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The effect of reflectors on Sound strength (G) and IACC in a fan-shape hall

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ABSTRACT

The effects of various reflecting surfaces on the audience G and IACC were investigated by using open-type 1:10 scale model. In this study, the orchestra shell and three types of reflector were designed to increase the G_{mid} and 1-$IACC_{E3}$. The reflectors were composed of triangular panels; the area of basic module was designed as 9 m^2, based on the previous study [Nakajima et al., J. Acoust. Soc. Am. 92, 1443–1451 (1992)]. In addition, the shape of reflectors was optimized by genetic algorithm to increase G and 1-IACC. Measurements of open-type 1:10 scale model were conducted to investigate the effect of reflectors on early sounds in the auditorium. The results indicated that G and IACC were changed around 5.8 dB and 0.29, respectively, when all the reflectors were installed.

INTRODUCTION

In general, a large fan-shaped hall has the acoustical deficiency in terms of loudness and spaciousness especially in the middle part of the auditorium; it is caused by lack of reflections from the lateral walls. Thus additional reflecting structures are to be installed for the acoustical quality of the auditorium. In this study orchestra shell and 3 types of reflectors were designed in the large fan-shaped auditorium with 3,000 seats. Additional reflecting structures were designed to provide the strong reflections to audience area and the effect of the structures on the acoustical quality of the large auditorium was investigated.

The direction of each structure was to improve the sound strength G and IACC by providing early reflections to the audience area. 1:10 scale model measurements were carried out to investigate the effect of reflecting surfaces on the sound strength G_{mid} and binaural quality index (BQI) 1-$IACC_{E3}$.

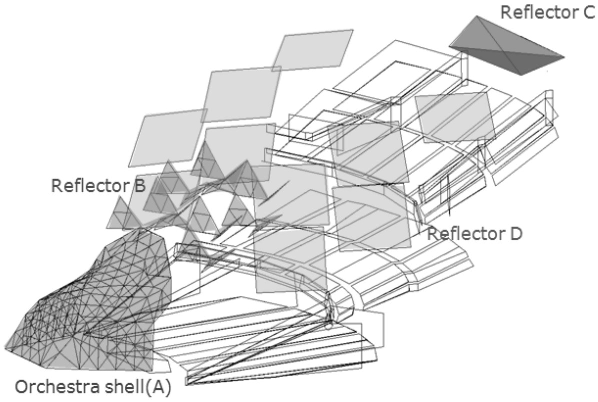

Figure 1. Schematic design of orchestra shell and reflectors

DESIGN OF REFLECTING STRUCTURES

As shown in Figure 1, the orchestra shell (A) and 3 types of reflectors (B, C, and D) was considered as a reflecting structures. The shape and location of each reflector were determined to improve G and IACC at the audience area.

Each reflecting structures were comprised of non-planar triangular panels, reflects the early sound energy onto the audience, arriving shortly after the direct sound based on previous study [1]. After reviewing the reflectors in Fujita Hall and Tanglewood Music Shed, the area of the triangular panels was determined as 6-9 m^2. The geometrical shape of each reflecting structure was optimized using genetic algorithm to increase sound pressure level and spaciousness at the audience area.

Orchestra shell

Shape of the orchestra was designed to reflect the sound energy to the whole audience, similar to the stage enclosure of Tanglewood Music Shed, Lenox, MA. Generally, sound pressure level at the audience is increased with decreasing the volume of stage. Thus, modified orchestra shell was designed to have a minimum volume on the basis of required area of stage. The maximum area of the orchestra shell was around 200 m^2, and it was planned to control the stage area according to the program.

Modified orchestra shell consist of triangular panel with an area of 6-9 m^2 considering the frequency characteristics of reflected sound.

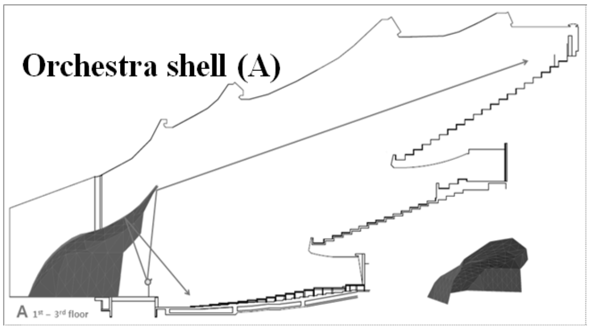

Figure 2. Modified orchestra shell (A)

Ceiling reflector (B)

Ceiling reflector over the front part of the audience, and was consist of four rows of triangular panels. It was designed that the first and second rows cover the 2nd floor and the others cover the 3rd floor. For the even distribution of early reflections to 2nd and 3rd floors, the ceiling reflections were tilted by 30◦.

