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Effects of stage volume and absorption on acoustics of concert halls

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ABSTRACT

The effects of stage volume and absorption for stage design on the acoustical characteristics of concert halls were examined using computer simulations. A hall with different stage elements was investigated by comparing the dimensions of the stage and the acoustical parameters of the hall: a shoebox hall was selected with variation of stage volume and absorption. Results showed that the stage volume mainly affected both stage support and audience sound strength, whereas and the seating behind platform mainly affected reverberation. Accordingly, design considerations for stage enclosures were discussed for both stage and audience acoustics.

INTRODUCTION

Stage enclosures including platform in concert halls have been acoustically evaluated mainly in terms of stage support parameters. ST_{Early} is a typical stage measure since it had been suggested from the series of field measurements and auditory tests with musicians [1, 2]. Recently, distribution of ST_{Early} in a concert hall stage has been investigated by scale model testing; relationship between stage size and stage support parameters was reported [3, 4]. However, there has been still little knowledge about the effect of stage elements on auditorium (audience) acoustics.

As the most important design elements in concert hall acoustics, the stage enclosure is regarded as the main surfaces for early reflections. Stage design elements include stage width, depth, height, area, volume and seating behind platform. Accordingly, there are many kinds of stage shapes based on the dimensions (height, width and depth). Stage volume can also be regarded as a dimensional aspect for stage design, which includes the area of platform. On the other hand, stage absorption is also important to determine the characteristics of early sounds. Finishing materials of stage enclosure, audience seating behind platform and on-stage performers are the major stage absorptions. Therefore, the stage absorption together with the size is important to identify the acoustical influences and to determine the stage shape for concert hall design.

In this paper, the effects of stage volume and stage-seat absorption on concert hall acoustics were investigated in a rectangular concert hall using computer simulations.

METHODOLOGY

Stage design elements

Stage volume ratio (V_S/V) is defined as the stage volume (V_S) per total volume of the hall (V). The stage volume (V_S) includes the upper volumes of both platform area (S_o) and seating area behind platform (S_c). Figure 1 shows the distribution of the stage volume ratios from existing concert halls (26 rectangular shaped halls). The hall volumes were ranged from 10,500 to 25,000 m^3 and the seating capacity was ranged from 1,200 to 2,900 seats. The average stage volume ratio was 24.1% (ranged from 11 to 49%). The proscenium style concert halls do not have seating behind platform, and the stage volume ratio of the proscenium halls was ranged from 11 to 26%.

Stage seating area ratio (S_c/S_a) is defined as seating area behind platform (S_c) per total audience area (S_a). Sc is directly related to stage absorption as it is close to the sound source. Figure 2 shows the distribution of stage seating area ratio in the same 26 rectangular concert halls. Among them, the 14 halls had an audience seating behind platform. The average S_c/S_a for the 14 halls was 15.6% (ranged from 2.4 to 38.0%).

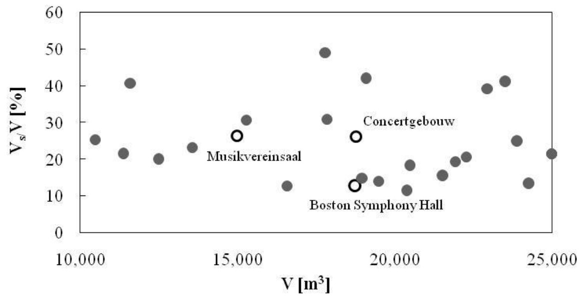


Figure 1. Stage volume ratio in rectangular shape concert halls.

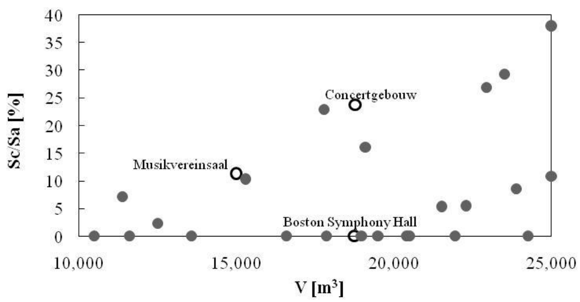


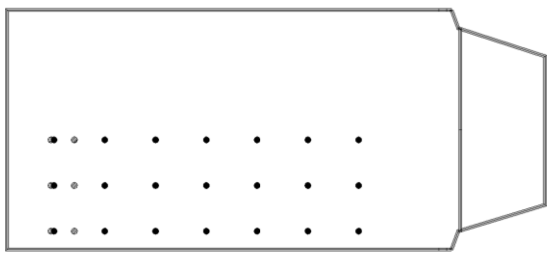
Figure 2. Stage seating area ratio in rectangular shape concert halls.

