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THE CONCERT HALL ACOUSTIC DESIGN OF THE BEIJING NATIONAL GRAND THEATRE OF CHINA

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ABSTRACT

The National Grand Theatre of China is a complex of three performing halls: the Opera (2400 seats), the Concert Hall (2000 seats) and the Theatre (1100 seats). These three halls are covered by a super-ellipsoidal shell made out of titanium and glass.

The proposed concert hall design with a slightly curved shoe-box shape will be presented. The hall has two galleries, the first starting from main floor and surrounding the orchestra platform, the second starting from the organ wall and going around the entire hall. Some design specifications such as the large stage reflector for musician support and the diffuser placed around the stage will be discussed in detail.

Predictions estimate a reverberation time of 2.2 s at 500 Hz. The calculated acoustic criteria such as Clarity and Lateral Efficiency will be presented.

During the preliminary design, auralisation calculations have been carried out at some crucial receiver positions to allow qualitative assessment of the acoustics by Chinese officials.

INTRODUCTION

Paul Andreu and AdPi won the international competition for the creation of the future National Grand Theatre of China. The complex includes three halls including an Opera House (2400 seats), a Concert Hall (2000 seats) and a Theatre (1100 seats) which are placed under a glass and titanium dome (see Fig 1).

Figure 1.- Paul Andreu architectural project for the NGTC

The Concert Hall is especially aimed at an international symphonic repertoire. Therefore the acoustic of the Concert Hall is one of the most important issues. It fixed and dedicated the requirements for classical or romantic pieces, including organ play, soloist or with orchestra.

DESCRIPTION OF THE CONCERT HALL DESIGN

The most famous and well-appreciated concert halls in the world are shoebox shaped, because this shape promotes a rich sound. For the same reason, the proposed basic shoebox shape (see Fig 2 and 3) of the Concert Hall, curved slightly, will give a rich and warm acoustic. The height and the shape of the hall have been chosen to give a large volume (~ 20000 m^3) in which the reverberated sound can expand naturally. The maximum width is 35 m. The mean ceiling height is 16.5 m. The maximum length at the upper level is 50 m. The farthest seat is at a distance of 38 m from the central stage.

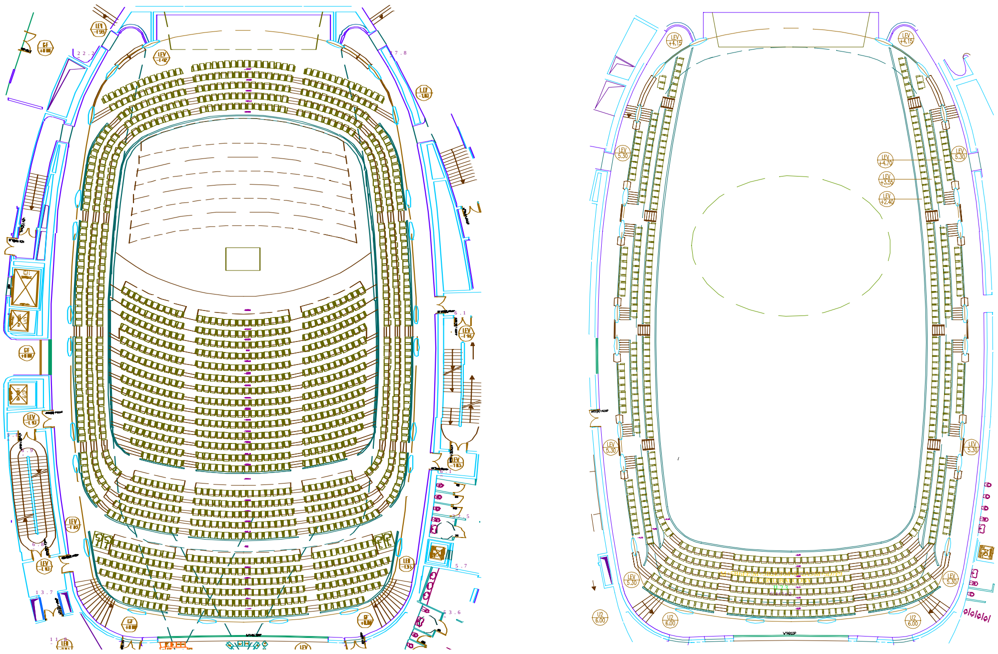

Figure 2.- Plane section view of the Concert Hall

The orchestra platform stands in an almost central position. The walls surrounding the orchestra platform are highly reflecting and diffusing to give good acoustic contact between orchestra players and to project the sound into the hall. The ceiling height above the orchestra is approximately 18 m.

The main floor has a higher than usual slope to reduce the loss of low frequencies produced by the seat dip effect and promote warm acoustics.

