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SCALE MODELLING OF TRAIN NOISE PROPAGATION IN AN UNDERGROUND STATION

J. Kang
The Martin Centre, University of Cambridge,
6 Chaucer Road, Cambridge CB2 2EB, England

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1. INTRODUCTION

Most underground stations are typically long enclosures, in which the sound field is not diffuse and thus classic room acoustic theory is not applicable [1–3]. In order to investigate the basic characteristics of train noise propagation in underground stations and the effectiveness of various architectural acoustic treatments for reducing train noise, a series of measurements was carried out in a 1:16 scale model of St. John's Wood underground station in London. The dimensions and frequencies below relate to full scale, except where indicated.

2. MEASUREMENT METHOD

The scale model was a plastic pipe with a length of 8000 mm (128 m full scale) and a diameter of 405 mm (6·48 m full scale), as illustrated in Figure 1. The model was successfully calibrated against full scale measurements [4, 5]. A Brüel and Kjaer (B&K) Sound Source HP1001 was positioned at one end of the model to simulate train noise from the tunnel.

A ribbed structural element, which can often be found in underground buildings and which acts as a diffuser, was simulated by a hard plastic grid with a distance of 20 mm (32 cm full scale) between the grid lines. The thickness and width of the grid lines were 5 mm (8 cm full scale). Model absorbers were simulated by a 10 mm thick (16 cm full scale) plastic foam, which has an absorption coefficient of around 0·9 over the model frequency range.

3. RESULTS

As expected, the sound pressure level (*SPL*) decreases continuously along the length, which is fundamentally different from classic room acoustic theory [6]. As an example, the measured sound attenuation at 1 kHz is shown in Figure 2. It is noted, however, that despite the *SPL* attenuation along the length, train noise still has a significant effect on the station [5].

To reduce train noise, a strongly absorbent section near the tunnel entrance is effective. In Figure 2 the noise reduction caused by such a section from 12 m (see Figure 1) is demonstrated. In the measurement the ceiling and walls in this section were covered by absorbers. It can be seen that with a length of 12·8 m, the absorbent section can bring more than 10 dB extra attenuation at 1 kHz. The absorbent section is less effective with a shorter length.

Diffusers are also useful for reducing train noise. The extra attenuation at 500 Hz and 1 kHz caused by ribbed diffusers arranged from 10 m to 40 m (see Figure 1) is shown in Figure 3. It can be seen that the maximal extra attenuation is about 4 dB, which occurs

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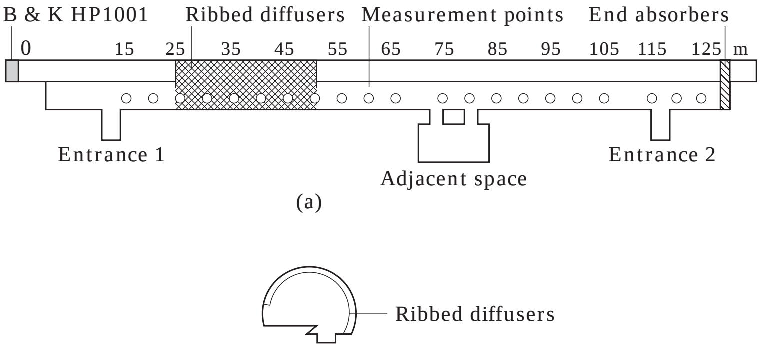


(a)

(b)

Figure 1. A 1:16 scale model of an underground station and the experimental arrangements. (a) Plan view; (b) cross-section.

just after the area with diffusers. In principle, this is in agreement with Kuttruff's theory [1]. With a better diffuser, the extra attenuation can even be greater [7, 8].

The absorbent treatment on an end wall is helpful for train noise reduction within a certain range near the end wall. In Figure 4, a comparison of the *SPL* attenuation with and without absorbers on an end wall (see Figure 1) is shown. It can be seen that within about 30 m from the end wall, the *SPL* difference is about 1–3 dB at 500 Hz and 1kHz.

Even a small area of absorption can systematically increase the sound attenuation along the length. As an example, the extra attenuation at 500 Hz and 1 kHz caused by opening Entrance 1, where the open area is 2·4 m × 3·2 m (see Figure 1), is shown in Figure 5. It can be seen that the extra attenuation, although only around 0·8 dB, is systematic, especially in the area near the entrance.