Hall description

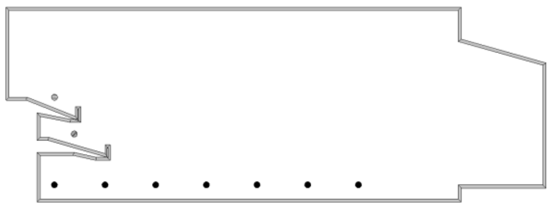
The simulation model was based on the Boston Symphony Hall to investigate effects of controlled stage dimensional parameters on the audience acoustics. The model hall has 2,625 seats with 18,750 m^3 of the hall volume. The stage of the model hall was simplified. The stage area (S_o) is 130 m^2 and stage volume (V_S) is 1,651 m^3.

Computer simulation

Acoustical simulation program (ODEON) with hybrid ray tracing method was employed to estimate the acoustical parameters from the model hall. The computer model has fitted acoustical parameters with the measurement results of the real hall, such as ST_{Early} for stage acoustics and $RT_{mid,occ.}$, $EDT_{mid,unocc.}$, $C80_{3B,unocc.}$ and $G_{mid,unocc.}$ for auditorium acoustics. In the simulation, sound source was located at 3 m from the stage front of the center line. As shown in Figure 3, the receivers were distributed uniformly at 27 positions throughout the audience areas.

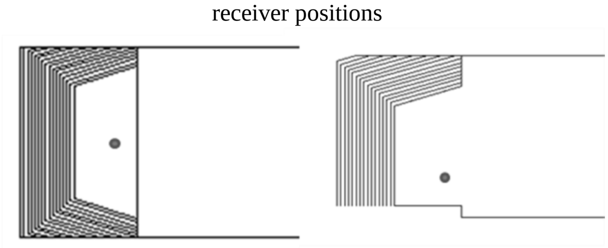


(a) Floor plan



(b) Section

Figure 3. Floor plan and section of the computer model with receiver positions



(a) Floor plan of stage (b) Section of stage

Figure 4. Variation of stage volume in computer simulations

EXPERIMENT I: EFFECT OF STAGE VOLUME RATIO (V_S/V)

Simulation settings

Stage dimensions of a rectangular hall model were modified in 13 steps to evaluate the effect of stage volume on the auditorium acoustics. As shown in Figure 4 and Table 1, height, width and depth of the stage were simultaneously extended according to the increased stage volume, which was ranged from 1,650 to 5,982 m^3. Based on the distribution of the stage volume ratios of the existing halls, the stage volume ratio of the simulation model was controlled over the range of 9 to 26%.

Table 1. Descriptions of the stage dimensions according to variation in stage volume

Case No.	S_o [m^2]	V_S [m^3]	V_a [m^3]	V [m^3]	V_S/V
1	130	1,650	17,100	18,750	8.8
2	145	1,900	17,100	19,000	10.0
3	160	2,175	17,100	19,275	11.3
4	175	2,450	17,100	19,550	12.5
5	190	2,735	17,100	19,835	13.8
6	208	3,078	17,100	20,178	15.3
7	225	3,423	17,100	20,523	16.7
8	241	3,790	17,100	20,890	18.1
9	257	4,065	17,100	21,165	19.2
10	285	4,470	17,100	21,570	20.7
11	299	5,039	17,100	22,139	22.8
12	324	5,550	17,100	22,650	24.5
13	345	5,982	17,100	23,082	25.9

