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Effects of absorption elements and stage set on the stage house acoustics in a proscenium hall

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ABSTRACT

Acoustical characteristics of a stage house and their effects on auditorium acoustics were investigated in a proscenium hall using computer simulation and scale models. The effects of a fly tower, the upper part of a stage house, were investigated with variable upper batten densities and covering materials. In addition, influences of the lower part of the stage house were examined by controlling the installation of absorptive finishing materials. As a result, it was found that effects of banners inside fly tower could be constant when the ratio between the banner and fly tower volume become over 13.0%. Absorptive finishing materials on the lower stage structure were also found to be influential on stage acoustics. Finally, as several types of stage sets are utilized for the lower stage structure during performances, stage sets were classified into three types, and their effects on the stage and auditorium acoustics were investigated.

INTRODUCTION

Prior to actual construction of auditoriums, acoustical design is thoroughly examined and predicted using various methods to confirm whether the hall has an acoustical capacity appropriate for various performances [1-5]. Auditoriums with a proscenium arch, especially, require a high variability of acoustical capacity in order to be appropriately utilized in various genres such as opera, musical performances, dramas, or orchestral performances [6-7]. This requirement is different from that of concert halls that are not equipped with stage houses of extensive volume. Therefore, in the case of auditoriums with a stage house and fly tower, evaluations of the acoustical characteristics of the stage house during performances and via a standardized process of acoustical prediction are necessary. Also, the stage house generally has a larger volume than that of the auditorium [6, 8], which implies a high likelihood of influencing not only the performers on the stage, but also the audience in the auditorium [9-10]. Thus, it is necessary to examine the acoustical characteristics of a stage house with a fly tower from perspectives of the audience, as well as the main stage, in various genre environments.

Many studies have been conducted on the acoustics of stage houses in proscenium halls by considering the relationship between the stage and the audience area. Prodi [10] investigated the balance of the orchestra pit and stage, while Alessandro [7] examined acoustical features of the stage according to the shape of the stage house. The effects of source locations on the stage house acoustics were examined previously in opera houses [8]. Also, the influence of stage sets on the acoustics of the audience area has been investigated by several researchers [11].

However, few studies have been conducted on the design of a proscenium hall according to the acoustical characteristics of the stage house. Specifically, the acoustical features and effects of a fly tower have not been thoroughly evaluated. In addition, although stage sets which are used during performances such as musicals, dramas, and operas were expected to be significantly influential to the auditorium acoustics, they were not fully examined in terms of various stage set conditions.

In the present study, the absorptive characteristics of stage house and stage sets were investigated through computer simulation and a 1:50 scale model. For the experiments, a 1,500-seat proscenium hall was introduced. The hall was consisted of stage house and auditorium parts as typical proscenium halls do. The stage house part was considered as two spaces; upper and lower spaces which were corresponded to fly tower and lower stage house, respectively. The lower stage house included main, sides and back stages. The volumes of fly tower and lower stage house were around 9,237 and 23,546 m^3, so that the volume of whole stage house was around 32,783 m^3 in real scale. Regarding the volume of auditorium, around 13,200 m^3, volume of stage house was about two-and-a-half times larger than that of auditorium in this hall.

EFFECTS OF STAGE HOUSE ACOUSTICS

Effect of the absorptions of the fly tower

As shown in Fig. 1, the sound source was positioned at the center of the main stage, with receivers on the main, side, and back stages. For the acoustical measurements in the 1:50 scale model, a high voltage igniter [12] was used as an omnidirectional spark source, and 1/8-inch microphones were applied as receivers. An additional 1/8-inch microphone was used as a reference microphone, which was positioned 20 mm – which is 1.0 m in real scale – apart from the spark source to calibrate the sound level of the source.

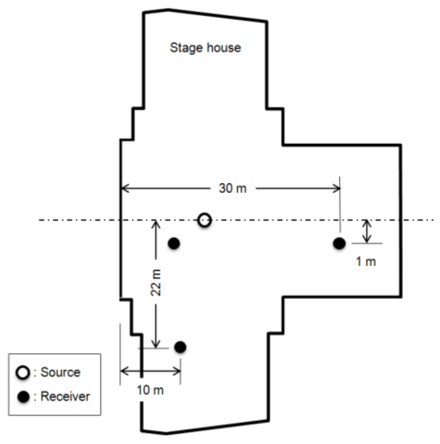

Figure 1. Source and receiver positions in the hall plan for stage house acoustics measurements

The materials for different parts of the scale model were carefully selected to properly reflect the sound characteristics of the actual hall. Absorption coefficients of the materials were measured based on ISO 354 [13] and are described in Table 1. The material of the stage house walls was constructed using sprayed medium density fiberboard (MDF). Velvets were used to represent the batten of the fly tower. The combination of thin fabrics and velvets shown in Table 1 were used to embody the absorptive finishing materials of the walls.

