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Acoustical Renovation of Large Auditorium to Enhance Sound Strength and IACC

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ABSTRACT

The Grand Theater in the Sejong Performing Arts Center is a proscenium theater with 3,022 seats. Originally built in 1978, the first renovation was conducted in 2004 to provide variable reverberation time (RT) using a sound system. Recently, a renovation was again planned to enhance the acoustic quality, especially sound strength (G) and spatial responsiveness (IACC), based on architectural acoustic design. The orchestra shell and various ceiling/wall reflectors were redesigned to improve the acoustic quality in calculation of G and IACC. The side balconies were added to provide lateral reflections to the audience sitting in the stalls. Materials of the walls and chairs were changed for longer RT and higher G. In this paper, the results of a computer simulation as well as the acoustical design process were presented.

INTRODUCTION

Recently, many concert halls and theaters have been remodeled in order to improve the acoustical quality in the audience area. But most remodeling turned out to be mere change of finishing materials and ceiling reflectors due to preservation of the frame structures. As a target condition of the acoustic quality of remodeled theatres, reverberation time has normally been considered at the design stage.

However, the installation of reflecting structures may change the direction of reflection, and absoption and scattering at the surfaces. Especially those problems are frequenctly occurred in large auditorium, relatively to the small hall, because proportion of the remote seats from the sound surce and reflecting structure is high [1]. Therefore, careful consideration must be given to the architectural acoustics: overall values and distributions of acoustical parameters such as SPL, IACC and C80 need to be estimated in the audience area.

Vineyard configuration with additional reflecting surfaces can be considered to improve the acoustical quality of the auditorium, especially in terms of loudness and spaciousness, by providing more early reflections to the audience area [1-3].

In this study, an acoustical renovation plan of the Grand Theater in Sejong Performing Arts Center was introduced: a schematic design to improve the acoustic quality of the Grand Theater in terms of sound strength and spaciousness as well as reverberation time. Computer simulation results for the renovation design were also discussed.

OUTLINE OF GRAND THEATER IN SPAC

Remodeling history

The Grand Theater in Sejong Performing Arts Center is a proscenium theater for multi-purpose with 3,022 seats, which was built in 1978. Since opened in 1978, major remodeling was conducted in both 2004 and 2006.

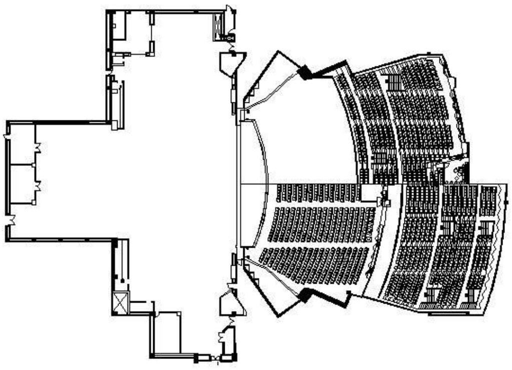
Dominant features of the first remodeling were reduced seats (from 3,800) and electronic reverberation system for a variety of reverberation times. Absorbers were installed in the rear walls and soffits under balcony overhangs to decrease the reverberation time. However, architectural components such as the hall shape and balcony depth were not changed.

In the second remodeling, the pieces of orchestra shell near proscenium were added because performers complained the lack of early reflections. Even though the remodeling was carried out twice, the acoustic quality of the Grand Theater in SPAC was not enough for various performances such as drama, opera, and orchestra. In addition, two of nearby performing venues such as the Hangang Arts Island and the IFEZ Arts Center will be open in a few years time. Therefore, additional remodeling was decided in order to improve the acoustic quality and to strengthen the competitiveness.

