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Acoustical Design for Concert Hall in the Science and Art Centre of Xiamen University

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Abstract: Xiamen University is located in the Fujian Province, South East of China. Xiamen University Concert Hall is the essential musical education site for the college students, as well as for holding important meetings. The concert hall has 560 seats. It has a comparatively long reverberation time to offer a fullness and reverberant sound field for music performance. At the same time, rich early reflections from the ceiling and the side walls together with the enough signal-to-noise ratio guarantee speech intelligibility when using a loudspeaker system. With this conception in the acoustical design of the concert hall, the use of changeable absorptive components was avoided which may influence the brightness and liveness of the chamber music hall. After the completion of the building, acoustical measurements were taken and the measurement results are also given in this paper. Since autumn 2010 when the concert hall was finished, music performance and meeting events have been successfully held in the hall. It has become the main hall for the musical education and performance, as well as the meeting center for the college.

Keywords: Concert hall, acoustical design, speech intelligibility

1. Introduction

In 2008, Xiamen University decided to build a Science and Art Center in its campus. The building includes two main facilities, one of them is a concert hall seating 560, and another one is a conference hall seating 900. Xiamen University trusts us to do acoustical design for these two halls. This paper introduces the acoustical design and acoustical measurement works for the concert hall in detail. This paper will offer some experiences for similar works as a reference. The outer view of the building is shown in Fig. 1. The concert hall is located at the second floor of the building. Exhibition hall is planned at the first floor.

2. Acoustical design objects

In view of that the main usages of the concert hall are for holding symphony or chamber music performances and at the same time for holding conference events as well, above both functions must to be simultaneously satisfied in our designing. According to our experience in doing design work for halls such as for Lingnan Hall of Baiyun International Conference Center in Guangzhou¹, we know that we can set a longer reverberation time for the hall to hold a symphony or chamber music performances and design a reasonable sound system for the hall to hold conference events. This is because that speech intelligibility assessed by STI (Speech Transmission Index) is mainly relied on SNR(Signal-to-noise ratio) and secondly relied on RT, and modern sound system can guarantee an enough SNR to satisfy the requirement of speech intelligibility for conference events even under quite longer RT condition. Thus, we can achieve

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a perfect effect of having both functions for a hall to be used as concert hall and conference hall at the same time.

Therefore, the objects of the acoustical design for the concert hall are set as follows: Background noise level: NR-25 standard; Occupied reverberation time at medium frequency bands: 1.8 ± 0.1 s; Bass ratio:(BR):1.0~1.3s; Clarity factor C80:-2~+2dB; Lateral Energy fraction (LEF) :0.15~0.3; Strength factor $G \geq 2$. The reverberation time for the sound control room of the concert hall:0.4s and its frequency character must keep to be even one.



(a) Day view



(b) night view

Figure 1 Outer view of the Science and Art Center in Xiamen University campus

3. Volume Per Seat and Shape Design

According to the architectural design plan and the reverberation time requirement of the concert hall, the volume per seat of the hall is set to be around $10 \sim 11 \text{ m}^3$ per seat, thus, the predicted volume of the hall must achieve around 6000 m^3 . In accordance with this volume, the height of the ceiling can be decided also. It was decided that the ceiling has to be set near the underneath of the floor slabs of above rooms to guarantee an enough volume for the hall. The section plan of the hall is shown in Fig. 2.

The shape of the concert hall is also revised from the viewpoint of acoustics, especially, the original plan of the stage shows too large (494 m^2) and too deep (21.9m). Therefore, the authors suggested that the depth should decrease firstly. After exchanging with the architecture designer, client and interior decorator, the depth of the stage was changed to 16m. And a moveable partition has to be set to divide the stage space so that the depth of the stage for the musicians can be changed from 16m to 10.9m and the area of the stage changed from 257 m^2 to 190 m^2 . The revised plan of the concert hall is shown in Fig. 3. The hall has a suitable stage and volume per seat and thus lays a foundation for having a good acoustics.

