Architectural and acoustic features of the caisson ceiling in traditional Chinese theatres

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ABSTRACT

One of the great features of traditional Chinese theatres is the caisson ceiling, which is a sunken panel placed in the centre of the stage ceiling. Although caisson ceilings were rare in general traditional Chinese architecture, for one particular architectural type, traditional Chinese theatres, they were rather common, especially in southern China. Firstly, this paper briefly analyses the historical origins, cultural connotation and evolution of caisson ceilings, and categorises the caisson ceilings in traditional Chinese theatres based on its architectural forms. Since there are two opinions about the effectiveness of caisson ceilings in traditional Chinese theatres, namely concentrating or diffusing sounds, in the main part of this paper, detailed analysis of various architectural acoustic features of such caisson ceilings has been carried out, based on computer simulation. The initial results suggest that because of the hemispherical shape, caisson ceilings tend to have the acoustic function of concentrating sounds. In the meantime, caisson ceilings are beneficial for providing early reflections to the actors and audience standing close to the stage.

INTRODUCTION

Shape and function of the caisson ceiling

The caisson ceiling is regarded as a special architectural shape in traditional Chinese buildings. It evolved from simple to complex types and also from a functional architectural structure to a decorative one. The original caisson ceiling that existed was the dome carved with lotus petals in the grotto, and the dome makes the grotto appear more open [1]. Simultaneously, Chinese ancients placed great emphasis on the construction of the caisson ceiling. By using wooden structures, they usually constructed the caisson ceiling into a square, round or octagonal shape that had different layers protruding upwards. The edge of each layer is made by the bracket which supports the beam and the dome of the ceiling. The vertical lotus column is built in the most central part of the caisson ceiling with the shape of two dragons toying with a pearl. The patterns on it are very luxuriant.

Therefore, the wooden caisson ceiling, which is stacked up without nails but with tenons, mortises and brackets, is a rather unique, complex and colorful decorative technology in China. As an example, Figure 1 shows the oldest wooden caisson ceiling which was built in 984, and Figure 2 shows the most luxurious caisson ceiling of Qing dynasty.

Along with the development of the Song, Yuan, Ming and Qing dynasties, the caisson ceiling also evolved from the early Dou Ba (Chinese: 斗八, it is an octagonal pyramid ceiling composed of beams at eight angles) into a myriad of complex shapes [1]. From the Ming to Qing dynasty, the caisson ceiling, both in official buildings and in folk buildings, was developed towards more complex shapes. It did not reach the peak of its development until the mirror symbolising heaven on the central top of the caisson ceiling was exchanged into a dragon holding a pearl in its mouth downwards on the ceiling in the Qing dynasty, as shown in Figure 2. At the same time, the caisson ceiling was also called Dragon Well (Chinese: 龙井) as its alias.

Source: (Traveltime Company, 2007)
http://www.traveltime.cn/data/2007/0103/article_7511.htm
Figure 1. Caisson ceiling of Du Le temple, Guanyin cabinet, Ji county, Tianjin City (天津蓟县独乐寺观音阁)

Source: (Xinglei Pang, 2006)
http://news.163.com/06/0105/15/26NAOL750001124T_3.html
Figure 2. Caisson ceiling of Hall of Supreme Harmony, Forbidden City, Beijing (北京故宫太和殿)

The caisson ceiling has traditionally been considered as an architectural decoration with a symbolic meaning of leading people to heaven from the real world [1]. Therefore, most of them were built in the main house of large temples or palaces. Later on, they slowly appeared in the gods' temples in relatively smaller towns, assembly halls, and ancestral halls, as well as on the stage of some large gathering places.

Cultural connotation of the caisson ceiling

Besides its decorative function, caisson ceilings have a very profound cultural connotation by embodying traditional Chinese aesthetics. Chinese traditional architecture was mainly constructed with wooden structures. Hence, fire prevention became a top priority. Early caisson ceilings generally used algal patterns for decoration. Algae are sub-aquatic plants. In traditional Chinese theory of allelopathy, yin-yang and the five elements (Chinese: 阴阳五行、相生相克), water can quench a fire. Accordingly, the caisson ceiling with algal patterns meant avoiding fire in ancient times [2]. In order to gain safety and good luck, any important traditional buildings which needed to be protected from fire are all decorated with the caisson ceiling. Moreover, the caisson ceiling is a symbol of ancient feudal hierarchy. Only the most prestigious buildings can be decorated with the caisson ceiling, which is the symbol of status and power.

In addition to the meaning of the fire prevention and the symbol of the social hierarchy, the deeper implication of the caisson ceiling is the traditional Chinese concept of unity of heaven and human beings (Chinese: 天人合一). Chinese ancients worshiped the natural world and the natural phenomena with the feeling of awe, and then proceeded to stand up for the concept of unity of heaven and human beings. Caisson ceiling was the reflection of this idea on the architecture. The shape of the caisson ceiling was derived from the shape of an ancient skylight, which is round above and square below, conforming with the ancient view of the universe——Tales From The Flat Earth (Chinese: 天圆地方) [2]. Therefore, just like the dome in the western church standing for the sky, the caisson ceiling being a miniature of the celestial body also has the symbolic meaning of the sky.

Categories of the caisson ceiling

Although the caisson ceiling was rare in general traditional folk architecture, in traditional folk theatres it was rather common, especially in southern China. In addition, it is still commonly constructed even now in small theatres in rural areas. The caisson ceiling was usually fixed as the canopy of the central bay of the stage which was the performance area and the most beutiful and fascinating place of the theatre. The caisson ceiling of traditional Chinese theatre was constructed with three parts: top of well, fornix and bottom of well. In terms of the forms of caisson ceiling, they can be generally classified into six types as follows:

1. Luoxuan type (Chinese: 螺旋式) [3]

The caisson ceiling is in the form of spiral, and its shape is exceedingly dynamic, as shown in Figure 3.

2. Julong type (Chinese: 聚拢式) [3]

The caisson ceiling is in the form of vertical convergence to the center, and its shape has the character of intense centripetal, as shown in Figure 4.