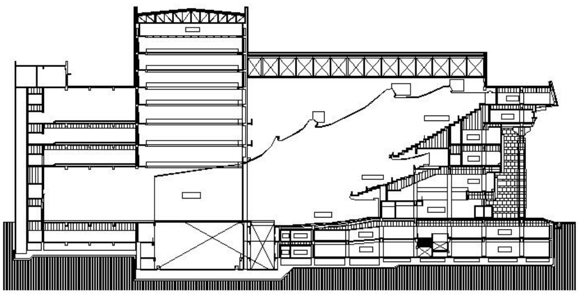
Plan and section

As shown in Figure 1, the Grand Theater is a fan-shaped hall and the averaged width (W) measured between sidewalls in the audience area was around 43 m. The distance from the front of the stage to the most remote listeners (D) was 48.5 m. Most of the wall surfaces were covered with perforated panel absorbers. Thus, reflections from the lateral walls did not reach to a central area of each floor, and the listener envelope and loudness could not be expected. Moreover, overall liveness was not achieved because of lack of reverberance.

The depth of balcony overhang on the second floor was 11.7 m, and it was much larger than height 4.6 m. Thus, the reflections from ceiling could not reach to overhang seats, and it caused low loudness.



(a) Floor plan



(b) Section

Figure 1. Plan and section of the Grand Theater in SPAC

Four curved ceiling reflectors with full coverage were installed but they did not provide reflections to the frontal seats of the main floor. Especially, the first ceiling reflector was started in the height of 12 m from the stage floor, but there was no returned reflection to the stage. Therefore, the the orchestra was used to set back to the inner stage even though the orchestra pit was expanded to the stage.

In case of concert mode with orchestra shell, the volume per seat capacity was around 10.0 m^3 per seat, and the height and width of the proscenium arch were 12 and 20 m, respectively.

Measurement results

Acoustic measurements were conducted in a situation with orchestra shell and unoccupied in to investigate the acoustical characteristics of the Grand Theater. Omni-directional speakers were located at three positions on the stage representing the solo, woodwind, and brass. A total of 24 receivers were positioned in the audience seats.

Measurement results are listed in Table 1. Reverberation time and early decay time were 1.59 and 1.52 s, respectively. Lateral fraction (LF) and 1-$IACC_{E3}$ representing spaciousness were 0.10 and 0.36, too small due to the lack of lateral reflections. From the measurement results, it was concluded that the Grand Theater was not appropriate for orchestra in terms of spaciousness as well as reverberation time. Averaged strength (G) was measured as 0.1 dB. In most cases, measurement results were smaller than regression line predicted by Barron's revised theory. Especially, the differences between measurement and prediction were much increased in the overhang seats and remote seats. Therefore, the remodeling should be conducted to increase the strength as well as reverberation time and spaciousness.

Table 1. Results of the acoustical measurements in the existing Grand Theater (unoccupied condition)

RT [s]	EDT [s]	C80 [dB]	LF	1-$IACC_{E3}$	G [dB]
1.59	1.52	2.03	0.10	0.36	0.1

ACOUSTICAL DESIGN

Direction of acoustical design for remodeling of the Grand Theater was suggested to solve the problems appeared in the hall measurements. The main principle for the remodeling is that the acoustic quality of the Grand Theater should be improved by architectural acoustics. The objectives for remodeling are as follows:

- Optimum reverberation time according to performance

- Evenly distributed higher sound pressure levels

- High spaciousness with strong lateral reflections

- Audience seats with acoustical intimacy

Audience chairs and finishing material

To achieve the objectives stated above, three strategies were considered. The first strategy for the remodeling of the Grand Theater was the change of finishing materials in order to increase the reverberation time. The average unoccupied reverberation time of the Grand Theater is below 1.6 s with an unoccupied condition coused by the absorptive fnishing materials (see Figure 2). Thus it was planned to replace the panel absorbers and thin plywood by hard materials with unit weight of 45 kg/m^2 or above, such as granite or GFRG (Glass Fiber Reinforced Gypsum).

It was decided to change the absorption of seats as well because the seating of the Grand Theater was categorized into 'heavily upholstered' from the measurement. Chair height will decrease by more than 100 mm (the present height is 1,000 mm), and thickness and length of the floor cushion will also decrease by 60 and 20 mm, respectively, in order to minimize the absorption of the chair. Reduction of absorption of chair and finishing material will produce the increment of the reverberation time.

