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Noise
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3pNSc5. Improvement of the acoustic environment inside the high-speed train stations depending on the increase of the train speed
Chan Hoon Haan* and Chan Jae Park

*Corresponding author's address: Architectural Engineering, Chungbuk National University, Sunghong-ro 410, Cheongju, 361-763, Chungbuk, Republic of Korea, chhaan@chungbuk.ac.kr

The speed of trains has been increased due to the development of railway technologies. Recently, operation speed up to 400Km/h is come to effect in Korea. But, it can be easily predicted that noise and vibration could be increased depending on the speed of trains. Especially, train stations are exposed to much noises for 24-hours at the nearest place when high-speed trains stop or pass the terminals. In the present study, noise levels of the passing high-speed trains were measured in four different stations and noise levels at the speed up to 400Km/h were calculated. Also, the predicted noises were analyzed and compared with the interior noise criteria (NC-curve). As a result, it was found that the noise levels exceed 10dB higher than the noise standards in average when train speed was 350km/h. Based on the results, some design proposals are suggested to satisfy with the noise standards including reinforcement of walls and ceilings, change of finishing materials which can improve the sound insulation of rooms in the train stations.

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INTRODUCTION

Since 1981 when the high-speed rail service was opened to the public, efforts for the speed-up of the train have been made until now. In case of Korea, Korea Train Express (KTX) is able to run at 400km/h as well, but the speed has not commercialized as the speed created noise and vibrations, and civil petitions. However, social interests and demands on the speed-up of high speed train have been increased steadily. In this mood, KORAIL has recently formulated a policy to have its trains running at 300km/h run at over 350km/h. The policy has also raised a concern of noise and vibration the high-speed railway service may create, and especially noise impacts on the station buildings are considered to be a burning issue. Regarding the situation, it is required to suggest strategies and measures to reduce the indoor noise impacts caused by the speed-up of trains. Comparing them to the indoor noise allowance, and evaluation of the noise would be undertaken.

The present study selected five high-speed train stations run by KORAIL, and conducted indoor noise measurements and evaluated the appropriateness of the sound scape based on the noise level expected through simulations. Also the present study suggested measures and strategies to reduce noise in stations, which can practically help to build a purposefulness sound environment.

STUDY METHOD

Targets

The station of high-speed railway in Korea can be largely divided into four types depending on the geographical topology between the rail and station building; underground, under-rail, ground, on-the-rail station. The present study selected one station out of each type for the noise measurement and analysis. Finally five target stations are selected and analyzed. The noise measurement is carried out on major rooms and facilities where passengers and agents are crowded; platforms, Waiting areas, offices and lodging facilities. The following Table 1 summarizes the formation of target stations, pass-through speed of trains before and after speed-up, and the location of rails and major rooms and facilities.

<table>
<thead>
<tr>
<th>Contents</th>
<th>Passing Speed (km/h)</th>
<th>Location (floor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Type</td>
<td>Railway</td>
</tr>
<tr>
<td>A</td>
<td>Underground</td>
<td>140* (190**)</td>
</tr>
<tr>
<td>B</td>
<td>Under rail</td>
<td>280* (330**)</td>
</tr>
<tr>
<td>C</td>
<td>Ground</td>
<td>280* (330**)</td>
</tr>
<tr>
<td>D</td>
<td>Ground</td>
<td>280* (330**)</td>
</tr>
<tr>
<td>E</td>
<td>On rail</td>
<td>110* (160**)</td>
</tr>
</tbody>
</table>

*The passing speed when the driving speed is 300km/h, **The passing speed when the driving speed is 350km/h,

Railway and Platform, Station, Ground
Noise Measurement

To measure the noise in the major rooms and facilities by stations, on-site noise measurement is carried out. Every room and facility has one noise receiving point on its center including railroad, while the measurement devices are in sync to measure at the same time the noise of a train, while it passes through the station with its speed shifted from 300km/h to a lower gear.

Equation of noise levels for increase of the train speed

Noise variation depending on the changes in the speed of the train is estimated by using the relation between sound power level and sound pressure level of the trains. The estimation can be expressed as the following.

\[ PWL = 23 \log V + 65 \quad (1) \]

where, \( V \) : speed of train (km/h)

\[ PWL = SPL + 10 \log(d) - 10 \log \left( \frac{d}{2\pi} \right) + a \quad (2) \]

\[ SPL = PWL - 10 \log(d) + 10 \log \left( \frac{\theta}{2\pi} \right) - a \quad (3) \]

where, \( d \) : distance between train and measure point(m)
\( \theta \) : angle between front and rear of the train (rad)
\( a \) : decrease of noise levels according to barriers and etc.