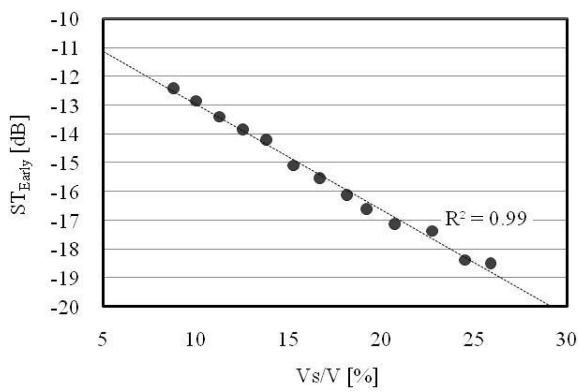
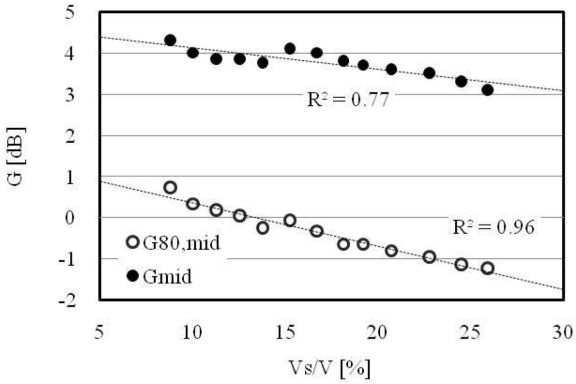


Figure 5. Averaged ST_{Early} values at the stage area according to variation in stage volume ratio

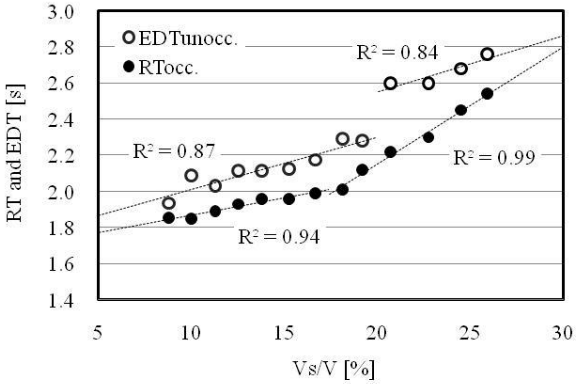
Results

Figure 5 shows the simulation results of ST_{Early} according to variation in Vs/V. With the increased Vs/V by 17% (averaged from 9 to 26%), ST_{Ealry} for stage acoustics evaluation is significantly reduced by 6 dB (from -12.4 to -18.4 dB). ST_{Early} showed very strong linear relationship with the stage volume as well as the previous studies [2, 4]. Since the early reflection from 20 to 100 ms mainly influences ST_{Early} calculation, the smaller stage volume reflects more early energies back to stage. As discussed by Beranek [5], the stage volume ratio should be designed as 15% or less to secure a desirable range of ST_{Early} (-14.4 dB to -12 dB).

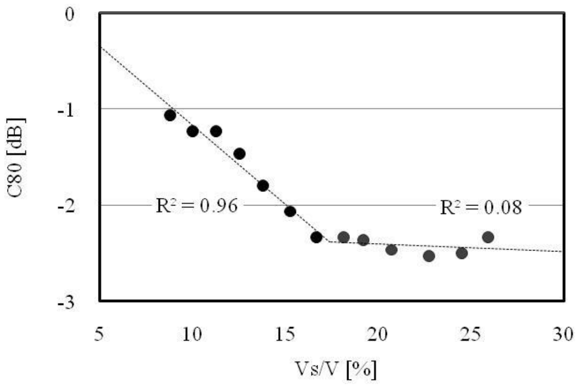
Acoustical parameters at the audience area were investigated in terms of loudness, reverberance and clarity. For loudness evaluation, G and G80 (early sound strength up to 80 ms) were calculated. As shown in Figure 6 (a), both G and G80 were decreased – G80 is more sensitive – by an increase in Vs/V. It seems that the stage volume mainly affected early energy level at audience area.



