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Absorption of orchestra platform measured for the acoustical design of concert halls

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ABSTRACT

The absorption of an orchestra on various orchestra platforms was measured using scale model concert halls. The acoustical characteristics for both stage and audience areas were examined as a function of stage absorption by varying the number of orchestral players. From the measurements, it was found that large orchestra increases absorption on stage and so reduces RT for the audience up to 0.1 s with linear relationship to the number of players; EDT decreased at an even higher rate, and sound strength (G) was also reduced by 0.3 dB. Computer modeling for the occupied stage condition was undertaken to acoustically match the scale model results.

INTRODUCTION

Acoustical characteristics of concert halls should be ideally evaluated in a fully occupied condition with all players and audiences as an actual performance state. However, usual objective measurements are carried out under unoccupied state. Several studies reported the effect of seat and audience on the absorption in concert halls [1, 2]. Although, some procedures on estimation of audience occupied condition are available based on the real measurements [2], acoustical effects of orchestra players in concert halls have not been fully investigated.

BBC provided the absorption coefficient of a real audience measured in reverberation chamber [3]. Hidaka *et al.* reported the absorption power according to orchestra arrangements in a concert hall [4]. Some researches used the miniature musicians for acoustical scale model testing of halls [5, 6]. However, the previous researches did not deal with the acoustical effects of the players' absorption on sound fields in concert halls. Only orchestra chairs have been considered as relevant variables that affect sound pressure level of audience seats in terms of stage acoustics [7]. For this reason, there is no reliable estimation procedure of player's absorption in computer simulation although Nayor had partially suggested simulation method of players [8].

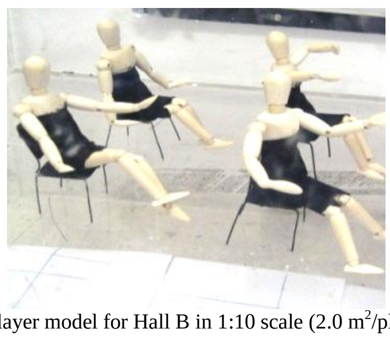
Therefore, in this paper, acoustical characteristics of fully-occupied condition with audience and players were evaluated in a scale model concert hall. A model player was reproduced based on the previous data from BBC in a reverberation chamber. In addition, a relevant simulation method was suggested via matching scale model and simulation results.

MINIATURE MUSICIANS

Reproduction of miniature musicians

Two realistic scale models of concert halls were constructed to investigate changes of the absorption condition by players: 'Hall A' in 1:50 scale and 'Hall B' in 1:10 scale. Miniature orchestra players were also reproduced based on the absorption coefficient data from BBC [3] as shown in Figure 1.The absorption power per player was measured in the 1:10 reverberation chamber. Figure 2 shows the results of the measured absorption power per player for the model musicians of both Hall A and Hall B.

(a) Player model for Hall A in 1:50 scale (1.9 m^2/player)



(b) Player model for Hall B in 1:10 scale (2.0 m^2/player)

Figure 1. Images of scale model musicians

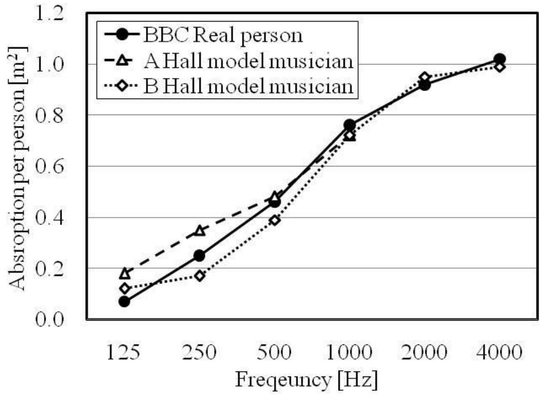
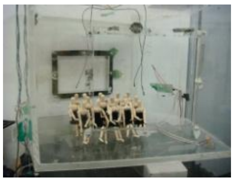


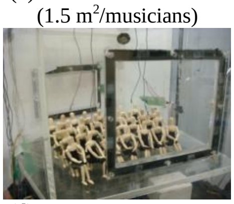
Figure 2. The measured absorption power per player of the model musicians in reverberation chamber. All measured data was converted into thre real scale values.

