PROCEEDINGS of the
International Symposium on Room Acoustics

15 to 17 September 2019 in Amsterdam, Netherlands

Scaled model experiments for the investigation of acoustic characteristics of rectangular music rehearsal room with diffusers

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ABSTRACT

In this paper, effects of diffusers in a rectangular music rehearsal room are investigated by evaluating acoustic characteristics of diffusers and a rehearsal room. Two types of diffusers are installed in the investigated rehearsal room of 1485 cubic meters. One is installed in front of walls and consists of reflecting plates inclined at various angles with respect to the back wall. The other is installed on the ceiling and consists of lattices with air space. First, random incidence absorption coefficients and scattering coefficients of diffusers are measured in the 1:5 scaled reverberation room as an evaluation for diffusers. Secondly, omni-directional impulse responses in both 1:10 scaled rehearsal room with and without diffusers are assessed and changes in the reverberation (*EDT*), clarity (C_{80}) and loudness (G) are investigated. Finally, to investigate the contribution of diffusers to the spatial information, inter-aural cross correlation coefficients are evaluated using the 1/10 scaled dummy head and visualizations of the sound arrival direction are conducted using the 6-channel cardioid microphone.

Keywords: Acoustic diffuser, Music rehearsal room, Scaled model experiment, Scattering coefficient

1. INTRODUCTION

Music rehearsal rooms are basis for the musical activity and require a relevant reverberation, clarity, loudness and easiness of the ensemble. However, filling of these requirements is difficult since, for architectural constraints, room shapes often become rectangular in which excessive reverberation arises for multiple reflections between opposite walls. To control reverberation in musical spaces, an application of acoustic diffusers is often preferred because diffusers can prevent excessive reverberation with less sound energy losses [1]. It is important to grasp effects and desirable acoustics properties of diffusers in various rooms for beneficial application of diffusers. In concert halls, effects of diffusers have been investigated objectively and subjectively [2, 3, 4]. Additionally, as an example for non-musical spaces, there is also a work on detailed examination with respect to effects of diffusers in meeting room [5]. However, rectangular music rehearsal rooms are basically designed using absorbers such as perforated panels. Effects and utilization techniques of diffusers in there have not been discussed adequately. The construction of utilization techniques and design procedures of diffusers for music rehearsal room is very valuable for acoustics design in practice because diffusers have superior flexibility in designability and can also have sound absorption performance as well as scattering.

In this paper, effects of diffusers in a rectangular music rehearsal room are investigated by evaluating acoustic characteristics of diffusers and a rehearsal room. Figure 1 shows the interior view of investigated rehearsal room of 1485 m^3. This rehearsal room will be established in the Yamagata Prefectural Cultural Arts Center (Japan) and orchestra rehearsal or small concert are supposed in there. Two types of the unique diffusers are installed in the rehearsal room. Random-incidence absorption coefficients and scattering coefficients of the diffusers are evaluated in the 1:5 scaled reverberation room. Moreover, omni-directional impulse responses in both 1:10 scaled rehearsal room with and without diffusers are measured and then changes in the reverberation

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Figure 1 – Interior view of the investigated music rehearsal room.

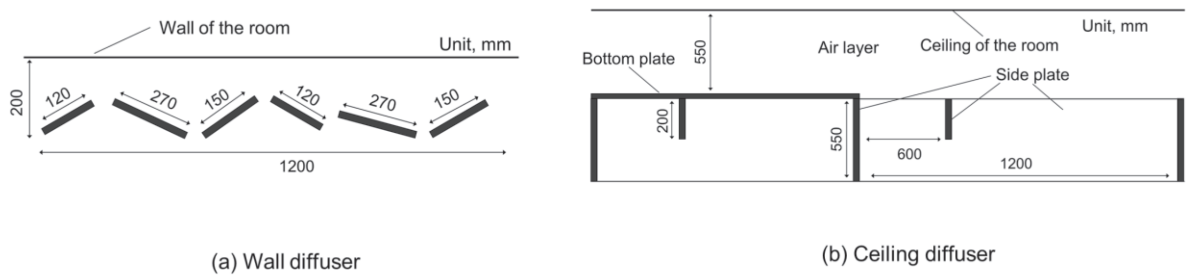

Figure 2 – Cross sections for (a) Wall diffuser and (b) Ceiling diffuser.

