9 m in scale model) away from the rear wall of platform in the longitudinal direction. In total, 14 receivers at a height of 1.6 m (0.064 m in scale model) were placed on either side from the sound source in the longitudinal direction. Distance between receivers was 2.5 m (0.1 m in scale model).

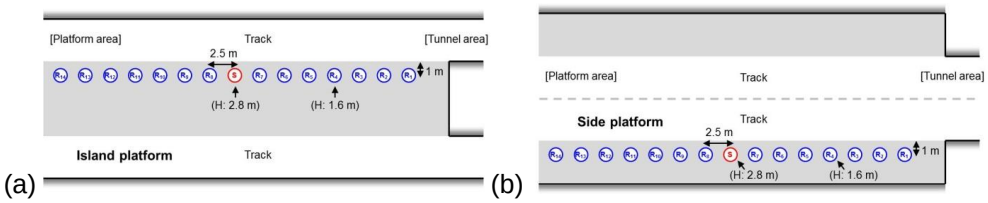


Figure 3: Source and receiver positions for evaluation of speech intelligibility of PA sounds (Configuration 1). (a) island and (b) side platforms.

As Configuration 2, Figure 4 shows source and receiver positions for evaluation of noise level of coming train to determine noise reduction effects of PSDs. Nine sound sources at a height of 0.5 m (0.02 m in scale model) were located along the track with a spacing of 15 m. Sound sources of S1 to S3 were located inside of tunnel area. At source positions of S1, S4 and S7, additional source heights of 2.3 m (0.092 m in scale model) and 4.1 m (0.164 m in scale model) were considered. In a total, thirteen receivers were located at a height of 1.6 m with a spacing of 5 m (0.2 m in scale model) in the same manner with the above configuration for sound field evaluation. R1 to R8 are classified as front receivers, whereas R9

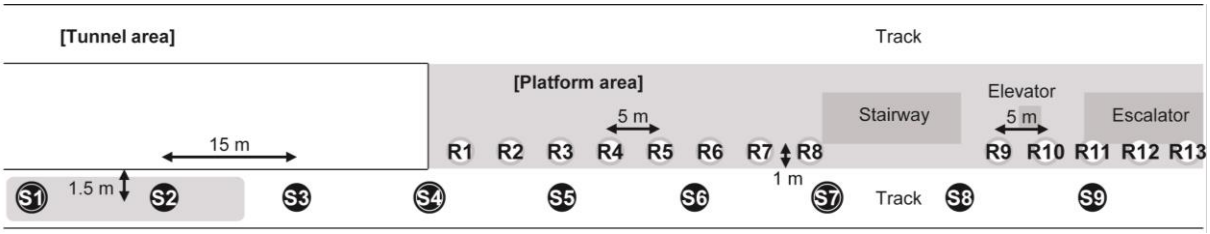


Figure 4: Source and receiver positions for evaluation of noise level of coming train (Configuration 2).

Acoustic parameters

Four acoustic parameters (IEC 60268-16:2003; ISO 3382-1:2009) were employed to quantify sound field characteristics using Configuration 1: speech transmission index (STI), sound pressure level (SPL), reverberation time (RT, T_{30}) and interaural cross-correlation coefficient (IACC). SPL and RT were averaged from 0.5 to 1 kHz. For calculation of IACC, A-weighted filter was included without spectral filtering. Additionally, noise reduction level (NRL) at overall bands was calculated as $SPL_{with\ PSDs}$ substracted by $SPL_{without\ PSDs}$ for evaluation of noise level of coming train using Configuration 2.

Measurement setup in scale model

Due to the scale factor of 1/25, a limited frequency range up to 3,840 Hz was measured through a tweeter loudspeaker (Clarion dome tweeter SRH294) and AD/DA converter (Roland Cakewalk UA-101) with a sampling rate of 192k Hz. Therefore, STI in scale model testing was averaged from 500 to 1k Hz. In addition, IACC was not derived in scale model testing due to use of monaural microphone (B&K 1/4" Type 4939-A-011, B&K NEXUS conditioning amplifier Type 2690). During the measurements, air temperature and relative humidity (RH) were 21 to 26 ºC and 61 to 65%, respectively. Air absorption was corrected for calculation of RT as a real-scale condition with 20 ºC and 50%RH (ISO 9613-1:2003).

RESULT 1: SOUND FIELD CHARACTERISTICS BY PSDS

Acoustic parameters were averaged from a single sound source and 14 receivers from Configuration 1. It was expressed as relative values with reference to NSD condition without any PSDs. Thus, for example, ΔSPL means that SPL without PSDs subtracted from SPL of each case.