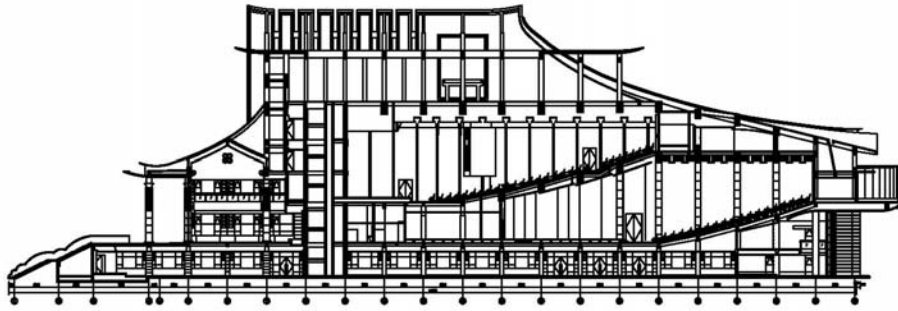


Figure 2 The section plan of the concert hall (the second floor)

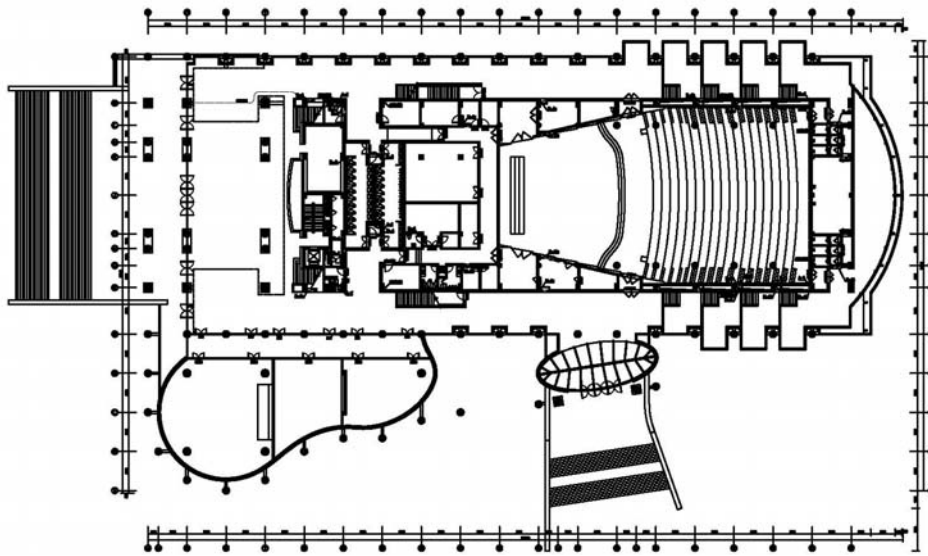


Figure 3 The revised plan of the concert hall

4. Surface Materials and Constructions.

To achieve the designed acoustical objects and considering the decoration effects, the materials and constructions for the surfaces of the concert hall are assigned as follows:

- (1) Side walls of stage and oblique parts of side walls of auditorium: 25mm wood planks (or 2 layers 12mm fiber reinforced gypsum boards covered with wood skin) decorated with MLS construction.
- (2) Parallel parts of side walls of auditorium: 25mm wood planks (or 2 layers 12mm fiber reinforced gypsum boards) designed as column form to diffuse sound waves.
- (3) Rear wall of auditorium: QRD diffusers made of wood. Absorptive curtain with a density of 750 g/m² is hung in front of the rear wall to change RT value and eliminate echo when holding conference events.
- (4) Rear wall of stage: Diffusers shaped like pyramid is designed in the back wall of the stage. The moveable partition is build with wood planks. The two sides of the partition are reflective or absorptive respectively. The absorptive surface is covered with absorbent having noise reduction co efficiency larger than 0.5. When holding conference, the absorptive side will appear.
- (5) Ceiling: The ceiling is made of fibre reinforced gypsum boards with density large than 40kg/m².
- (6) Floor of auditorium: Wood planks adhered to the floor slabs.
- (7) Floor of stage: Wood planks built on stilts.

