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Acoustical renovation of small auditoria using sound diffusers

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ABSTRACT

This paper describes the acoustical design for two small halls using diffusers: the Chamber Hall (450 seats) and M-theater (630 seats) in Sejong Performing Arts Center, Seoul. The Chamber Hall was completely refurbished as a recital hall with a volume of 3,200 m^3 from a rectangular conference space. The saw-tooth shaped wall reflectors were designed for sound diffusion. The M-Theater was also renovated for musical and small opera performances as a live and intimate space; its volume of audience area was 4,800 m^3 including spaces above ceiling reflectors. The box-type diffuser profile in the M-Theater was designed using Glass Fiber Reinforced Gypsum in consideration of middle to high frequency sound diffusion. The measured scattering coefficient of the diffuser was 0.75 at the average of 500 to 3,150 Hz. The effects of diffusers in both halls were investigated through 1:25 scale models and actual hall measurements.

INTRODUCTION

There has been increased in the number of remodeling practices of performing halls, when found the existing facilities leg behind with unsatisfactory sound performance, or needed to carry out other genres with different sound requirement than the hall initially aimed. The sound diffuser, often considered as a significant solution for improvement of sound performance, is recognized as a contributing factor to middle to high frequency bands of sound diffusion [1-2]. Diffuser has not only been used for acoustical quality improvement in terms of spatial impression, but it also has been researched in performing centers' architectural sound design element in order to suppress any flaws such as flutter echo, acoustic glare, and tone coloration [3].

This article aims 1) to introduce the case of Sejong Chamber Hall and M-Theater where diffusers were used for acoustical renovation, 2) to investiage the acoustical difference between pre- and post-renovation and the process of designing the diffuser, and 3) to propose how sound quality can be improved by acoustical renovation.

ACOUSTICAL RENOVATION DESIGN OF SEJONG CHAMBER HALL

Design overview

Sejong Chamber Hall (443 seats) was originally built as convention hall, but the venue was needed to be changed to professional chamber music hall. To set desirable aim for sound design of the chamber music hall, we have conducted research on all the recital halls in the world with capacity of 400-500 seats and investigated their acoustical design index. The average reverberation time (RT) of the world's halls was around 1.4-1.5 second and hence, that became the goal for the Sejong Chamber Hall when it is completely accommodated.

Acoustical design features

As shown in Figure 1, the new hall was designed as reversed-fan type plan to provide abundant lateral reflections to the rear part of seats. The side walls were leant over inner side to give better spatial impression and clarity by creating strong lateral reflections over the audience seats.

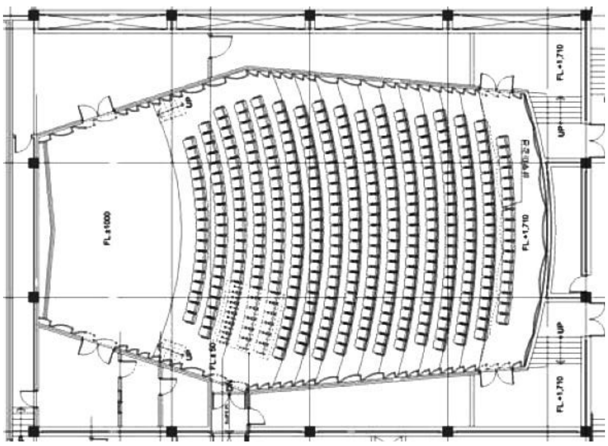


Figure 1. Plan of Sejong Chamber Hall

The angle of inclined lateral walls was decided by investigations of computer simulations [4]. The angle of the walls was varied and lateral energy fraction (LF) of audience seats was compared. The results showed that enough LF of around 0.28 was obtained when the inclination of the walls was 1:10. Considering usage of the auditorium to minimize reduction in capacity, the inclination of the side -wall was designed as 5°.

In order to provide enough reverberance of the hall, open ceiling was proposed as shown in Figure 2. Wooden louvers were applied to the architectural ceiling so that the ceiling became acoustically transparent but visually not. By introducing the open ceiling and having larger volume, smooth late reverberation was expected.