It is noted that the above treatments, which are mainly effective on reflections, are not necessarily as helpful when the train is in the station since, at this time, the direct sound is more significant than reflections.

To investigate the effect of train noise on adjacent spaces, measurements were carried

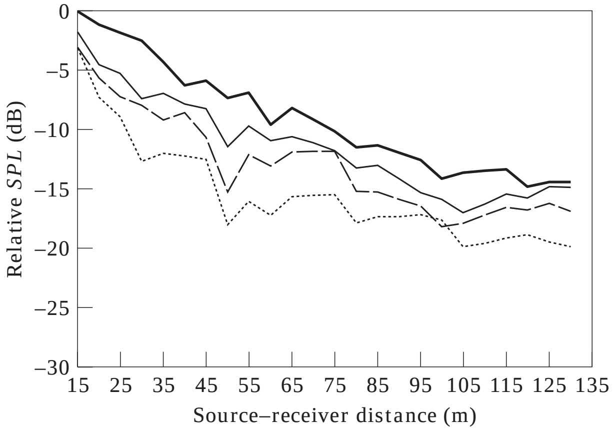


Figure 2. Sound attenuation along the length at 1 kHz (——) and the effectiveness of a strongly absorbent section with a length of 12·8 m (----), 7·2 m (———) and 3·2 m (——).

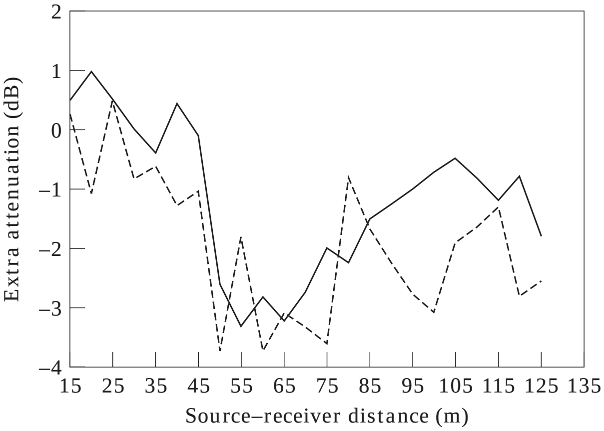


Figure 3. Extra sound attenuation at 500 Hz (——) and 1 kHz (---) caused by ribbed diffusers arranged from 10 m to 40 m.

out along a cross-section at 77 m, as illustrated in Figure 6(b). The spacing between measurement points was 1·6 m. Correspondingly, the sound attenuation at various frequencies is shown in Figure 6(a). It can be seen that the *SPL* difference between the station and the adjacent space is about 3–7 dB, which means that train noise has a considerable effect on the adjacent space. Similarly, the noise in the adjacent space could also affect the station significantly. To reduce the disturbance between the two spaces, strong absorbent treatments in the connecting corridors could be effective.

For a circular cross-section, focused reflection is likely to be an acoustic problem. To investigate this, measurements were carried out on a series of cross-sections. As an example, the *SPL* distribution at various frequencies on the cross-section at 95 m is shown in Figure 7(a). Correspondingly, the measurement arrangement is illustrated in Figure 7(b). It can be seen that, for both low and high frequencies, there is no systematic *SPL* variation in the section. In other words, it appears that there is no focused reflection in this station.

4. CONCLUSIONS

A series of measurements in a scale model of an underground station has shown that:

