PERCEPTION OF SCATTERED SOUNDS IN CONCERT HALLS

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1 INTRODUCTION

Lateral wall structures close to the sound source on stage are considered major components influencing early sound fields in concert halls. However, as diffusive halls usually have the same proportion of irregular textures in all the walls, including the ceiling, absorption caused by extensive diffusive surfaces may cause insufficient reverberation and spatial responsiveness in the halls. Until recently, evaluation methods for scattering characteristics of wall profiles had not been developed, especially for in-situ diffusivity. As the diffusion characteristics measured in a laboratory do not deal with directional information, the predicted sounds using the laboratory data are often different from the actual sound fields. Therefore, to design a diffuser profile, an orthogonal parameter which evaluates the in-situ condition of diffusivity is required.

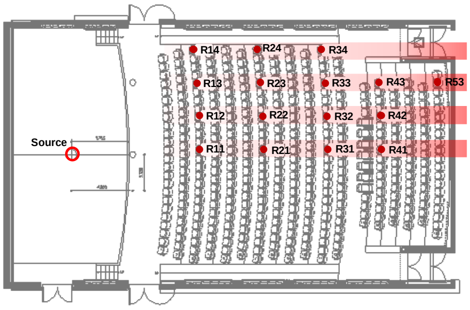
In diffusion studies, scale models were used to investigate the objective effects of diffusers on scattered sounds and acoustical parameters [1-3]. It has been noticed that the diffusive surfaces decrease SPL and RT as a result of weakened specular reflections and smoothed sound decay. Scattered reflections by diffusers also yield a decrease in the level of specular peaks, and increase the peak density in impulse responses. The difference of visual characteristics in impulse response energy time function plots was defined as a new parameter, the number of peaks (Np), for investigation of in-situ diffusion [4]. However, the parameter has not been fully verified through subjective evaluation in terms of diffusivity perception. Ando found that IACC was related to the subjective diffuseness [5]. Ryu and Jeon showed the preference model of scattered sound as a function of SPL, EDT and $IACC_{L3}$ [3]. However, there is still a lack of studies on the perception of scattered sounds in order to develop objective parameters for the design of diffuser sin concert halls.

In the present study, scattered sounds are evaluated objectively and subjectively by varying the wall conditions in actual halls; diffusive, reflective and absorptive surfaces are employed. In real halls, the acoustical parameters were measured together with Np to investigate the effect of scattered sounds. Then, auditory tests for convolved music in the measured positions were carried out using the different sound fields selected from the objective measurement result.

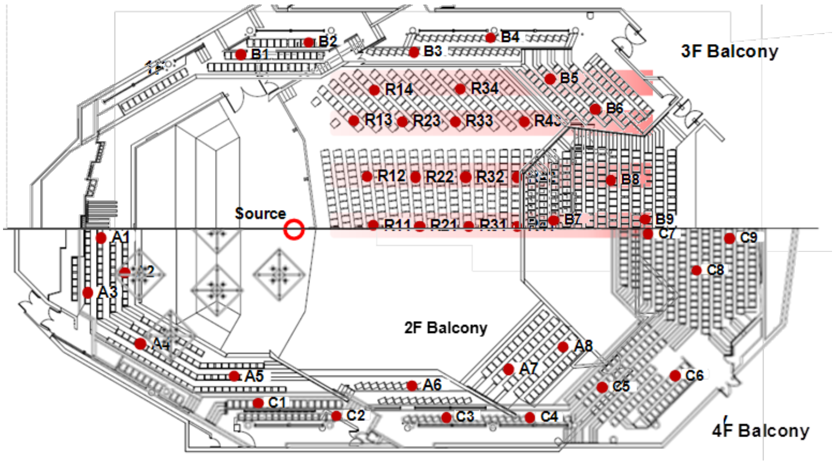
2 INVESTIGATION OF HALL DIFFUSION

The acoustical characteristics of arecital hall (450-seat) with highly diffusive lateral walls and a concert hall (2,300-seat) with relatively less diffusive walls were measured. From the impulse responses of the two halls, objective and subjective tests were conducted to investigate the difference of diffusive sound fields from the halls. Figure 1 shows the measurement positions of sound source and receivers in the halls: 16 receiver positions in the small hall and 42 in the large hall were selected. The conventional acoustical parameters such as RT and G were calculated. In addition, Np was calculated from the impulse response as counting peaks within the lapsed time for the effective amplitude drop (-20 dB) after the direct sound. In the auditory tests, 34 and 21 listeners attended for the two halls, respectively.