(T_{20}, EDT), clarity (C_{80}) and loudness (G) are investigated. Finally, to investigate the contribution of diffusers to the spatial information, inter-aural cross correlation coefficients ($IACC$) are evaluated using the 1/10 scaled dummy head and visualizations of the sound arrival direction are conducted using the 6-channel cardioid microphone.

2. ACOUSTIC CHARACTERISTICS OF INSTALLED DIFFUSERS

Random-incidence absorption and scattering coefficients of two types diffusers installed to the music rehearsal room were measured. Cross sections for the diffusers are illustrated in Fig.2. The one of diffusers consists wooden reflectors set with various angles at 1.2 m cycle with respect to walls (Wall diffuser). The other is an air layer-backed wooden lattice ceiling with various cavities which differ as for height of side plates and the presence of the bottom plate (Ceiling diffuser). These diffusers were designed for spatial and also temporal dispersion in reflection waves. As well as scattering, absorption deriving from resonance are expected for both diffusers because of their configuration having an elastic plate and rigid-backed air layer.

Random-incidence absorption and scattering coefficients were measured using 1/5 scaled model of reverberation room and both diffusers. Figure 3 presents the 1/5 reverberation room and circular-truncated diffusers. The volume of reverberation room and the diameter of diffusers for 1/1 scale are respectively 212 m^3 and 3.75 m. As for the absorption measurements, we followed ISO 354 [6]. The 1/5 diffusers were set on the floor of 1/5 reverberation room with it placed on a wooden circular base plate. As for the scattering measurement, we referred ISO 17497-1 [7] and [8]. The same samples as the absorption measurements were installed on a turntable. Moreover, the samples were surrounded with a plastic border with a thickness of 1 mm for suppressing baneful influence of diffracted waves from the edge of sample. Impulse responses in 1/5 reverberation room were measured using the swept-sine signal with signal length of 1.37 s in six setting of two loudspeaker and three microphones position. A continuous approach was employed to measure the reverberation

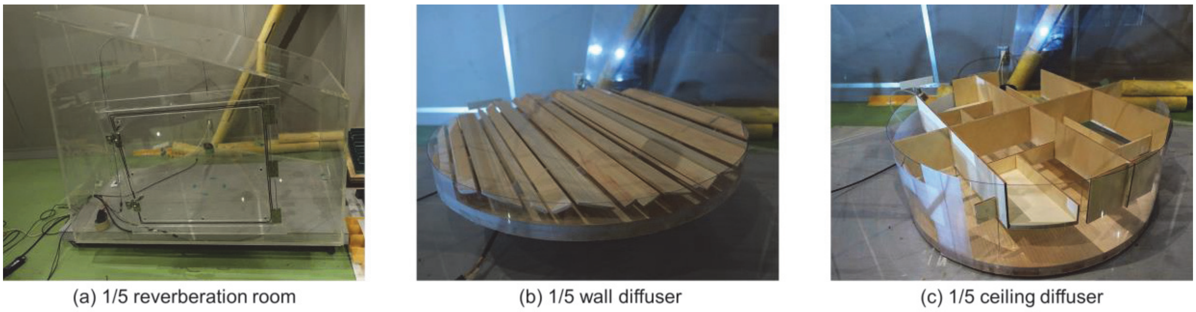

Figure 3 – 1/5 scaled models for the absorption and scattering measurements:
(a) 1/5 reverberation room, (b) 1/5 wall diffuser and (c) 1/5 ceiling diffuser.