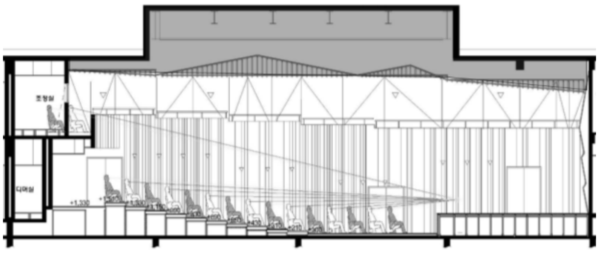


Figure 2. Section of Sejong Chamber Hall

Diffuser design

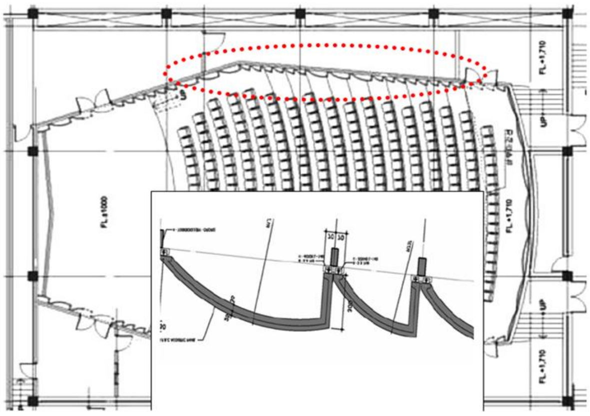
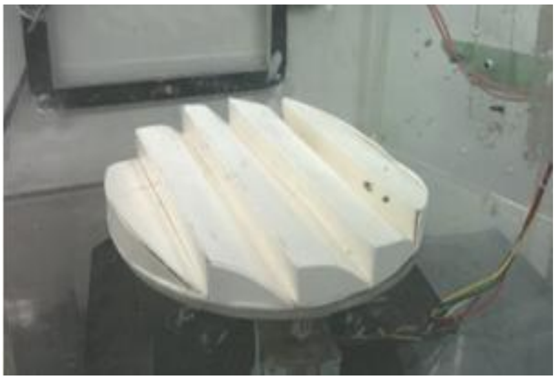


Figure 3. Plan of Sejong Chamber Hall and details of saw-tooth shaped wall



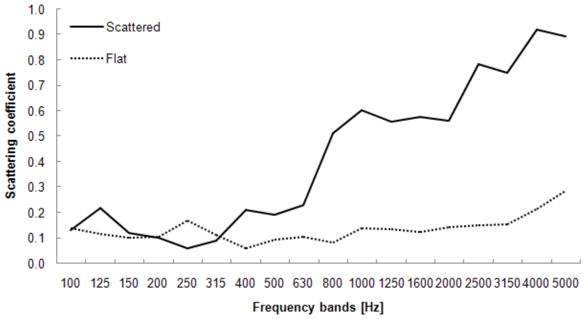
(a) Scattering coefficient

(b) Diffusion coefficient

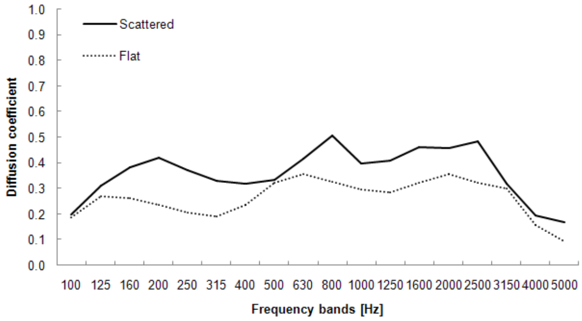
Figure 4. 1:10 scale model measurement for scattering and diffusion coefficients of Sejong Chamber Hall's diffuser

Diffusers were introduced to provide scattered sound field in the hall. In designing the diffuser, two major factors were considered; 1) strengthening the envelopment by scattered reflections, and 2) expanding the clarity by spreading out early stage reflections throughout the auditorium. Shape of the diffuser was designed as saw-tooth shape, as shown in the Figure 3, to achieve as even scattering coefficient as possible in each frequency band and to prevent acoustic glare and tone coloration.

In order to measure scattering and diffusion coefficients of the saw-tooth shape, a 1:10 scale model was made, as shown in Figure 4 [5-6]. As shown in Figure 5, scattering coefficient was 0.53 (500-3,150 Hz average), and diffusion coefficient was 0.36 (100-5,000 Hz average).



