Reverberation characteristics in a room with unevenly-distributed absorbers: Scale modeling study

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1. Introduction

When a pulse sound is generated in a room in which sound-absorbing material is distributed on the floor and ceiling, the sound is often perceived as if the pitch of the reverberant sound rises with time. In the present paper, the physical mechanism of this phenomenon was investigated through a scale model experiment and the effects of variation of the distribution of absorbers and room shape on the reverberation characteristics were examined.

2. Energy decay of impulse response

Figure 1 shows an example of impulse response measured in a scale model having an absorptive floor. A spectrogram of the response shows that the sound energy in the frequency range from 100 Hz to 300 Hz decreases rapidly, whereas that at higher frequencies remains, even in the later part of the response. In order to investigate this phenomenon quantitatively, an experiment was performed in order to clarify the reverberation characteristics.

3. Study on reverberation characteristics by a scale model experiment

3.1. Outline of the experiments

A 1/20 scale model experiment was performed in which the reverberation characteristics of various types of rooms were measured. The experimental set-up is shown in Fig. 2. In the experiment, a pulse sound is radiated from a spark discharge source and the room responses at a receiving point were detected with a 1/4-inch omni-directional microphone. The S/N ratio was obtained by 32-times synchronous averaging. After 1/3-octave band filtering from 1 kHz to 40 kHz (real scale: 50 Hz to 2 kHz), the reverberation time for each frequency band was obtained by the integrated impulse response method. The evaluation range for reverberation time was set to −5 to −25 dB based on the obtained S/N ratio of the impulse responses. Felt having a thickness of 2 mm was used as the absorber. The absorption coefficient of the felt as measured in a scale model reverberation chamber is shown in Fig. 3. The experimental conditions for the room are listed in Table 1. As a basic study, the effects of (i) the position of the absorbers and (ii) the height of the ceiling on reverberation characteristics were investigated for a rectangular 12 m × 24 m room. After the basic study, the effect of changing the room shape was investigated by attaching wall diffusers having a triangular shape (refer to Fig. 4) either vertically or horizontally to the walls and inclining entire wall surfaces (refer to Fig. 5).

3.2. Results and discussion

Figure 6 shows the variation of reverberation characteristics for various placements of absorbers. In two conditions, in which the room has either an absorptive floor ( ■ ) or an absorptive floor and ceiling ( ● ), there exist clear peaks of reverberation time at middle (630 Hz) and high (1 kHz) frequencies, respectively, indicating that an uneven distribution of absorbers causes unnatural reverberation characteristics. The same phenomena have been reported [1]. In order to determine the effect of ceiling height on the reverberation characteristics of a room with an absorptive floor and ceiling, the reverberation time was measured for rooms having four different ceiling heights: 2.4 m, 3 m, 4.5 m and 6 m. Figure 7 shows the experimental results. The reverberation time in the middle- and high-frequency ranges is long, regardless of the height of the ceiling. It should be noted that the peak frequency shifts lower as the height of the ceiling becomes higher. The same tendency is also seen for rooms in which only the floor is absorptive. Figure 8 shows the effect of wall diffusers. The tendency for the reverberation time to become long in the middle- and high-frequency ranges remains in the case of horizontal diffusers (Type A), whereas in the case of vertical diffusers (Type B), such unnatural characteristics were improved and the frequency characteristic became flat. Figure 9 shows the effect of wall inclination on the reverberation characteristics. Only the case in which all four walls were inclined (Type E) shows no peak in the reverberation time and a flat frequency characteristic. Figure 10 shows the impulse response and its spectrogram for a room (absorptive floor) with all walls inclined. Compared to the rectangular...
Fig. 1 (a) An impulse response, and (b) its running spectrogram, in a $12 \times 24 \times 3$ m room with an absorptive floor.

Fig. 2 Arrangement of the microphone and the sound source for the scale model experiment: (a) plan and (b) cross section.

Fig. 3 Absorption characteristic of felt.

Table 1 Experimental conditions.

<table>
<thead>
<tr>
<th>i. Position of absorbers</th>
<th>(1) no absorbers</th>
<th>(2) floor</th>
<th>(3) floor and ceiling</th>
<th>(4) all sides</th>
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<tbody>
<tr>
<td>ii. Room height [m]</td>
<td>2.4, 3.0, 4.5, 6.0</td>
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Fig. 4 Dimensions and arrangement of diffusers.

Fig. 5 Rooms with inclined walls (angle of 10°): short side walls inclined (Type C), long side walls inclined (Type D), and all walls inclined (Type E).

Fig. 6 Reverberation time in a room of 3 m in height.

Fig. 7 Variation in reverberation characteristics for various room heights.

room shown in Fig. 1, the waveform decays rapidly and the energy in middle- and high-frequency ranges is dissipated.

4. Conclusions
Through the scale model experiment conducted in the present study, reverberation time was confirmed to become longer in the middle- and high-frequency range in a room having an uneven distribution of absorbers. This phenomenon is caused by the existence of parallelepiped reflective walls.
Therefore, inclination of the walls and the placement of diffusers in order to disrupt parallel wave propagation are effective means of reducing the reverberation time.

References