As shown in table 1, two groups divided in the subjective preferences: one group preferred louder sounds, whereas another preferred higher number of early reflections (Np) despite of lower sound levels. On the other hand, in the bigger but less diffusive hall, one group preferred louder and clearer sounds but for another group, the influential factor is not Np but $1\text{-}IACC_{E3}$. This result indicates that there exist dominant acoustical factors for the diffusion perception affected by different surface diffusivities. However, there is a limitation in this study that the variation of the sound stimuli come from the same sound fields, which may overlook the single most important factor such as G. Therefore, for a further study, each sound field need to be controlled by varying absorption characteristics such as wall treatments.



(a) A small hall with highly diffusive walls



(b) A large hall with less diffusive walls

Figure 1. Hall floor plans and measurement positions

Table 1. Correlation coefficients between the preferences in scale values and the acoustical parameters for the highly and less diffusive halls

	Group	RT	EDT	G	C80	$1\text{-}IACC_{E3}$	Np
The small hall	S-I	0.02	0.57	0.84**	-0.22	-0.44	-0.90**
	S-II	0.30	-0.54	-0.72*	0.32	0.69**	0.75**
The large hall	L-I	0.44	-0.47	0.93**	0.97**	-0.72**	-0.47
	L-II	-0.23	0.59*	-0.80*	-0.81**	0.60*	-0.02

* $p<0.05$,** $p<0.01$

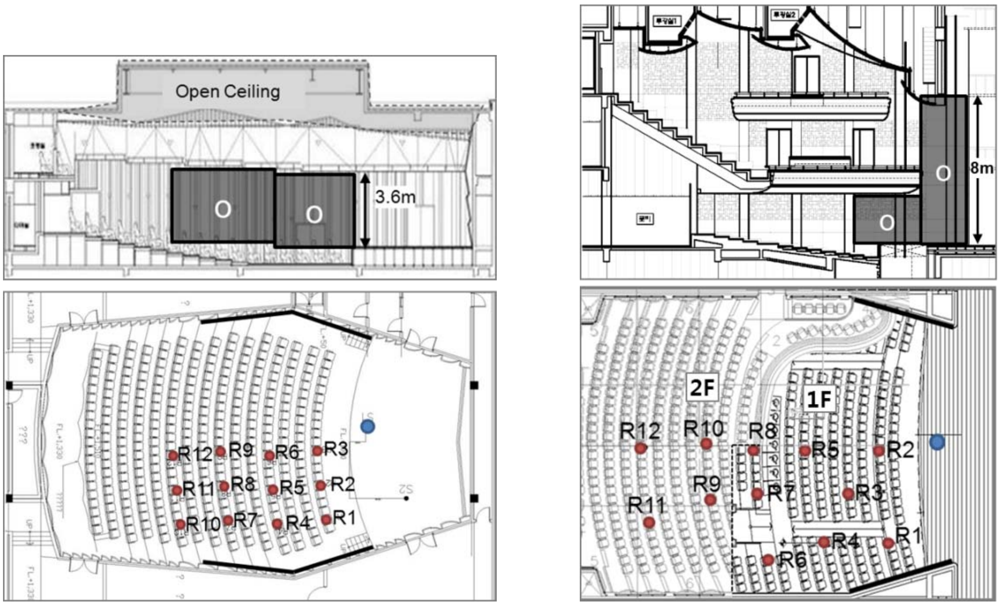
3 VARIATION OF SURFACE ABSORPTIONS

3.1 Experimental set-up

A chamber hall (443 seats) was designed as a reversed-fan shape with saw-toothed and tinted walls to provide scattered reflections to the audience seats. Comparatively within a same performing venue, a musical theater (630 seats) is next to the chamber hall to focus on its function of musical and operatic performances.

