The Simulation of Acoustics by ODEON in the Acoustic Design of Assembly Hall

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ABSTRACT
Because of keeping the balance of the speech articulation during meetings and the sense of reverberation during theatrical performances, the acoustic design of multi-function assembly hall remains the crucial and difficult points. This essay takes the acoustic design of Beiyang Hall at the new campus of Tianjin University as an example. Aimed at solving the original design defects of the assembly hall, such as the lacking of the first sound reflection and sound absorption quantity, and dealing the contradiction between speech articulation and sense of reverberation, the author utilized the acoustic computer simulation program ODEON which calculated a series of parameters, including the reverberation time (RT30), early decay time (EDT) and speech transmission index (STI). According to the theoretical foundation and datagiven by the simulation results, the author optimized the indoor acoustics design, including adjusting the shape of components, designing the acoustic diffusers and controlling the reverberation time at the appropriate level. After constantly adjusting the indoor acoustic design and changing the sound absorption materials of different positions, which include the side walls, back walls and ceiling of the assembly hall, the simulation program ODEON ultimately carried out an ideal solution of the assembly hall. This essay is an exploration of using the computer simulation software to aid the architectural design practices and solving the practical issues.

KEYWORDS
Acoustic Design, Assembly Hall, Computer Acoustic Simulation, Reverberation time, ODEON

1. INTRODUCTION
With the rapid development of higher education in China, it’s the common phenomenon of traditional colleges and universities to establish new campus. Moreover, there are many new campus located in the city suburb of university town, which are far away from the downtown. In order to meet the students’ life demand, so the new campus is needed to give new function to the traditional buildings. The multi-function Beiyang hall of the new university town is one of the typical representations. In order to rich campus life function for teachers and students, it not only has the traditional function of meeting, but also need to meet the demand of vocal music performance, the theater, film and so on. But on this type of hall
buildings, some acoustic requirements are different. In the process of the architectural acoustics design of the new campus of beiyang hall in TJU, we utilize the indoor acoustic computer simulation analysis software and conduct the simulation analysis of sound field characteristics and related acoustic parameter, in order to meet the needs of the multi-functions demand. We find the existing problems in the prior period of architectural design, and use the data analysis to provide the basis for the adjustment and designing of indoor acoustic optimization. We try to make the acoustic design go through the whole process of architectural design and interior design.

1.1 Project overview

The new campus of TJU is located between downtown and the Binhai New Area, in the middle of Jinnan District Haihe Education Park. Its total construction area is 1.3 million square meters. The first phase of the construction area is 830,000 square meters which include the main building, administration building, student activity center, interdisciplinary teaching building 21 groups, etc. The new campus would have basically completed in 2015, at which time the 11 schools will move to the new campus and students will reach 18000.

Beiyang assembly hall project is located in the first district, eastern end of the central axis, with total land area of 97645.4 ㎡.The first district buildings include a conference center, arts groups, and materials science and other group. Beiyang hall is in the conference center group, adjacent to the lecture hall and conference room.

Beiyang hall, a total construction area of 3500 ㎡, is divided into the stage area and audience area. It has a total number of 1746 seats, of which 718 seats at the first floor, 268 seats at side balcony and 450 seats at middle balcony.

1.2 Acoustic design specifications determination

The function orientation of the beiyang hall is described above. Design process starts with the function of the hall. Using the natural sound quality as the acoustic design core indicators, we try to show its good functionality without the combination of electro-acoustic. Acoustic indexes of multifunctional halls refer to the domestic and foreign experience, combined with the Design code for theater (JGJ57-2000). According to theatre design standard, Reverberation time of designing for the multi-function hall recommended value is 0.9 ~ 1.2s(1000Hz). Relevant parameters are shown in table 1.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>125Hz</th>
<th>250Hz</th>
<th>500Hz</th>
<th>1000Hz</th>
<th>2000Hz</th>
<th>4000Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverberation Time (s)</td>
<td>1.1~1.68</td>
<td>1.1~1.54</td>
<td>1.1~1.4</td>
<td>1.1~1.4</td>
<td>0.99~1.4</td>
<td>0.88~1.4</td>
</tr>
</tbody>
</table>
1.3 Design concept of buildings and indoor-decoration

Beiyang hall design concepts highlight the themes of growth and express that the first modern University-TJU has a long history of the century-old school and endless vibrant vitality. The hall design style is dominated by vertical lines, bold gradually from front to rear lines, expressing the growth of vibrant atmosphere. In the selection of material, we hope to utilize three kinds of materials with wood, brick, stone, which present the concept of long life, simple and natural style of designing. While the side wall are decorated by dark-colored hard stone, which easily leads to decreased acoustic clarity of language. Therefore, it is the key points and difficulties of acoustic design for Beiyang hall to meet the needs of multifunctional performance forms and to control the balance of aesthetics and acoustical design.