Speech transmission index

Figure 5 (a) showed the results of STI values changed by the presence of types of PSDs from computer simulation and scale model testing. Except for MCFH in computer simulation, STI was increased by PSDs. In case of MOFH, STI was maximally increased in both stations: by 3% in island platform, and by 6% in side

platform. MHH cases showed similar STI increments to MOFH cases. Since fully-closed cases (MCFH) showed worse performance, it was found that lower walls of PSDs were important to improve speech intelligibility. Scale model results also confirmed the effectiveness of PSDs to increase STI. However, MCFH in scale model showed increased STI because absorption properties of model PSDs was slightly higher (0.07 in mid-frequency) than those of real PSDs (0.03 in mid-frequency, tempered glass pane). In addition, PSDs in side platform were more effective to increase STI than those in island platform although STI of NSD case in side platform was 0.01 higher than that in island platform.

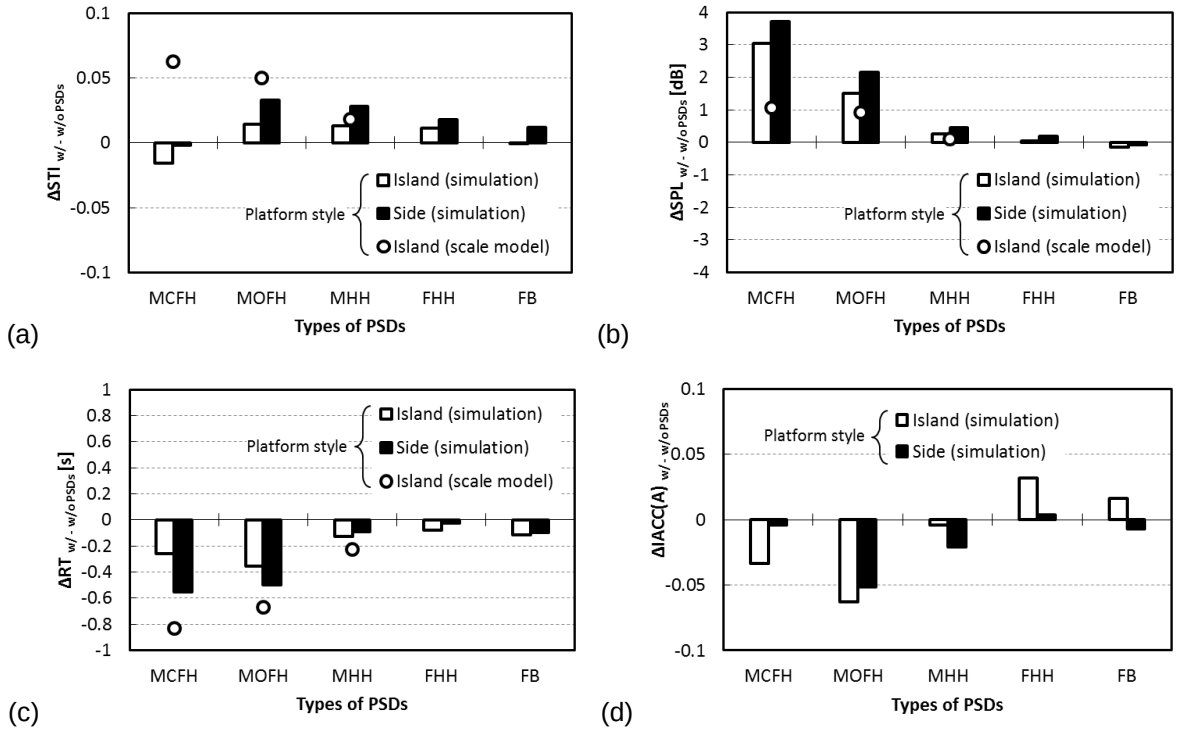


Figure 5: Difference of acoustical parameters between NSD and other cases with PSDs. (a) STI, (b) SPL, (c) RT and (d) IACC.

Sound pressure level

Changes of SPL according to types of PSDs were shown in Figure 5 (b). MCFH cases in both stations showed the maximum increases of SPL more than 3 dB. MOFH cases showed relatively high SPL reinforcements. This tendency also confirmed by scale model results although SPL in scale model was increased by 1 dB around due to different absorption properties of PSDs. However, other cases showed small changes of SPL. In particular, SPL was decreased in case of FB. Therefore, it was found that upper walls of PSDs were important to reinforce SPL. Similar to the results of STI, side platform was more effective to increase SPL than island platform.

Reverberation time

Figure 5 (c) showed the results of RT difference according to types of PSDs. Two full-height cases (MCFH and MOFH) showed larger RT reduction by PSDs in both stations. It seems that decrease of the effective room volume by PSDs mainly affected to reduce RT. In particular, MOFH cases showed similar results to MCFH cases despite its upper wall was opened. Scale model results confirmed the decrease of RT by PSDs. Additionally, side platform showed larger RT reduction for

only cases of MCFH and MOFH than island platform. FB also showed decrease of RT in comparison with the results of SPL.