The area of each triangular panel and the interior angle of an isosceles triangle were determined as 9 m^2 and 100◦, respectively based on the previous study [3]. It was expected that lateral diffraction from the edges of the panels maintain a uniform energy flow even down to very low frequencies.

As shown in Figure. 3, basic shape of ceiling reflectors, the 50% opened ceiling. And opening ratio and geometrical shape of reflector were optimized to increase the SPL and decrease the IACC at the audience. The variations of height in a cross section were 2 m and 3 m in both "W" and "M" shapes. Finally, 50% opened W shape was determined as an optimum case in terms of SPL and IACC.

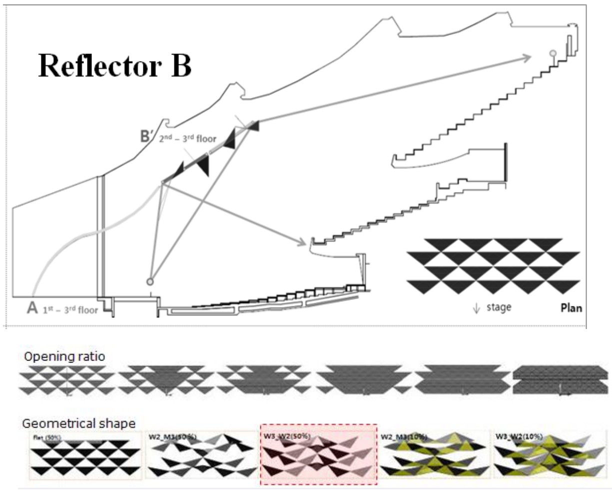

Figure 3. Ceiling reflector (B)

Reflector near the rear wall (C)

Reflector C was aimed to provide the reflections to remote listeners of 3rd floor. The shape of reflector was designed based on the reflections and the location, area and angle of reflecting surfaces were optimized using Genetic Algorithm to increase loudness and spaciousness at the 3rd floor. As shown in Figure 5, reflector C consists of 4 triangular panels and located around rear wall of 3rd floor and light room.

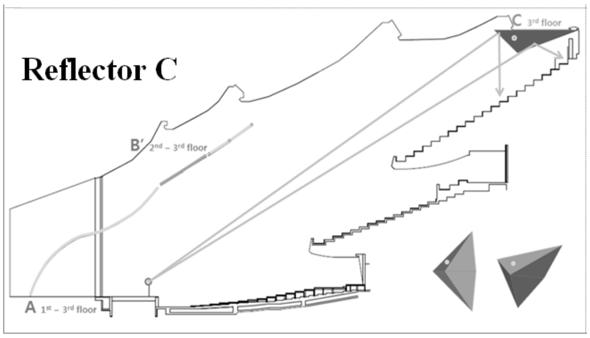

Figure 4. Reflector near the rear wall (C)

Side reflector (D)

In the fan shape hall the distance between lateral walls is increased with increasing the distance from the stage. Therefore the reflections do not reach to the central part of audience area although the lateral wall finished the reflecting material. Thus additional side reflector (reflector D) was designed for central audience area of 2nd and 3rd floor. The length and height of the panel was determined to reflect low frequency sound such as 250 Hz sound. Reflector D is consist of 10 panels and located near the side wall of each floor. The location and angle of reflector was determined roughly, considering the reflections and the sight line of audience. Finally, the detail location and angel was decided based on the result of computer simulation.