RESEARCH METHODS

In the early design period, the architects mainly take the considerations in architectural shapes and materials, but ignore some acoustical design issue, which leads to some problems in acoustics. The research method is to grasp the major problem of acoustic design first and utilize the computer simulation to figure out the design solutions and improvement methods. The relevant acoustic problems are listed as following.

2. The existing acoustic Problem of Beiyang hall

2.1 Audio and video are inconsistent

The shape of the beiyang hall is approximate to the shape of bell. The bell plane has the advantage of simple structure, the vast majority of the audience having better perspectives, voice in singing and the music within range of the directivity. But when capacity is larger, such as the capacity of more than 1700 seats as Beiyang hall, will lead to larger longitudinal length of auditorium. The maximum length difference of sight distances up to 43.2m (time lag: 0.127s). When using natural sound performed, the audiences of the back area would lead to the inconsistency of audio and video more than 30 meters distance away from the stage. But when using electronic sound equipments, the audio-visual inconsistencies will be eased.

2.2 Volume per seat is too large

The auditorium volume of Beiyang hall is 18500 m³ (without ceiling), including 1746 seats. The volume per seat preliminary estimate is 10.6 m³ /seat. According to the standard of theatre design, the best value of volume per seat is: 3.5~5.5 m³ /seat. The predicted value is too large, and larger volume per seat brings a certain degree of difficulty for achieving the optimum reverberation time. If failed to control the value in the early stages, it will cause the sharp rise in the cost of acoustic materials in later interior design period, what's more, it will also lead to extremely difficulties to achieve a good acoustic environment.

2.3 Lack of early reflections in the stalls
Controlling the early reflections within 50ms after the direct sound, it will effectively enhance the articulation and the fullness effect of the performance. Therefore, strengthening the early reflections plays an important role in improving the hall acoustics. However, lacking of effective reflection walls, according to sound ray analysis diagram (figure 2.3), we can see that the area of stalls is obvious lack of early reflections. When the sound source is located near the curtain line, the area of stalls in the middle lacks the reflected sound from the side walls of the previous. This phenomenon becomes worse when the sound source is located in the 3 meters back to curtain line. The area lacking previous reflections becomes larger.

RESULTS AND DISCUSSION

3. ODEON simulation using improved sound field distribution

Due to the architectural design phase of the hall did not give much thought to architectural acoustics, there are some problems mentioned above. Aiming at the existing problems in the process of special acoustic design of Beiyang hall, we utilize the computer simulation software ODEON to conduct acoustic voice analysis for adjustments of the hall, in order to achieve good acoustics performance.

3.1 Sidewall diffusers

Due to the angle of the side walls and the auditorium shape, it leads the stalls area lacking early reflections. On the basis of as little changes as possible on the layout of the building, we joineddiffusers in the side walls, in order to change the directions of the reflected sound(fig.4). It not only can effectively improve the early problems of insufficient reflected sound, also can improve sound field diffusion properties and expand the best listening area.

Geometric diffusers are usually cylindrical, spherical section, Prism, triangular prism, rectangular column and other forms. Meanwhile, in order to achieve effective diffusers for different wave lengths of the sound, the sizes of the diffusers also have different requirements. In Beiyang hall, the form and size of diffusers, not only need to consider the effect of decoration, also need to consider implementation issues.

Geometrical diffuser size according to the following formula to estimate:

$$\frac{2\pi f}{c} \geq 4, \quad \frac{b}{a} \geq 0.15$$

In the formula : $a$: Diffuser width (m); $b$: Prominent diffuser height (m);
c: The speed of sound in air (m/s); f: The frequency of the acoustic wave (Hz)
To 250Hz and 2000Hz for example, to calculate the effective diffuser body size:
250Hz: \(a \geq 0.865, \quad b \geq 0.129(m)\),
2000Hz: \(a \geq 0.108, \quad b \geq 0.016(m)\)

Therefore, by calculating the diffusers, the width can be drawn mainly for 100mm ~900mm, the height for 15~120mm.