Interaural cross-correlation coefficient

Difference of IACC according to types of PSDs was plotted in Figure 5 (d). MOFH showed the largest decreases of IACC in both stations. It seems that coupling effects by upper opening in MOFH affected to promote diffusion of reflections. Except for MOFH, MCFH in island platform and MHH in side platform also showed decrease of IACC. However, IACC was increased by the cases of FHH and FB in island platform.

RESULT 2: NOISE REDUCTION EFFECTS BY PSDS

NRL were averaged from 9 sound sources and 13 receivers from Configuration 2. Figure 6 shows the results of NRL of PSDs in island and side platforms. MOFH showed the highest NRL values for both island and side platforms. As for front receivers (R1 to R8), NRL by MOFH was 4.3 dB in side platform and 5.0 dB in side platform. This result shows good agreements with the previous study using field measurements (Soeta & Shimokura 2012). NRL by MHH was 1.4 dB in side platform and 1.1 dB in island platform. NRL by FHH and FB was 0.9 dB in side platform and 0.8 dB in island platform. Therefore, side platform showed higher NRL values than island platform. This difference seems to be caused by different boundary conditions of platform sound fields surrounded by PSDs and lateral walls.

On the other hand, middle receivers (R9 to R13) showed slightly higher NRL values of 0.1 to 0.6 than those of front receivers. Smaller PSD profile showed larger NRL difference between front and middle receivers. It seems to be affected by more diffusive interior elements in middle platform area than front platform area.

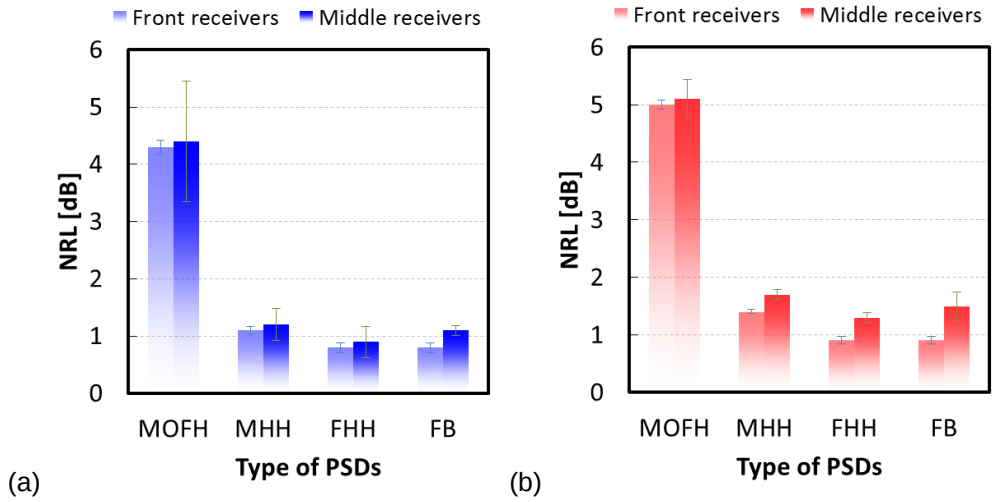


Figure 6: NRL values according to type of PSDs for (a) island and (b) side platforms.

Effects of receiver positions

As effects of receiver positions, NRL distribution was plotted as Figure 7. In frontal platform area, stable NRL values were observed with slight decay at R4 to R5 positions. However, in middle platform area, dramatic changes of NRL were observed. Especially, R10 position beside elevator shaft showed peak NRL values. Island platform showed more fluctuated NRL values than side platform. It seems to be caused by the opposite PSDs walls in island platform, whereas side platform has one PSDs wall.

