SOUND PROPAGATION AND SCATTERING IN PERFORMANCE HALLS WITH BALCONIES

L.Y. Cheung[1] and S.K. Tang [2]
[1] Department of Building Services Engineering,
The Hong Kong Polytechnic University, Hong Kong.
Email: louisa.cheung@polyu.edu.hk
[2] Department of Building Services Engineering,
The Hong Kong Polytechnic University, Hong Kong.

ABSTRACT

Numerous concert halls and auditoria in Hong Kong have been built and used for decades. Most of the halls in this congested city are designed for multi-purpose use and built with balconies for maximizing the space use. While objective and subjective evaluations on acoustic properties of performance halls have been done around the world, it is time for Hong Kong to have her own systematic research. Measurements have been done in a fan-shaped multipurpose theatre, a shoebox-shaped concert hall and an auditorium. The hall settings with and without the acoustic shell were both measured. Dual channel dummy head was used as receiver, while a Omni-directional sound source with room acoustics DIRAC were used for MLS production and computing. Measurement points were located throughout the halls, around four to five seats apart. In this paper, the number of reflections at each measurement point is evaluated and compared so as to find out if its balcony has produced additional reflections to any area. The measured energy ratios and other parameters are also compared to find out the effects from the balcony. Furthermore, computer simulations of one of the halls, with and without the balcony, are also done for comparison.

KEYWORDS

Concert hall acoustic parameters measurement, balcony.

INTRODUCTION

Different acoustic parameters have been developed to evaluate halls' acoustic performance since the Sabine time. For example, the sound strength (G), bass ratio (BR), reverberation time (RT), early decay time (EDT), clarity (C80), definition (D50) and interaural cross correlation IACC [1-3] . This paper includes a brief summary of hall acoustics and balconies and followed by a investigation by real hall measurements.

Hall acoustics and balconies

Although the acoustic effects of the design of different architectural elements in performance halls has been discussed extensively, the effects from the balcony edge has rarely been discussed. Sometimes, it is also neglected in predictions and evaluations.

Barron (Barron 1995) discovered that balcony and overhangs reduced the late sound energy and the subjective sense of reverberation and loudness and the solid angle for sound arriving. However, he mentioned it helps to maintain the sound level by the local reflection from the back walls and lower ceiling soffit.

The principle of acoustics states that a sound will be diffracted once it reaches a solid boundary. It passes over the boundary and continues to propagate until being reflected by another surface. Therefore, we can suggest that part of the sound energy can be reflected back as well as diffracted from the balcony edge to the stage and audience. From Beranek's survey (Beranek 1996), some musicians did mentioned about such phenomenon. Instead of reducing the acoustics properties as mentioned, such reflection and diffraction can be a benefit provided by the balcony to the hall.

In hall predictions, ray-tracing models are commonly used. However, the presence of complex structure like balconies and overhangs makes the computation complicated. Especially, the multiple scattering and diffraction at the balcony edge is not easy to model.

Inaccuracy happens in such modelling. For example, Edwards and Kahn (Edwards et al. 1998) reported that in some modelling for European horse shoe shaped opera house, the results showed that there is a lack of reflected sound while the halls and balcony surfaces were too absorptive. However, these opera houses are well-known for their good acoustics. Also, there are some other researchers discovered that even modern ray-tracing based programs include an approximation for surface scattering and edge diffraction (Lam 1996).

Lam (Lam 1996) and Hodgson (Hodgson 1991) introduced the diffuse-reflections into different tracing models to approximate some of the scattering and diffracting properties of reflecting surfaces. Chan and To (Chan et al. 2002) used computer simulation and ripple tank experiment to model the back scattering of the balconies. They indicated that a virtual source will be created at the lower corner of the balcony front which is close to the sound source. Hence, they suggested that by incorporating such considerations, back-scattering effect can be evaluated using computer models. Meanwhile, the cross-coupling effect between different panels should also be considered.

REAL HALL MEASUREMENT

Procedures

Measurements have been done in real hall to survey the acoustic properties in the hall and to investigate the effect of the balcony in accordance with ISO standard 3382-4:2009, Acoustics Measurement of room acoustic parameters, Part 1 Performance spaces. The halls are multi-purpose halls that use a demountable acoustic enclosure to convert from theatre setting to concert or chamber music setting. Therefore, the halls were measured with 2 scenarios: with acoustic enclosure and without acoustic enclosure in empty condition.