Keeping with the same architectural style with the conference center, designers use dark stone tiles cover the walls of the auditorium. Using different forms of bricks, it can form vertical diffusers of different sizes(Figure 3). The width of diffusers range from 120~960mm, the highlight of them, due to the limits of existing seats and aisle width, varies little from 60~120mm. Effective frequencies range from 250Hz to 2000Hz, basically covering the whole band. Under the same condition of others, the simulation only set one change of diffusers to find out the effects of interior sound field.

From the figure 5&6, we can find that after adding the diffusers, the uniformity of early decay time at 1000Hz improve in a certain degree, especially the back seats at the second floor. Except of the area of side balcony hard to control, the uniformity of reverberation time in the other sound filed becomes better. From the figure 7&8, we can find that before adding the diffusers, the speech transmission index reach about
0.7 at the front part and 0.62 at the back part. After adding the diffusers, the indexes reach about 0.76 at the front part and 0.7 at the back part. For the STI evaluation, the value of 0.75~1 is excellent, 0.6~0.75 is good, 0.45~0.6 is fair, 0.3~0.45 is poor, 0~0.3 is bad [3]. Therefore, after adding the diffusers, the speech transmission index has improved and basically reached the excellent level.

3.2 Balcony balustrade shape adjustment

Except using the side wall to reflect sound, it can also use part of the second floor balcony railing to reflect [4]. According to the form of the original design of the railing, we increased the fore rake of it and make it possible to reach the direct sound to reflect the sound energy. According to the Haas effect, the reflected sound can help to achieve the surround sound listening environment of the seats at front part. From the experiments, Haas show that if two simultaneous sources of the sound waves reach the listening time difference δ t within 5~35ms, people cannot distinguish between the two sound sources [5], and get a sense of just listening to the leading position sound ( ahead of the sound source ). After calculation, the difference between the reflected and direct sound in the sound path is about 10m (Fig. 9), less than 30ms. It will not result in a disunity of sound and image, while helping to build stereo listening environments.

3.3 Ceiling shape and height adjustment

According to the Design code for theater (JGJ57-2000), the best volume per seat is 3.5~5.5 m³/seat. When encountered the condition of overlarge volume, we should shrink the shape or reduce the height of ceiling to control the volume per seat, which can help to achieve the best reverberation time. The way to control the height of ceiling is the most effective way.

The auditorium volume of Beiyang hall is 18500 m³, including 1746 seats. The distance from the structural top to the grid frame is 3.2m. The main speaker is set at the top of the stage. The ceiling should include the two parts. It should control its average height from the roof at 5~6m. Take the best value as 5.5 m ³/seat, the Auditorium ceiling should be 10476 m³, therefore, the volume upper ceiling is about 8024 m³. According to cross-sectional area of 1085 m² of the auditorium, the average ceiling height is about 7.4m. Taking these factors above, and adjust the ceiling of the best locations for structures with an average distance of 6.5~7m. Meanwhile, the ceiling shapes should be able to better reflect the sound to the front row seating position in order to increase the overall sense of reverberation. (Fig.10)
4 Using ODEON to analog and adjust the reverberation time of the hall

The overall interior design of Beiyang Hall mostly uses light wood veneer with dark red tile-based. Due to the preliminary design of all the sidewall using the hard tiles as the material, it resulted in biased estimates of long reverberation time. Therefore, we set some sound absorption material at the rear of the side walls and the middle and side of the back wall, and the interior ceiling, in order to guarantee a certain reverberation time speech intelligibility and sound field.

4.1 Adjust the position and quantity of the acoustical tile of the side walls

There wasn't sound-absorbing structure for side wall at the original interior design, but what was found during the simulation process is that just using the rear wall and the seats to absorb the sound can't achieve good sound effect. Especially in the side balcony area, the distance between the sidewall is short, and the materials of them are hard tiles, so just relying on the sound absorptions of side rear wall are insufficient, which result in long reverberation time and poor speech intelligibility. Therefore, in order to ensure the diffusers and reflections of the sound at the front of the sidewall, there still retain the original hard cover. While because of the position of the triangular wall being the back and corner area, the effect of reflections and diffusers of sound are weak. Considering using the sound-absorbing brick, it can prevent the shocks of voice in the back wall, which ensures the balance and clarity of the sound.

