# PERCEPTUAL ASPECTS OF SOUND DIFFUSENESS IN CONCERT HALLS

**Conference Paper** · July 2016



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23rd International Congress on Sound & Vibration
Athens, Greece 10-14 July 2016

# PERCEPTUAL ASPECTS OF SOUND DIFFUSENESS IN CONCERT HALLS

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The effects of wall diffusing elements on sound-field diffuseness in a tenth-scale model hall were investigated by measuring surface diffusivity of the lateral walls covered with horizontal diffusers. Objective characteristics were investigated using conventional room acoustic parameters and the number of peaks (Np) computed for the measured impulse responses, which were recorded under diffusive and non-diffusive conditions. In addition, as a measure of the perception of diffuse sound fields, the different descriptions for subjective diffuseness were defined in terms of density, decay (early/late) and isotropy of reflections. Results showed that the diffusive surfaces caused a increase in C80, 1-$IACC_{E3}$ and Np. Auditory experiments revealed that clarity, loudness and intimacy was increased after installing diffusers and the perception of subjective diffuseness was found to be highly correlated with Np.

## 1. Introduction

For a concert hall, the diffuser is one of the main factors in acoustic design. Therefore, many researchers study how to evaluate the performance of scatter and diffusion [1,2]. They also study the characteristics of diffusers in terms of their scattering and diffusion coefficients [3]. Moreover, the necessity for estimating sound field diffuseness has risen in order to adjust the diffuser for acoustical design. Jeon et al. [4] proposed the number of peaks (Np), which counts local peaks to evaluate the diffusive reflections. Hanyu [5] proposed diffuseness, which quantifies diffusion using a fluctuation decay curve of reflected sound energy. Regarding the perceptual aspects of sound diffuseness, Vitale [6] investigated the influence of scattering coefficient variations in auralized and real concert halls; however, there is no evident result. The main purpose of this study is to investigate the perceptual aspects of sound diffuseness directly using one-tenth-scale model measurements and subjective evaluations in diffusive and non-diffusive concert hall environments. This paper focuses especially on the influence of diffusers and how listeners perceive the sound field diffuseness.

## 2. Methodology

### 2.1 Hall descriptions

The concert hall used for measurement is named Art Center Incheon (ACI), located in Incheon, Korea. It has a seating capacity of 1,750 and a fan-shape design. As shown in Figure 1, three types of diffusers were used according to the area to adjust the diffusivity of the hall. The diffuser arrangements were designed according to the scattering and diffusion coefficients, and the higher performance diffuser was located close to the stage in the audience area. This arrangement was intended to form an equal acoustic condition and optimize the sidewall reflections to the audience area. For the stage sidewall, a non-diffusive surface was arranged for stage support to the musicians.

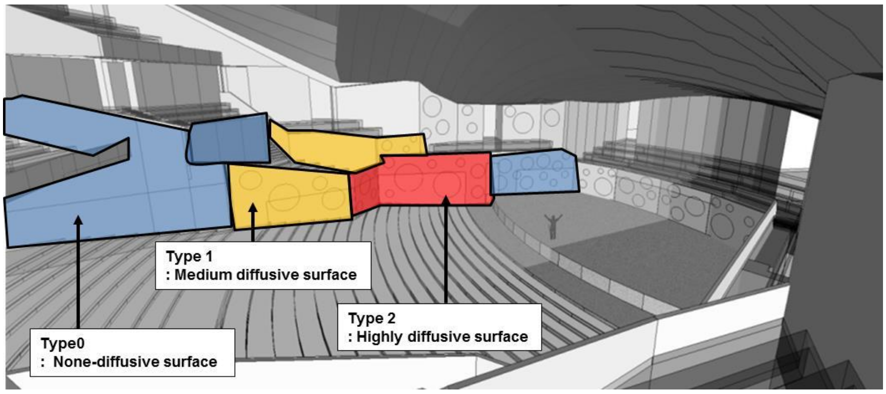


Figure 1: Diffuser designs in the concert halls.

## 2.2 Horizontal diffusers

The scattering (SC) and diffusion (DC) coefficients of the horizontal diffusers used in the hall are shown in Figure 2a, and the height information of each diffuser is presented in Figure 2b. The average coefficients were 0.05, 0.37, and 0.60 for SC and 0.24, 0.41, and 0.44 for DC at 500 to 3,150 Hz.