To measure the acoustic properties in the hall, the room acoustics software B&K DIRAC Room Acoustics Software Type 784 was used. The software employed an impulse response method in determining the values by using maximum length sequence (MLS) as its signal. It outputted an internal MLS through the loud speaker at the source point. By correlating the output and the input signal received from the microphones, the decay and other properties were calculated by the software.

Random positions were picked as receiver points throughout the audience area, in the stall level and on the balcony. All the measurements were done with the dual channel head with built in receivers - B&K head and torso simulator Type 4128C. Its built-in microphones were embedded at eardrum positions that were used as receivers. The measurement time was set at 2.73s, which is around a double of the reverberation time of the hall.

Measurement venues

A few halls were picked for the present investigation. Results of the hall are discussed in this paper.

Hall A

The hall is symmetrical and in fan shape. Its balcony is relatively shallow. There are only four rows of seats on the balcony. In addition to the balcony, there are two additional wings projected from both sides in the front stall area. Fig. 2 shows the layout of the hall. The marked points on the layout are the seats being measured. The drawing is not-to-scaled.

The seats in the hall are all upholstered mounted on timbre flooring. There are technical balconies on both sides next to the stage opening. The technical balconies are opened to the hall and appeared as voids. In the audience area and on the balcony, the side walls are covered with 2 kinds of material: grids of acoustics boxes at low to midlevel and motorised velour curtains covering the plastered walls at mid to high level. The main ceiling are with exposed catwalks and lighting bars. However, there are ceiling mounted acoustics boxes installed on the true ceiling above these facilities. Contrastingly, there are false ceiling under the balcony.

To convert this hall from a theatre setting to a concert setting, a full height acoustic enclosure is installed on the stage. The enclosure surrounds the stage and separates it from the back stage area and shuts off the stage from the fly tower above.

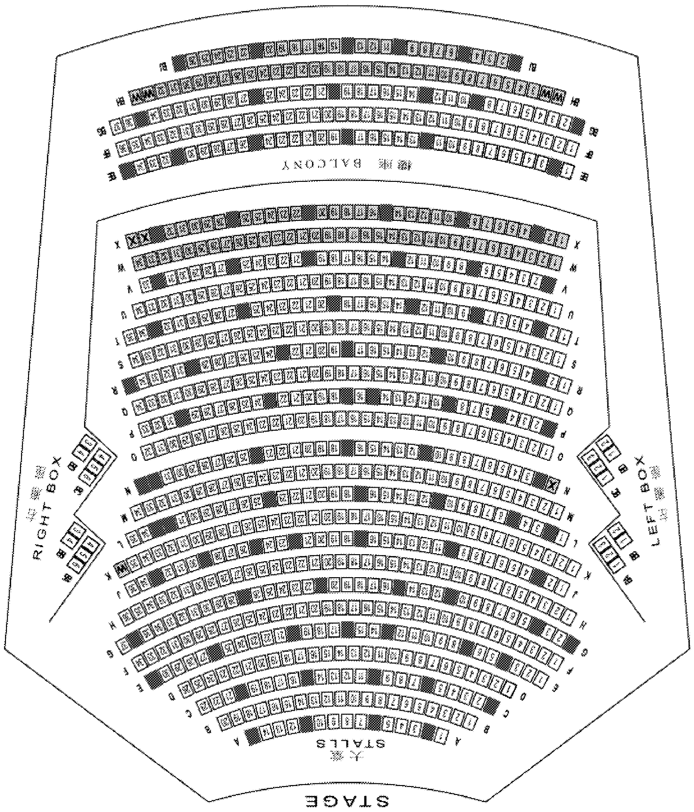

Figure 1 Layout of the measured hall A. All the shaded seats are the measurement locations.

RESULTS AND DISCUSSIONS

To study the difference between the measured results of different session of the audience, all the seats were divided into 4 receiver zones. Front stall includes the first few rows from the stage; the mid-stall includes the 5 rows on the stall before the balcony; under-balcony includes all the seats below the balcony.