To achieve diffusive, reflective and absorptive conditions, 5mm thick plastic boards and microfiber sheets were installed over the major diffusive surfaces on the lateral walls in both halls. The plastic boards were used for reflective condition, and the microfiber fabrics on the plastic boards were considered as absorptive condition. Average absorption coefficient of the 5mm thick plastic board was 0.08, not exceeding 0.20inany 1/3 octave frequency band. In case of microfiber on plastic board, average absorption coefficient was 0.44. In addition, the absorption coefficient of microfiber and plastic board with 100mmair gap was measured as 0.68. As shown in Figure 2, the surface areas for the additional materials used in the chamber hall and the drama theatre were 77 and 55 m^2, respectively.

Figure 2also shows the measurement positions in both halls. A dodecahedron loudspeaker was located at the soloist position on the front stage and 12 receivers were located over the audience area in both halls. Measurements were conducted in unoccupied conditions. The acoustical parameters were derived: RT (Reverberation time, T20), EDT (Early Decay Time), G (Sound Strength), C80 (Clarity) and IACC (Interaural Cross-correlation). Mid-frequency bands (500 to 1k Hz) were considered for averaging RT, EDT and G, and 3-bands (500 to 2k Hz) were considered for averaging $C80_{3B}$ and $1\text{-}IACC_{E3}$.



(a) The chamber hall (b) The drama theatre

Figure 2. The measurement position and wall condition

Table 2. Acoustical parameters of selected stimuli for the auditory tests

	Receiver	Condition	RT [s]	EDT [s]	G [dB]	$C80_{3B}$ [dB]	$1\text{-}IACC_{E3}$	Np
Chamber hall	R4, R8, R12	absorb/ reflect/diffuse	0.99-1.21	0.95-1.15	6.9-9.3	1.5-5.0	0.41-0.76	31-426
Drama theater	R3, R6, R12	absorb/ reflect/diffuse	0.90-0.97	0.66-0.85	2.6-6.6	4.9-8.2	0.26-0.76	22-418

4 AUDITORY EXPERIMENTS

4.1 Set-up

Auditory experiments were conducted using paired comparison method. Violin motif of Mendelssohn concerto (7 s) for the chamber hall and soprano motif of Mozart opera (7 s) for the drama theater were used for the music sources. The music dry sources were convolved with the selected impulse responses to be experimental music signals. The auralized music was presented to the subjects through headphone system (Sennheiser HD 600) with randomized pairs. Total of 15 subjects of musicians and acousticians participated in the tests. All subjects were asked to judge which sound was preferred.

Three receiver positions were selected with three wall conditions from each hall according to the Np values from the objective measurement results. Table 2 shows the acoustical characteristics which were analyzed from the selected impulse responses. Among the selected sounds, Np was varied from 31 to 426 in the chamber hall and from 22 to 418 in the drama theater. The sound level difference was 2.4 dB due to the different distances in the chamber hall and 4.0 dB in the drama theater.

4.2 Results

Figure 3 shows the scale values of preference in the chamber hall, when the lateral walls are varied from the original walls (diffusive) to the reflective and the absorptive conditions. The effects of wall conditions on the subjective responses were compared at the same receiver positions. The diffusive condition is preferred than the other conditions. The correlation between the number of peaks and scale values is statistically significant. From the results of the chamber hall, Np is the main factor to affect the preference of the sound fields. However, the sound strength is not correlated with the scale values. On the other hand, as shown in Figure 4, the reflective surfaces are preferred in the drama theater. The subjects seem to judge the sound fields based on the sound level: the sound strength is highly correlated with the scale values in the drama theater.