Equation (2) can be derived based on the formula of sound power level forecast using equation (1), and then rearranged to equation (3) which can calculate the noise levels depending on the speed variations.

Noise Criteria (NC)

The present study aims to evaluate the appropriateness of sound impacts which are led by speed-up of high-speed train and effect on major rooms (or facilities) of stations. Due to the absence of practical standards of noise allowance applicable to rooms and facilities of stations, the criteria of noise evaluation has not been available as well. Therefore the present study adopts a sound condition with similar purpose, among indoor noise allowances suggested by Beranek, and establishes the criteria for the noise evaluation. The following Table 2 represents the criteria of indoor noise allowances depending on the practical purposes.

<table>
<thead>
<tr>
<th>contents</th>
<th>NC</th>
<th>dB(A)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting area</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td>Office</td>
<td>40</td>
<td>47</td>
</tr>
<tr>
<td>Lodging facilities</td>
<td>30</td>
<td>39</td>
</tr>
</tbody>
</table>

* Equivalent Level (dBA)

\[ TL = 20 \log(m \times f) - 43 \quad (4) \]

where, \( TL \) : transmission loss
\( m \) : surface density of materials
\( f \) : frequency

Transmission loss calculation of each room

To forecast noise level of the speed-up of trains by rooms and facilities, and to suggest countermeasures against the noise out of the indoor noise allowance ranges, the present study evaluates sound insulation performance first using the following equation (4). More specifically, the present study calculates the performance by structures on each room/facility whose expected noise level is out of allowance range, and then evaluates the insufficient sound insulation capabilities by each room/facility. Based on the figures resulted from the insufficiency evaluation, the present study suggest measures to remedy a deficiency for the sound insulation against the train noise. However the sound insulation calculation based on TL formula has a disadvantage; when using the calculation method, it is not easy to forecast the sound insulation performance depending on the intermediate space and stud. For more precise evaluation of the sound insulation performance, the present study adopted INSUL 5.1, professional sound insulation forecasting tool, to evaluate performance output calculated based on TL, and provide more precise forecasts on the performance.
RESULT OF HIGH-SPEED TRAIN NOISE MEASUREMENT

To understand the indoor noise status, the noise impact is measured at every pass-through of trains. The following table shows the measured point location of each station.

<table>
<thead>
<tr>
<th>name</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>underground</td>
<td>under rail</td>
<td>under rail</td>
<td>ground</td>
<td>on rail</td>
</tr>
</tbody>
</table>

**TABLE 3.** Measurement point locations of each station.

Figure 1 represents the noise measurement taken under current condition (i.e. before the speed-up of train), and compares the noise properties between rooms and facilities.

**FIGURE 1.** Noise measurement results of high-speed trains passing the stations.
Platform

A platform is a place directly opened to the rail and has the largest proportion of distribution of passengers, which increases the probability of noise impacts. According to the measurement result, noise level before the speed-up of train is 97.1dB on average, while B station shows the highest figure with 99.8dB. However the noise level on C and D stations are that high as well (with 99.6dB). The speed of pass-through train is highest in B, C and D stations with around 280km/h records. On the other hand, E station shows 110km/h, the lowest speed, with noise in a relatively very high level 96dBA.

Waiting Area

The optimum level of indoor noise allowance for waiting areas is NC-50 and 56dBA in noise level terms. All the noise measurements of Waiting areas in stations exceeds 60dBA, meaning that no platform meets the optimum allowance criteria. E station shows the highest noise level even though the on-the-rail station (meaning that the station building is located above the rails in a tunnel formation) has 100km/h of pass-through speed, which is smaller than that of B, C and D stations.

Office

Office is a place for agents and workers of the station and thus is significantly affected by the noise in that the workers usually work in it for a long while. The indoor noise allowance of medium-large offices is around 47dBA. According to the noise measurement results, E station shows 58.1dBA of noise level, which is the highest among all the 5 stations. However besides B station, the noise level of all the other station exceeds 50dB, the threshold of allowance for offices. This means the current sound environment is not appropriate when regarding the purposes. On the other hand, the noise level of B station is approx. 49.6dBA, which is very close to the allowance threshold for office (49dBA).

Lodging Facilities

For the night time shift and rest of crews, stations provide crews lodging spaces for their rest and relaxation. As previously mentioned, lodging spaces in stations require a very rigid noise criteria; NC-30 (39dB). According to the measurements, average noise level of the lodging spaces in 5 stations is 49.2dB, exceeding the threshold by 10dB. Regarding that the B station shows the lowest level of noise, 46.6dBA, we can say that the noise impacts on the lodging spaces are severe on average terms.

