Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Acoustical design and scale model test for the opera house of Zhongshan city

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The opera house of Zhongshan City in Guangdong province of China is a performing art center of the city. It was completed in October, 2005. The opera house has 1400 seats including 833 orchestra seats and another 484 seats on two levels of balcony. The volume of the auditorium is 12000m^3 and the V/N is 9.1m^3 per seat. The main purpose of the building is for the performance of opera and ballet. Some music and conference events are also held there. Therefore, the occupied reverberation time at medium frequencies is set to be 1.6s and its background noise level has to meet NR-20 standard. At the acoustical design stage, a 3D computer simulation model established with ODEON software and a 1:20 scale model were made to analyze the sound fields of the auditorium with and without a music shell on the stage. After the completion of the building, an acoustics test was carried out. Several performances show that its acoustics reaches a quite high level.

1 Introduction

Zhongshan city is a prefecture-level city in the south of Pearl River Delta in Guangdong Province in southern China. The city was originally a county renamed in honour of Dr. Sun Zhongshan, who is also known as Sun Yat-sen and considered by many to be the "Father of the modern China".

The opera house of Zhongshan City was initiated in December 2000, and completed in October 2005. The construction costs some 65 million RMB yuan. Fig.1 shows its outward apparence. The plans and the longitudinal section of the auditorium are given in Fig.2. The auditorium has 1400 seats including 833 orchestra seats and another 484 seats on two levels of balcony. The average width of the stall is 29m. The volume of the auditorium is 12000m^3 and the volume per seat V/N is 9.1m^3 per seat. The main stage has an area of 30m×24m (width × depth). There are 2 side stages and a back stage. The areas of each side stage and the back stage are 15m × 18m and 23m × 16m respectively. They are powered turntable - slip stage as well as slip stages. The width and height of the stage opening are 18m and 11.5m respectively. The main purpose of the building is for the performance of opera and ballet. Besides, some musical and conference events are also held there. Therefore the occupied reverberation time at medium frequencies is set to be 1.6s, the bass ratio 1.1～1.3, the clarity factor -2～+2dB, the strength factor: 0~4dB，the room acoustical speech transmission index: 0.6[1], and the background noise levels has to meet NR-20 standard.