In addition, the reverberation time should also be shortened for opera and drama by absorbing curtains that are drawn out with varying length from the suspended housings distributed throughout the ceiling, sidewall, and rear walls. The location of the curtain will be further considered through computer simulation and scale model measurement.

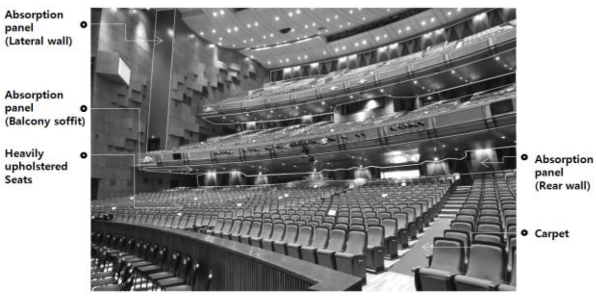


Figure 2. Absorbtive finishing materials in the Grand Theater

Seats rearrangement and side balconies

The second strategy was to rearrange the seating block and to install side balconies in order to increase the lateral reflections and to obtain the intimacy.

In the Grand Theater, it was hard to expect intimacy between performers and remote audience; because it was absorptive inside and the distance from the front of the stage to the most remote listeners (D) was more than 45 m. The depth of the balcony overhag was too deep for the reflection from the ceiling reflector. Thus, the seats near the rear walls should be removed to improve the acoustical quality of the auditorium. But the capacity of the seatings was important to the client. Therefore, the continental seating was introduced and distance between each row was decreased from 1,000 mm to 950 mm inorder to increase capacity of the seats. Seating capacity increased by around 400 seats through the rearrangement of seating areas. Therefore, it was decided to remove the seats near rear walls on the second and third floor, and consequently D/H of overhang on the second floor was improved to 1.9 from 2.5, and D was decreased up to 44.8 m.

The side balconies were installed both in the stalls and on the third floor. The elevated seats on the first floor were gradually sloped to the second balcony level and the floor level of audience seats near sidewalls on the third floor was increased by 2 m. It was expected that early reflections are produced by walls created at the edges of six seating trays. Plan and perspective view from the stage for rearranged seating areas are shown in Figure 3.

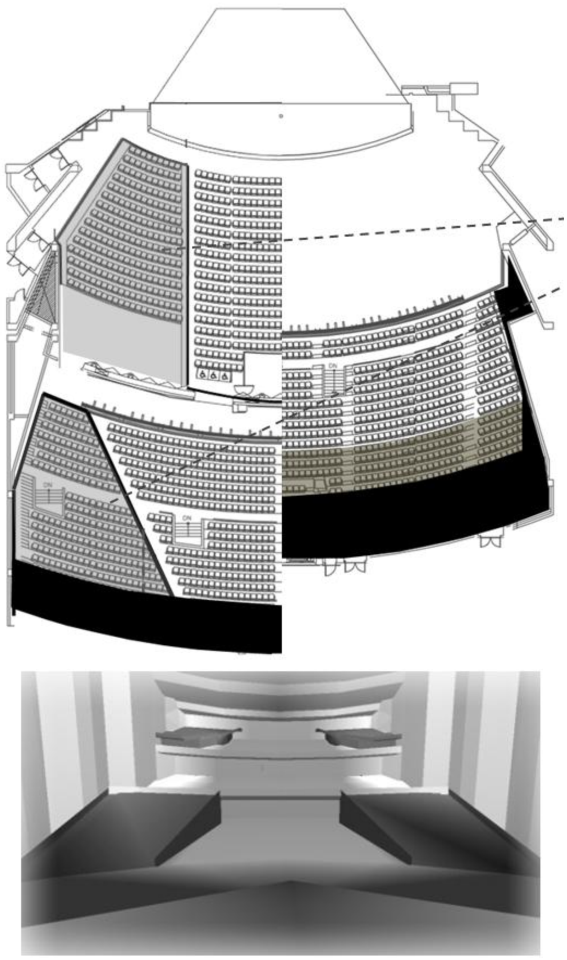


Figure 3. Seats rearangement and installation of new side balcony

Orchestra shell and reflector

As shown in Figure 4, the last strategy for the remodeling of the Grand Theater was the orchestra shell (A) and reflectors (B, C, and D) to provide the strong reflections. Both orchestra shell and reflectors were comprised of non-planar triangular panels, reflecting the early reflections onto the audience shortly after the direct sounds. The area of the triangular panels was determined as 9 m^2 to get the fine frequency response up to low frequency [3].