3. Xuanpeng type (Chinese: 轩棚式) [3]

The caisson ceiling is in the form of vertical convergence to the center based on the architectural structure of Xuan (Chinese: 轩), and its shape is largely ornamental, as shown in Figure 5.

4. Diese type (Chinese: 叠涩式) [3]

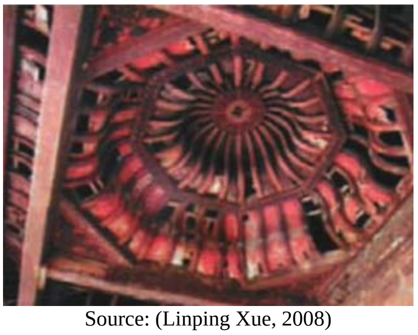
The caisson ceiling is made in the form of overlapping by large-scale corbel brackets, and its shape is richly decorative, as shown in Figure 6.

Source: (Linping Xue, 2008)

Figure 3. Caisson ceiling of QuanJin guild hall theatre in Suzhou city, Jiangsu province (江苏苏州全晋会馆戏台)

Source: (Linping Xue, 2008)

Figure 4. Caisson ceiling of traditional theatre in Jinxi village, Jing county, Anhui province (安徽省泾县金溪村戏台)



Source: (Linping Xue, 2008)

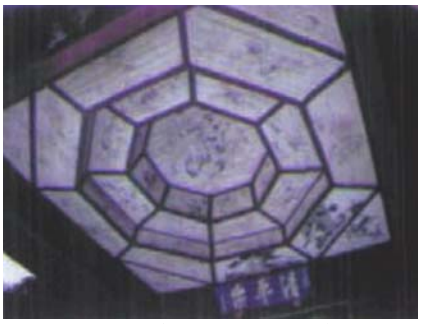
Figure 5. Caisson ceiling of Yu Qin hall theatre in Zhulin village, Qimen county, Anhui province (安徽祁门县珠林村余庆堂戏台)

Source: (Linping Xue, 2008)

Figure 6. Caisson ceiling of the mammon temple theatre in Pingyao county, Shanxi province (山西平遥县财神庙戏台)

5. Cengshou type (Chinese: 层收式) [3]

The caisson ceiling is in the form of contraction, each layer is formed by flat plates, and its shape is very succinct, as shown in Figure 7.



Source: (Linping Xue, 2008)

Figure 7. Caisson ceiling of He's ancestral shrine hall in Guodong village, Wuyi county, Zhejiang province (浙江武义县郭洞村何氏宗祠戏台)

6. Fuhe type (Chinese: 复合式)

In traditional Chinese theatrical buildings, the form of the stage ceiling is mostly constructed in the single-caisson ceiling type which has only one caisson in the middle of the ceiling directly above the stage. However, contrasting with this type of caisson ceiling, it is very strange that there are few traditional theatres that adopt the type of multi-caisson ceiling, such as the two-caisson ceiling, the three-caisson ceiling and the five-caisson ceiling. The definition of the two-caisson ceiling or the three-caisson ceiling is that two or three caisson ceilings covering the stage which were built over two central bays (Chinese: 明间) and extended lengthwise to the center of the courtyard, as shown in Figures 8 and 9. In addition, it is worth noticing that the shape of the five-caisson ceiling only adopts octagonal caisson, as shown in Figure 10.

Source: (Ninghai News, 2006)
http://nh.cnnb.com.cn/gb/nhnews/xiangzhen/qth/node1795/userobject1ai145043.html

Figure 8. Two-caisson ceiling of Pan's ancestral shrine hall in Panjia'ao village, Ninghai county, Zhejiang province (浙江宁海县潘家岙潘氏宗祠戏台)

(a) (b)

Source: (a: Ningbo Evening News, 2003; b: Ninghai News, 2005)
a:http://www.cnnb.com.cn/gb/node2/newspaper/nbwb/2003/07/node11152/node11164/userobject7ai587416.html
b:http://nh.cnnb.com.cn/gb/nhnews/news/shizheng/userobject1ai125675.html

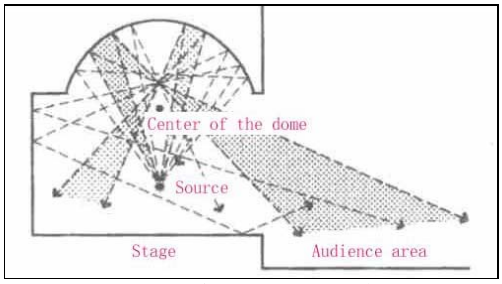
Figure 9. Three-caisson ceiling of Hu's ancestral shrine hall in Qiaohu village, Ninghai county, Zhejiang province (浙江宁海县乔胡村胡氏宗祠戏台)

Source: (Heritage Management Office of Ninghai County, 2008)
http://www.zjww.gov.cn/news/2008-09-09/147468636.shtml

Figure 10. Five-caisson ceiling of Zhendong temple theatre in Tangxia village, Xidian town, Ninghai county, Zhejiang province (浙江宁海西店镇塘下村镇东庙戏台)

Acoustic features of the caisson ceiling

For the acoustic features of the caisson ceiling, there are two main view-points in the architectural acoustics community. The first view is that the caisson ceiling has the function of concentrating sound [4]. In other words, the caisson ceiling can improve the actor's envelopment of the stage and his/her self awareness when the opera play is being performed. It is worth noticing that envelopment, the second component of spaciousness, as used here to describe the actor's impression of the strength and directions from which the sound reflected from the caisson ceiling seems to arrive [5]. Actor envelopment of the stage is judged highest when the reflected sound seems to arrive at an opera actor's ears equally from all directions of the caisson ceiling——forward up, backward up, upper left, upper right and overhead. In addition, Chinese scholars also call it Long Yin (Chinese: 拢音), meaning concentrating sounds from all directions. At the same time, because the center of the dome is close to the bottom of the caisson ceiling, it can also scatter the sound to some extent, and would not cause a sound focusing phenomenon that bring some interference effects around the actor's ears, as shown in Figure 11.