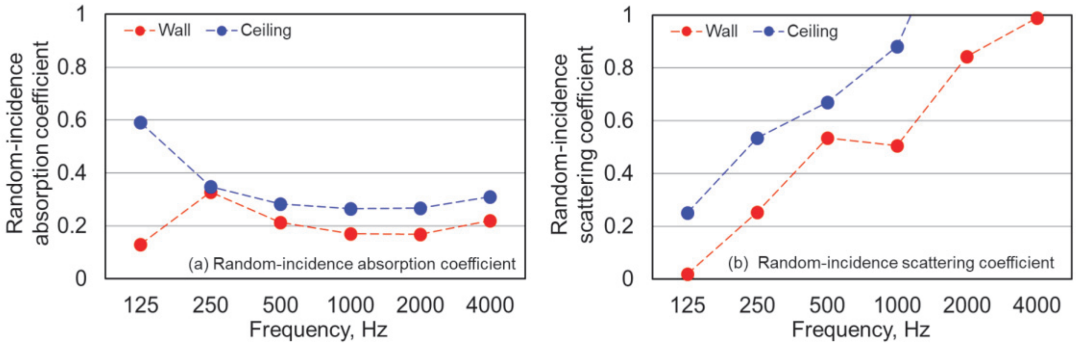

Figure 4 – Acoustic characteristics of the diffusers. (a) Random-incidence absorption coefficient and (b) Random-incidence scattering coefficient.

times for rotating conditions with revolution period of 162 s/rev and 116 signals. Note that following measured scattering coefficient for the ceiling diffuser is only reference value because the height of ceiling diffuser was higher than maximum structural depth presented by ISO of 1/16 of the diameter of the base plate.

Figure 4 presents random-incidence absorption and scattering coefficient of the diffusers. Both diffusers showed a resonance-type absorption characteristic with the peak frequency of 125 Hz for the ceiling diffuser and 250 Hz for the wall diffuser. The ceiling and wall diffuser showed absorption coefficients of around 0.6 and 0.3 respectively at peak frequency. Despite having no acoustic resistance element such as the porous materials or perforations, both diffusers indicated reasonable absorption performances. Additionally, high values in scattering coefficients were observed in both diffusers at above mid-frequency. The values exceeded 0.5 after 250 Hz for the ceiling diffuser and 500 Hz for the wall diffuser, and exceeded 1.0 after 2 kHz for the ceiling diffuser.

3. OMNI-DIRECTIONAL IMPULSE RESPONSES MEASUREMENT IN 1/10 SCALED REHEARSAL ROOM

Omni-directional impulse responses in a 1/10 scaled rehearsal room for the condition without and with the diffusers were measured. Moreover, T_{20}, EDT, C_{80} and G were compared to investigate effects of diffusers in objectively acoustic parameters. The dimension of rehearsal room and the plane with a source point (S) and nine receivers (R1 ~ R9) are shown in Fig.5. The source signal of swept-sine emitted from a small sized dodecahedron loudspeaker was collected by 1/4-inch omni-directional microphone. An oxygen concentration in the scaled rehearsal room was set to around 1% by the nitrogen purge to suppress the air absorption for higher frequencies. The above acoustic parameters were calculated at nine receivers in the range of 125 Hz to 2 kHz after transforming the impulse responses to real scaled values.