The shape of the orchestra shell was designed to reflect the sound energy on to the whole audience similar to the stage enclosure of Tanglewood Music Shed, Lenox, MA [6]. 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. Reflector B, the 50% opened ceiling, was designed to reflect the early sounds to mainly the second and third floors. Reflector C was aimed to provide the reflections to remote listeners on the third floor, and reflector D was designed for central audience area on the second and third floors. The orchestra shell and reflectors B-D were optimized using genetic algorithm.

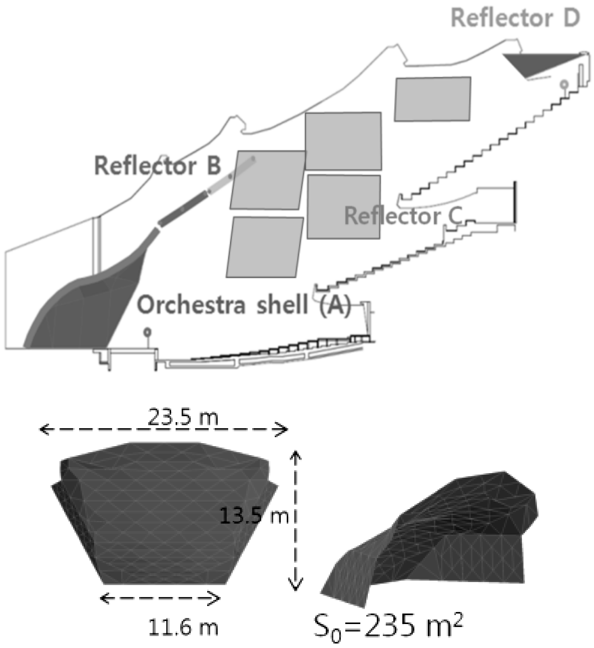


Figure 4. Schematic design of orchestra shell and reflector

ACOUSTICAL EVLAUATION

Outline of computer simulation

Computer simulations were carried out to investigate the effect of main features of schematic design: 1) replacement of finishing materials and audience chairs, 2) rearrangement of seating blocks and installation of side balconies, and 3) installation of orchestra shell and reflectors for the situation of concert mode with orchestra shell.

Computer simulation results were predicted by using Odeon 10.0. The omni-directional source 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 source was 1.5 m above the floor. The receivers were located in the audience area and positioned 1.2 m above the floor. All parameters such as sound strength (G), early decay time (EDT), clairity (C80), lateral fraction (LF) were predicted in the situations with unoccupied except for reverberation time (RT).

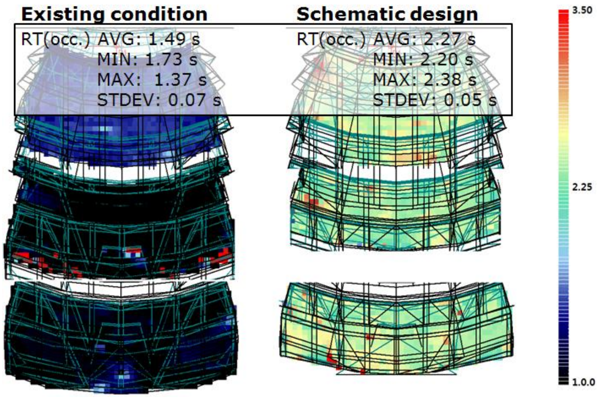


Figure 5. Simulation result: RT_{mid} (occ.) [s]