Table 1. Absorption coefficients of materials used in scale model

Mat.	Frequency [Hz]				Avg.
	125	250	500	1k	
Lacquered MDF 12 mm	0.03	0.04	0.05	0.10	0.06
Thick paper	0.22	0.17	0.13	0.20	0.18
Thin fabric	0.06	0.14	0.20	0.32	0.18
Velvet	0.42	0.62	0.73	0.83	0.65

In order to investigate the effects of batten area in the fly tower, the batten area was varied from 0 to 5,600 m^2 with seven steps in an increment of about 800 m^2. The experiments were conducted within the volume of stage house only by blocking the proscenium opening with sprayed MDF. Also, during the experiments for the batten area effects, all of the walls in fly tower and lower stage house were utilized as sound reflective walls using sprayed MDF. Table 2 indicates the results from computer simulations. As shown in Table 2, variations of reverberation time were significant after battens of more than 800 m^2 were applied. However, when battens of more than 3,200 m^2 were applied, the average reverberation time was not significantly affected over the entire frequency range. This implies that the absorptive capacity of the batten is nearly maximized with battens of 3,200 m^2.

As described in Table 3, the results from scale model showed the similar tendency with those from simulations. The effects on reverberation time inside the stage house were relatively insignificant when battens of an area greater than 800 m^2 were used. Installation of battens from 800 m^2 to 5,600 m^2 led to similar reverberation times over the entire frequency range. By assuming the thickness of a batten as about 0.5 m in real scale, volume of a batten which has an area of 800 m^2 could be calculated to 400 m^3. Then, the volume ratio between the battens and fly tower could be induced. With the same manner, effects of banners inside fly tower could be constant when the ratio between the banner and fly tower volume become over 13.0%, which is corresponded to volumes of 1200 and 9237 m^3 for banners and fly tower, respectively.

Table 2. Reverberation time of stage house as a function of batten absorption (simulation results; unit, s)

Batten area [m^2]	Frequency [Hz]				Avg. (500-1k)
	125	250	500	1k	
5,600	5.0	4.4	4.1	2.7	3.4
4,800	5.0	4.3	3.9	2.8	3.4
4,000	4.9	4.1	3.9	2.9	3.4
3,200	5.3	4.3	3.9	2.8	3.4
2,400	6.0	5.0	4.7	3.2	4.0
1,600	6.9	5.6	5.2	3.4	4.3
800	10.0	7.3	6.6	3.8	5.2
0	23.2	16.4	14.5	6.1	10.3

Table 3. Reverberation time of stage house as a function of batten absorption (scale model results; unit, s)

Batten area [m^2]	Frequency [Hz]				Avg. (500-1k)
	125	250	500	1k	
5,600	10.6	9.4	5.9	3.5	4.7
4,800	10.7	9.4	5.9	3.4	4.7
4,000	10.5	9.4	6.0	3.4	4.7
3,200	10.7	9.5	6.0	3.5	4.8
2,400	10.6	9.3	5.9	3.4	4.7
1,600	10.6	9.3	5.9	3.4	4.7
800	10.4	8.8	5.6	3.7	4.7
0	11.9	10.8	7.3	5.0	6.2

In order to investigate the effects of the absorption powers within the fly tower part on the stage house, absorption characteristics were varied in four cases by changing the absorption areas of the battens and the fly tower walls: 1) no batten without absorption walls, 2) 13.0% batten without absorption walls, 3) no batten with absorption walls, and 4) 13.0% batten with absorption walls. For the above four cases, the combined absorption material made of the thin fabrics and velvets in Table 1 were installed on the lower stage house walls. Also, the experiments were made within the volume of stage house by blocking the proscenium opening with sprayed MDF.

Table 4. Reverberation time of stage house according to absorption power variations within fly tower (scale model results; unit, s)

	Frequency [Hz]				Avg. (500-1k)
	125	250	500	1k	
No batten without absorption wall	3.5	3.7	3.4	3.1	3.3
13% batten without absorption wall	2.7	1.7	1.8	1.6	1.7
No batten with absorption wall	3.6	3.5	3.2	2.7	3.0
13% batten with absorption wall	2.7	1.6	1.8	1.6	1.7

As results of scale modeling, as shown in Table 4, removing battens and absorptive materials in the fly tower led to a reverberation time of 3.3 s. After absorptive battens were installed in the fly tower, the reverberation time decreased to

3.0 s. However, the installation of absorptive materials was not influential on reverberation time, as a time of 1.7 s was observed in both conditions. This result indicates that installation of absorptive materials is not as effective as the use of battens for bringing about a reduction in reverberation time. Therefore, the installation of absorptive materials in the fly tower did not significantly affect the acoustical characteristics of the hall.