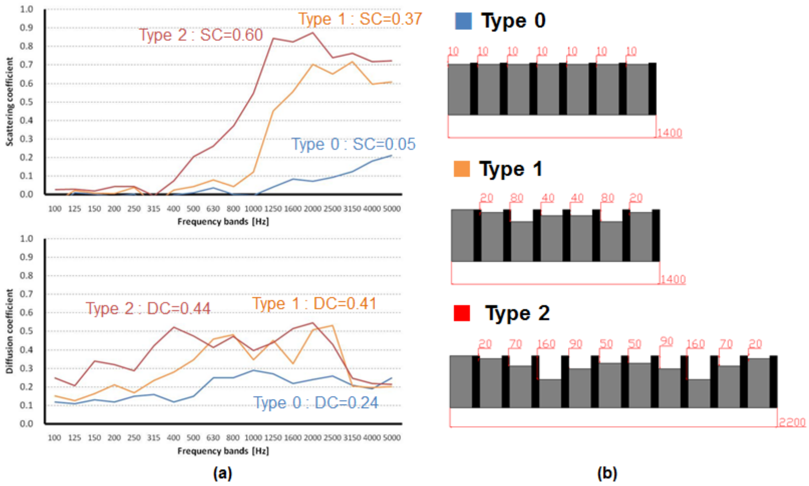


Figure 2 Detail of diffusers in the concert hall: (a) Scattering and diffusion coefficients and (b) Section.

## 2.3 Acoustical measurements

In order to investigate the influence of diffusers, a one-tenth-scale model was constructed, and measurements were conducted both with and without diffusers. For the scale model measurements, a one-tenth-sized loudspeaker and dummy head were used at five positions, as shown in Figure 3.

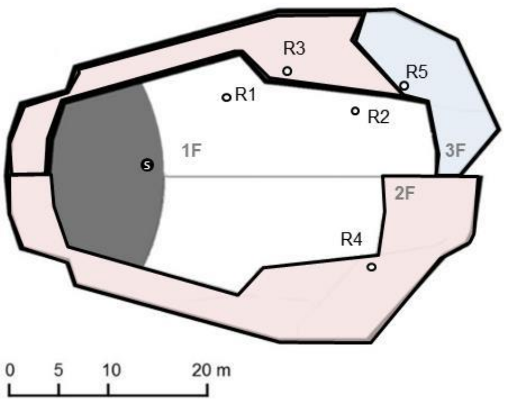


Figure 3: The source (Black circle, S) and receiver (White circle) positions in the concert hall.

### 2.4 Subjective evaluations

Thirty audio engineers and postgraduate acoustics students participated in the auditory experiment in order to investigate the response from diffusers. A 15-second soprano motif was convolved with measured impulse responses at five seats (R1 to R5) in diffusive and non-diffusive situations. Subjects listened to a total of 10 stimuli through headphones (Sennheiser HD 650) in the listening room with 25 dBA of background noise. The auditory experiment was conducted using an 11-point scale, and stimuli were repeatedly generated by themselves for comparison. In the auditory experiment, semantic differential scales were evaluated for 12 subjective impressions: clarity, reverberance, envelopment, intimacy, loudness, brilliance, bass ratio, reflection density, decay curve smoothness, reflection smoothness, isotropic directivity, and overall impressions. Before the subjective evaluation, subjects received a detailed explanation of the impressions [7].

## 3. Results

### 3.1 Room acoustic conditions

Room acoustical parameters such as EDT, RT, C80, G, and 1-IACC$_{E3}$ were analyzed from the acoustical measurements. We also calculated the number of peaks (Np) [4] and diffuseness [5] to compare the diffusivity of the concert hall. Overall, the parameters RT, EDT, and G decreased when diffusers were installed due to the increase in the absorption area. On the other hand, the diffused sound increased the C80, 1-IACC$_{E3}$, Np, and diffuseness.

Table 1: Averaged room acoustical condition of diffusive and non-diffusive concert hall.

| Diffuser | EDT | RT | C80 | G | 1-IACC$_{E3}$ | Np | Diffuseness |
|---|---|---|---|---|---|---|---|
| ○ | 2.22 | 2.01 | -1.0 | 5.0 | 0.70 | 97 | 18 |
| × | 2.24 | 2.18 | -1.4 | 5.4 | 0.65 | 79 | 23 |
| Difference | -0.02 | -0.17 | 0.4 | -0.4 | 0.05 | 17 | -5 |

### 3.2 Subjective responses

After installing diffusers in the concert hall, the subjective impressions increased overall, as shown in Table 2. Even though the sound strength decreased, the clarity, loudness, and intimacy increased. In the case of impressions related to the frequency characteristics, brilliance increased while the bass ratio decreased. In addition, the perception of diffuseness increased. Based on all the subjective impressions, the subjects' overall impression was higher for the diffusive case than for the non-diffusive case. Moreover, all differences between the two cases were statistically significant.