(a) Case A: Empty condition



(b) Case B: 16 musicians (1.5 m^2/musicians)

(c) Case C: 16 musicians (3.0 m^2/musicians)



(d) Case D: 32 musicians (1.5 m^2/musicians)

Figure 3. Measurement cases of 1:10 model musicians in reverberation chamber

Effect of musician arrangements

The effect of musician arrangements on absorption was investigated. As shown in Figure 3, four cases according to musician arrangement were measured in 1:10 reverberation chamber. Measurement cases were determined according to individual occupied area and total number of musicians. Case A indicates the reference condition to calculate relative absorption of musicians. Figures 4 shows the measurement results of absorption power per person by musician arrangement. By comparing 'Case B' and 'Case C', it is turned out that small density and larger coverage area yielded more absorption at above 1 kHz. Besides, small member of musician arrangement have larger absorption at above 2 kHz based on the comparison of 'Case C' and 'Case D'. Therefore, different absorption characteristics by musician arrangement should be considered.

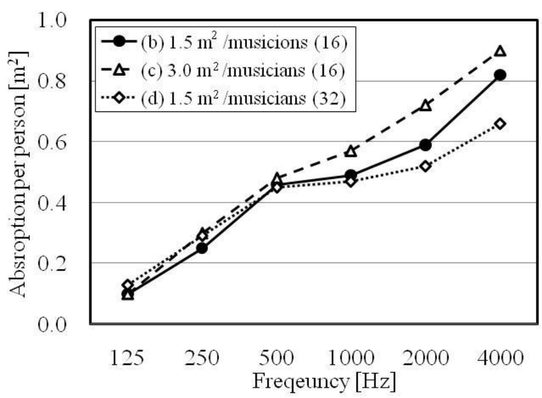


Figure 4. Measurement results of absorption power per person by musician arrangement

(a) Audience unoccupied condition (b) Audience occupied condition

Figure 5. Measurement cases in 'Hall A'

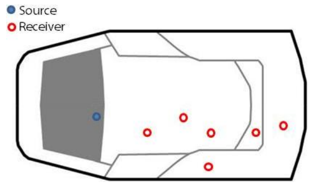
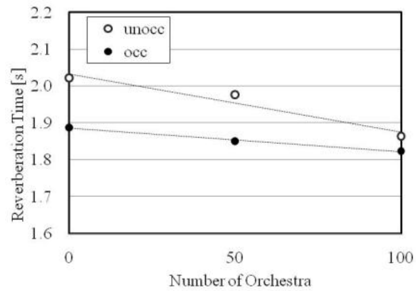


Figure 6. Measurement positions in 'Hall A'

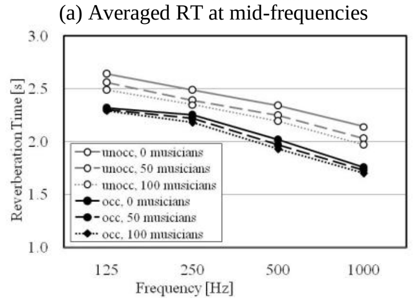
ACOUSTICAL EFFECTS OF MUSICIANS IN 1:50 CONCERT HALL (HALL A)

Experimental setup

A scale model of a 2,100-seats rectangular concert hall was built in 1:50 scale to evaluate effect of musicians on reverberation time of the hall. As shown in Figure 5, measurements were carried out in both unoccupied and occupied conditions according to the number of musicians on platform (0, 50 and 100 persons). Impulse responses were measured in the 6 receiver positions by using 1/8" microphone as shown in Figure 6. Electrical spark source was employed. Sampling rate of the AD/DA converter was 192 kHz. Measureme results was converted into the real scale, thus, the results cover the frequency range of 125 Hz to 1 kHz in 1:50 scale model.