(8) Seating: The seating is lightly upholstered. The absorption coefficient of the seats is shown in Table1. It was measured in the reverberation chamber of SCUT before install in the concert hall.

Table 1 – Absorption coefficients for seating

Frequency (Hz)	125	250	500	1k	2k	4k
Absorption coefficient	0.32	0.46	0.64	0.66	0.68	0.63

5. Computer Simulation

According to the revised shape and the decoration design of the concert hall, a 3D model for acoustic simulating was built as shown in Fig.4. The covering area by the first order reflections from the side walls and the ceiling of the stage is shown in Fig.5. From Fig5 one can see that plentiful early reflections are given to stage so that musicians can improve their mutual hearing. The audiences in the stall can also receive plentiful reflections.

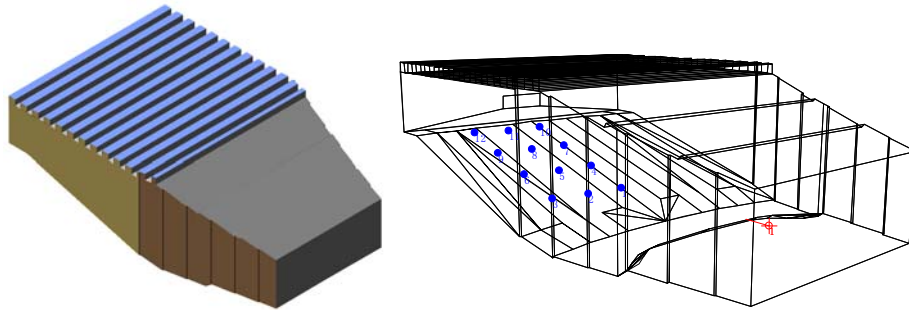


Figure 4 The 3D model of concert hall for acoustics simulating

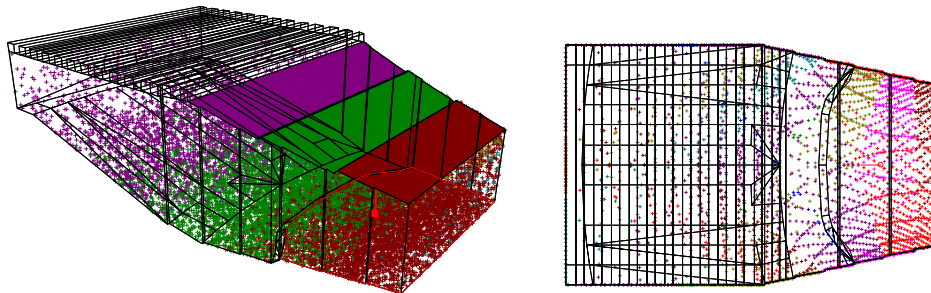


Figure 5 First order reflections from the ceiling of the stage and from the side walls.

The occupied reverberation time at each frequency band is shown in Fig.6. The predicted data are calculated provided that 92 musician are located on the stage. Fig7 gives the C_{80} , G and LF data. These simulated data are within the preference or allowance limits and are agreeable to the design objects. This demonstrates that the acoustics of the hall can be considered as excellent.