(a) Scattering coefficient



(b) Diffusion coefficient

Figure 5. Comparison of scattering and diffusion coefficients between flat plate and saw-shaped diffuser

Figure 6. GFRC diffuser constructions

In actual hall, the diffuser was made of Glass-Fiber Reinforced Concrete (GFRC), which is remarkable material in compactibility and high surface density, as shown in Figure 6. It is known as effective material to control the low frequency energy loss so that delievers enough reflective sound energy, even at low frequencies, to the audience seats.

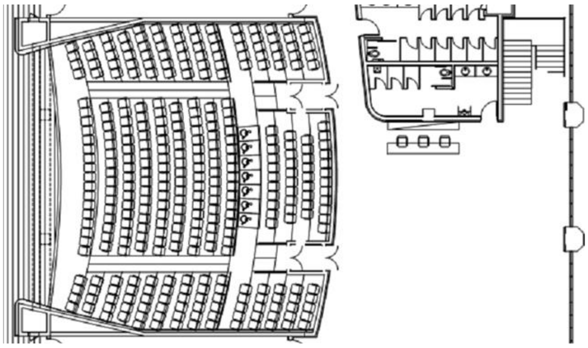
ACOUSTICAL RENOVATION DESIGN OF SEJONG M-THEATER

Design overview

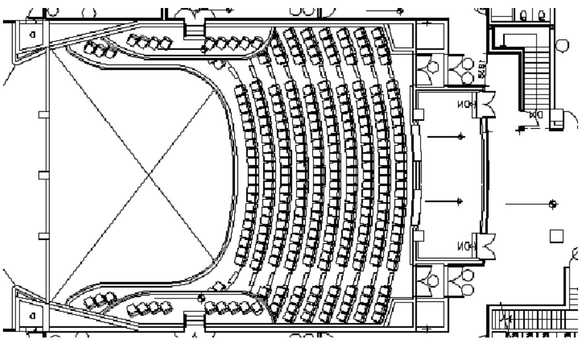
Another venue of Sejong Center, Sejong M-theater (630-seats), was renovated for better acoustic performances. The renovation of M-Theater was focused on its function to embrace musical and small opera, and increment of seat capacity. Keeping basic proscenium-type stage to accommodate composite arts, it was decided to install variable acoustic elements such as orchestra pit and shell, so that acoustical conditions can be changed for different genres. For plays or musicals, the reverberation time was aimed to be around 1.0 s, and for classical music such as orchestral music where orchestra shell is to be installed the reverberation time can be enlarged to around 1.8 s.

Acoustical design features

Renovated M-Theater's plans and section are as shown in Figure 7 and 8, respectively. Orchestra pit was installed in 1st floor and it can be varied to extended-stage or extended-audience area depending on the production requires. In order to secure better view from the auditorium, rake of the floor was increased and staggered seat formation was introduced.



(a) 1st floor



(a) 2nd floor

Figure 7. Plans of Sejong M-theater

Figure 8 indicates the section of Sejong M-theater with reflection rays of ceiling reflectors. The ceiling reflectors were introduced to enlarge the reflective sound energy at the rear part of audience seats. The ceiling reflectors were consist of three parts; the first shell covers the whole auditorium, the second shell covers the rear part of the 1st floor and the 2nd and 3rd floors, and the third shell covers rear part of the 2nd and 3rd floors. Glass-Fiber Reinforced Gypsum (GFRG) boards were used as material for the ceiling reflectors to secure the reverberation time and diffused sound field.

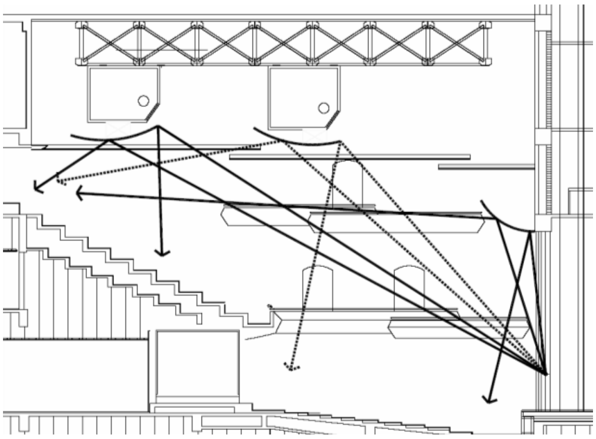
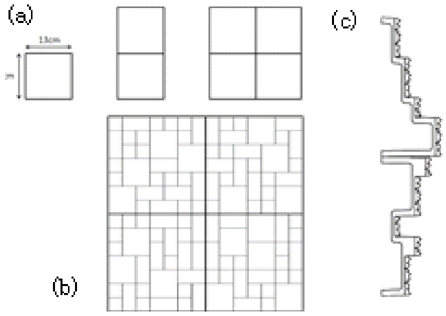