(a) Averaged RT at mid-frequencies

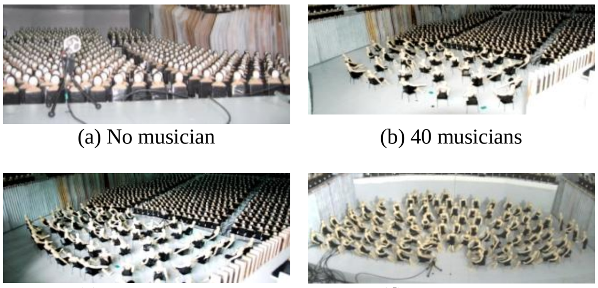


(b) Frequency characteristics of RT

Figure 7. Measured reverberation time in audience area by audience and orchestra musician occupancy

Results

Figure 7 shows the measurement results of reverberation time (RT) according to number of musicians. In audience unoccupied condition, RT decreased by 0.16 according to the 100 musicians. However, in audience occupied condition, RT decreased by 0.07 according to the same 100 musicians. This indicates that musicians on stage are definitely absorptive elements in concert hall acoustics, but musicians with fully occupied audiences less affect RT in spite of the same absorption.



(a) No musician (b) 40 musicians

(c) 70 musicians (d) 90 musicians

Figure 8. Measurement cases in audience occupied condition in 'Hall B'

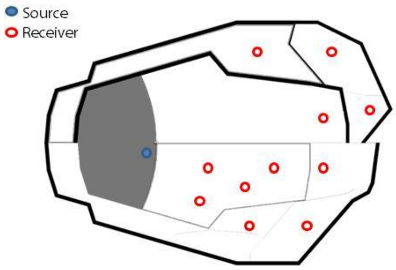
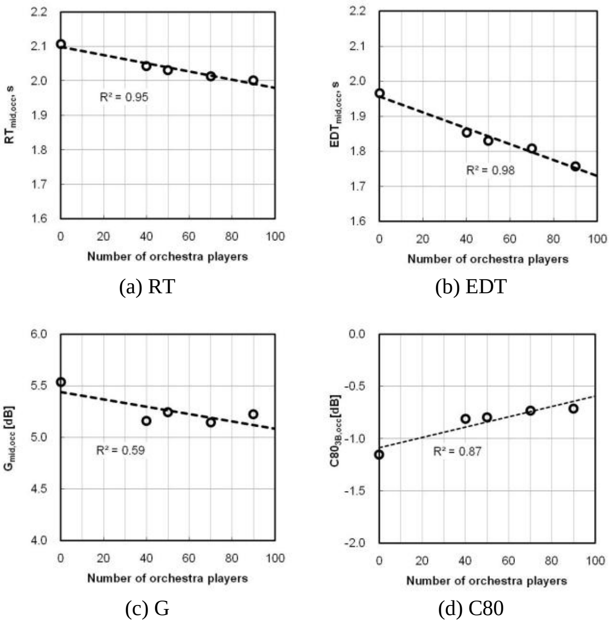


Figure 9. Measurement positions in 'Hall B'

ACOUSTICAL EFFECTS OF MUSICIANS IN 1:10 CONCERT HALL (HALL B)

Experimental setup

A scale model of a 1,750-seats concert hall was built in 1:10 scale to evaluate effect of musicians on acoustical characteristics of the hall. As shown in Figure 8, measurements were carried out in audiecne occupied conditions according to the number of musicians on platform (0, 40, 50, 70 and 100 persons). Impulse responses were measured in the 11 receiver positions by using 1/8" microphone as shown in Figure 9. Miniature dodecahedron loudspeaker was employed. Measureme results was converted into the real scale, thus, the results cover the frequency range of 125 Hz to 4 kHz. G, RT, EDT and C80 were derived from the measured impulse responses.