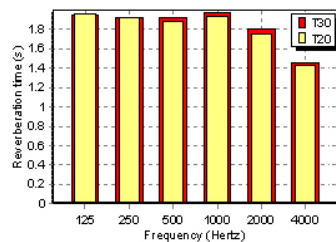


Figure 6 Predicted occupied reverberation time

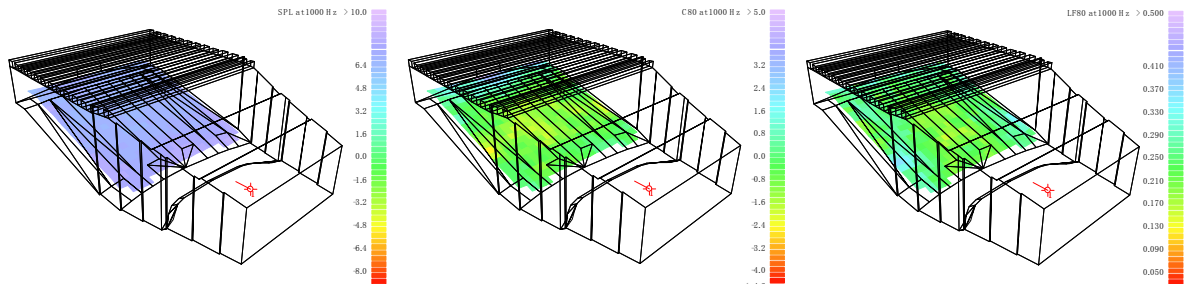


Figure 7 Acoustics parameters C_{80} , G and LF data in seating area

6. Sound Insulation and Noise Control

To achieve the requirement of NR-25 for the background noise level of the hall, sound insulation and noise control have to be carefully considered. The surrounding walls of the hall consist of two layers made of 190mm light concrete blocks. In the gap between the two layers wall, air-conditioning tubes are placed. To increase the sound insulation ability of the surrounding structures, 12mm fiber reinforced gypsum boards backed 75mm rock wool sheets (density: 120Kg/m^3) are added on the inner layer. The partitions on stage are made of 120mm reinforced concrete. The doors of the hall consist of sound locks with two door panels. Their sound insulation index each is 30dB.

Noise control methods include choosing lower noise level ventilator, using flexible pipes to connect the vibrating equipment, setting absorptive materials inside the ducts and isolators to support the packaged air-conditioning system and so on. The inlet and outlet air velocities are set to be 1.5m/s and 1.8m/s respectively.

7. Acoustic Measurement

The concert hall of the Science and Art Center of Xiamen University was completed in 2010. Fig. 8 shows the inner view of the hall. After its completion, acoustic parameters measurements are taken by our laboratory. The Dirac software (B&K7841), B&K4296 omni-directional loudspeaker, B&K2716 power amplifier, B&K Nexus 2690 conditioning amplifier, VX Pocket V2 soundcard and B&K4189 microphone were used to measure the acoustics parameters. MK2B dummy head was used for measuring the IACC parameters. During the measurement the curtain in front of the rear wall of auditorium was uprisen to make QRD diffusers appearing. Reverberation time, Early decay time, Clarity factor, Strength factor and Lateral Energy Fraction, Inter-aural cross correlation coefficient data are given in Table 2. These data are all located within preference or allowance ranges showing that the concert hall will have good acoustics.

Table 2 – Acoustics parameters of the unoccupied concert hall

Frequency (Hz)	125	250	500	1K	2K	4K
RT(s)	1.95	1.96	1.94	1.98	1.96	1.79
EDT(s)	1.96	1.86	1.83	1.95	2.00	1.82
C_{80} (dB)	-2.28	-2.05	-2.12	-2.51	-2.59	-1.89
G(dB)	8.2	7.3	7.3	6.6	6.4	5.6
LF	0.12	0.13	0.18	0.22	0.23	0.24
IACC _E	0.94	0.9	0.59	0.53	0.48	0.46
IACC _A	0.92	0.82	0.32	0.19	0.18	0.15



Figure 8 Inner view of the concert hall

8. Conclusions

After completion, music performances and meeting events have been held frequently inside the concert hall. Practice demonstrates when the sound system is turned off, symphony or national music are all suitable to be performed in this hall. The unification of fullness and clarity and suitable loudness are all obtained. The musicians and audiences highly appreciate its acoustic quality. Nowadays, the concert hall has become one of most important concert halls in Xiamen City. At the same time, when the sound system is turned on, good speech intelligibility is also achieved for successfully holding conference events. Many conferences are held in this hall for the university as well as for the city. This project once again demonstrates that the new thinking of setting a longer RT for a hall to hold music performances and designing a reasonable sound system to guarantee speech intelligibility for holding meeting events is feasible. This new thinking can let a hall to have both functions of concert hall and conference hall so that a lot of funds can be saved.

References and links

¹Shuoxian Wu and Yuezhe Zhao, "Acoustical Design for Linguan Mall of Baiyun International Conference Centre in Guangzhou," Proc. of ICSV16. (Krakov, Poland ,2009), P141.