All the values used in table and plots are the average of the two channels measured. In all the plots below, data of different receiver zones are represented with respective legends: △- front stall, ✳- mid stall, □-underbalcony and ○- balcony. The roman number I, II, III, IV indicates the 4 receiver zones correspondingly: front stall, mid-stall, under-balcony and balcony.

RT, Reverberation time

Table 1 The mean RT and their standard deviation (in italic) in sec measured at 250Hz, 1000Hz and 4000Hz with and without acoustic enclosure on stage.

	No enclosure			With enclosure		
Zone	250Hz	1000Hz	4000Hz	250Hz	1000Hz	4000Hz
I	1.50	1.26	0.99	1.39	1.51	1.29
	0.16	*0.05*	*0.02*	*0.05*	*0.03*	*0.02*
II	1.50	1.25	1.00	1.38	1.51	1.31
	0.12	*0.06*	*0.02*	*0.13*	*0.03*	*0.01*
III	1.49	1.24	0.99	1.36	1.50	1.30
	0.15	*0.04*	*0.02*	*0.05*	*0.02*	*0.01*
IV	1.55	1.30	0.99	1.39	1.52	1.29
	0.12	*0.04*	*0.03*	*0.05*	*0.02*	*0.02*

Reverberation time is the time that it takes for a sound to drop 60dB after emission. Table 1 summarizes the mean of the RT measured in the hall. From the measured results, the RT at 1000Hz and 4000Hz are longer with the acoustic enclosure while that at low frequency 250Hz is shorter. The overall RT at each frequency band is quite uniform across the hall. With the acoustic enclosure, the reverberation time at low frequency is more uniform across the whole audience, excluding the mid stall area.

Clarity, C80

The clarity factor C80 is a measure, in dB, of the strength of the early sound to the reverberant sound. The larger the value, the larger the intelligibility of the music and vocal sound is.

Table 2 The mean C80 and their standard deviation (in italic) in sec measured at 250Hz, 1000Hz and 4000Hz with and without acoustic enclosure on stage.

	No enclosure			With enclosure		
Zone	250Hz	1000Hz	4000Hz	250Hz	1000Hz	4000Hz
I	3.27	5.39	7.63	0.69	2.27	2.55
	1.66	*1.21*	*1.85*	*2.13*	*0.64*	*1.60*
II	2.63	4.63	6.46	-0.50	2.24	2.54
	1.60	*0.62*	*0.93*	*1.65*	*0.79*	*0.95*
III	4.03	5.29	6.81	0.50	3.13	3.53
	2.06	*1.02*	*1.05*	*1.41*	*0.99*	*1.03*
IV	2.89	3.78	5.03	1.42	1.46	3.47
	1.74	*0.59*	*1.16*	*1.45*	*0.75*	*1.18*

Table 2 shows the mean of the C80 at low, mid and high frequency with their standard deviations. The results show that the acoustic enclosure reduced the early sound to the reverberant sound. The C80 values decrease with distance from the front of the stall to the seats in front of the balcony and up to the balcony. However, from Fig.2 the values at the seats below the balcony are relatively higher than those on the balcony.