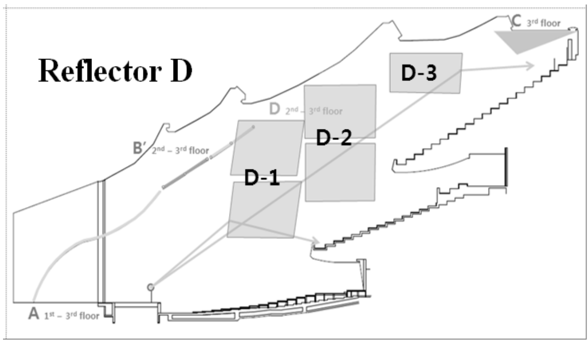

Figure 5. Side reflector (D)

1:10 SCALE MODEL MEASUREMENTS

Outline

A 1/10 scale model measurement was carried out to validate the effect of designed orchestra shell and reflectors in order to improve the large fan shape hall. As shown in Fig. 4, both new designed orchestra shell and ceiling reflectors were made of 3-5 mm-thick acrylic and fixed to the frame near the roof using 0.5 mm-thick wire.

Each reflecting structure was aimed to provide early reflections in the audience area, especially central part of the audience, in order to increase loudness and spaciousness. Thus the measurement was conducted without out any enclosures such as ceiling and wall, in order to investigate the effect of structures on early sound. The measurements were performed in a room with a reverberation time of 0.6 s. Side walls of the room and ceiling were already covered with polygonal absorption panel, and velour with a unit weight of 0.25 kg/m^2 were installed in the floor in order to prevent the reflections.

Figure 6. 1:10 Open-type scale model

Equipment

As shown in Figure 7, sinesweep was generated using 1:10 scale omni-directional speaker and binaural signal were recorded using 1:10 scale dummy-head. And binaural impulse responses were drawn by convoluting the recorded signals and inversefilter of played sinesweep. Then the sampling rate of the signal was modified based on the similarity law. Adobe audition and aurora 4.1 addon softwares were used at the measurement and analysis.

Figure 7. 1:10 dodecahedron loud speaker (left) and 1:10 dummy head (right)

In case of room acoustics measurement, sound source is specified as an omni-directional sound source in the ISO 3382. The directional deviation limit of sound power is also provided according to the frequencies. And 1:10 scale omni-directional loud speaker used in the measurement was satisfied with ISO regulation. (Deviation limit- ±1dB; 500Hz, ±1dB; 1000Hz, ±2dB; 2000Hz)

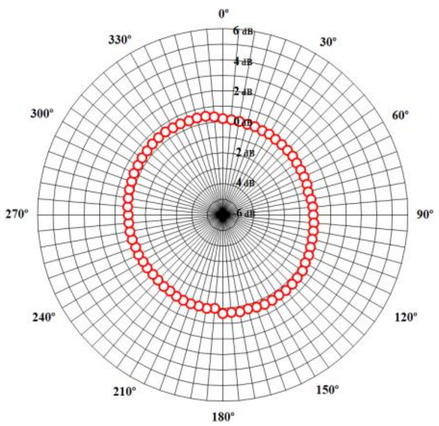

Figure 8. Directivity of 1:10 loud speaker (SEL_{mid}, dB)

Measurement points

Supposition of the 3,000 seats scale auditorium, source and receiver points were determined considering the distance from source and lateral wall. As shown in Figure 8, the omni-directional loud speaker was placed at a distance of 1 m from the front edge of the stage and 1 m from the centerline. The height of the sources was 1.5 m above the floor. The twenty four receivers were located in the audience area, and the receivers were positioned 1.2 m above the floor. The receivers located near the center line classified as the line 1 group, receivers located between lateral wall and center line classified as the line 2, and located near the lateral wall classified as the line 3. The height of the receivers in the 2nd and 3rd floor was adjusted using tripod considering the rake and elevation of 2nd and 3rd floors of the auditorium.

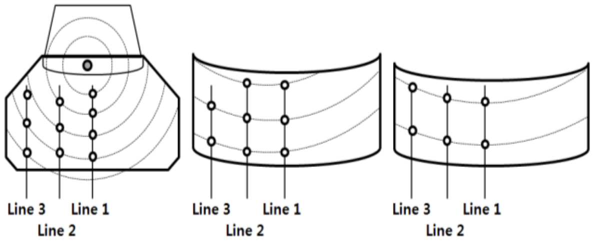

Figure 9. Measurement points on 1st floor (left), 2nd floor (middle), 3rd floor (right)

Measurement result

In the scale model measurement, the effects of designed structures on the loudness and spaciousness in the audience area were investigated. Sound strength, G_{mid} [dB] and BQI ($1\text{-}IACC_{E3}$) were applied to evaluate loudness and spaciousness. Measured results of each case were expressed by deviation (Δ; with reflector - without any reflector) of G and 1-IACC compare to the reference (without reflecting structures case). Measurement results were averaged according to the floor and line respectively.

