Effects of stage volume ratio on the acoustics of simulated concert halls

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ABSTRACT

Simulations were carried out to investigate the effects of changes in stage volume on acoustic parameters of an auditorium in order to propose a suitable design for improving the volume of concert hall stages and to identify the correlations between them. First, nine concert halls of various shapes, including shoebox and fan, were selected for an ODEON simulation. AutoCAD was used to construct a simulation model of the stage volume, which was regularly adjusted in the range of -20% to 30% with increments of 10%. In addition to the volume of the stage, only depth was changed among the physical parameters of the stage (height, depth, and width) to reduce the effects of other factors. To quantify the change in stage volume, the ratio of the stage volume to the total volume of the hall (V_o/V) was calculated. In the simulation, the sound source was located at the center of the stage, auditorium seats were set in a grid at intervals of 2 m, and the sound receiver was placed at a height of 1.2 m. The results show that as the stage volume decreases, the initial energy increases, reverberation time of the auditorium decreases, and degree of clarity increases for most hall shapes. Furthermore, we observed that the stage volume ratio has a significant effect on the Bass Ratio and Bass Index of the concert hall.

Keywords: Stage volume ratio, Computer simulation, Room acoustic parameters

1. INTRODUCTION

The design elements of the stage of a concert hall include parameters such as width, depth, height, area, volume, and sound absorption area. The concert hall forms various types of stage shapes and stage volumes depending on the combinations of these design elements. One of the most important factors affecting early reflections in the acoustic of the concert hall is the stage enclosure and it affects the initial sound. The material of the stage enclosure, the audience and the performer on the stage also play an important role. Therefore, it should be designed considering both stage size and finishing material. Barron and Lee (1988) reported that when the structure of a stage is close to the sound source, it has an important effect on the early reflections (1, 2). Barron proposed minimizing the stage area for strong early reflections (3). Therefore, The stage of a concert hall can be considered a place where the sound source is directly located, and is an important design factor influencing the overall room acoustics. In this context, this study examined the change of acoustic characteristics of the concert hall according to the change of the stage volume, which is one of the main determinants of the shape of the stage at the early stage of design. For this purpose, we used computer simulation models of concert halls with various shapes and investigated the change of concert hall sound while changing the stage volume in a single model.

2. METHODOLOGY

2.1 Stage design elements

Stage volume can be considered in the initial design stage of the concert hall. It can be divided into the stage factor of the stage volume (V_o) itself, and volume (V_c) including stage seating and chorus seating. In the case of V_c, the influence of the shape of the hall and the arrangement of the audience is much affected. Therefore, a limitation arises in that the effect of the stage volume on the

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sound of the concert hall is difficult to determine. In this study, we considered the stage volume based on V_o, which means only the volume of the stage itself, and set the stage volume ratio (V_o/V) of the stage volume (V_o) to the volume (V).

2.2 Hall description

In order to investigate the effect of various concert hall shapes and varying stage volume ratio on room acoustics of the concert hall, we selected nine models of 11 European concert halls provided by Odeon software version 14 where the stage volume could easily be changed. Four shoebox shaped halls (Boston Symphony Hall, BO; Vienna Grosser Musikvereinssaal, VM; Amsterdam Concertgebouw, AM; London Royal Festival Hall, LF), two fan-shaped halls (Salzburg Festspielhaus, SA; Gothenberg Konserthus, GK), and three other shapes (Edinburgh Usher Hall, EB; London Barbican Concert hall, LB; Stuttgart Linderhalle Beethovensaal, ST) were selected, and their basic dimension information is summarized in Table 1.

The stage volume of the nine halls was 1,128–3,385 m^2. When the stage volume ratio was examined, concert halls with a stage area of less than 200 m^2 were more than 10% except for VM. Comparing halls with a stage area of 150 m^2 to a hall with a stage area of 200 m^2 or more, the stage volume ratio (V_o/V) is almost the same or slightly increased, even though the area increases by 1.5–2 times.