Fig.1 The Opera House of Zhongshan City

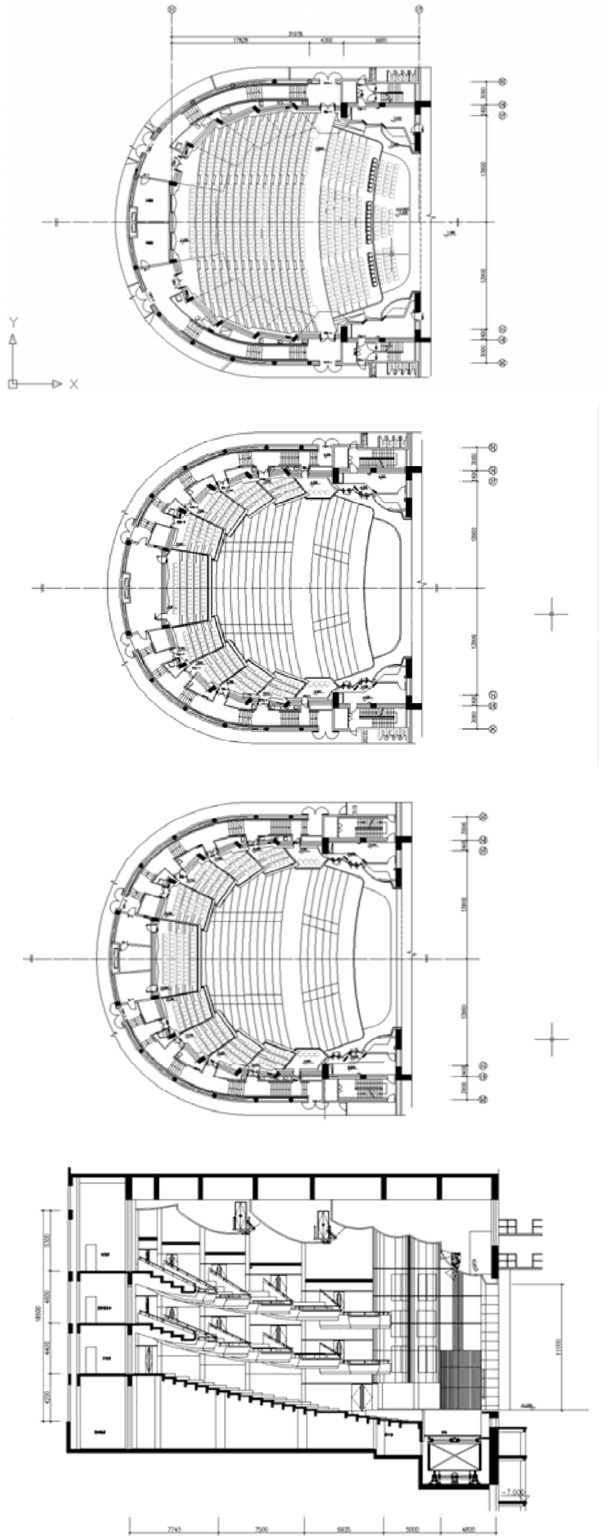


Fig.2 The plans at different levels and the section of Zhongshan Opera House

The seats are medium upholstered chairs with only 50mm thickness cushion covered by porous cloth on the chair and 25mm thickness cushion on the back. The floors of both stall and balconies are covered cork tails on concrete. The ceiling of the auditorium is made of two layers' of 12mm thickness plasterboard on steel frame with 50mm mineral wool in cavity. The same construction is also applied to the underneath surface of the balconies. Most walls are covered with 25mm wood facing on 12mm plasterboard on frame over cavity, forming a projective shape to diffuse sound wave. The diffuser panel with some irregularities on it and of the order of 25mm which is designed according to the MLS theory to reduce acoustic glare caused by flat surface are also used on the side walls [2]. The same construction and detail are also used on the surfaces of the front railing of the balconies to diffuse sound and prevent echoes generating from these surfaces. The stage floors are made of wooden boards on wooden subbase over the powered turntable- slip stage and the slip stages. On the stage, two kinds of sound absorbing materials are put on the back and side walls to prevent more sound energies feedback from the stage space to the auditorium. They are 25mm thickness of glass-fibre boards and 25mm wood wool boards with 50mm cavity. To ensure a low background level, we placed emphasis on the noise control for the air-conditioning system. The air velocities for the air supply system and the return system are limited to be 1.5m/s and 1.8m/s respectively.

2 3D computer simulation of the sound field

A 3D computer model (see Fig.3) was established for acoustical design and ODEON software was used to analyze the sound fields of the auditorium with and without the acoustical shell on the stage. In the simulation, the materials were put on each surface according to the design scheme. The simulation results show the covered area by the early reflections from each main surface, and the impulse response at each receiver as well as the data of main acoustics parameters on the seat area.

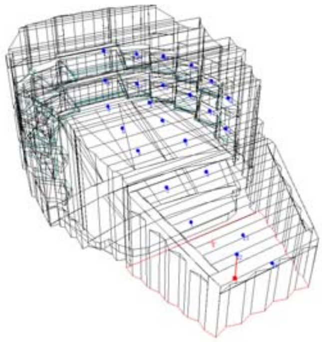


Fig.3 3D Computer model of the opera house with acoustic shell on the stage

The results of the simulation show that the data of some main parameters, such as RT, G, C_{80}, etc locate within the range of designed preferred values, and that the early reflections from the surfaces on two sides of the stage opening and from the ceiling can cover most audiences quite evenly. The surfaces above the orchestra pit can reflect the sound from the pit to the stage, which means they are beneficial to the mutual hearing of both the actors / actresses on the stage and the musicians on the pit. The results also show that the reverberation time when the acoustical shell is set on the stage will increase by around 0.2s. In a whole, the computer simulation shows that the auditorium has a good acoustics. Fig.4 presents an example of the simulated reflectogram at a receiver. And Fig.5 describes the seat area covered by the early reflections from the main surfaces. Fig.6 gives the simulated C_{80} data distribution in the auditorium with and without a music shell on the stage.