The Concert Hall (see Fig 2 and 3) has two narrow galleries with seats placed at the lateral walls, The lower gallery surrounds the main floor seating and the orchestra platform, the higher one starts from the organ wall and goes around the whole hall. These galleries will produce early lateral reflections to the stalls and increase the diffusity of the sound field. The upper walls are composed of wide flat columns. Behind them an extra volume is coupled to the room to give some late reverberated sound in the hall.

The almost flat ceiling is partly reflecting and partly diffusing to achieve a homogeneous sound level over the audience. It includes several spot light flaps. The walls, floor and ceiling are reflecting. They are made out of plaster, wood or other hard material, mostly thick to give high reverberation in the low frequencies.

The approximately 2000 seats are upholstered, with reflecting back and an equivalent absorption area as close as possible to that of the occupied seat, in order to minimise the reverberation time change between concert and rehearsal conditions. The V/N is approximate 10.0 m^3 per seat. The target reverberation time is 2.0 s at mid frequency.

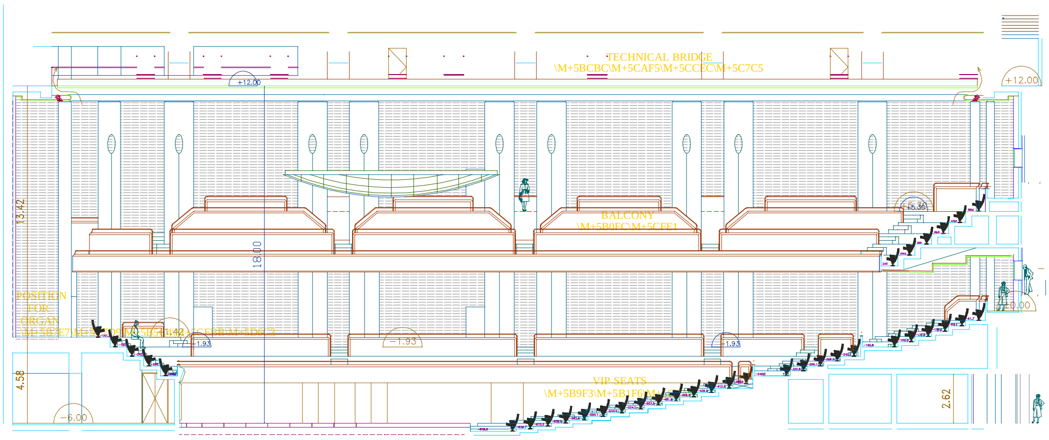

Figure 3.- Longitudinal section view of the Concert Hall

SOME DESIGN SPECIFICATIONS

Because the Concert Hall should be able to host organ music performances, it was decided to construct an pipe organ on the wall behind the orchestra and the first gallery (see Fig 4). For this the most well-known organ constructers have been consulted. In January 2004 Johannes Klais Orgelbau, has been chosen to build the pipe organ. The pipe organ will have more than 100 stops.

Figure 4.- 1:10 Scale Model of the Concert Hall

Some architectural modifications took place during the preliminary design notably at the walls surrounding the orchestra platform, at the front of the galleries and on the ceiling. The walls surrounding the orchestra platform are covered by vertical MLS-Diffusers (see Fig 5) which will eliminate bad reflections on the orchestra platform and support the sound homogeneity for the listeners.

The most important acoustical change relative to the preliminary design consists of a large stage reflector which has been added for more musician support and to increase the diffusive reflections. The large reflector is placed at 12 to 13 m above the orchestra platform (see Fig 3 and 5).

A window placed on the side of the hall at the upper gallery level is planned. It is made for visual contact from the outside of the hall with the concert hall. Of course its sound insulation characteristic needs to fulfil the requirement that no noise from outside of the Concert Hall will disturb the performances and the listener’s acoustic comfort in the concert hall.

For all details which have changed during the final stage design complementary tests have been carried out to finalise them.

Figure 5.- Construction progress January 2007

COMPUTER MODELLING OF THE CONCERT HALL

The numerical acoustic calculations of the Concert Hall have been done with the CSTB Epidaure ray-tracing program. Figure 6 gives the plane and longitudinal section of the geometrical model. Figure 7 gives an axonometric view of the Epidaure geometrical model derived from the architect drawings including the source and receiver positions.

The main source (omni-directional) is set on the orchestra stage 6 m away from stage border on the main axis. The sound power level of the source is 100 dB(A). 10 microphones are placed in one half of the hall in the audience area: 5 at the main floor, 2 at the first gallery and 3 at the second gallery. Receiving surfaces are defined over half the audience area using a grid of 800 microphones (omni-directional and bi-directional). Main criteria mapping is performed on these surfaces.

