THE JOURNAL OF THE ACOUSTICAL SOCIETY OF KOREA VOL.25, NO.3E 2006. 9 pp. 95~100

Comparison of Predicted Acoustics with the Measured Acoustic Properties of a Multi-Purpose Hall

Chan-hoon HAAN*
*Dept. of Architectural Engineering, Chungbuk National University,
(Received Jun 12 2006; Revised August 22 2006; accepted August 29 2006)

Abstract

The present study presents the design procedures and the acoustic properties of the main hall of Ansan Cultural Arts Center in Korea which has opened in 2004. The acoustic design values are compared with the measured acoustic properties of the completed multi-purpose hall.
Acoustic design criteria were suggested in the design stage through the 3-dimentional computer simulations. The acoustic parameters including SPL, RT, C80, D_{50}, RASTI were measured in the hall after completed. Acoustic measurements were carried out in the 40 measurement points using MLS sound source signal in 4 different sound source points.
The results show the even distribution of sound levels within the 2.0dB of difference among all seats. The reverberation time of 1.66sec was measured which is similar to the objective value of 1.65 sec in empty states. It was also found that average C80 values lie in the objective extents of C80 from -1 to 3dB and average D50 value of 54 was measured. Thus, it is concluded that the hall can be used as a multi-purpose hall with a suitable acoustic conditions.

Keywords: *Multi-purpose hall, Acoustic simulation, Acoustic measurements, Sound definition, SPL, RT, C80,* D_{50}, *RASTI*

I. Introduction

Ansan Cultural Arts Center was opened to the public in 2004. It has three multi-purpose auditoriums. Among them, main hall has the seat capacity of 1,750 seats and has a fan-shaped plan with a proscenium. Computer modeling was accomplished to predict the acoustic parameters at the design stage and the interior designs were suggested which satisfied with the objective goal of acoustics. After completion, acoustic measurements were carried out to evaluate the acoustic performance of the hall. The measured data were compared with the design values. The present study represents the whole procedures of the acoustic design and measurement of a performance hall in a scientific manner.

Corresponding author: Chan-hoon HAAN (chhaan@chungbuk.ac.kr)
Dept. of Architectural Engineering, Chungbuk National University, Cheongju, 361-764, Korea

II. Acoustic Modeling and Design

Architectural measures of the hall designed are listed in the Table 1 including air volume, surface area and dimensions of the hall. The main hall is fan-shaped and has two balconies with extended seats along with side walls. Figures 1 & 2 illustrate the each plan of the hall showing the positions used in the both acoustic modeling and measurement. Optimum reverberation times at 500Hz were suggested for various types of performances which are expected to be played in the hall. (refer to Table 2) The optimum reverberation times were calculated following the Knudsen's table with current air volume of 14,500 m^3. The average reverberation time at the center frequencies was designed as 1.50sec in occupied state since the hall is mainly to be used for music. Objective reverberation times of each 1/1 octave

Table 1. Architectural measures of the hall.

Measures	Length	Width	Height
Maximum dimension	33m	37m	21m
Average dimension	30.5m	28.5m	17.5m
Volume (V)	14,500 m^3		
Surface Area(S)	5,146 m^2		
Floor Area (F)	1,580 m^2		
Number of seats (N)	1,750 seats		
V/N	8.29 (m^3/seats)		
Stage Area	1,273 m^2		

Table 2. Optimum reverberation times at 500Hz with various types of performances expected in the hall (current air volume is 14,500 m^3).

Performance type	church music	music	multi-purpose	chamber music	theatre, cinema	speech
RT (sec)	1.75	1.50	1.30	1.22	1.14	0.92

Table 3. Objective reverberation time at 1/1 octave centre frequencies.

Hz	125	250	500	1K	2K	4K	Tmid
RT	1.80	1.60	1.50	1.50	1.50	1.42	1.50

frequency band are listed in Table 3.

Also, it was designed to have even sound distribution of seats within the deviation of ±2.0 dB. The objectives of the speech clarity criteria of D50 and RASTI were set to 0.5 and 0.6 respectively.