Source: (Jiqing Wang, 2002)

Figure 11. Cross-section showing reflected sound rays of the caisson ceiling

The second view is quite the opposite. It considers that instead of having the function of concentrating sound, the caisson ceiling has a strong ability to diffuse sound [6]. The reason is that the caisson ceiling is composed of lots of corbel brackets in different sizes, and each size has its own certain function of diffusing sound. So, in the case of the whole caisson ceiling, it certainly does not have the so-called function of concentrating sound. However, the only common phenomenon recognised by these two viewpoints mentioned above is that the caisson ceiling is beneficial for providing early reflections to the actors and audience standing close to the stage. Therefore, the purpose of this paper is to explore which viewpoint is more reasonable. Simultaneously, further comprehensive research and analysis has been processed on the stage acoustic characteristics of the caisson ceiling according to its different architectural styles and shapes.

RESEARCH METHODOLOGY

Acoustic siumlation tool

Detailed simulations were made by using acoustic software CATT-Acoustic (Version 8.0d). CATT is based on the combination of image source model for early part echogram qualitative detail and ray-tracing [7].

Acoustic indices

According to the stage acoustic characteristics of the caisson ceiling, this paper mainly uses the following acoustic indices to make the qualitative and quantitative research below. They are: sound pressure level (SPL), lateral fraction (LF), lateral fraction coefficient (LFC), strength factor (G), definition (D_{50}) and clarity (C_{80}). Because of the semi-open stage, and also because the focus of the analysis is on the acoustic effects of the caisson ceiling on the stage and the audience area, rather than the acoustic quality of the theatre itself, the two most important acoustic indices of the theatrical building, namely, reverberation time (RT) and early decay time (EDT), are not paid main attention.

Model settings

Various architectural types and shapes of the caisson ceiling have been compared. The basic model is a hemispherical caisson ceiling with a 3.5-meter radius, at 4 meters above the ground. Meanwhile, the boundary of the ground is a square of 60 by 60 meters. The sound source is located below the center of the caisson ceiling and at 1.6 meters above the ground. 30 receivers are considered along a line from the source, with a spacing of 1 meter. The receiver height is also 1.6 meters. The model is shown in Figures 12 and 13.

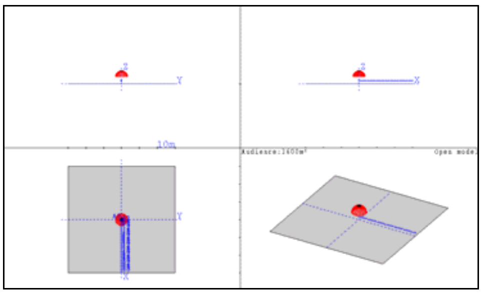
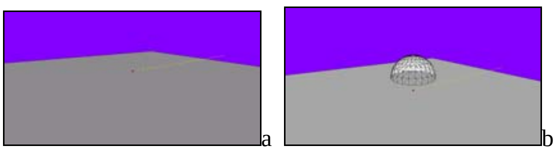


Figure 12. Basic model of the caisson ceiling



a b

Figure 13. A stage with and without the caisson ceiling

Simulation settings

In the simulation, the acoustic properties of the caisson ceiling and ground are approximately assigned based on relevant tables in CATT. The absorption coefficient of the ground is < 2 2 3 4 4 5 >, and absorption coefficient of the caisson ceiling is < 14 10 6 8 10 10 >. Their diffusion coefficients are both < 10 10 10 10 10 10 > initially but comparisons with a series of different values have also been made. The effects of surface diffusion have been intensively discussed in literature [8-9]. The reason for using relatively small values initially is to examine the relfection patterns more clearly.

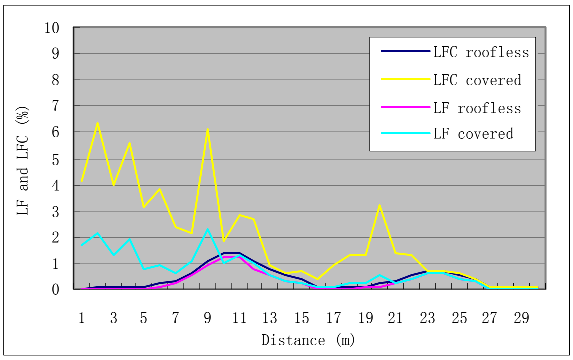
The sound source setting is based on the CATT-Acoustic (Version 8.0d) database, namely 70 73 76 79 82 95: 95 95. An omni-directional sound source is assumed.

RESULTS AND DISCUSSIONS

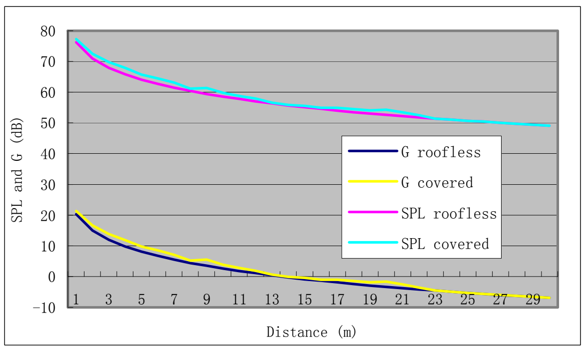
Effect of the caisson ceiling

Compared with that of a roofless stage of an open-air theatre in Figure 13(a), the sound field of the stage covered with a round caisson ceiling in Figure 13(b) has a higher value of SPL, LF and G, as can be seen from Figure 14, and a lower value of D_{50} and C_{80}, as can be seen in Figure 15, where the yellow area in the color picture of D_{50} expresses the maximum value of definition, whereas the maximum value of clarity is clear white in the color picture of C_{80}. The reason is that the round caisson ceiling can provide a certain amount of reflected sounds, but the reflected sound energy is rather small. At the same time, because there are no walls surrounding the stage, the sound attenuation level of this covered stage is still very high. Therefore, it can be seen from Figure 14 that the increasing range of the value of SPL, LF, LFC and G is rather small, or even not obvious. However, the amount of the energy of the sound reflected later from this covered stage appears much higher than that of a roofless stage whose reflected energy is almost equal to zero. Consequently, it can be seen from Figure 15 that the decreasing range of the value of D_{50} and C_{80} is very large and also broadly apparent.