Table 1 – Detailed description for nine existing concert hall

Hall	Shape	Seats	Receivers	V[m^3]	S_o[m^2]	V_o[m^3]
Symphony Hall Boston (BO)	Shoebox	2,625	54	18,750	159	2,027
Grosser Musikvereinssaal Vienna (VM)	Shoebox	1,680	33	15,500	151	3,385
Concertgebouw Amsterdam (AM)	Shoebox	2,037	39	18,780	145	1,940
Royal Festival Hall London (LF)	Shoebox	2,907	59	21,950	226	2,167
Festspielhaus Salzburg (SA)	Fan	1,286	44	10,700	171	1,128
Konserthus Gothenberg (GK)	Fan	2,158	47	15,500	340	1,380
Usher Hall Edinburgh (EB)	Other	2,502	51	15,700	243	2,225
Barbican Concert Hall London (LB)	Other	1,803	41	17,000	218	2,028
Liederhalle, Beethovensaal Stuttgart (ST)	Other	2,000	122	16,000	178	1,559

2.3 Computer simulation

In this study, to examine the influence of the stage volume change on the audience, the stage volume ratio was increased from -20% to 30% of the existing hall dimension by 10%. At this time, considering the orchestra riser, modeling below -20% (V_o/V) was not performed. AutoCAD 2016 software was used for modeling. The stage volume was changed by adjusting the depth with the maximum stage height. The maximum stage width was fixed by separating the stage and the audience from the stage front. Since the ODEON library model is based on concert hall measurement data in the unoccupied state, the surface sound absorption coefficient was applied. Therefore, the surface material is adjusted similarly to the measured data (4-6). For the analysis of the room acoustic parameters, the transition order was set to the second order, the impulse response length was set to 5000 ms, and the late ray was set higher than the recommended value of 15,000.

In the case of a sound receiver, at least one sound receiving point per 25 seats was considered. The sound source was set at a height of 1.5 m in the solo position. The acoustic parameters of the concert hall are Reverberation time ($RT_{30,occ.}$), Early decay time ($EDT_{unocc.}$), Clarity ($C_{80,unocc.}$), Strength ($G_{mid,\ unocc}$), base ratio (occupied), and bass index (unoccupied).

3. RESULTS

3.1 Effect of stage volume ratio (V_o/V)

Figure 1 shows the simulation results of the acoustic parameters of the concert hall based on the stage volume change (V_o/V). First, in the case of RT, the value increases when the overall stage capacity ratio increases. The difference between the maximum and minimum values of RT in the hall (EB, VM), which has a relatively large stage volume compared to the total volume, was 0.49s which is the highest difference. The EDT also showed a positive relationship with the overall increase in stage volume ratio, similar to RT. C80 showed a tendency to decrease as the stage volume ratio increased, as opposed to the overall RT and EDT, and to change more sensitively than reverberation related parameters. The G value, which represents the sound strength, is lower than 1 dB, although it decreases as a whole. The Bass Ratio clearly shows a tendency to decrease as the stage volume increases, except for the LB hall, as well as the difference in values from 0.8 to 1.1 on average for each hall. The Bass index decreased with increase in the stage volume ratio in most halls, and especially the fan-shaped halls showed a larger reduction rate (7).