The 3-D model of the hall is illustrated in Fig. 3. Computer modeling was undertaken using ODEON room acoustic software (v.6.2) and 20000 rays were traced calculating 2000 reflections as the maximum limit. The detail measures of the computer simulations are listed in Table 4. Predictions were made for acoustic measures such as reverberation time (T30), sound pressure level (SPL), clarity index (C80), sound definition(D50), lateral energy fraction (LF) and sound transmission index (STI) at the receiver positions. As a result, reverberation time of each seat was calculated and the distribution map of audience area was plotted as in Fig. 4.

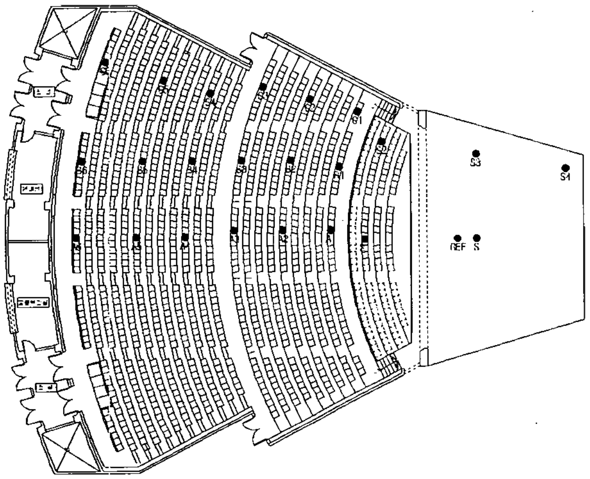


Fig. 1. Measurement points at the stalls.

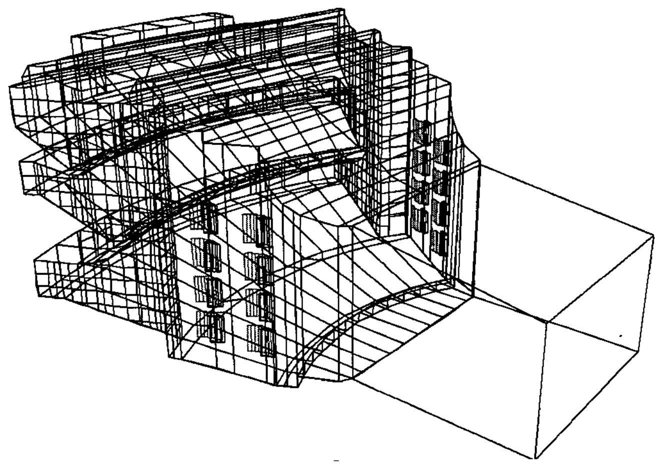


Fig. 3. 3-D image model of the hall.

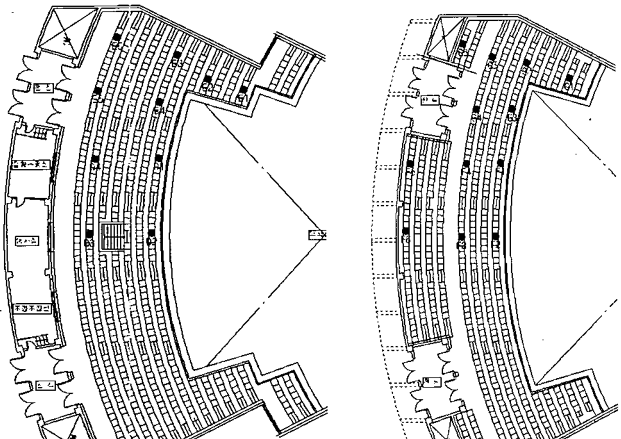


Fig. 2. Measurement points at the balcony floors.

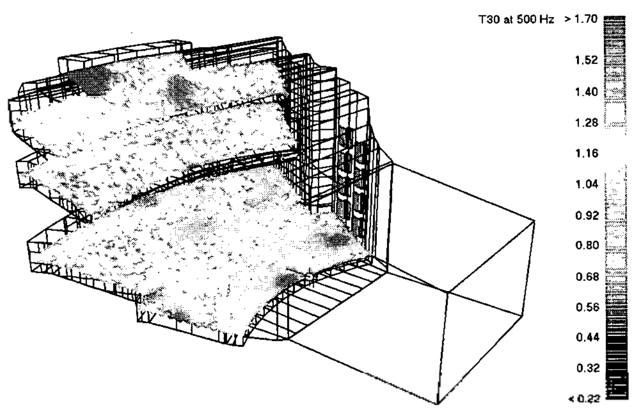


Fig. 4. RT distribution map of the hall.