As can be seen from Figure 11 and 12, the effect of the joined in the sidewall acoustical tile is quite obvious, and the early decay time (EDT) of the side gallery at 1000Hz is declined, and the local original value of EDT reached 1.45s or even longer, which on average there are 1.3s. After joining shale acoustical tiles in the sidewall, the value of the EDT basically controlled in average 1.2s, and the local high places also declined and controlled below 1.4s. After ODEON simulation, according to the calculation results, adding absorption masonry shale brick to the at the side of the local back wall although has little effect to improve the overall sound absorption of the hall, but for the regulation and control of the reverberation time at the local small side balcony space, the effect is still very obvious and significant.
4.2 Adjust the absorption material of the back wall

After ODEON’s estimating simulation reverberation time, the overall quantity of sound-absorbing in the audience hall are inadequate, especially the low-frequency sound reverberation time is too long. Initially we chose two wooden sound-absorbing acoustic panels as an alternative material for the back wall’s sound-absorbing construction, which absorption coefficient is in the following table 2. Using computer software simulates the two kinds of sound-absorbing panels as the back wall sound-absorbing material respectively. According to the simulation results obtained, the sound-absorbing material can be selected, and the location and the size of the sound-absorbing material can be also determined.

**Table2. Material acoustic absorptivity of rear wall [2]**

<table>
<thead>
<tr>
<th>Name</th>
<th>Material property</th>
<th>construction</th>
<th>acoustic absorptivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thickness: 18, bore diameter:2mm</td>
<td>Material A+50mm Glass wool+100mm Cavity of air</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>pitch-row:14mm</td>
<td>Perforation rate:7%</td>
<td>0.7</td>
</tr>
<tr>
<td>Material A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickness: 18, bore diameter:3mm</td>
<td>Material B+50mm Glass wool +200mm Cavity of air</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pitch-row:13mm</td>
<td>Perforation rate:12%</td>
<td>0.95</td>
</tr>
<tr>
<td>Material B</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig.13 Result of T20&T30 adding absorption material with 100mm cavity of back wall](image1)

Fig.13 Result of T20&T30 adding absorption material with 100mm cavity of back wall

![Fig.14 Result of T20&T30 adding absorption material with 200mm cavity of back wall](image2)

Fig.14 Result of T20&T30 adding absorption material with 200mm cavity of back wall

From the results (Figure 13 and 14), after thickening the cavity, the reverberation time T20 & T30 of low frequency 63 and 125Hz decreased significantly. Since the absorption coefficient is similar to other frequencies, the time has no particularly significant change. Therefore, in the design of the back wall, the structure of the 200mm back cavity was selected, which hopes to reduce excessive low frequency sound situation. At the same time, this kind of structure of the perforated acoustic panels has little change for each brand of the absorption coefficient, and can more uniformly absorb voice of each band which making the sound of each band will not lead to too high or too low. In addition, wooden sound-absorbing panels can maximize the preservation of the original interior design style selection, which is both beautiful and functional.
4.3 absorption material over the ceiling

As can be seen from the schematic (Figure 15), the front portion of the ceiling has a large gap, and the sound can enter the interior from the gap over the ceiling. Therefore, there is the necessity to join the sound absorbing structure inside the ceiling. The original design was to put the absorption of cotton mat on the ceiling wood grill. Since the problem of the keel can bear load, then the K-13A plant fiber coating materials were selected, and the floor materials selected metal mesh panels, which the material surface is rough and applying to the higher roof, ceiling and interior wall whose surface is not easy to receive collision [6]. The specific sound absorption parameters are shown as follows. Simultaneously spraying the material to the ceiling and the sidewall inner the ceiling also has an effect to reduce the background noise. Different thickness and coated on different substrates also make the sound absorption performance different.

Table 3. 25mmplant fiber coating materials & 25mm, 32kg/m³ glass wool

<table>
<thead>
<tr>
<th>Name</th>
<th>acoustic absorptivity</th>
<th>NRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-13A</td>
<td>0.47 0.9 1.1 1.03 1.05 1.03</td>
<td>0.75</td>
</tr>
<tr>
<td>glass wool</td>
<td>0.1 0.31 0.61 0.85 0.96 1.07</td>
<td>0.7</td>
</tr>
</tbody>
</table>

What can be seen is that, plant fiber coating material in the low-frequency sound absorption performance is much higher than wool when the sound-absorbing materials has the same thickness. It has an important role in the effectively controlling of low frequency sound.

CONCLUSION

Based on the new campus of Tianjin University Beiyang Hall’s acoustics design, we aim at the problems arise in the preliminary design, including building size, reflected sound, sound absorption quantity and so on, to make targeted sound field simulation. Using the simulation results comparison of the before and after, we can control the acoustic design, and propose improving method. This design process is an exploration by using computer simulation software to assist architecture design.

REFERENCES