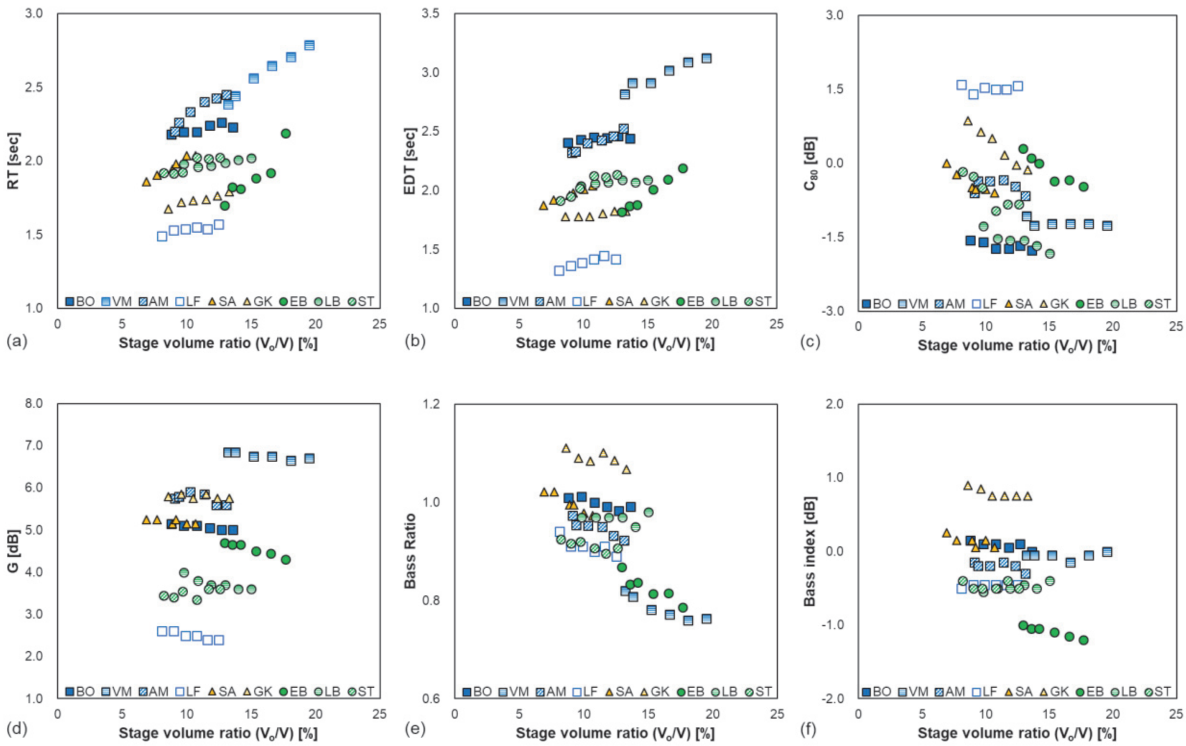

Figure 1 – Acoustic parameters according to the stage volume ration (V_o/V) (a) RT, (b) EDT, (c) C80, (d) G, (e) Bass Ratio, (f) Bass index

3.2 Effect of stage absorption (A_c)

As the stage volume ratio of the concert hall changes, the area of the stage and the wall also increases and decreases, such that the sound absorption amount of the whole hall also changes. The sound absorption coefficient of the interior finishing material is a very important element for determining the acoustic parameters of the room. Therefore, the sound absorption coefficient (A_c), which is the total sound absorption power of the concert hall divided by the total surface area, is calculated. Figure 2 shows the distribution of the acoustic parameters of nine halls based on A_c. RT, EDT and G tended to decrease with the increase of the sound absorbing coefficient of the concert hall; C80 tended to increase the Bass Ratio and Bass index tended to increase to a certain level and then decrease.

4. DISCUSSION

Linear regression analysis was performed for each acoustic parameter to investigate the contribution of concert hall sound factor (V_o/V), stage area ratio (S_o/S) and sound absorption coefficient (A_c) of the concert hall. The results are shown in Table 2. It was confirmed that the stage volume ratio had a statistically significant effect on all acoustic parameters. In the case of RT, EDT, C80, and G, the variation of the sound absorption rate due to the change in the stage volume of the hall has a very large influence, and the independent contribution of the stage volume ratio is low. However, the indicators of the bass characteristics of the concert hall sound such as the Bass Ratio and Bass Index were observed to have almost the same or less influence on the sound absorption rate of the hall itself. Therefore, if the stage volume ratio is designed to be small in the initial design stage of the concert hall, securing enough warmth in the acoustic environment is possible.