Table 4. Conditions of computer simulation.

No	Classification	Measure
1	Number of rays	20,000
2	Impulse response length	1,800 ms
3	Max. number of reflections	2000 times
4	Sound power level	90 dB
5	Number of sound sources	3
6	Number of receiver points	29
7	Number of surfaces	1575

The interior finishing materials of each area of the hall were suggested which satisfy with the acoustic conditions designed. Reflective curved ceilings were introduced to give uniform distribution of sound level at every auditorium seat. Absorptive and reflective panels are applied to the side walls in parallel with the dividing moldings. Fig. 5 illustrates the side wall elevation of the hall showing the area of absorptions and reflections. Large-scale sound diffusers were proposed to enhance lateral reflections and the early reflected sound energy to the audience. The detail of the sound diffuser on the side walls is plotted in Fig. 6. Rear walls were treated as absorptive with acoustic ribs.

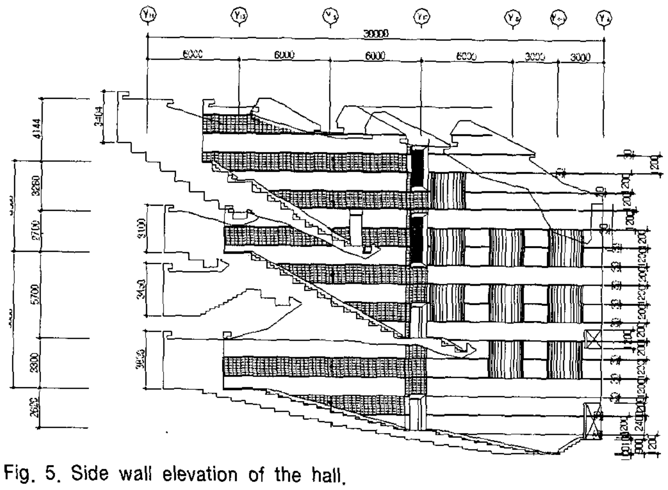


Fig. 5. Side wall elevation of the hall.

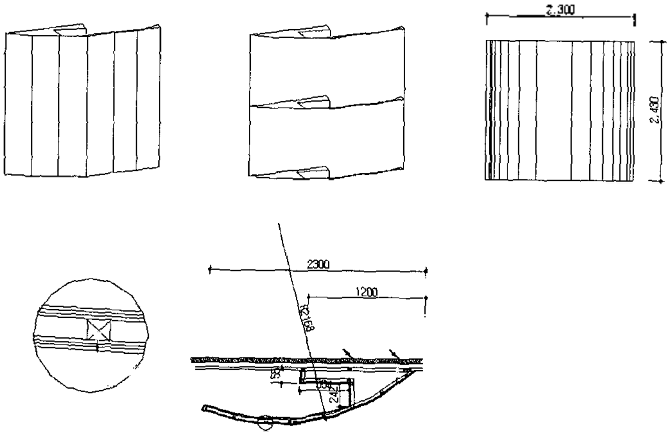


Fig. 6. Detail of the sound diffuser on the wall.

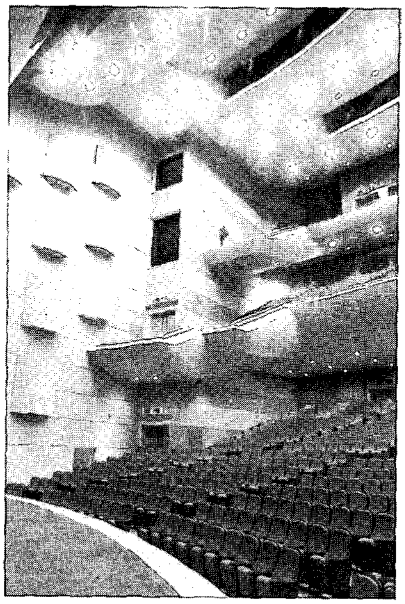


Fig. 7. Interior perspective of the hall.