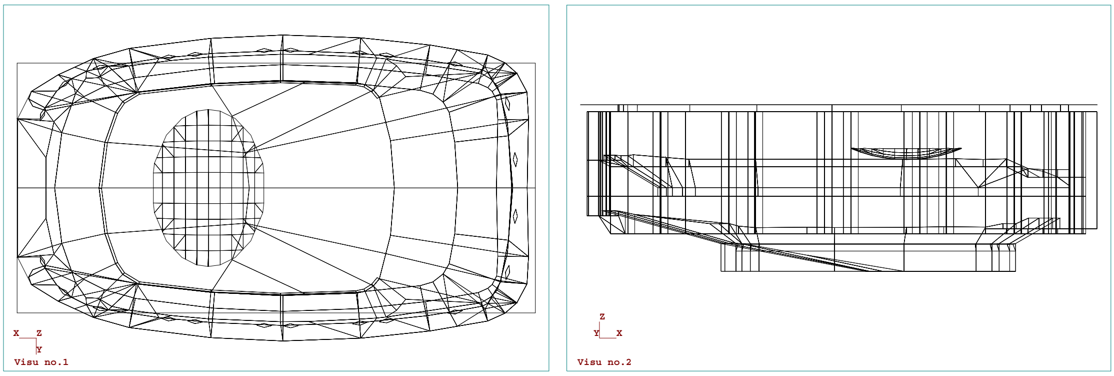

Figure 6.- Plane and longitudinal section of the geometrical model of the Concert Hall

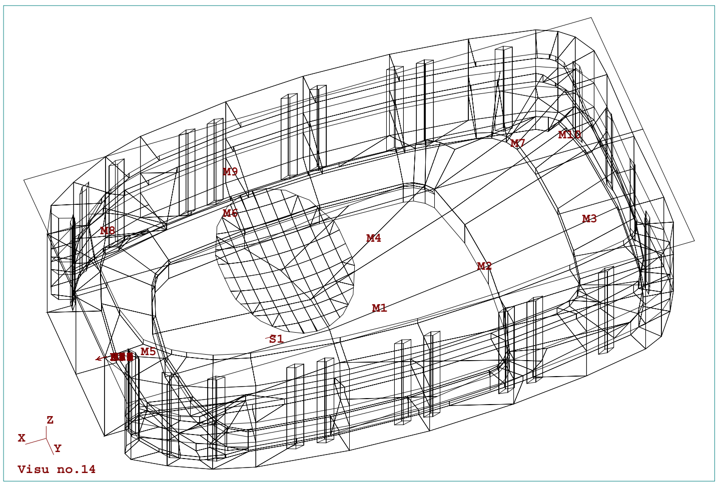

Figure 7.- Axonometric view of the geometrical model of the Concert Hall including the source and receiver positions

CALCULATION RESULTS

Figure 8 gives the echograms and the decay curves of a distant microphone on the main floor (3) and of the farthest microphone (10) in the second gallery. One can observe the very linear slope of the sound decay curve.

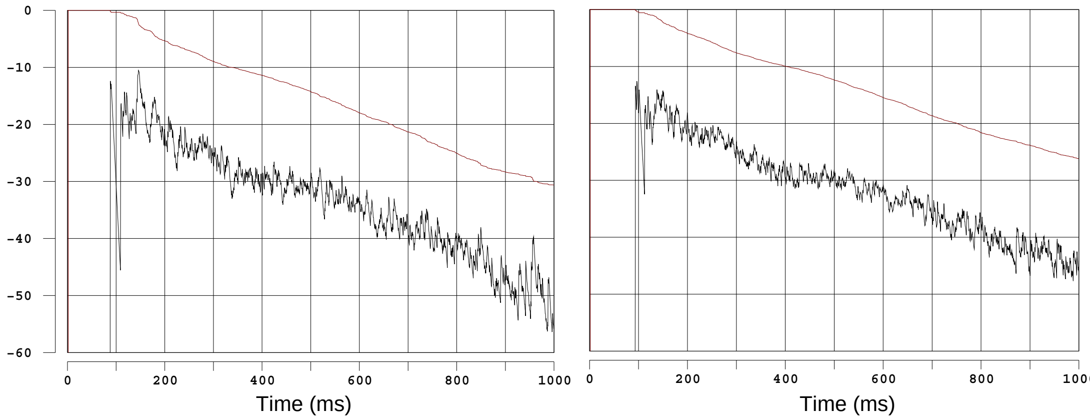

Figure 8.- Echograms at the microphones 3 and 10 – Octave band 500 Hz

Figures 9 and 10 give different criteria maps calculated for the seating area: sound pressure level, lateral efficiency, clarity and speech intelligibility, respectively. The map of the sound pressure level shows that it is evenly distributed over the audience. The maximum difference between the best seat and the worse seat is around 4 dB if the first few rows of seating which are always very loud are excluded. The lateral efficiency is quite high at the main floor but as expected rather low around the stage. The clarity is around or below 3 dB except for some seats close to the stage. The echogram analysis gives an average clarity value at 500 Hz of 0.9 (see table I) which means that the sound, even with a long reverberation will be rather clear. The speech intelligibility is around 50 % which is not very high, but seems suitable for symphonic music.