(a) Sound strength (G)



(b) Reverberation time (RT) and Early decay time (EDT)

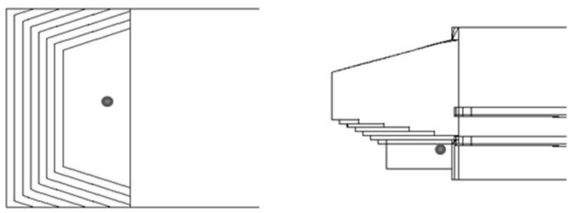


(c) Clarity (C80)

Figure 6. G, G80, RT, EDT and C80 values at the audience area by variation of stage volume ratio

Table 2. Descriptions of the stage dimensions according to the variation of the occupied stage seating area

Case	Occupied seating rows behind platform	$S_{c,occ.}$ [m^2]	S_a [m^2]	S_c/S_a [%]	S_o [m^2]	V_s/V
0	0	0	1,338	0	130	16.9
1	1	34	1,338	2.5	130	16.9
2	2	68	1,338	5.1	130	16.9
3	3	104	1,338	7.8	130	16.9
4	4	136	1,338	10.2	130	16.9
5	5	166	1,338	12.4	130	16.9
6	6	193	1,338	14.4	130	16.9
7	7	217	1,338	16.2	130	16.9



(a) Floor plan of stage (b) Section of stage

Figure 7. Variation of occupied seating area behind platform in computer simulations

As shown in Figure 6 (b), both RT and EDT were increased by an increase in Vs/V. It is confirmed that more volume yields more reverberation. However, when Vs/V is around 20%, there are breakpoints, which come from the coupling effects between stage and auditorium.

C80 for clarity factor showed similar results with RT and EDT as shown in Figure 6 (c). C80 was dropped by 1.27 dB for the increased Vs/V of 17%. When Vs/V is 16% or less, more stage volume decreases music clarity. However, stage volume is little influential to the clarity when Vs/V is over 16%.

EXPERIMENT II: EFFECT OF STAGE SEATING AREA RATIO (S_C/S_A)

Simulation settings

To evaluate stage absorption, the hall model was modified according to the choir seating area around stage. The added choir seating consists of 7 rows as shown in Figure 7. The model hall has 130 m^2 of stage area and 16.9% of stage volume ratio.

The most absorptive element in the hall is the audience; stage absorption power was controlled by locating occupied seating in the 7 orders as shown in Table 2. Accordingly, S_c/S_a for stage absorption was ranged from 0 to 16.2%.

Results

Figure 8 shows the simulation results of ST_{Early} according to variation in S_c/S_a. Though the seat absorption in terms of S_c/S_a was increased by 16.2%, ST_{Early} was not significantly affected by stage absorption: the average value of ST_{Early} was around -12.4 dB. The results were compared with Experiment I: the small stage area resulted in high ST_{Early} values.

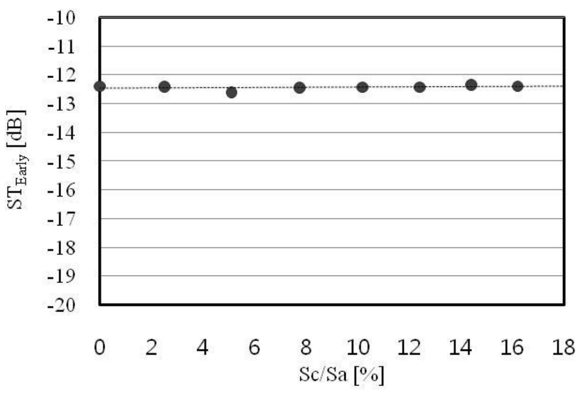
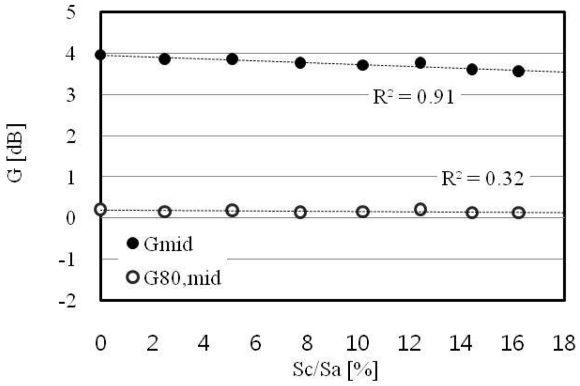
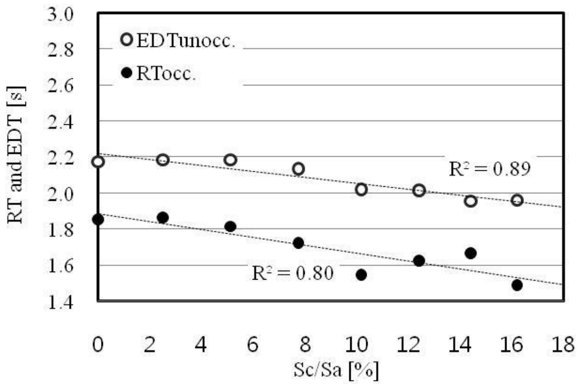