In addition, it can also be seen from Figures 14 and 15 that the farther from the stage, the smaller increasing range of the value of SPL, LF and G is (or there is even no increase); and the smaller decreasing range of the value of D_{50} and C_{80} is (or there is even no decrease). This is because the sound reflected from the round caisson ceiling has a certain range of coverage area. The value of various acoustic indices mentioned above increases or decreases within this range. Otherwise, they do not have any changes beyond this range of coverage area. In addition, a square caisson ceiling was also considered. In terms of the difference between a stage with and without a caisson ceiling, there is no significant difference between the square and round shapes.

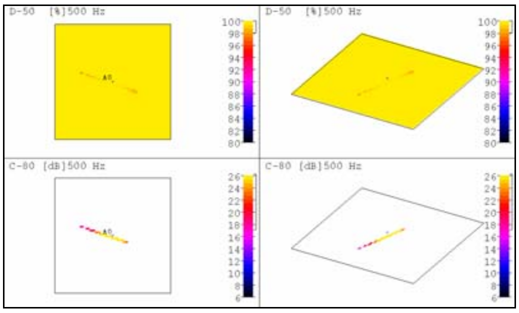


(a)

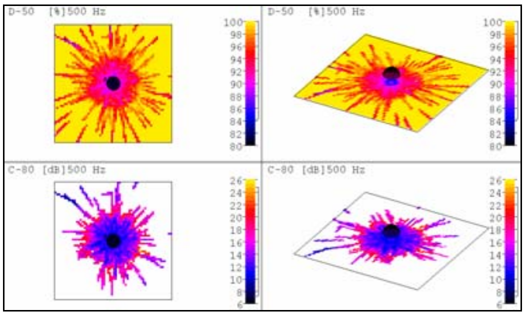


(b)

Figure 14. The difference of LF and LFC (a), SPL and G (b) between a roofless stage and a covered stage



(a)



(b)

Figure 15. The difference of D_{50} and C_{80} between a roofless stage (a) and a covered stage (b)

Effect of the depth of the caisson ceiling

A comparison was made between a deep (3.5m in depth) and a shallow (1.75m in depth) caisson ceiling, as illustrated in Figure 16, while maintaining the same height and shape of the bottom of the round caisson ceiling. Firstly, as expected, it can be seen from Figure 17 that for the stage covered with a round caisson ceiling the influence range of SPL, LF, G, D_{50} and C_{80} of the sound field becomes smaller when the depth of the round caisson ceiling was incresed.

Secondly, compared with changes of SPL, LF and G respectively, it can be seen from Figure 17, especially from the color pictures of LF, that the actor envelopment of the stage is improved by increasing the depth of the round caisson ceiling. This is because the area of the surface used to provide lateral reflection sound becomes larger when the depth of the round caisson ceiling changes from shallow to deep. This would lead to enhancing the strength of the lateral reflection sound reflected from the round caisson ceiling. At the same time, the ability to concentrate sounds from various directions of the round caisson ceiling is also enhanced by increasing its depth. Accordingly, its actor envelopment of the stage is improved. Similarly, the area of the surface used to provide vertical downward sound reflection becomes smaller when the depth of the round caisson ceiling is changed from shallow to deep. This accordingly leads to a decrease in the strength of sound vertically reflected from the round caisson ceiling. Therefore, it can be seen from the color pictures of SPL in Figure 17(a1) and (b1) that the yellow point below the shallow caisson ceiling is slightly brighter than that of deep caisson ceiling.

Thirdly, the fluctuation phenomenon of color transformation in pictures of C_{80} and D_{50} in Figure 17(a2) and (b2) can be easily understood by the theory of geometrical acoustics.

Calculations also show that for a square caisson ceiling, all the results mentioned above are similar, although these are not presented in this paper.

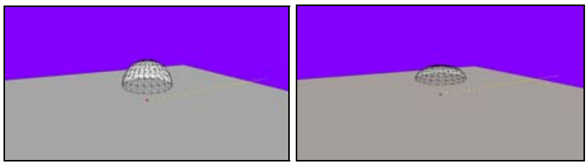
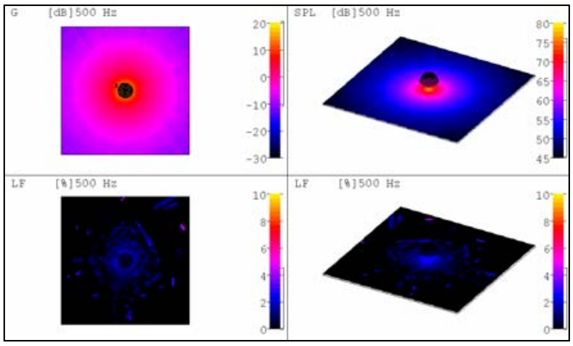
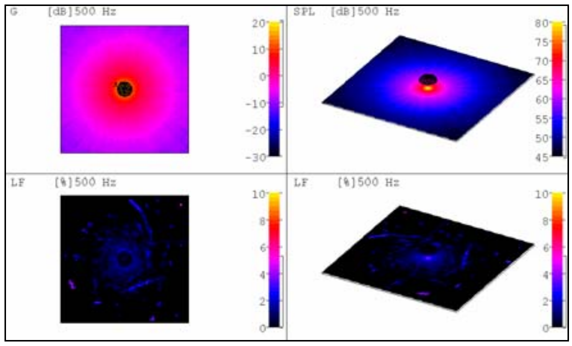


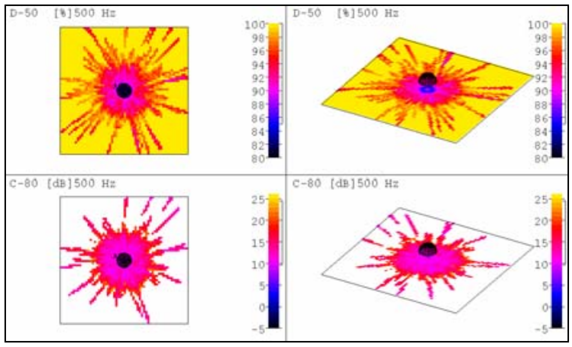
Figure 16. A deep caisson ceiling and a shallow caisson ceiling