(a) RT (b) EDT

(c) G (d) C80

Figure 10. Measurement results of acoustical parameters by number of musicians in 'Hall B'

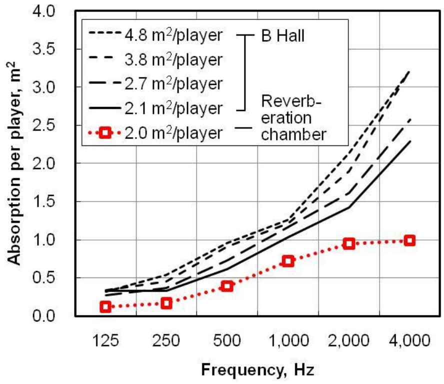


Figure 11. Calculated absorption power of musicians from 1:10 Hall B and 1:10 reverberation chamber

Results

Figure 10 shows the measurement results of acoustical parameters. RT, EDT and G were decreased according to the number of musicians. As shown in Figure 10 (a) and (b), RT and EDT showed strong linear relationships with the number of orchestra players (R^2=0.95 for RT and R^2=0.98 for EDT). RT was dropped by 0.11 s and EDT was droped by 0.21 s according to the added 100 musicians. This emphasizes that musicians on stage especially affect early sound decays.

As shown in Figure 10 (c), G was dropped by 0.3 dB and C80 increased by 0.4 dB according to the added 100 musicians. However, the tendency of G is slightly different from those of RT and EDT. R-squared value of G and number of musicians was 0.59 which was relatively small in comparison with the cases of RT and EDT. Averaged G values of 40-musician case and 90-musician case were not much different. On the contrary, G in case of 40 musicians was rather higher than G in case of 90 musicians. This indicates that the presence of musicians on stage yield the reduced sound strength, not the number of musicians.

Discussions

Miniature musician model was reproduced through absorption power measurement in reverberation chamber. However, the measured RT in scale model halls reveals that the actual absorption power of musicians in halls is different from the reverberation chamber condition. Figure 11 shows the calculated absorption power of musicians from 1:10 Hall A and 1:10 reverberation chamber. The results showed that smaller number of musician arrangement yielded larger absorption per player, particularly at high frequency bands. Therefore, this difference of absorption should be considered to estimate acoustical characteristics of occupied halls.

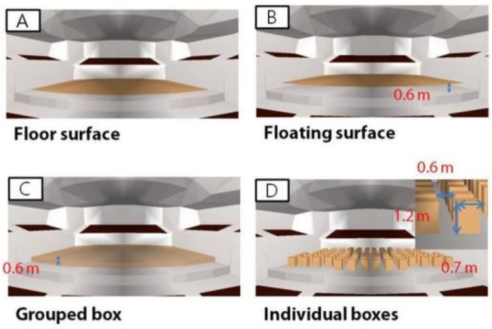
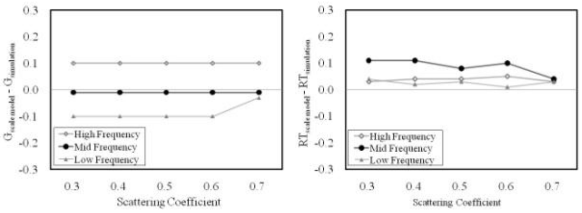


Figure 12. Modelling methods of musicians in computer simulation model of 'Hall B'