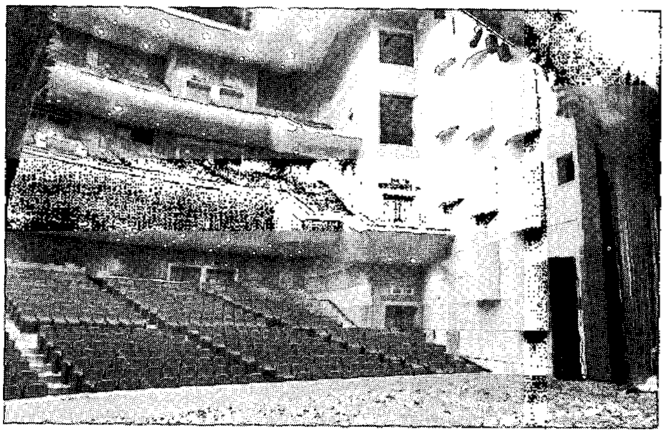
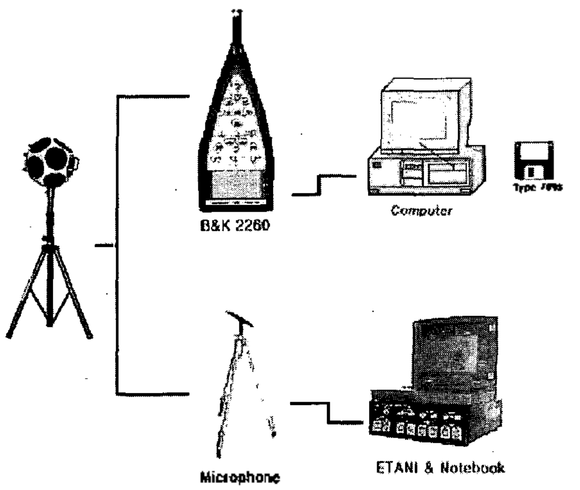


Fig. 8. Interior perspective of the hall.

Finally, a design of the hall was suggested based on the results of the computer modeling. The average reverberation time of the proposed hall was 1.5 sec in occupied state. Figs 7 & 8 show the interior pictures of the hall.

III. Acoustic Measurements

After completion of the Arts Center, acoustic parameters such as SPL, RT, C80, D_{50}, RASTI which relate with the acoustic performance of the multi purpose halls were measured at the 44 measurement points with same sound power level of sound source. (refer to Figs 1 & 2) In each measurement, an omni-directional speaker was used as the sound source and MLS signal was used as the sound source signal. In each measurement, 90dB of sound energy was radiated and the signal was taken by



(a) Set-up of measurement devices

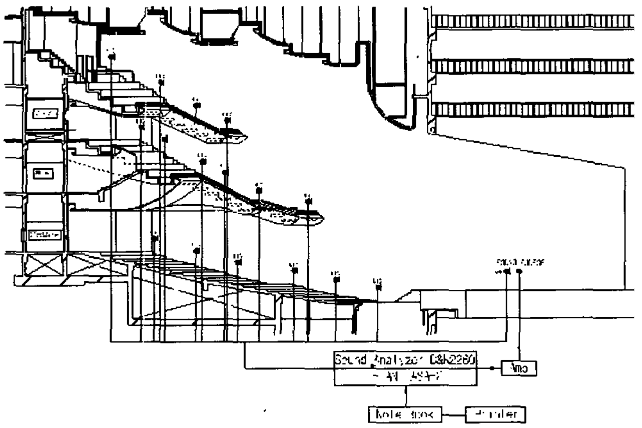

(b) Measurement installation in the hall

Fig. 9. Measurement set-up for room acoustic parameters.

microphones which were set at the height of 1.1m position from the audience floor. The measurements were carried out during the night and the background noise level was 35.2dB(A) at 500Hz. All the measurement procedures were carried out following the ISO 3382 standards.

Fig. 9 shows the measurement set up of the devices and acoustic measurement set-up for room acoustical parameters is illustrated in Fig. 9. Sound pressure levels were measured using B&K 2260 and other acoustic parameters were analyzed using ETANY ASA-2 audio sound analyzer.