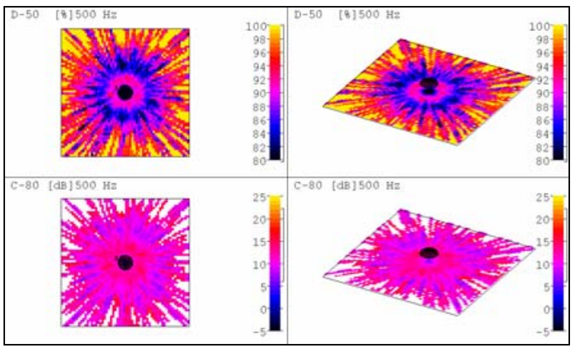
(a1)



(b1)



(a2)



(b2)

Figure 17. The difference of G, SPL, LF, D_{50} and C_{80} between a deep caisson ceiling (a1; a2) and a shallow caisson ceiling (b1; b2)

Effect of the size of the caisson ceiling

A comparison was made between a large (3.5m in diameter) and a small (1.75m in diameter) caisson ceiling, as illustrated in Figure 18. It can be seen from Figure 19 that the influence range of SPL, LF, G, D_{50} and C_{80} of the sound field of the stage covered with a round caisson ceiling becomes smaller when reducing the size of the caisson ceiling proportionally by 70%, while maintaining the same height of the bottom of the caisson ceiling. Simultaneously, the value of SPL, G and LF decreases within this influence range by about 0.49dB in SPL, 0.49dB in G and 0.1% in LF on average, whereas, the values of D_{50} and C_{80} increase. This is because the area of the surface used to reflect sound and the coverage range of the sound reflected from the caisson ceiling all become smaller when the size of the caisson ceiling is reduced proportionally. Thus, the energy of the sound reflected from the caisson ceiling decreases, the actor envelopment of the stage also becomes worse and various acoustic indices mentioned above increase or decrease along with this change as well. Again, for a square caisson ceiling, all the results mentioned above are similar.

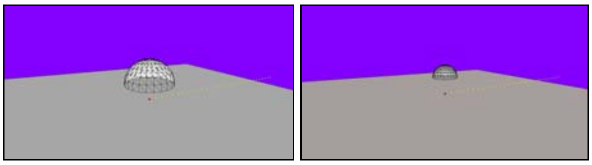
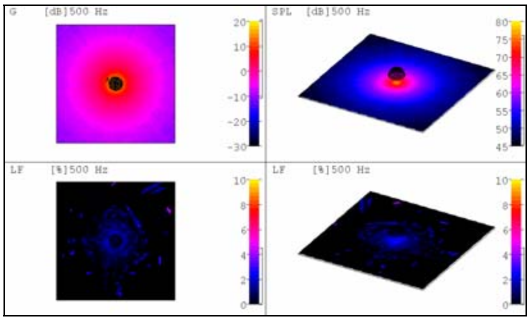
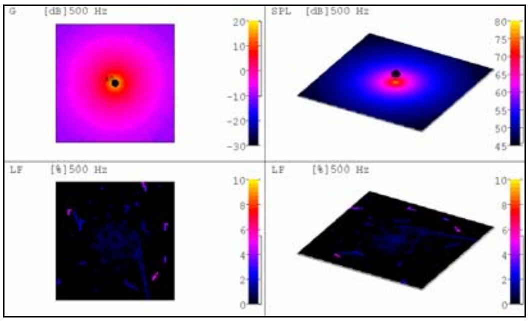


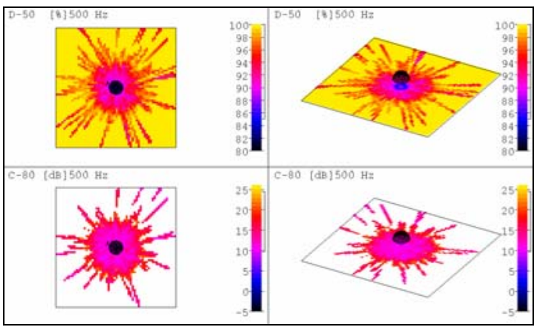
Figure 18. A big caisson ceiling and a small caisson ceiling



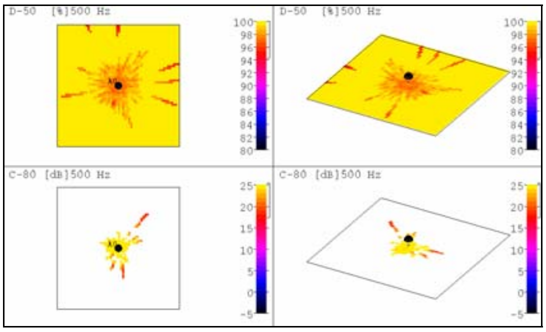
(a1)



(b1)



(a2)



(b2)

Figure 19. The difference of G, SPL, LF, D_{50} and C_{80} between a big (a1; a2) and a small caisson ceiling (b1; b2)

Effect of the height of the caisson ceiling

A comparison was made between a 6m and a 2m high caisson ceiling, as illustrated in Figure 20. As expected, it can be seen from Figure 21 that when the shape and size of the caisson ceiling stay the same, the influence range of SPL, LF, G, D_{50} and C_{80} of sound field of the stage covered with a caisson ceiling, whether the shape was round or square, becomes smaller when the height of the caisson ceiling is changed from high to low. Besides, it can be seen from the color pictures that the actor envelopment of the stage is improved as well, whereas the value of C_{80} and D_{50} decreases. This is because the lower the caisson ceiling is, the closer it gets to the sound source. This would strengthen the sound pressure level of the surface used to receive and reflect the direct sound. The sound reflected from this surface is therefore strengthened along with this change of the caisson ceiling. Consequently, the actor envelopment of the stage is improved and the value of C_{80} and D_{50} decreases.