Figure 8. Section of Sejong M-theater with reflection rays of ceiling reflectors

Diffuser design

Sound diffusers were applied to the auditorium walls and balcony fronts. Figure 9 explains the profiles of diffuser with plan and sections. Combinations of differenct sized boxes were designed to scatter the sound rays at mid-to-high frequency ranges. The inclination of the wall was determined to make early reflections delivered to the bottom of the auditorium so that it creates appluent diffused sound field. Also, longitudinally-striped ribs in each module using GFRG were added to the diffuser modules for additional horizontal diffusions at high frequencies.



(a) Module, (b) Plan, (c) Section

Figure 9. Diffuser profile unit of Sejong M-theater

Figure 10. 1:10 scale model measurement for scattering coefficients of Sejong M-theater's diffuser

Scattering coefficient of the diffuser was measured in the 1:10 scaled reverberation chamber, as shown Figure 10. As shown in Figure 11, around 0.75 (500~3,150Hz in average) of scattering coefficient was obtained that proper diffusion can be realized at the actual hall. The result was similar to the hemisphere diffuser which have 40 mm diameter of the Authors' previous studies.

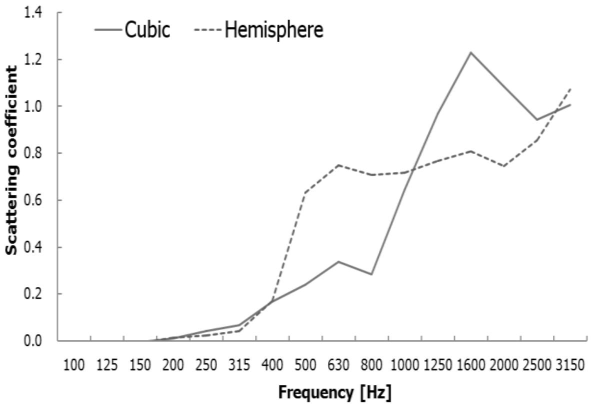


Figure 11. Comparison of cubic and hemisphere diffuser's scattering coefficient

CONCLUDING REMARKS

This article discussed on architectural re-design of convention hall into Chamber Hall, and acoustical renovation of Small Theatre into auditoria M-Theater at Sejong Performing Arts Center. Overall shapes of plan and section were renovated and ceiling reflectors were newly designed. Also, sound diffusers for each hall were designed and the effects of these were verified by the acoustical measurements of diffusion and scattering coefficients with 1:10 scale model of diffuser specimen.

In the case of Chamber Hall., diffuser installation resulted in theater's spatial impression enhancement by changing Binaural Quality Index (BQI) to 0.71. The impulse responses showed evenly scattered sound field within the auditorium. This is because sounds reflected from side walls were scattered and delivered the sound energies to the auditorium evenly providing higher spatial impression. In the case of M-theater, comparison of scale model experiment with and without diffuser was conducted. The results indicated that when diffuser was installed the sound-absorbing area increased so that the reverberation time was reduces about 0.1 s. However, difference was not found in early phase attenuations. In impulse response, long path reflections were diffused especially in short path reflections, as shown in Figure 12, so that smooth decay pattern of sound energies was achieved. It is expected that the renovation methods described in the present study can give furter ideas for more detailed acoustical design of music performance venues.

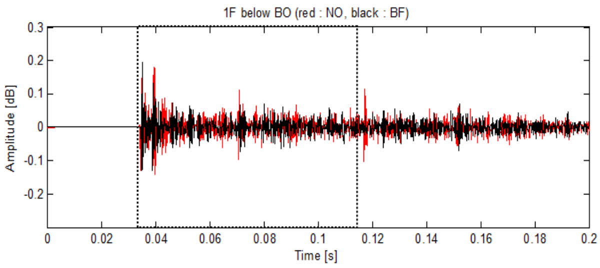


Figure 12. Comparison of impulse responses with and without diffuser of M-theater
(Black: with diffuser, Red: without diffuser)

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