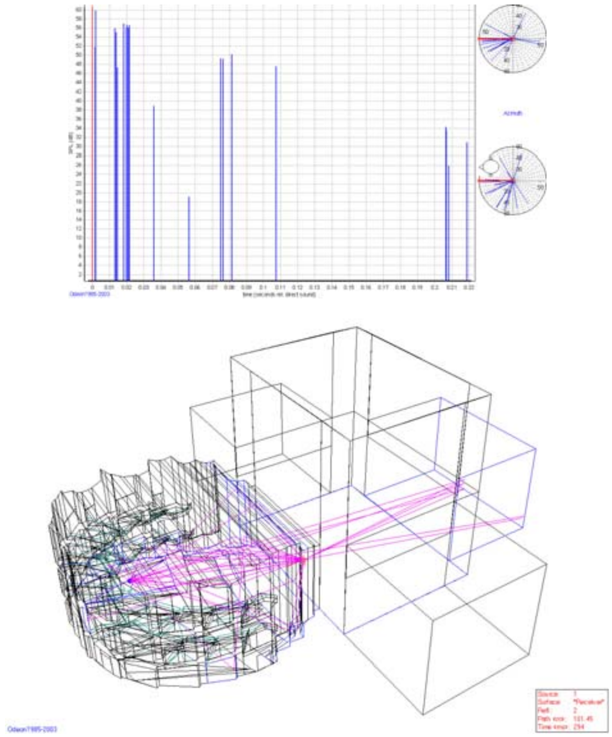


Fig.4 The reflectogram at a receiver position

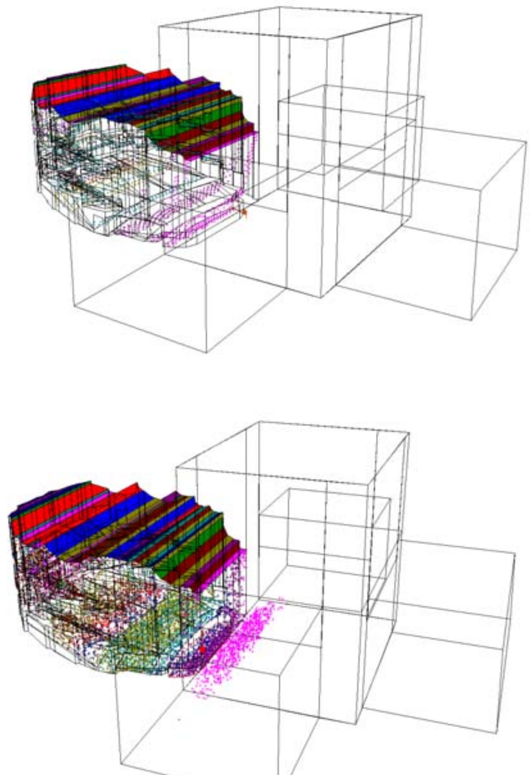
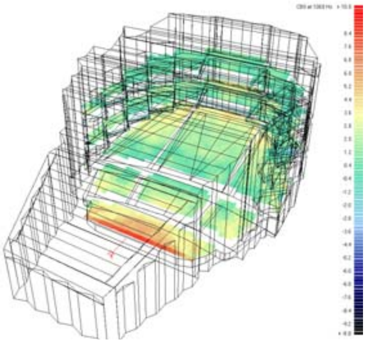
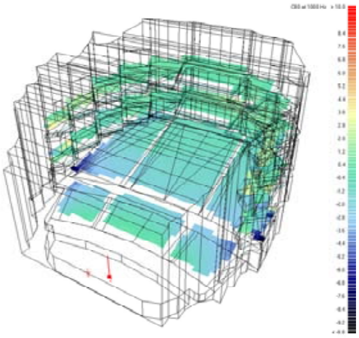