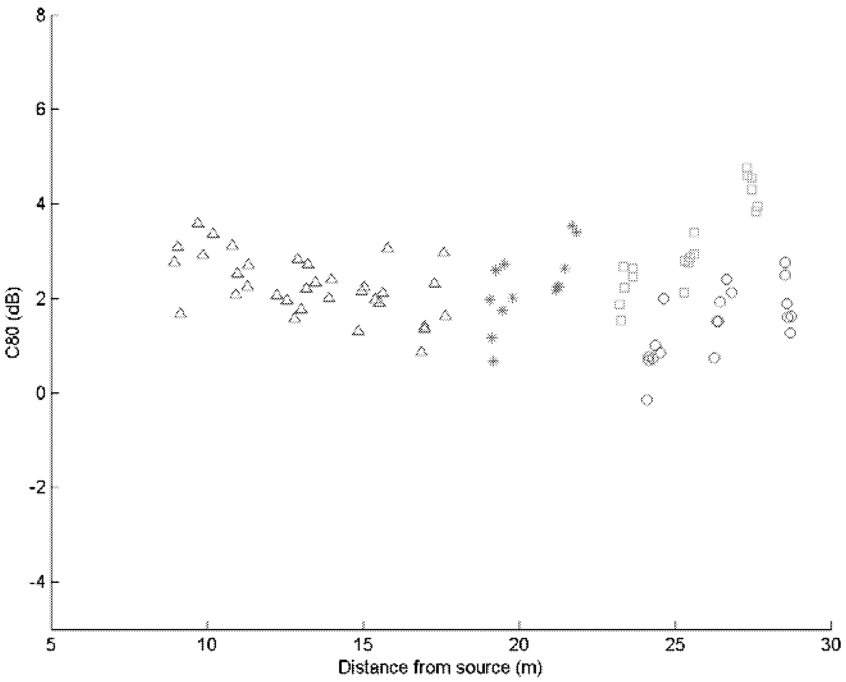

Figure 2 The plot of C80 at 1000Hz against distance for Hall A with acoustic enclosure

Strength Factor, G

Figure 3 shows the plot of the relative sound strength at 1000 Hz plot against distance. The values decreased with distances between the source and receivers.

As shown in fig.3, there are some points with smaller G values the front stall area. This happened around the sixth to eighth rows of seat in the stall in all frequency bands.

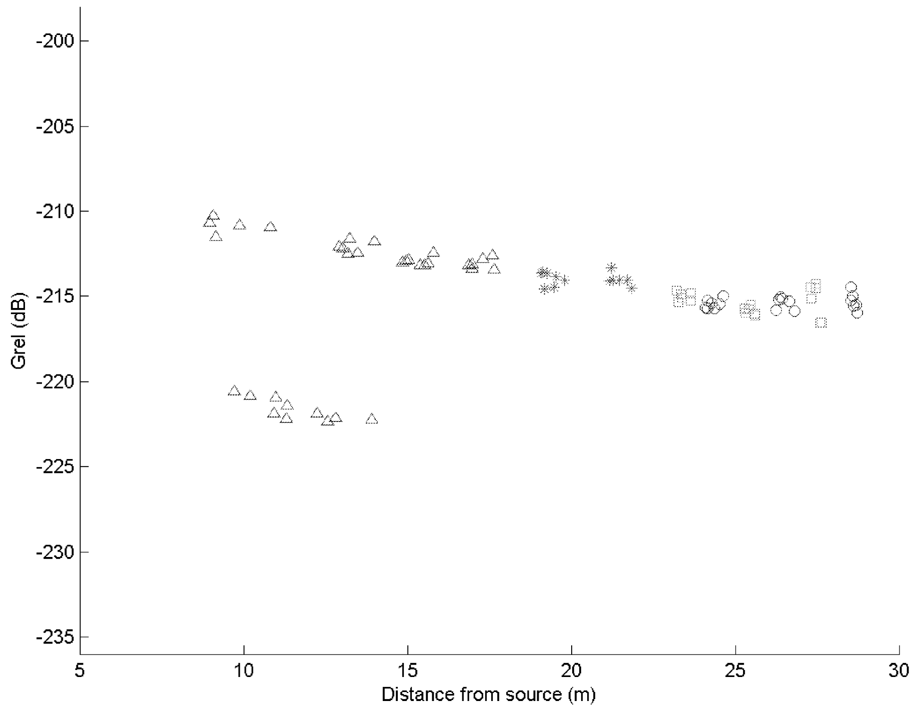

Figure 3 The plot of relative G at 1000Hz against distance for Hall A with acoustic enclosure

Bass Ratio

The bass ratio is calculated from the RT at low and mid frequencies by the dividing the sum of the RT at 125Hz and 250Hz by the sum of RT at 500Hz and 1000Hz.

Not much correlation between BR and distance from source can be shown from the results in fig. 4. Most of the BR values lies in the range of 0.8 to 1. From this plot and table 3, one can observe that the BRs in the presence of the acoustic enclosure are smaller than those without the enclosure but they are less diverging.