IV. Results of Acoustic Measurements

4.1. Sound Pressure Level (SPL)

SPL of each point was measured with 1 octave band in empty state. The standard deviation of sound level among seats is ±1.8 dB in low frequencies, 1.6dB in mid-frequencies and ±1.5 dB in

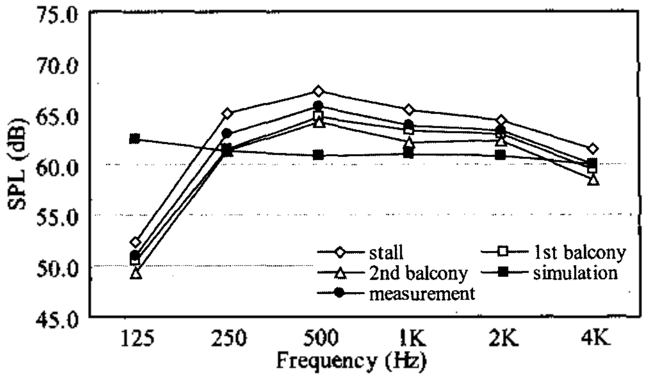


Fig. 10. Comparison of measured SPL in each area of the hall with the average predicted value.

high frequencies.

Fig. 10 displays the sound levels measured in each audience area of the hall as the function of frequencies. The average measured sound level is also plotted with the average sound level calculated from the computer modeling. The both sound levels were made in the empty state of the hall. Comparing both the sound levels of modeling and measurement, it was shown that the measured sound level has lower value at 125Hz while average calculated SPL has constant value at each frequency. It is due to the basic assumption of ray-tracing algorism which was used in the acoustic prediction software. Normally, the data from the computer simulations is qualified above 250Hz.

4.2. Reverberation Time (RT)

Due to the relatively large volume of the hall the objective reverberation time was set as around 1.5 sec in occupied state. Reverberation times of each point were measured and analyzed depending on the area of the hall. The average reverberation time was plotted as the function of frequency in Fig. 11. The average

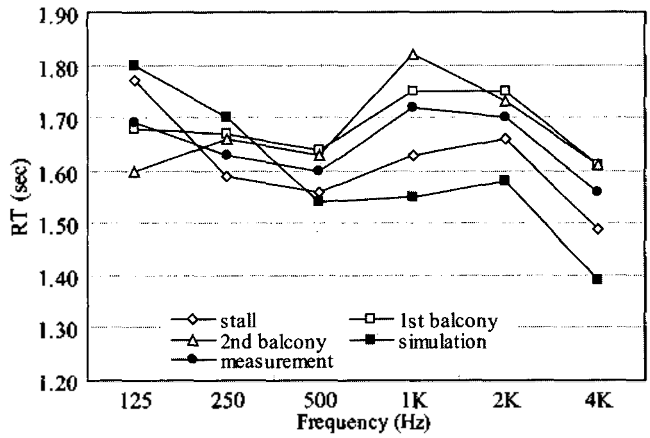


Fig. 11. Comparison of measured RT in each area of the hall with the average predicted value.

RT in empty state of the hall is 1.66sec at the mid-frequencies. This implies that the reverberation time of the hall is closely set comparing with the design goal.

The average calculated RT curve from the modeling is also plotted in the Fig. 11. Comparing the both RT values it was shown that RT predictions are larger than the real value in the low frequencies. However, the RT curve at the rest of frequencies seems to follow the frequency characteristics of the measured values.

4.3. Sound Clarity (C80) & Sound Definition (D50)

The average measured sound clarity (C80) and definition (D50) of each audience area are plotted as the function of frequency in Fig. 12 & Fig. 13 respectively. As shown in the Figs, the frequency characteristics of both parameters are similar in every audience area of the hall. It was found that the average C80 value of all seats is 3.6dB which is similar with the optimum value of sound clarity of multi-purpose halls. Also, average measured D50 value is 53.7 which is higher than the objective value of 50. The values of C80 and D50 of stalls are much smaller than the values of balconies. It is due to the long sound path of reflections from the ceiling and side walls. It was also shown that the average calculated values of C80 & D50 are smaller than the average measured values at each frequency.