125 Hz, 500 Hz and 2 kHz 1/1 octave limited impulse responses at R5 up to 1.0 s compared

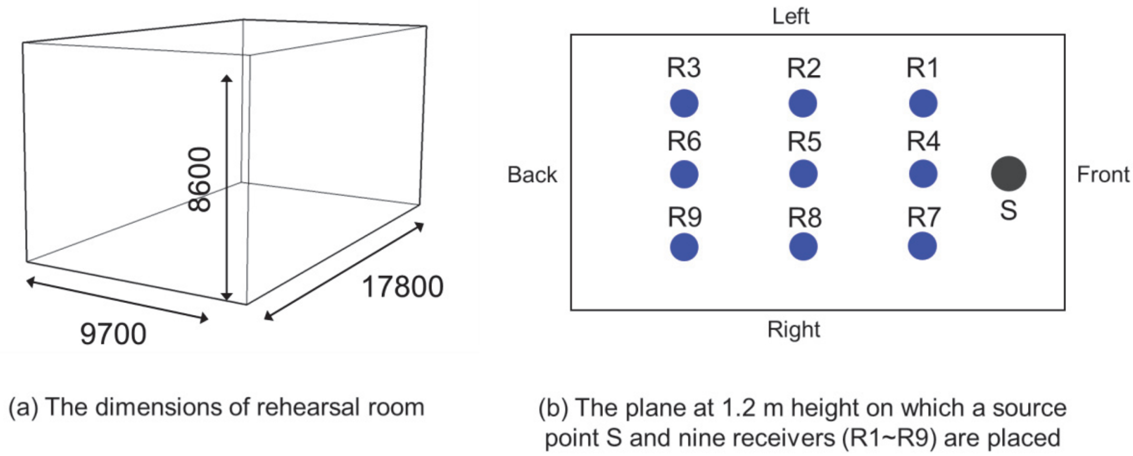

Figure 5 – (a) The dimensions of rehearsal room and (b) The plane at 1.2 m height on which a source point S and nine receivers (R1 ~ R9) are placed.

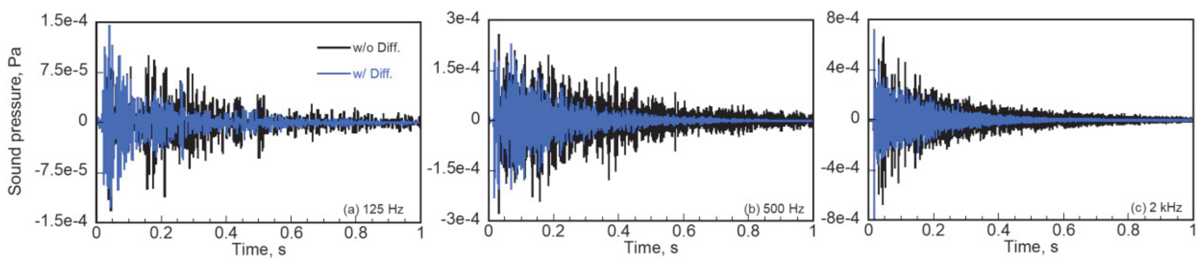

Figure 6 – Comparisons of 1/1 octave limited impulse responses at R5 up to 1.0 s compared between the scaled rehearsal room without and with diffusers at (a) 125 Hz, (b) 500 Hz and (c) 2 kHz.

between the scaled rehearsal room without and with diffusers are indicated in Fig.6. At 125 Hz, conspicuous early reflections were observed regardless of presence of diffuser. After that, the impulse response for the case with diffusers converged fast compared to the case without diffusers for high absorption property of the ceiling diffuser. However, slow dissipation of waves propagating in a horizontal plane, which derived from the low absorption and scattering properties of wall diffuser, were observed. At 500 Hz, prominent reflections were weakened by moderate absorption and scattering properties of both diffusers. At 2 kHz, by high scattering properties of both the wall and ceiling diffusers, intense reflections were thoroughly dispersed and the impulse response decreased smoothly. Comparisons of spatial averaged values for T_{20}, EDT, C_{80} and G between the conditions without and with diffusers are presented in Fig.7. As for reverberation, T_{20}s were reduced from 2.23 ~ 2.83 s to 1.12 ~ 1.65 s and EDTs were reduced from 2.25 ~ 2.69 s to 1.04 ~ 1.33 s. Installation of diffusers changed reverberation in the rehearsal room greatly due to their compatible performances in absorption and scattering. At 125 Hz, a difference between T_{20} and EDT was larger compared with other frequencies. It derived from that waves propagating in the horizontal plane of rehearsal room decreased slowly for low absorption of the wall diffuser. C_{80}s were improved 4.02 ~ 6.17 JND (1 JND = 1.0 dB [9]). The values were changed largely, especially, at 125 and 250 Hz which corresponded the peak frequencies of absorption coefficients of each diffuser. Gs were reduced with 2.07 ~ 3.26 JND (1 JND = 1.0 dB [9]) which were smaller JND values than the case of clarity. There is possibility that the results that clarity was more improved than loudness are unique benefit for the application of diffuser with high scattering performance to rectangular music rehearsal room. To validate it investigations for acoustics properties of rehearsal rooms with only absorption treatment or not absorptive diffusers are required.