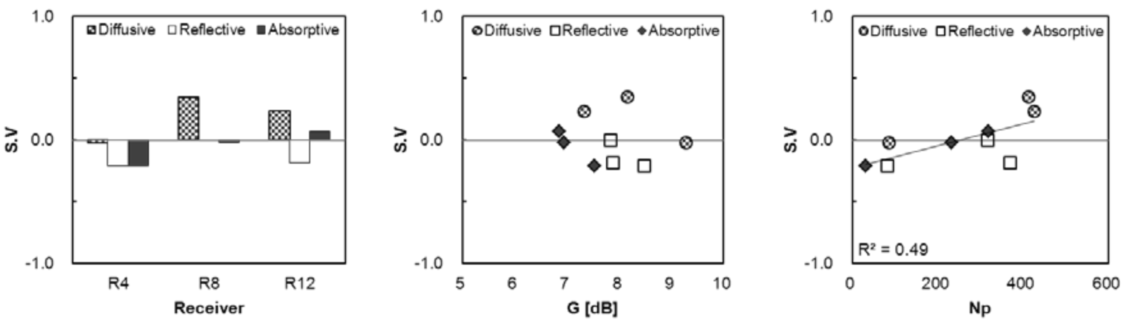


Figure 3. The scale values of preference in the chamber hall

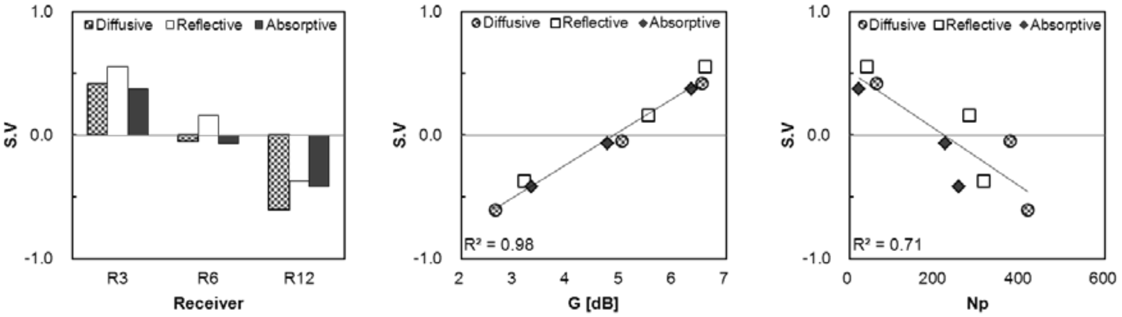


Figure 4. The scale values of preference in the drama theater

4.3 Correlation analysis

In order to clarify the perception model for scattered sounds, scale values of preference were compared with acoustical parameters. Table 3 shows the correlation between the scale values of preference and the halls' measured objective parameters. In the case of the chamber hall, the subjective response is not affected by the Np value, but not the G value. On the contrary, in case of the drama theater, higher G value affects the preference more. Naturally in a hall, G has negative correlation with Np by the source to receiver distance, due to inevitably higher reflection density with distance from the source.

Table 3. Correlation coefficients between the scale values and the acoustical parameters for the chamber hall and the drama theater

	RT	EDT	G	C80	$1\text{-}IACC_{E3}$	Np
Chamber hall	0.25	0.18	-0.13	-0.49	0.39	0.69*
Drama theater	-0.33	-0.30	0.99**	0.76*	0.39	-0.85**

* p<0.05,** p<0.01

5 CONCLUDING REMARKS

In this paper, scattered sound fields have been objectively and subjectively investigated in different halls with different surface diffusion. From the acoustical measurements of the halls, different ranges of the acoustical parameters including in-situ diffusivity index (Np) were shown from different seats in each hall.

From the subjective evaluation of the chamber hall, Np was found to be the dominant parameter, whereas the sound strength was dominant for the drama theater. There are possible reasons for the difference: one is that the effective range of sound strength within a hall might affect the subjects' judgment (4 dB in the drama theater and 2.4 dB in the chamber hall). The difference of hall usage typically presented with instrumental and vocal sources could be another reason. The experiments were carried out as a pilot test with only 15 subjects. The results should be verified with sufficient number of individual responses with a different set-up. This paper demonstrated that Np, the local maxima in the impulse responses, could be an effective parameter for acoustic quality. The difference limen of Np in relation with perceivable range of sound strength needs to be further investigated.

6 ACKNOWLEDGEMENT

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