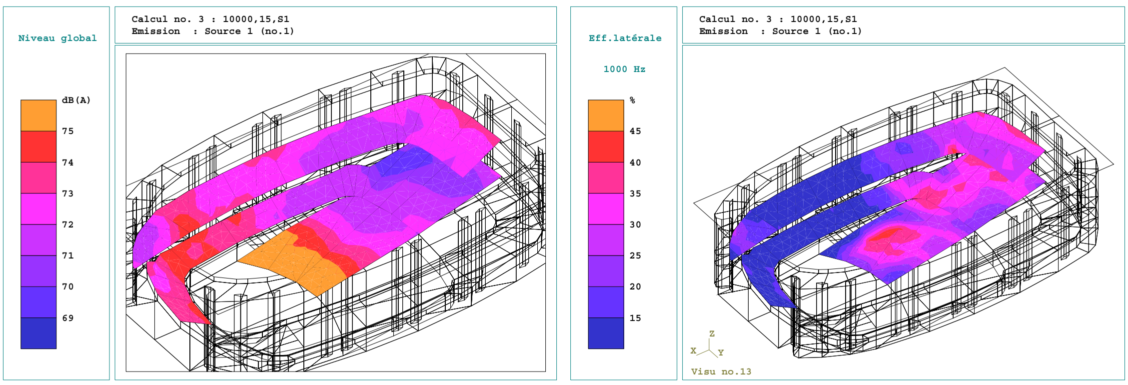

Figure 9.- Sound Pressure Level and Lateral Efficiency maps over the audience (central source)

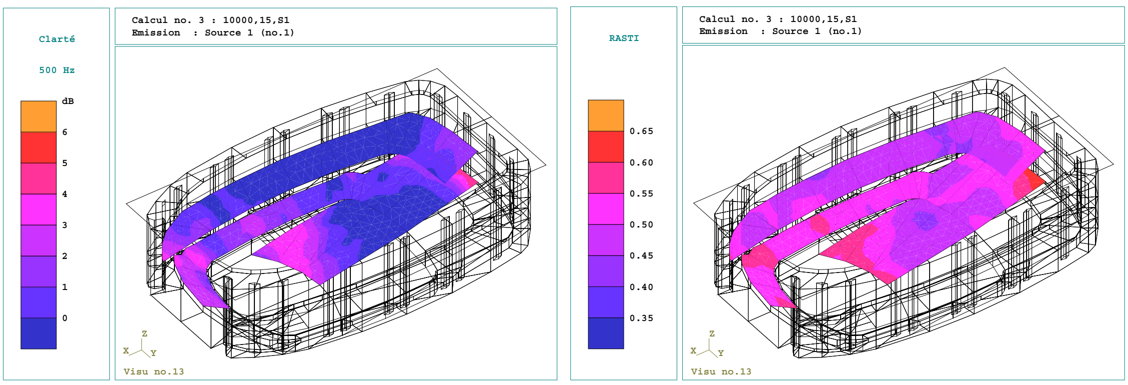

Figure 10.- Clarity 80 and Speech Intelligibility maps over the audience (central source)

Table I gives the expected values of the acoustic criteria averaged on the receiver positions. The reverberation time exceeds the target of 2 seconds by 1/10th second, which is acceptable for the simulation accuracy. It means that enough volume is provided and the shape is satisfactory.

Frequency	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
RT 20	2.07	2.31	2.10	1.98	1.91	1.65
EDT	2.53	2.30	1.90	1.72	1.65	1.42
Definition 50	31.8	34.4	39.3	42.1	43.3	46.9
Clarity 80	-1.4	-0.5	0.9	1.7	2.0	2.8

Table I.- Average expected values of the acoustic criteria

The above results show that the future Concert Hall will have broad acoustics similar to those of other first-class concert halls.

CONCLUSIONS

The acoustic design of the Concert Hall has been studied and approved. The hall is currently under construction. The work is planned to be finished by the end of 2007. The expected acoustic quality will place this Concert Hall amongst the best in the world. Before the opening CSTB will carry out final verification tests and measurements with an orchestra on stage.

References: [1] L. Cremer, H. A. Müller: Principles and Applications of Room Acoustics. Applied Science Publishers (1982)
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[3] L. Beranek: Concert Halls and Opera Houses. Springer (2004)