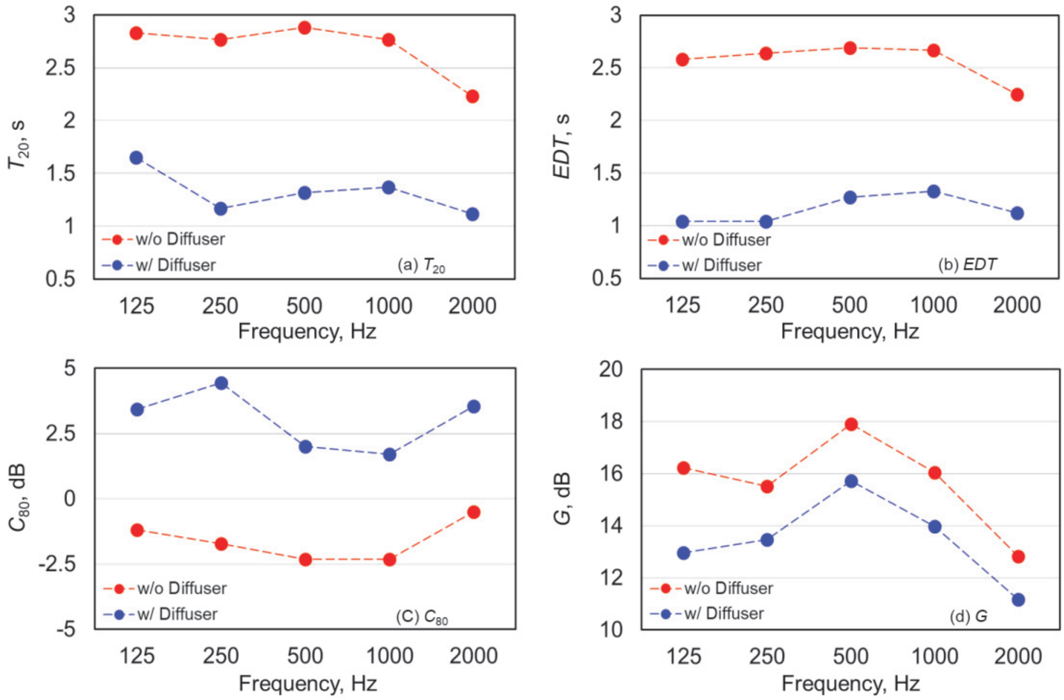

Figure 7 – Comparisons of acoustic parameters averaged at 9 receivers between the rehearsal room without and with diffusers. (a) T_{20}, (b) EDT, (c) C_{80} and (d) G.

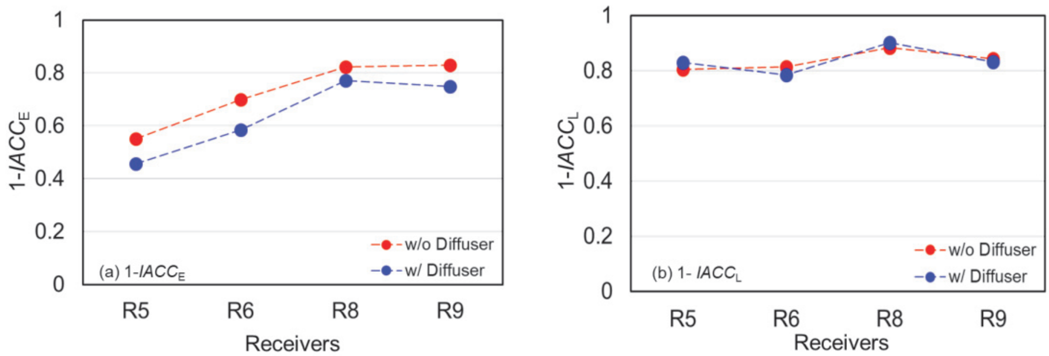

Figure 8 – Comparisons of $IACC$s between the rehearsal room without and with diffusers. (a) 1-$IACC_E$ and (b) 1-$IACC_L$.