RESULT OF NOISE LEVELS FOR INCREASE OF THE TRAIN SPEED

To understand the indoor noise status at the major rooms and facilities, the noise level at the pass-through of higher speed train is estimated based on the measurement results. According to the forecasts, the increase in the noise level is highest in E station by 3.7dB, while the noise in A station increases by 3.5dB and B, C and D stations by 1.6dB. The following Figure 2 allows us to more easily compare the forecasts with indoor noise allowance criteria. In the figure, green lines represent the allowance criteria of each room and facility in frequency and overall values. The bars with dotted lines represent the noise measurements at the current speed while ones in solid lines refer to the forecasted noise levels.

Waiting area

As for the Waiting areas, at the condition of higher speed the forecasts all show figures exceeding 56dBA. Noise level of the E station, a on-the-rail station, for example, is exceeding the noise allowance criteria (82dB) by 26dB, when the speed of pass-through train is increased to 350km/h from 300km/h. This means not only that the noise impact level is not appropriate for the Waiting area in terms of its purpose, but also that the noise can give passengers unpleasant feelings and inconveniences.
According to the noise forecasts under assumption of increased train speeds, the noise level of B station is smallest to 51.2dB, which is closest to the noise allowance criteria, 49dBA. Beside the B station, almost all station shows noise level ranging from 51.dB to 9.1dB, which shows the possibility that the higher speed of train can have negative noise impacts on station offices. Regarding that agents and workers stay in the station offices to work, the impacts of noise is highly likely to be severe compared to other rooms/facilities.

Lodging facilities

The indoor noise allowance criteria adopted in the present study is NC-30 and 39dB in noise level terms. The threshold refers to a very calm sound environment which is prone to the noise such as that in the sleeping condition. However when the speed of train is increased to 350km, the indoor noise level exceeds by 9.2dB at the minimum and up to 14.6dB. In conclusion the noise is highly likely to hamper the relaxation in the lodging places such as sleeping.

IMPROVEMENT OF THE ACOUSTIC ENVIRONMENT

Based on the indoor noise forecasts, rooms/facilities with abnormal noise levels (i.e. ones exceeding the allowance criteria) are identified and insufficiency in their noise insulation performance is calculated. Based on these results, improvement measures can be derived by analyzing the insulation performance of walls, ceilings and ground. The measures for the improvement of the insulation performance required to meet the noise allowance criteria can be achieved by changing the materials and structures of walls, ceilings and ground to remedy the deficiency in their sound insulation performance.

This chapter suggests measures to reduce the noise in the case of office of C station. The following Figure 3 shows indoor finishing materials after the sound insulation performance improvement, and represents the improved insulation performance which calculated by TL formula and computing tools in graphs.

Figure 4, on the other hand, represents the indoor noise forecasts before and after the improvement of indoor finishing materials, and compares the forecasts with corresponding indoor noise allowances to evaluate the appropriateness.

![FIGURE 2. Transmitted noise calculations of each room depending on the train speed.](image)
### FIGURE 3.
Interior finishing materials suggested to increase the sound transmission loss of the station C.

<table>
<thead>
<tr>
<th>Walls</th>
<th>Floor</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before</strong></td>
<td>Vinyl sheet 2mm</td>
<td>Air cavity</td>
</tr>
<tr>
<td></td>
<td>Panel heating system 150mm</td>
<td>Gypsum board 2ply</td>
</tr>
<tr>
<td></td>
<td>Concrete 100mm</td>
<td>+ wallpaper</td>
</tr>
<tr>
<td></td>
<td>Water proof plywood 9mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insulation 60mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air cavity</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>After</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Porous absorber 130mm</td>
<td>Insulation in air cavity</td>
</tr>
<tr>
<td></td>
<td>Gypsum board 4ply</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ wallpaper</td>
<td></td>
</tr>
</tbody>
</table>

**Before the improvement,**  **After the improvement (calculated by equation)**  **After the improvement (calculated by program)**

### FIGURE 4.
Comparison of the noise calculations before and after the improvement of interior finishing materials.
CONCLUSIONS

The present study aims to forecast the noise impacts when the speed of high-speed train is increased to 350km/h from 300km/h, and to identify the impacts of the noise on the major rooms/facilities in stations which is the closest building to the rail lines.

According to the noise measurements and forecasts on major rooms/facilities, the noise impact on almost every room/facility is exceeding the noise allowance criteria at the pass-through of trains at a speed of 350km/h, a normal speed. If the train speed is increased to 350km/h or more, the excess will increase, and thus the negative impacts of the noise will also be profound.

In conclusion, it is needed to improve the station facilities such as through modification of construction plan and upgrade of indoor finishing material, to prevent passengers and workers from being affected by the noise created at the pass-through trains at higher speed.

REFERENCES