Effect of lower stage house absorptions

In this step, the absorption power of the wall of the lower stage structure was varied to investigate the effects of regional absorptive characteristics by using scale modeling. As shown in Table 5, around 1.0-1.5 s difference in reverberation time was observed upon the installation of battens. On the other hand, different absorptive conditions of the lower walls of the stage house yielded about 3.1-3.6 s difference in reverberation time. In the case of the fly tower, the absorptive characteristics were observed to be stable when a batten of a certain area was applied, while the acoustical features of the lower stage structure were significantly controlled and varied due to the absorption coefficients of the covering materials. Therefore, acoustical design of a stage house may require thorough investigation into the absorptive characteristics of not only the fly tower, but also the lower stage structure to achieve successful acoustics.

Table 5. Reverberation time of stage house according to absorption power variations within fly tower and lower stage house (scale model results; unit, s)

	Frequency [Hz]				Avg.
	125	250	500	1k	(500-1k)
No batten without absorption lower wall	11.9	10.8	7.3	5.0	6.2
13% batten without absorption lower wall	10.6	9.4	5.9	3.5	4.7
No batten with absorption lower wall	3.3	3.2	2.9	2.2	2.6
13% batten with absorption lower wall	2.2	2.2	1.8	1.3	1.6

EFFECTS OF STAGE SET

The effects of stage set on the auditorium and stage acoustics were investigated. Three conditions were introduced for evaluation: 1) type of stage set, 2) absorption materials, and 3) influence of space coupling. In order to classify the various types of stage set, actual constructions of stage sets in several opera houses and theatres were investigated by literature review [14]. The stage sets were classified to 3 cases (Case A-C). Case A was constructed with a cyclorama and side sets, which were standing aside the main stage. Case B was the same as Case A with the addition of a ceiling structure, and Case C was constructed using only a cyclorama. By considering the dimensions of existing stage sets and those of the main stage of the hall which was involved in this study, the depth, height, and width of the cyclorama were determined to be 20.5, 15.0, and 26.0 m, respectively, as shown in Fig. 2. The stage set was constructed using wood, and the cyclorama was made of thick paper. A series of four columns were also made from wood and were regarded as the side sets. The side sets were positioned laterally to the main stage. In order to vary the absorption characteristics of the stage set, velvet, as described in Table 1, was applied to the wooden base of the stage set. The absorption coefficients of the stage set materials were 0.15, 0.69, and 0.18 for the wood, velvet, and thick paper, respectively.

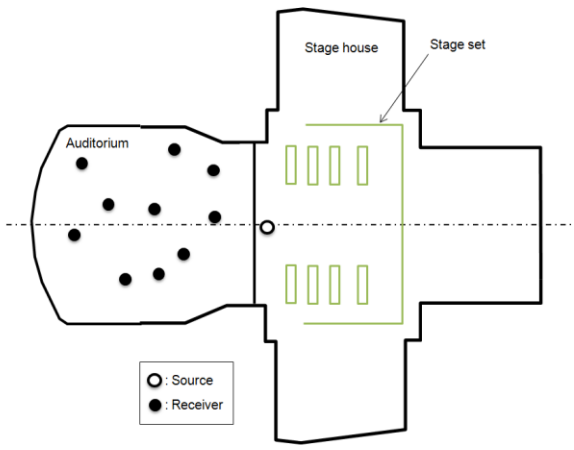

Figure 2. Source, receiver and stage set positions in the hall plan for auditorium measurements

Effect of stage set on audience area

The scale model results are shown in Figs. 3-6. As shown in Fig. 3, the measured reverberation times were obtained as 1.32, 1.41, 1.33, 1.43, and 1.45 s for no stage set, Case A, Case A with velvet, Case B, and Case C, respectively, at the mid-frequency range. Reverberation time was varied by approximately 0.12 s overall. This indicates that acoustical characteristics of stage sets which are normaly ignored for acoustical measurements of hall can affect the reverberation time of audience area to the amount of around 0.1 s.

As shown in Fig. 4, sound strength was ranged from 5.2 to 5.8 dB, and a 0.6 dB variance was observed in the audience area based on the type of stage set. It seemed that installation of stage set should be considered for acoustical measurements because it affects the sound strength of auditorium. Clarity index, as shown in Fig. 5, varied by 2.0 dB, and definition index, as shown in Fig. 6, differed by approximately 6%.