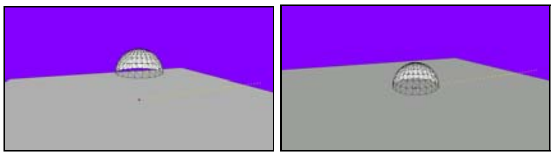
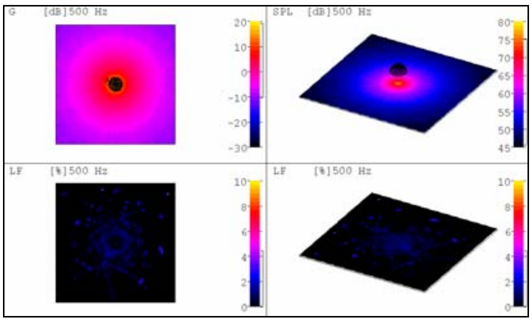
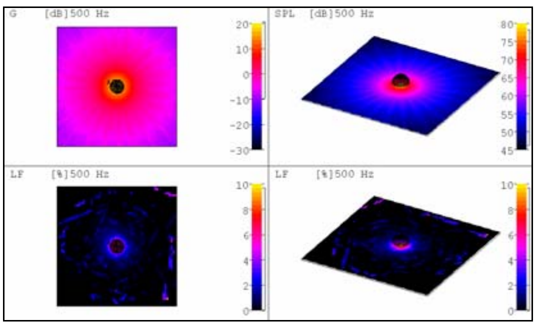


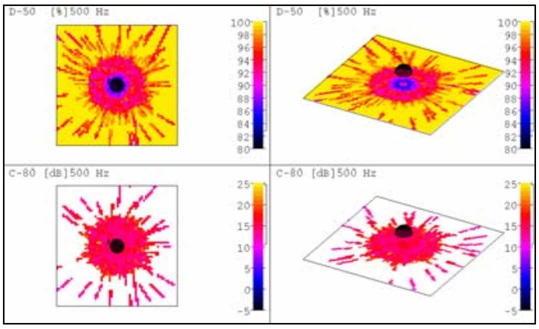
Figure 20. A 6-meter-high caisson ceiling and a 2-meter-high caisson ceiling



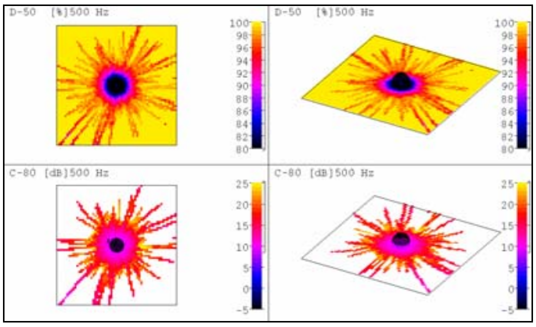
(a1)



(b1)



(a2)



(b2)

Figure 21. The difference of G, SPL, LF, D_{50} and C_{80} between a 6-meter-high caisson ceiling (a1; a2) and a 2-meter-high caisson ceiling (b1; b2)

Effect of the shape of the caisson ceiling

The caisson ceiling of the stage of traditional Chinese theatres contains various sizes and forms, but can be simply summed up into either a round or a polygon shape, where the latter also contains two types which are quadrilateral and octagon, as shown in Figure 22.

By comparing the color pictures of LF in Figure 17(a1) and Figure 23(a1), it can be seen that the actor envelopment of the stage under a round caisson ceiling is better than that with a quadrilateral caisson ceiling. Although the area of the surface of the quadrilateral caisson ceiling used to provide lateral reflection sound is larger than that of a round caisson ceiling, leading to the LF of quadrilateral caisson ceiling being greater than that of round caisson ceiling, due to the fact the quadrilateral caisson ceiling's reflected sound is not as uniform in all directions as the round caisson ceiling's, its actor envelopment of the stage is therefore inferior to the round caisson ceiling.

However, the more sides the polygon caisson ceiling has, the better the stage's actor envelopment, which can be seen by comparing Figure 23(a1) and (b1). This is because the shape of a polygon is closer to the shape of a circle when its sides are increased. This accordingly leads to an increase in the number of main directions of incoming sound reflected from the caisson ceiling, and these main directions converge more. Consequently, the reflected sound from the surface of the octagonal caisson ceiling arrives at the actor's ears more equally from various directions than that from the surface of the quadrilateral caisson ceiling. As a result, the stage's actor envelopment is obviously improved, even as good as that of the round caisson ceiling. Moreover, the difference in the stage's actor envelopment between the round caisson ceiling and the octagonal caisson ceiling can be easily seen by comparing the color pictures of LF in Figure 17(a1) and Figure 23(b1). Because the value of LF of the octagonal caisson ceiling is also significantly higher than that of a round caisson ceiling, its actor envelopment of the stage is clearly superior to the round caisson ceiling. On the whole, the actor envelopment of the stage of the octagonal caisson ceiling is the best, followed by that of the round caisson ceiling, and the last is that of the quadrilateral caisson ceiling.

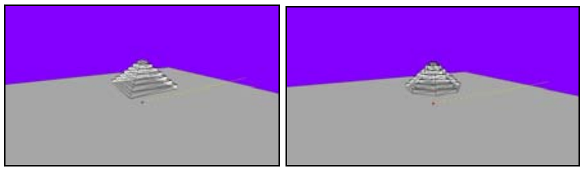
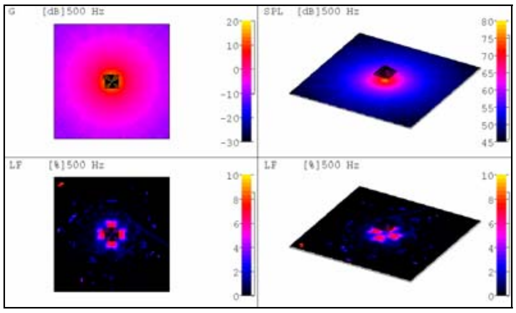
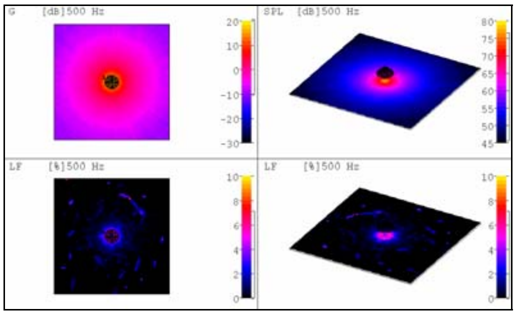