Figure 8. Average ST_{Early} values at the stage area by variation of stage seating area ratio

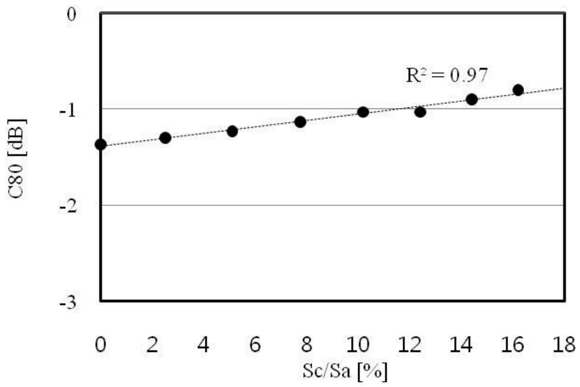
In audience area, G and G80 were decreased by 0.4 dB and 0.1 dB respectively according to the increased S_c/S_a by 16.2% as shown in Figure 9 (a). Contrary to the stage volume, stage absorption significantly affects the overall sound level. The early sound level did not show the significant correlation with stage absorption. As shown in Figure 9 (b), RT and EDT were decreased by 0.37 s and 0.22 s, respectively, according to the increased stage seating area ratio by 16.2%. C80 was increased by 0.57 dB for the increased stage seating area ratio of 16.2%. Clarity showed the most significant correlation with the stage absorption.



(a) Sound strength (G)



(b) Reverberation time (RT) and Early decay time (EDT)



(c) Clarity (C80)

Figure 9. G, G80, RT, EDT and C80 values at the audience area by variation of stage seating area ratio

DISCUSSIONS AND CONCLUSION

In this study, the effects of the stage dimensions on auditorium acoustics were investigated using computer simulations. Stage volume ratio for dimensional aspect and stage seating area ratio for stage absorption were manipulated as stage design elements.

The existing halls show a diverse range in stage volume from 11 to 49%. In the computer simulation models of the rectangular halls, it was found that large stage volume tends to reduce stage support, audience sound level and clarity, but increase reverberation at the audience area. Particularly, early energy level and early sound decay are more affected by stage volume. The coupling aspect between stage and auditorium spaces was observed in the variation of RT, EDT and C80 values.

The stage seating area ratios of the existing halls are also diversely ranged from 2.4 to 38.0%. It was found that stage absorption affect RT and EDT, but has little connection to the stage support or the audience sound level.

Performers' evaluation is important for designing stage enclosure. However, the effect of stage design elements on audience area should be considered. From the results in this study, stage enclosure should be minimized with minimum absorption for better stage and audience acoustics. This is natural, but many design cases ignored the importance of stage enclosure.

In the schematic design phase, the hall volume is normally determined according to a given reverberation time. In the same manner, the stage volume should be determined according to the target sound strength. It must be considered that the relative ratio of stage and auditorium spaces is proper and the stage volume is minimized to fulfil the target values of both RT and G. Since there is little advantage of stage absorption on concert hall acoustics, seating behind platform such as choir should be designed not to increase stage volume.

Further, the effects of stage design elements are needed to be investigated in various hall shapes to develop stage design parameters such as stage volume or seating area behind platform. In addition, the effects of stage area or valid reflective surfaces around the stage are needed to be separately studied.

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