4. DIRECTIONAL IMPULSE RESPONSES MEASUREMENT IN 1/10 SCALED REHEARSAL ROOM

4.1 2-channnel impulse response measurement

To examine contribution of diffusers to the spaciousness, $IACC$ in the 1/10 rehearsal room were evaluated using 1/10 2-channel dummy head microphone for the cases without and with diffusers. The dummy head microphone was set with its front facing the direction of front in the plane of Figure 5(b). The swept-sine signal was used as a source and binaural impulse responses were measured at 4 receivers (R5, R6, R8, R9). $IACC$ for the early reflections ($IACC_E$) and for the late reverberant sounds ($IACC_L$) averaged at 0.5 k, 1 k and 2 kHz were respectively calculated as indexes for the apparent source width (ASW) and listener envelopment (LEV). Figure 8(a) presents the

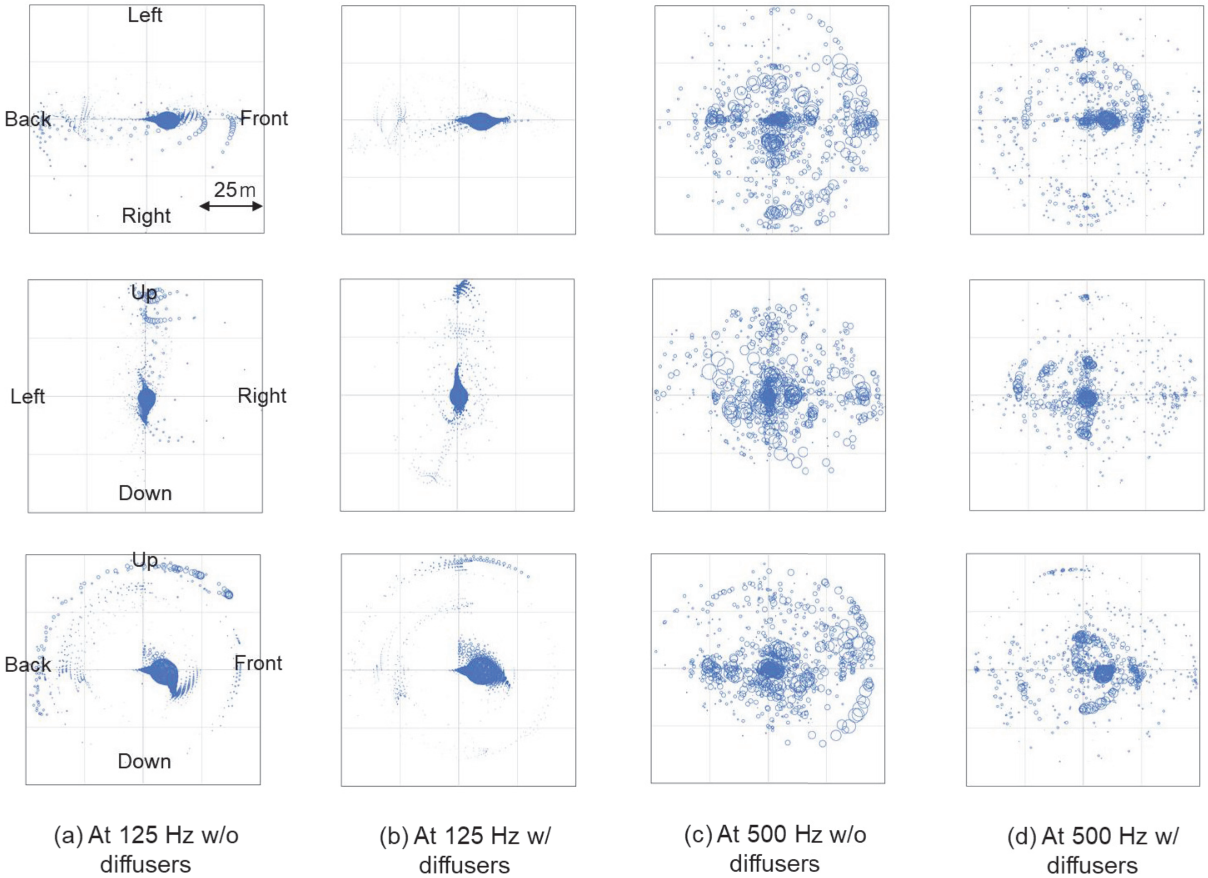

Figure 9 – Visualizations of virtual image source distributions for four conditions:(a) At 125 Hz without diffusers, (b) At 125 Hz with diffusers, (c) At 500 Hz without diffusers and (d) At 500 Hz with diffusers.

comparison of 1-$IACC_E$ at 4 receivers between the scaled rehearsal room without and with the diffusers. The diffusers reduced 1-$IACC_E$ averaged at 0.5 kHz to 2 kHz independent of receiver's positions. Therefore, diffusers in the reflective rectangular room have the potential of suppressing ASW for positive correlation of 1-$IACC_E$ and ASW. Figure 8(b) presents the comparison of 1-$IACC_L$ at 4 receivers. The result showed that the diffusers affected LEV scarcely.

4.2 6-channnel impulse response measurement

The sound arrival directions in the scaled rehearsal room were visualized using sound intensity to discuss how diffusers affected a structure of reflections. To access sound intensity, impulse responses measurement with 6-channel cardioid microphone were conducted. Torn burst signals with center frequencies at 1.25 and 5 kHz were adopted as sources. Directional impulse responses were measured at R5. Figure 9 shows the visualizations for virtual sound source distributions in the rehearsal room at 125 and 500 Hz. Virtual sound sources were visualized by blue circles, of which size indicated the magnitude of intensities. A distance from the center means temporal delay of incident sounds. Grid