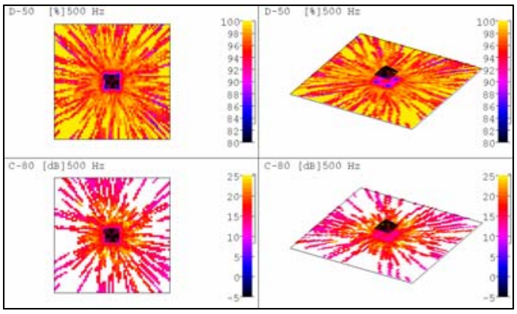
Figure 22. A quadrilateral caisson ceiling and an octagonal caisson ceiling



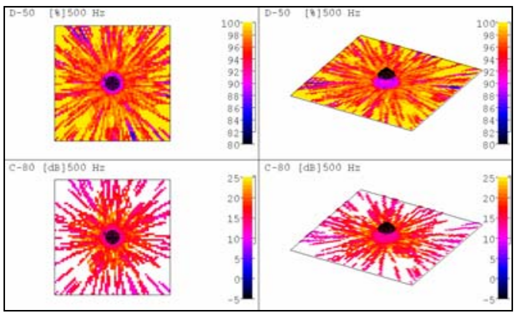
(a1)



(b1)



(a2)



(b2)

Figure 23. The difference of G, SPL, LF, D_{50} and C_{80} between a quadrilateral caisson ceiling (a1; a2) and an octagonal caisson ceiling (b1; b2)

Effect of the number and pattern of the caisson ceiling

According to the discussion in the introduction section above, there are different patterns and numbers of caisson ceilings in traditional Chinese theatres. Therefore, as shown in Figure 24 and Figure 26, four of its existing forms including one-caisson ceiling (type A), two-caisson ceiling (type C), three-caisson ceiling (type D) and five-caisson ceiling (type B) were simulated, compared and analysed. The results show that the actor envelopment of the stage of type A and B is better than that of type C and D. Among them, it can be seen that the actor envelopment of the stage of type A is the best of all by comparing Figure 25(a1), 25(b1), 27(a1), and 27(b1). This is because the actor envelopment of the stage not only relates to the intensity of reflected sound, but also to the directional uniformity of the reflected sound arriving at an actor's ears. The greater the intensity and the higher the directional uniformity of the caisson ceiling is, the better the actor envelopment of the stage is. Therefore, this phenomenon can also be easily understood by the theory of geometrical acoustics. By comparing Figure 25(a2), 25(b2), 27(a2), and 27(b2), it is seen that the acoustic effect on the audience area of type C and type D is superior to that of type A and type B. This is because the acoustic effect on the audience area mainly relates to the coverage range of the sound reflected from the caisson ceiling. The larger the coverage range of the caisson ceiling is, the better the ceiling's effect on the audience area is. It can be easily seen from Figure 24 and 26 that the area of type C and D is much larger than that of type A and B. This would lead to the coverage range of reflected sound of type C and D being much larger than that of type A and B. Therefore, the result is that the two-caisson ceiling and the three-caisson ceiling has a better acoustic effect on the audience area compared to both the one-caisson ceiling and the five-caisson ceiling.

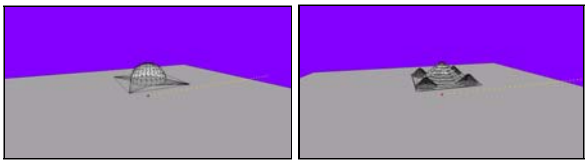
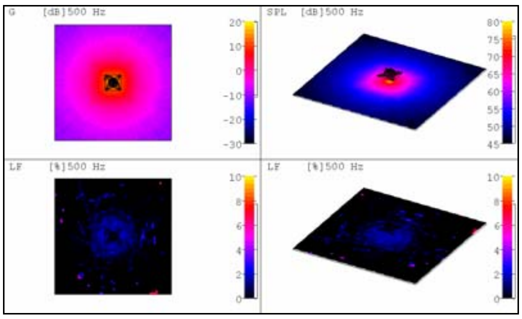
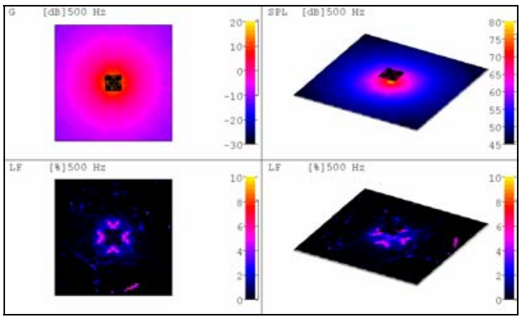


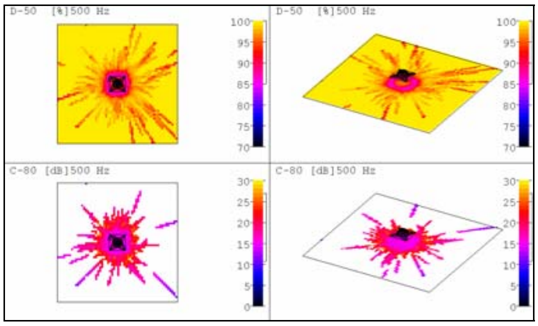
Figure 24. A one-caisson ceiling (type A) and a five-caisson ceiling (type B)



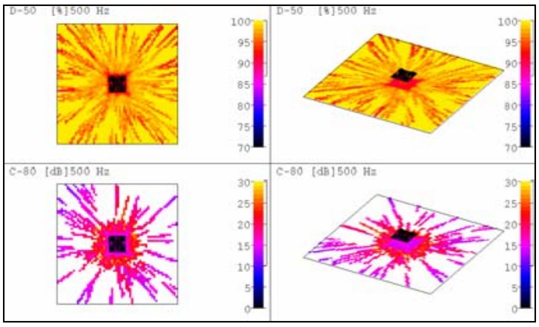
(a1)