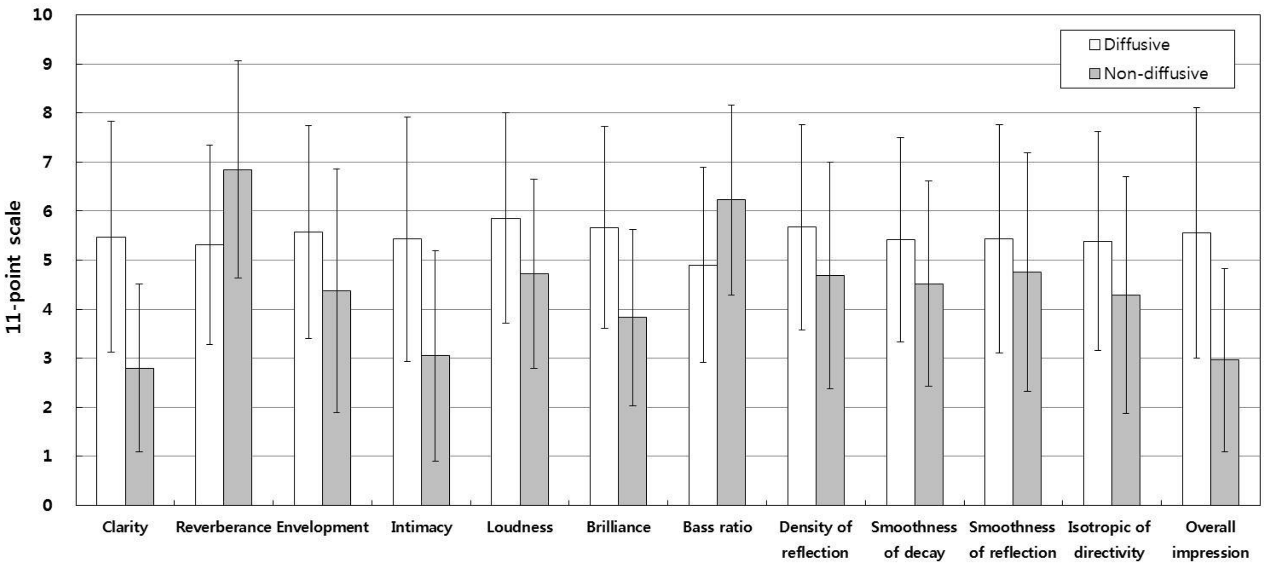


Figure 4: Averaged subjective impressions of diffusive and non-diffusive cases.

### 3.3 Relationships between acoustical parameters and subjective impressions

From the correlation analysis results (Table 3), it was found that the impressions related to the perception of diffuseness have significant relationships between Np and diffuseness. Moreover, the positive correlations between clarity, brilliance, and Np show that diffusers may boost the high-frequency range and give listeners clearer sound.

Table 3: Pearson's correlation coefficients between acoustical parameters and subjective impressions. Only cases with significance, $p<0.05$, are shown and those with $p<0.01$ are shown in bold face.

| | EDT | RT | G | C80 | 1-IACC$_{E3}$ | Np | Diffuseness |
|---|---|---|---|---|---|---|---|
| Clarity | | **-.64** | **-.19** | **.19** | **.24** | **.47** | **-.34** |
| Reverberance | | **.38** | **.22** | **-.18** | | **-.32** | **.25** |
| Envelopment | **.23** | **-.28** | | | | **.23** | **-.16** |
| Intimacy | | **-.52** | | **.21** | **.16** | **.38** | **-.30** |
| Loudness | **.21** | **-.29** | **.40** | **.18** | | | **-.21** |
| Brilliance | .13 | **-.50** | | **.19** | .13 | **.35** | **-.32** |
| Bass ratio | | **.30** | | | | **-.28** | **.19** |
| Density of reflection | | **-.26** | | | .15 | .13 | -.12 |
| Smoothness of decay | | **-.28** | -.13 | | .12 | **.17** | -.13 |
| Smoothness of reflection | | **-.21** | **-.18** | | | **.17** | -.12 |
| Isotropic of directivity | | **-.25** | **.27** | | | **.18** | **-.21** |
| Overall impression | | **-.56** | -.11 | .14 | **.18** | **.45** | **-.29** |

## 4. Conclusion

This study investigated the perceptual aspects of sound diffuseness in a concert hall by using a one-tenth-scale model and subjective evaluation. From the acoustical measurements, we can derive the effects of diffusers with regard to the acoustical parameters, including Np and diffuseness. In the subjective evaluation, clarity, intimacy, and loudness increased after installing diffusers despite the lower sound strength. Brilliance increased but the bass ratio decreased, which might have affected the perceptual clarity and intimacy. Subjective impressions related to the perception of diffuseness increased and have a positive correlation to Np and diffuseness. Further study will address the detailed perceptual aspects and characteristics of a diffusive environment in a concert hall.

## Acknowledgement

This work was supported by the Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2013R1A1A2062079).

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