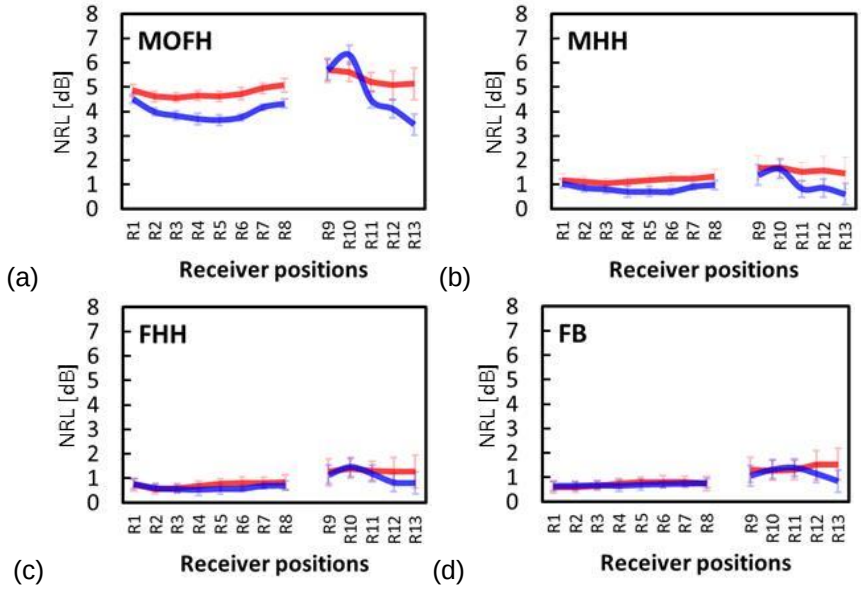


Figure 7: Variation NRL values according to receiver positions for (a) MOFH, (b) MHH, (c) FHH and (d) FB (red line: side platform, blue line: island platform).

Effects of source positions and heights

Figure 8 shows the results of NRL values according to source positions in case of MOFH. Each NRL value of each receiver position was averaged for S1, S4 and S7, respectively. MOFH showed higher NRL values for sound source in tunnel area than other source positions. This means that PSDs are helpful to reduce relatively lower level of train noises. Especially, large fluctuation of NRL was observed in middle platform area of island platform. Side platform shows relatively stable NRL values than island platform.

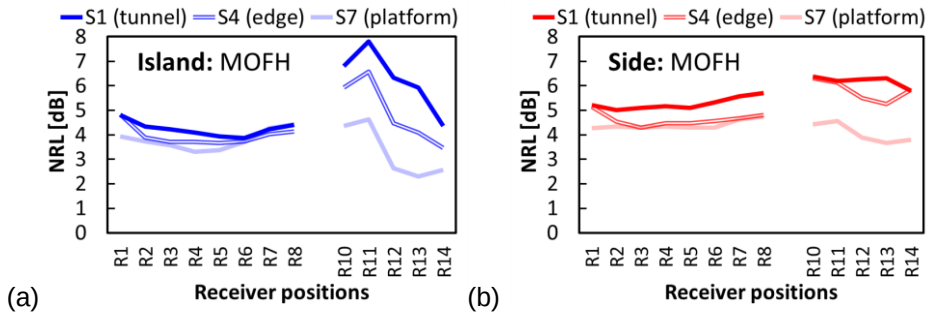


Figure 8: Variation NRL values according to source positions in case of MOFH for (a) side and (b) island platforms.

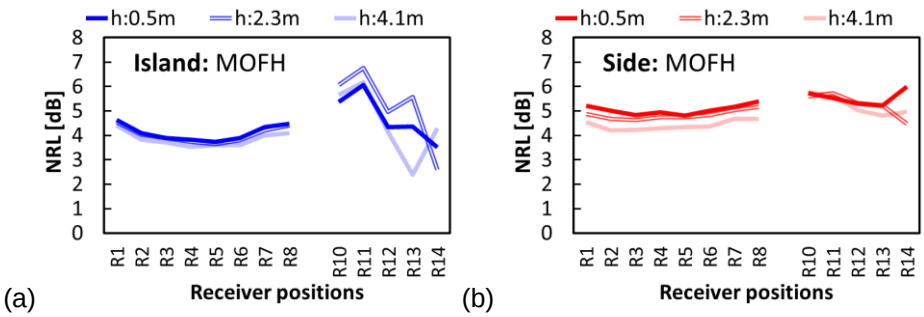


Figure 9: Variation NRL values according to source heights in case of MOFH for (a) side and (b) island platforms.

Figure 9 shows the results of NRL values according to source heights in case of MOFH. Each NRL value of each receiver position was respectively averaged for heights of 0.5 m, 2.3 m and 4.1 m as for averaged for S1, S4 and S7. In island platform, frontal receivers showed stable NRL values against source height variation. However, middle receivers in island platform and frontal receivers in side platform showed relatively large variation of NRL values for different source heights. Lower sources tend to show higher NRL values.

CONCLUDING REMARKS

In this study, the effects of PSDs on sound field characteristics and noise reduction effects were investigated using both computer simulation and scale model testing. As results, it was found that most types of PSDs were effective to increase STI with higher SPL and lower RT except for the cases of MCFH. Especially, MOFH was found as the most effective type for maximizing speech STI with the lowest IACC. In addition, noise reduction levels of PSDs for train noises were derived according to type of PSDs. PSDs in side platform showed higher noise reduction performances around than PSDs in island platform. In particular, noise reduction level by MOFH was 4.3 dB in side platform and 5.0 dB in island platform. Middle platform area showed unstable NRL values than frontal platform area due to diffusive interior elements such as elevator or stairways. In conclusion, PSDs are helpful to reinforce speech intelligibility and loudness for public address announcements with reducing train noises. As a further approach, presence of background noise levels and passengers' absorption could be considered to provide more actual simulation results.

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