COMPUTER SIMULATIONS

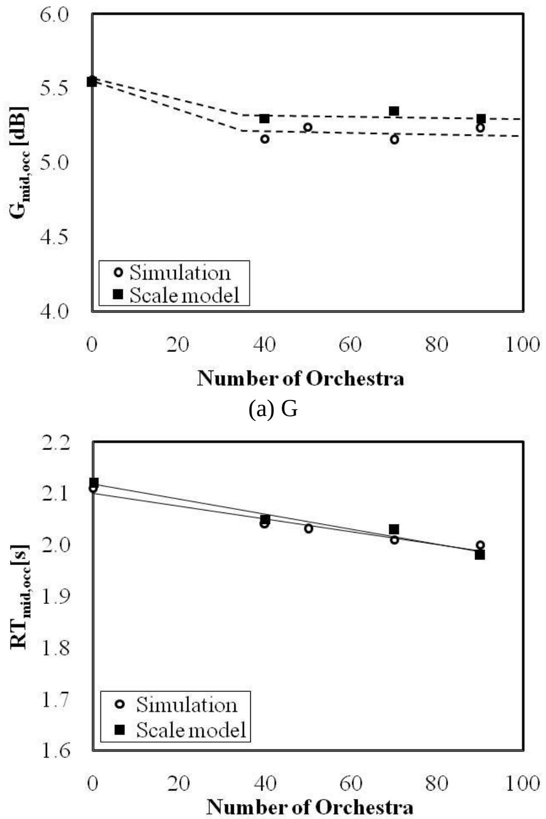
Musician modelling methods

'Hall B' was reproduced in 3D acoustic model to find out proper modelling method of musicians in computer simulation. Four types of musician model were considered as shown in Figure 12. The absorption coefficient of model musician measured in the 1:10 reverberation chamber was assigned, and scattering coefficient was varied from 0.3 to 0.7. In 'Type A', stage floor itself was assigned as musician. In 'Type B', musicians were modelled as flat surface at 0.6 m high in consideration of musician height. In 'Type C', musicians were modelled as a grouped box with 0.6-m height. In 'Type D', musician was individually modelled as a single box with 0.7-m height. The same measurement positions with the scale model testing were considred (See Figure 9). Through the computation of RT and G by number of musicians, the difference between scale model and simulation was derived.



(a) G (b) RT

Figure 13. Comparison of G and RT differences between scale model and simulation results according to the various scattering coefficient in case of 'Type C'



(a) G

(b) RT

Figure 14. G and RT between scale model and simulation results according to the number of musicians

Results

Computer simulations were conducted according to the musician modelling types. As results, 'Type C' showed the most similar results with the scale model testing results in terms of G and RT. Figure 13 shows the results of G and RT difference between scale model and simulation results according to various scattering coefficients in case of 'Type C'. The most fitted scattering coefficient for 'Type C' model was 0.7 in consideration of frequency characteristics.

Using 'Type C' modelling method, acoustical parameters of the scale and simulation models were compared according to the number of musicians. Figure 14 shows the results of G and RT by number of musicians. Both G and RT showed the well agreed tendencies between scale and simulation models.

SUMMARY

In this study, the effects of the orchestra musicians on acoustical characteristics of concert halls were investigated using scale models. Model musician was reproduced through the absorption coefficient check procedure. The model halls were reproduced realistically in various scale factors.

From the scale model testing, absorption power of a musician increases at above 1 kHz according to larger occupied area, but decreases at above 2 kHz according to larger arrangement in terms of number of musicians. This mainly caused by the different surface area by musician arrangement. In concert halls, musicians in unoccupied audience condition are more influential to the hall absorption than those in occupied audience condition. By arrangment of musicians, RT, EDT and G are decreased, but C80 is increased at audience area in comparison with empty stage condition. Additionally, the proper simulation modelling method for musician was found as grouped box with absorption coefficient measured from reverberation chamber and scattering coefficnet of 0.7. The simulation results were well agreed with the scale model results in terms of G and RT.

Based on the experiments using scale models of a hall, it is turned out that existence of players on the stage also has significant influences on the acoustical condition of the hall as well as their chairs. Furthermore, orchestra players need to be more vitally deemed as a varying factor since they are the main sound source, or in case of solo playing, very close to the sound source.

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