Fig.5 The coverage of the first-order reflections from the ceiling



(a)



(b)

Fig.6 Simulated C_{80} data distribution in the auditorium (a)With a music shell on the stage (b) Without a music shell on the stage

3 Scale model test

In order to consider the effect of the sound wave propagation on the acoustics, a 1:20 scale model was also made. The walls of the model are made of 8mm acrylic panel. The surfaces on both sides of the stage opening and the ceiling are made of PVC panel. Woollen blanket is used for simulating the absorption affected by the audience. Fig.7 shows the scale model. During the acoustical test, a spark generator was used as the sound source which can produce a sound ranged from 50k～100k Hz and can guarantee enough signal to noise ratio. The signal received by 1/8″ B&K 4138 microphone is transferred to B&K PULSE sound analyzer which can properly analyze the sound signal under 200K Hz. The impulse responses at each receiver inside the model are then analyzed by B&K 7841 software and the correction for the excess air absorption at very high frequencies is also considered. When testing, the source is set on the central line of the stage, 15cm from the main curtain fall line, 7.5cm in height. A total of 23 receivers are located on the pit, stall as well as on the two level balconies. The test results show that each receiver can receive many early reflections within 50ms (Fig.8). Neither the seat or the stage are disturbed by echoes.In comparison with the orchestra seating and first level balcony seating, the seats on the second level balcony can receive more plentiful early reflections. And these reflections are more evenly distributed. The sound field with a music shell on the stage is also tested. The shell is also made of PVC panel. The test shows that the shell can offer more early reflections for orchestra seating as well as for the balconies' seating and therefore is beneficial to the acoustics of the opera house.

4 Acoustic measurement

The opera house was completed on Oct. 2005. Fig.9 shows its inner view. After the completion of the building, an acoustics measurement was taken. The measuring instruments include: B&K 2260 D investigator, B&K 4189 microphone, omnidirectional loudspeaker B&K 4296, and amplifier B&K 2716. The measurements were taken under both situations with and without the music shell on the stage. During measuring, the temperature was 25.7°C, and the relative humidity was 69%. The sound source was located at the point where the central line of the stage crossed with the main curtain fall line. Its height was 1.5m. The receivers were distributed on one side of the auditorium including stall and balconies. The measurement results show that the unoccupied reverberation times at medium frequencies with and without the music shell on the stage are 1.6s and 1.8s respectively (Fig.10). The frequency characteristics of reverberation time meet the aim

Fig.7 1:20 scale model of the auditorium

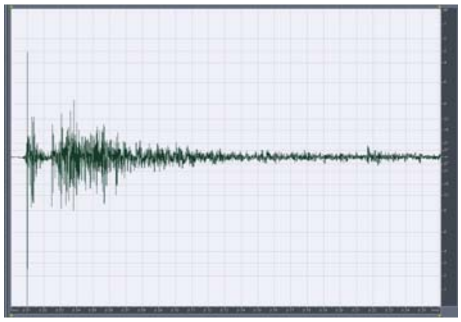


Fig.8 Measured impulse response
at a receiver inside the scale model

Fig.9 The inner view of the auditorium of Zhongshan opera house

preset by the design. The background noise level also meet NR20 standard (Fig.11). The binaural impulse responses at each receiver were also recorded for calculating other parameters and for auralization test.