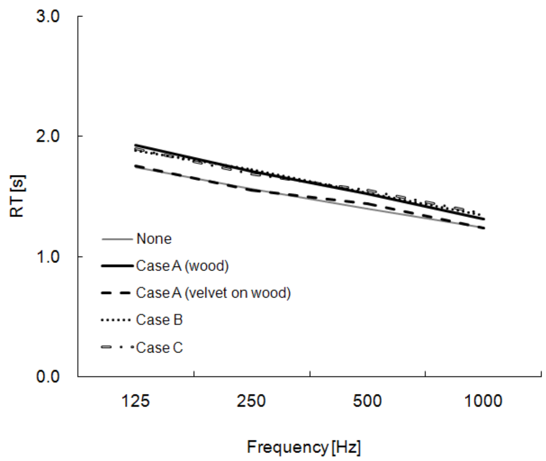

Figure 3. Reverberation time of auditorium according to stage sets

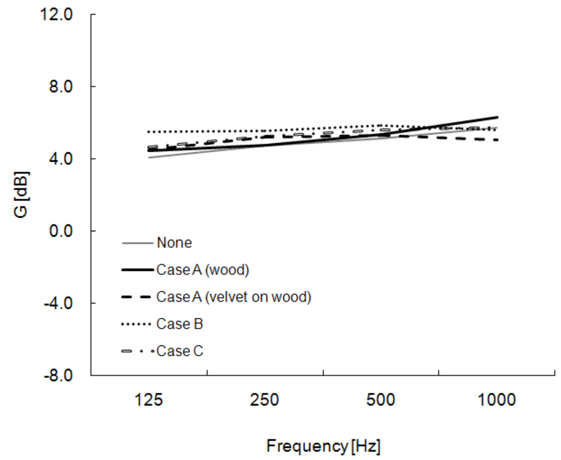

Figure 4. Sound strength of auditorium according to stage sets

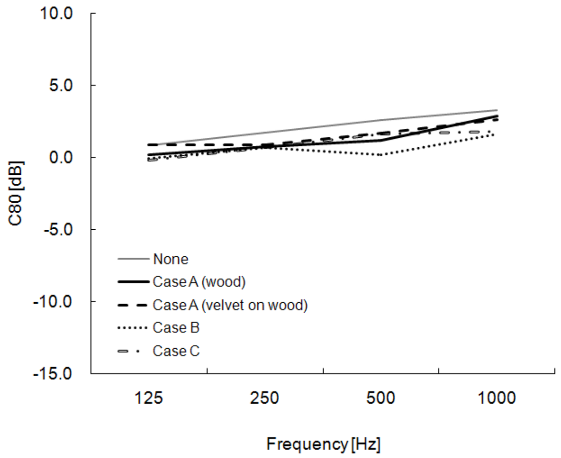

Figure 5. Clarity index of auditorium according to stage sets

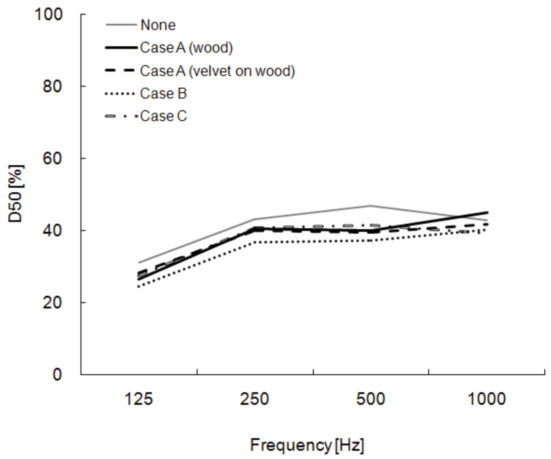

Figure 6. Definition index of auditorium according to stage sets

DISCUSSION AND CONCLUSIONS

The effects of batten on the fly tower, the absorption characteristics of the stage house walls, and the stage sets on the acoustics of a stage house and auditorium area were investigated using computer simulation and a 1:50 scale model hall. It was found that the effects of absorption walls of the fly tower were relatively large compared to those of battens on the sound field of the stage house. When the batten absorption area was greater than 1.8 m^2 with a total fly tower volume of around 0.11 m^3, the acoustical characteristics of the stage house varied slightly, e.g., less than 1.8 m^2 would be appropriate for the batten design in a proscenium hall. In order to generalize the design guidelines for the absorption powers inside the stage house, additional case studies should be performed, and equations should be developed to express the absorption power. The effects of absorption materials installed on the walls of the lower stage house were more influential to the stage sound field than were those of the upper stage house, such as fly tower. Therefore, an additional design guideline should be provided for the absorption materials of the lower walls of a stage house in a multi-purpose hall.

In addition, the stage set which is used for various performances can affect the sound fields of the stage and audience. The installation of a stage set could increase the reverberation time by approximately 0.1 s in the audience space, and the absorptive materials of the stage set could reduce the reverberation, as well as the sound strength. Therefore, realistic conditions such as the stage set of musical performances should be considered in the acoustical design of proscenium theatres which are equipped with a stage house.

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