The result shows that G and BQI were increased by installing the reflecting structures which provide the early reflections to the audience area. In case of orchestra shell (A) affect to the whole audience and it shows the largest contribution of increment of sound pressure level among the designed structures. G and BQI were increased 3dB and 0.11 respectively. Especially, orchestra shell contributes to increase of loudness and spaciousness at the 1st floor and the center part of audience area.

In case of ceiling reflector (B), effect of various condition of reflector such as geometrical shape (flat, "M" and "W" shapes) and opening ration (0-50 %) was investigated. And similar to the result from computer simulation, the measurement result shows that "W" shape which has variations of height in a cross section around 2 m and 3 concluded as an optimum case in terms of SPL and IACC, among the tested cases. Thus, only the result from optimum case was expressed in Figure 11 and 12. The result shows that G and BQI were increased around 1 dB and 0.05 in the whole audience area (especially line 1 and 2nd floor) by installing ceiling reflector (B)

The contribution of Reflector D is very low in increment of averaged value of G and BQI. But it affects to improve the loudness and spaciousness in the 3rd floor and line 2.

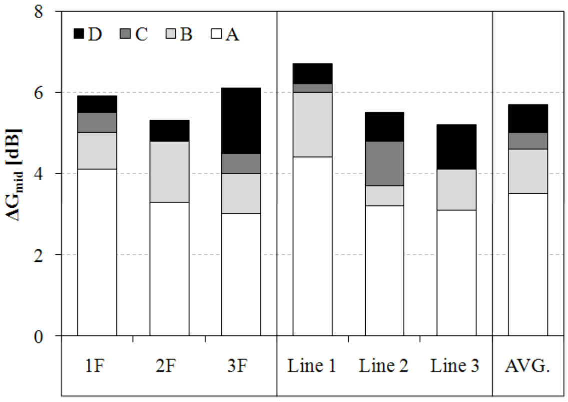

Figure 10. Measurement result: ΔG_{mid}, [dB]

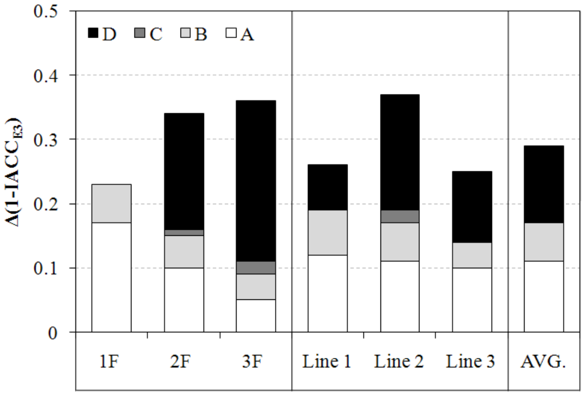

Figure 11. Measurement result: $\Delta(1\text{-}IACC_{E3})$

The G and BQI were increased on average by 0.12 and 1dB by installation of side reflector (D) which is aimed to provide the early reflections to 2nd and 3rd floor. Especially it contributes to increase the loudness in the 3rd floor and the spaciousness in the 2nd and 3rd floor.

In case of whole reflecting structures were installed, G and 1-IACC increased on average by 5.8 dB and 0.29. The increment of G and BQI shows the larger value in the 3rd floor and central area of the audience. Thus the structure investigated in this study can be improve the acoustical quality of large fan shape auditorium, especially center part and remote area from the stage that indicate the poor loudness and spaciousness.

SUMMARY

In this study, in order to improve acoustical quality such as loudness and spaciousness of auditorium, several reflecting structures were designed to provide early reflections to the audience area. Orchestra shell and 3 types of reflectors were suggested as reflecting structure and effect of each structure on sound strength G and BQI was investigated using 1:10 scale open-type scale model measurement. The result shows that G and 1-IACC were increased on average by 5.8 dB and 0.29 by installing the whole reflecting structures.

Open-type scale model method is aimed to examine the change of the early sound by additional reflecting surfaces. It can be used as an evaluation method which can complement the result of computer simulation.

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