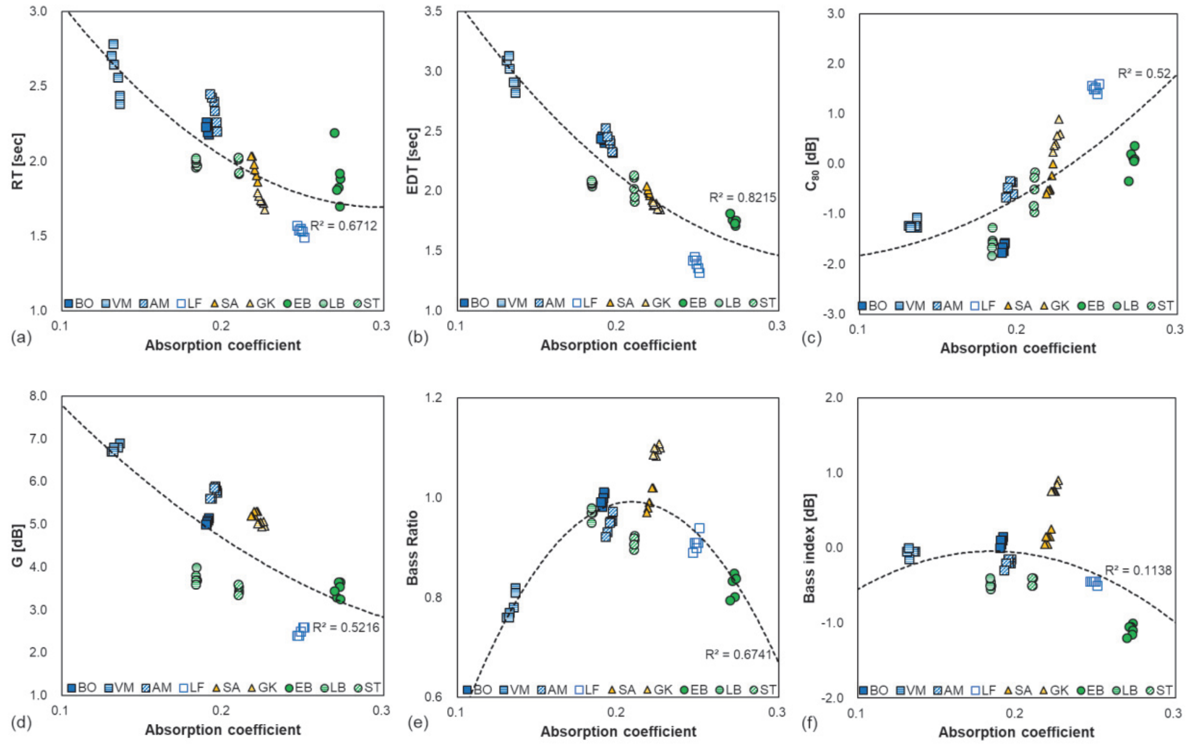

Figure 2 – Acoustic parameters according to the hall absorption coefficient (A_c) (a) RT, (b) EDT, (c) C80, (d) G, (e) Bass Ratio, (f) Bass index

Table 2 – Summary of linear regression for acoustic parameters with stage design factors

Parameter	Model	Unstandardized Coefficients	Standardized Coefficients	t	*p*
RT	(Constant)	2.73		13.10	< 0.01
R^2=0.72	V_o/V	0.04	0.33	4.25	< 0.01
	S_o/S	0.01	0.09	1.22	0.23
	A_c	-5.84	-0.71	-9.27	< 0.01
EDT	(Constant)	3.20		12.18	< 0.01
R^2=0.77	V_o/V	0.05	0.34	4.89	< 0.01
	S_o/S	0.00	0.02	0.22	0.22
	A_c	-8.32	-0.73	-10.45	< 0.01
C80	(Constant)	-1.94		-2.40	< 0.05
R^2=0.57	V_o/V	-0.08	-0.22	-2.30	< 0.05
	S_o/S	-0.07	-0.30	-3.19	< 0.01
	A_c	15.50	0.61	6.31	< 0.01
G	(Constant)	7.10		5.25	< 0.01
R^2=0.31	V_o/V	0.07	0.15	1.26	0.21
	S_o/S	0.02	0.08	0.65	0.52
	A_c	-16.53	-0.49	-4.04	< 0.01
Bass Ratio	(Constant)	1.12		13.54	< 0.01
R^2=0.48	V_o/V	-0.02	-0.63	-5.89	< 0.01
	S_o/S	0.00	0.20	1.96	0.06
	A_c	0.02	0.01	0.09	0.93
Bass Index	(Constant)	1.74		3.21	< 0.01
R^2=0.29	V_o/V	-0.07	-0.41	-3.30	< 0.01
	S_o/S	0.01	0.09	0.76	0.45
	A_c	-5.70	-0.43	-3.48	< 0.01

5. CONCLUSION

Computer simulation of nine concert hall models was conducted to investigate the influence of the stage volume ratio on the sound of the concert hall. As a result, it was found that the stage volume ratio has an overall effect on the acoustics of the concert halls, and it was found to be a major factor in determining the bass characteristics of the acoustics in the concert halls. However, in the present study, only the physical acoustical characteristics are examined. Therefore, additional research is required to determine if these bass characteristics are auditory. The results of this study can be used as an important guideline for the stage design of concert halls when determining the basic shape of the concert hall in the early design phase.

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