size of 25 m corresponds around 0.074 s delay. At 125 Hz, reflections from upper were softened by ceiling diffuser. However, the visualizations for virtual sound source distributions at low frequency was not appropriate for detailed analysis since reflections from both sides were not visualized for their long wave length. At 500 Hz, for the case without diffusers, intense sounds arrived from various directions in wide time range. In this case, late reflections become the masker for tones played by others in ensemble. On the other hand, intense reflections were prevented by scattering in the case with diffuser. Therefore, the diffusers help for differentiation of sounds for ensemble in which tones are played simultaneously from various directions.

5. CONCLUSIONS

The present paper investigated effects of diffusers in the rectangular music rehearsal room of 1485 m^3 using scaled model experiments. Acoustic characteristics of the installed diffusers were evaluated through the measurement of absorption and scattering properties using 1/5 scaled diffusers. Both diffusers showed high values of scattering coefficients above mid-frequency and reasonable absorption performances. Effects of these diffusers in the sound field of rehearsal room were examined with 1/10 scaled rehearsal room. For the installation of diffusers which balance absorption and scattering properties, T_{20}, EDT, C_{80} and G were improved even though there were no absorbers. Especially, reverberation and clarity changed drastically than loudness. Finally, the contribution in spatial information was examined by measurements for 2-channnel or 6-channel directional impulse responses. These approaches cleared that the diffusers in the reflective rectangular room reduce ASW but did not affect LEV. Additionally, visualization of virtual image source distributions suggested that the diffusers helped sound image localization by elimination of intense reflection arriving in wide time range. For more detailed discussions, we will work on visualization of virtual image source distributions for high frequencies, which are expected observation of more scattering sounds, and listening tests to examine subjective effect of diffusers.

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