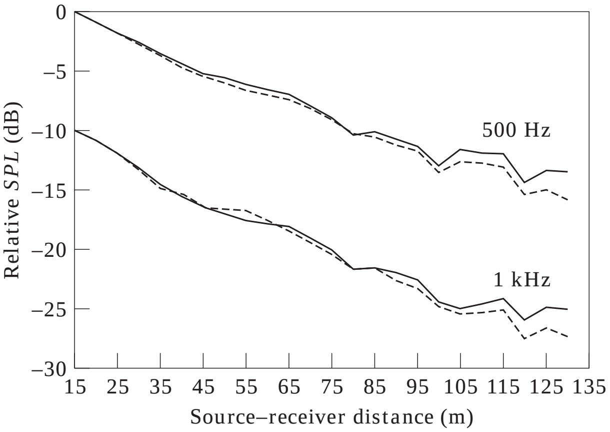
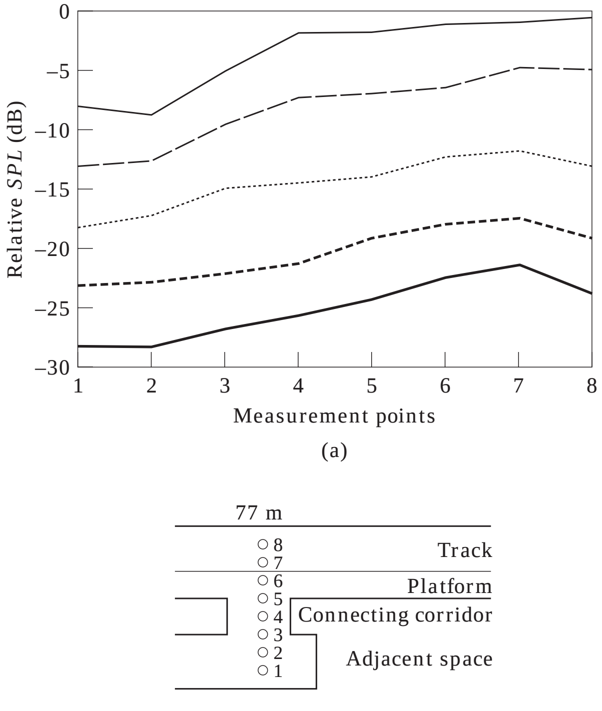


Figure 4. A comparison of the sound attenuation with (---) and without (——) absorbers on an end wall.

Figure 5. The extra attenuation at 500 Hz (——) and 1 kHz (---) caused by opening Entrance 1.

(1) classic room acoustic theory is unsuitable for train noise propagation in a long station; (2) when a train is in the tunnel, train noise can be reduced by a strongly absorbent section near the tunnel entrance, diffusely reflecting boundaries, absorbent end walls, etc.; (3) train noise could have a considerable effect on adjacent spaces; and (4) with train noise there is no focused reflection in this station.



(a)

(b)

Figure 6. Sound attenuation from the station to the adjacent space. (a) Measured sound attenuation at 63 Hz (——), 125 Hz (---), 250 Hz(·····) 500 Hz (– – –) and 1 kHz (——); (b) a plan view of the measurement arrangement.

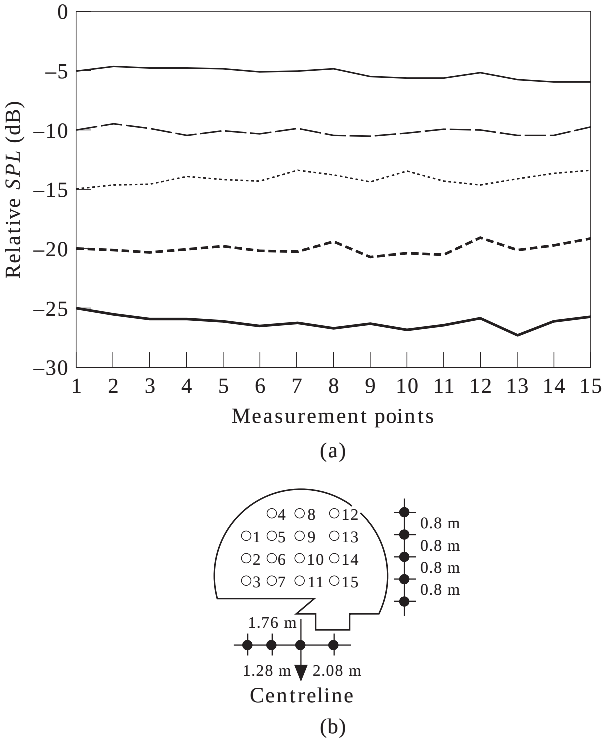


Figure 7. The sound distribution on the cross-section at 95 m. (a) The measured sound distribution at 63 Hz (——), 125 Hz (———), 250 Hz (· · · · ·), 500 Hz (– – –) and 1 kHz (——); (b) the measurement arrangement.

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