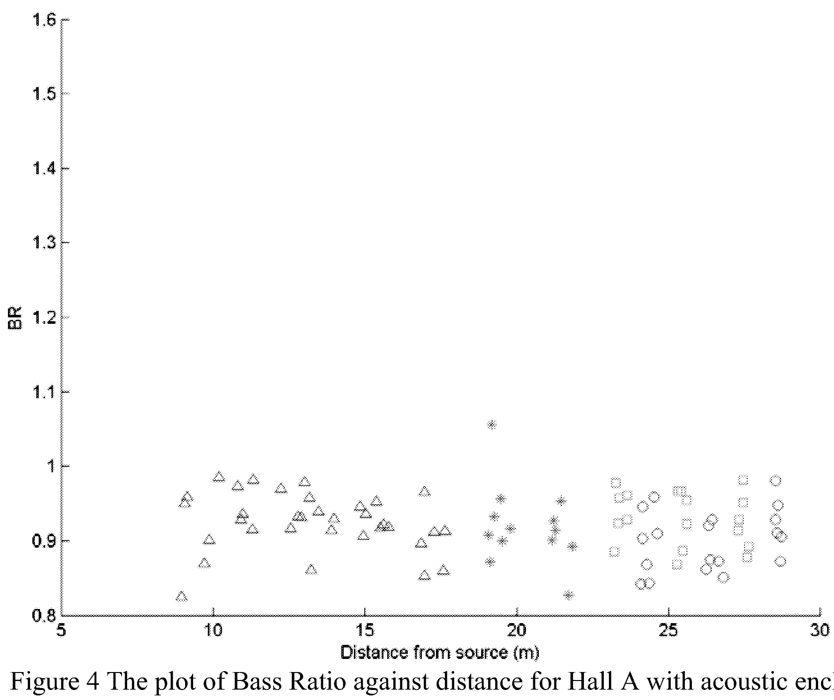

Figure 4 The plot of Bass Ratio against distance for Hall A with acoustic enclosure

Table 3 The mean Bass Ratio(BR) and their standard deviation (in italic), with and without acoustic enclosure on stage.

Zone	No enclosure	With enclosure
I	1.27	0.92
	0.13	*0.05*
II	1.29	0.92
	0.09	*0.07*
III	1.26	0.94
	0.08	*0.04*
IV	1.25	0.90
	0.10	*0.05*

CONCLUSION

Multi-purpose halls were measured using impulse response method with dual channel receivers in this study. For each halls, the measurements were done in empty condition and both the concert hall and theatre settings.

In Hall A, the measured reverberation times without the acoustic enclosure were shorter than those with the enclosure. The measured clarity is smaller with the use of the enclosure. It also decreased slightly with the distance from the source. Comparing points with similar distance from the source, those seats under the balcony have larger values. The measured sound strength decreases with distance as well. It attained a minimum at the seats in the stall area. With a decrease the reverberation time at low frequency while a increase in mid and high frequency, the bass ratio became smaller when the enclosure was used.

This measurement surveyed the acoustics properties in the halls. Despite the effects of distance, we can say that the balcony affects the reflection received at seats under the balcony. Further investigation and modelling is needed to find out the effects of the balcony and the actual scattering and possible reflection happening at the balcony front and edge for their contribution to the acoustics in different parts of the hall.

ACKNOWLEGEMENT

L.Y. Cheung is supported by a studentship from the Hong Kong Polytechnic University.

REFERENCES

Barron, M. (1995). "Balcony overhangs in concert auditoria." *The Journal of the Acoustical Society of America* 98(5), 2580-2589.

Beranek, L. L. (1996). *Concert and Opera Halls : How They Sound.* Woodbury, N.Y., Published for the Acoustical Society of America through the American Institute of Physics.

Chan, T. M. and W. M. To (2002). "Modelling of Scattering from Balcony Fronts." *Building Acoustics* 9, 219-231.

Edwards, N. and D. Kahn (1998). "Why do traditional opera houses work so well for opera?", *The Journal of the Acoustical Society of America* 103(5), 2784.

Hodgson, M. (1991). "Evidence of diffuse surface reflections in rooms." *The Journal of the Acoustical Society of America* 89(2), 765-771.

Lam, Y. W. (1996). "A comparison of three diffuse reflection modeling methods used in room acoustics computer models." *The Journal of the Acoustical Society of America* 100(4), 2181-2192.