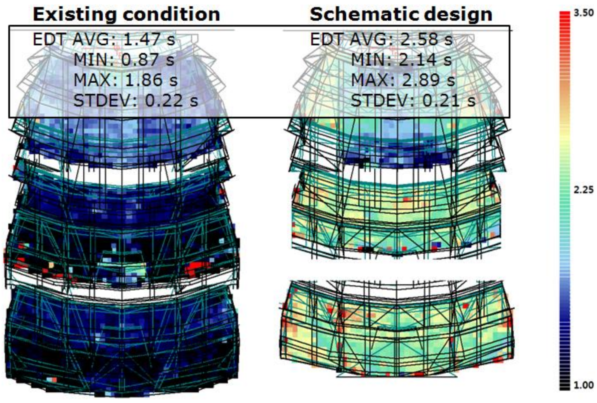


Figure 6. Simulation result: EDT_{mid} [s]

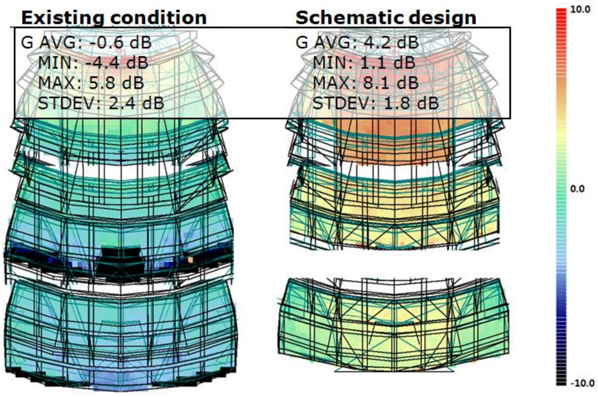


Figure 7. Simulation result: G_{mid} [dB]

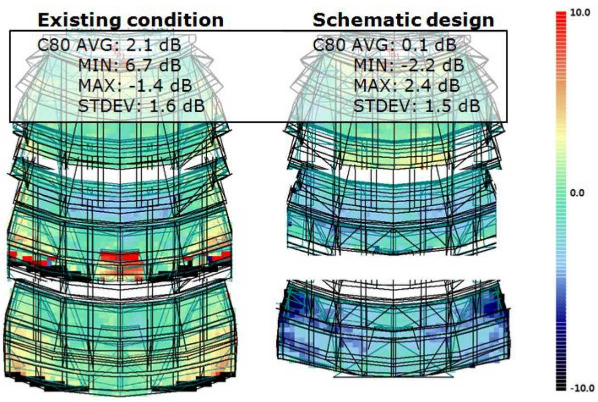


Figure 8. Simulation result: $C80_{3B}$ [dB]

Results

The simulation results of acoustical parameters were shown in Figures 5 to 8. Acoustic quality of schematic design was much improved comparing with current situation of the Grand Theater. When the orchestral shell and three reflectors were installed, the 1-$IACC_{E3}$ and LF increased up to 0.52 and 0.21, respectively. This indicates that strong early reflections from ceiling and reflectors were effective to increase the spatial impressions even though the distances between sidewalls were still more than 40 m. But RT and EDT did not increased much due to the absorption of additional reflectors.

In the situation with rearranged seating area, RT and EDT were around 2.0 s, much larger than those of the case with orchestra shell and reflectors. 1-$IACC_{E3}$ was also slightly larger than that of the situation with orchestra shell and reflectors but LF was almost same. The reason of the increases of 1-$IACC_{E3}$ and LF is that the walls created at the edges of six seating trays have an effect on the reflection of the early sound energy.

Computer simulation results shows that the schematic design plans of this study are effective to improve the acoustic quality of the current situation. In case of all the new design elements were applied, each acoustical parameter was satisfied by the target values: G more than 4 dB, RT and EDT above 2.0 s, C80 ±1 dB, 1-$IACC_{E3}$ more than 0.5, LF more than 0.20. And the distribution of each parameter was also improved by additional reflecting structures.

SUMMARY

In this study, the schematic design plans to improve the acoustic quality of Grand Theater in Sejong Performing Arts Center were presented and the designs were investigated through computer simulation. The results showed that reverberation time was increased by the replacement of finishing materal. And loudness and spaciousness were much improved through applying additional structures such as side balconies and reflectors.

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