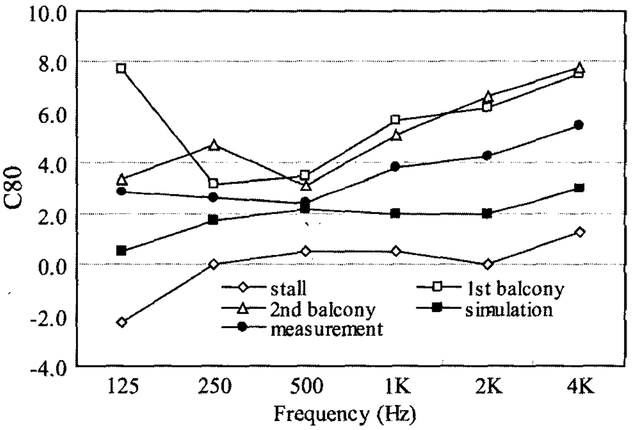


Fig. 12. Comparison of measured C80 in each area of the hall with the average predicted value.

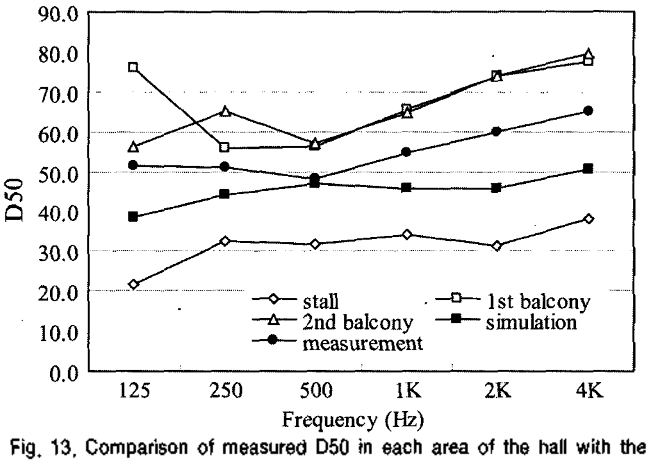


Fig. 13. Comparison of measured D50 in each area of the hall with the average predicted value.

4.4. RASTI

Average measured RASTI values of each area of the hall were analyzed with the average calculated value of modeling. As similar as shown in the D50 distribution, average RASTI value was low (0.48) in the stalls and high (0.65-0.67) in the balconies. The average value in total is 0.59 which is very close to the lower limit of the good quality of RASTI values. This means that the hall is suitable for the speech communication as well as the music performance with more than 1.5 sec. of reverberation times.

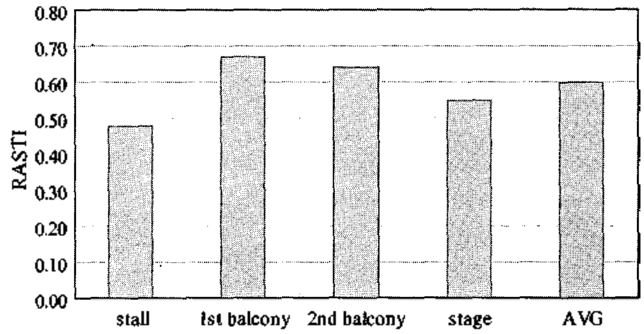


Fig. 14. Comparison of measured RASTI values in each area of the hall.

V. Summary

The present study presents the design procedures and the acoustic properties of the main hall of Ansan Cultural Arts Center. The acoustic design values derived from computer modeling was compared with the measured acoustic properties of the hall.

The results show that the design values of the acoustic parameters are well acquired and the current acoustic condition satisfy with the objective target of acoustics as a multi-purpose hall. The results also show that the hall is suitable not only for the speech communication but also the music performance due to the rich reverberation times. This implies that the hall is a successful multi purpose auditorium which can accommodate various performances.

Acknowledgment

The Present work was supported by the 2006 Chungbuk National University Research Grant.

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[Profile]

•Chan-hoon HAAN

received BEng. in Architecture from Hongik Univ. in 1983 and MEng. in architectural engineering from Yonsei Univ. in 1985. He obtained Ph.D in Architecture from University of Sydney in 1994. Since 1994, he has been a professor in the Architectural Engineering Dept., Chungbuk National University, Korea. He was also research fellow in the Salford Univ. UK in 2000?2001. His research interests include architectural acoustics and noise controls in buildings.