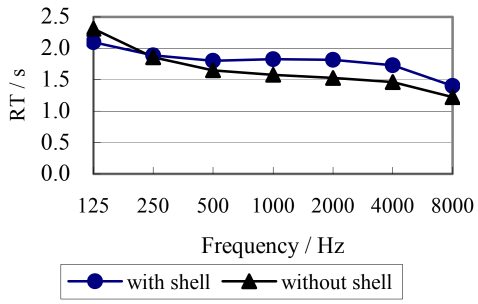


Fig.10 The field-measured unoccupied reverberation time

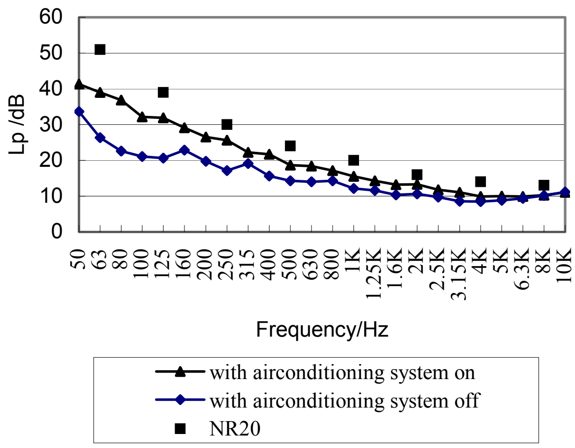


Fig.11 The field-measured background noise level

5 Conclusion and Discussion

Several performances including opera and symphonic music were presented in the opera house after the completion of the building. Its acoustics is appreciated by all musicians, actors and actresses, conductors and audiences. They comment that the opera house has an clear and live acoustics. With the shell on the stage, the opera house is also suitable to symphonic music performance. They rate the acoustics of Zhongshan Opera House the best one in south China.

At present, several techniques including advanced 3D computer simulation, auralization as well as scale model test based on digital signal process are developed. These techniques will help the acoustical design for performing halls rising to a new level with more accurate and quantitative results.

Nowadays, with the quick development of economy, a lot of grand theatres or opera houses were built or to be built throughout China. Although these halls are mainly designed for opera or ballet performances, they are usually called multi-purpose halls, for in their practical uses, conference and musical events are frequently held. Therefore, in these buildings, a hydraulic orchestra-pit-stage-apron lift and an acoustical shell are usually installed to attend to orchestra performance. Also, a sound system is installed to attend to conferences. Many people including some experts believe that some adjustable absorptive components are necessary for a multifunctional hall to change its reverberation time so that the hall can meet the need on both situations of orchestral performance and conference. Say, 1.8s for the former and 1.0s for the later. In our opinion, this is not necessary, because modern sound reinforcement system can offer much better directivity characteristics and enough signal to noise ratio S/N. Therefore when the reverberation time of the hall is not too long, the properly designed sound system can ensure satisfied speech intelligibility. In a previous paper [3], the authors have proved that the allowable reverberation time for ensuring speech intelligibility with a loudspeaker has an ideal directivity characteristic inside a rectangular room of 22.5m×15m×11.7m can reach to 2.62s for achieving RASTI > 0.45. In general cases, adjustable sound absorbing components are not necessary, because they are usually inconvenient to use. What's more, in order to change the RT to a notable result, a lot of absorptive materials are needed. In this case, not only a lot of materials are wasted, sound brightness may be lost as well. At most, some adjustable absorptive curtains can be installed on the rear wall of an auditorium to absorb excessive sound energy casted from the loudspeaker to the wall to guarantee the speech intelligibility. Zhongshan opera house is an example to testify the feasibility of this opinion.

6 Acknowledgements

Special thanks are due to Mr. Sun Haitao, Mr. Chen Jinniu, Mr. Liu Peijie, Dr. Wang Hongwei and Mr. Luo Zehong for their cooperation in the scale model test. Thanks for Dr. Qiu Jianzhen for her cooperation in the earlier stage of the acoustical design of the opera house.

Thanks also given to the support of the 111 Project (111-2-13).

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[3] Wu Shuoxian, Yin Weiwen and Zhao Yuezhe, “Allowable RT value for ensuring speech intelligibility with sound reinforcement system”, *Proceeding of the 2nd International Symposium on Temporal Design*, Kirishima, 59-62, 2005.