(b1)



(a2)



(b2)

Figure 25. The difference of G, SPL, LF, D_{50} and C_{80} between type A (a1;a2) and type B (b1;b2)

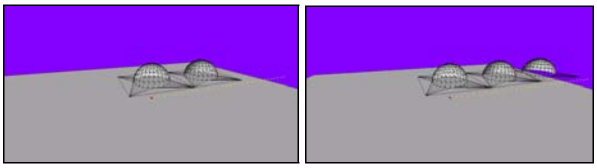
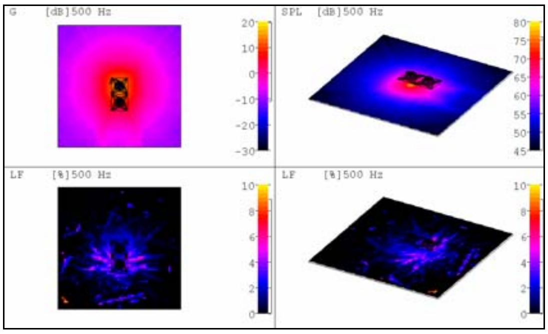
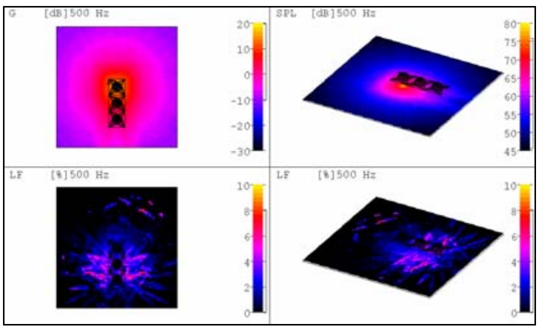


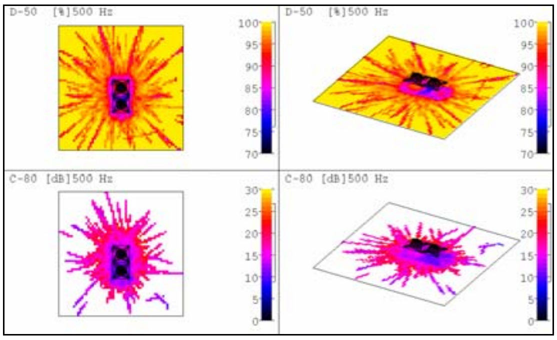
Figure 26. A two-caisson ceiling (type C) and a three-caisson ceiling (type D)



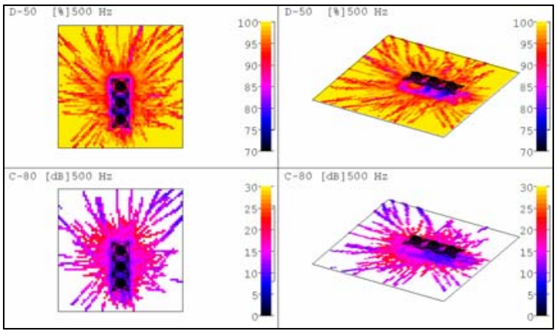
(a1)



(b1)



(a2)



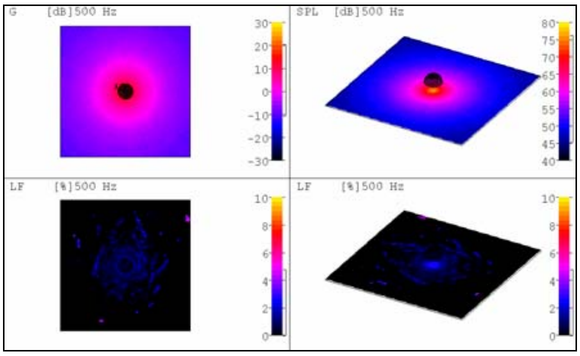
(b2)

Figure 27. The difference of G, SPL, LF, D_{50} and C_{80} between type C (a1;a2) and type D (b1;b2)

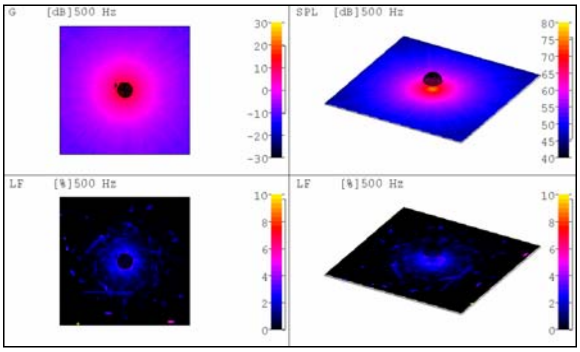
Effect of the scattering and absorption coefficient of the caisson ceiling

A comparison was made by setting the scattering coefficient of the caisson ceiling set as 0, 50 and 100. It can be seen from Figure 28 that the influence range of SPL, LF, G, D_{50} and C_{80} of sound field of the stage covered with a caisson ceiling, whether the shape was round or square, enlarges along with increasing the scattering coefficient of the caisson ceiling when absorption coefficient of the caisson ceiling stays the same. This is because the capacity of scattering sound of the surface of the caisson ceiling is enhanced with increasing scattering coefficient. Accordingly, the range of coverage area of the sound reflected from the caisson ceiling is enlarged. Furthermore, it can be seen from Figure 29 that the difference between maximal and minimal values of various acoustic indices mentioned above is almost maintained unchanged. This is because the amount of energy of sound reflected from the caisson ceiling is affected to a minimal extent by changing the scattering coefficient of the caisson ceiling. However, it can be seen from the color pictures of LF in Figure 28 that its actor envelopment of the stage becomes worse. The reason for this is that the capacity of concentrating the sound of the caisson ceiling becomes weak when the capacity of the scattering sound is enhanced.

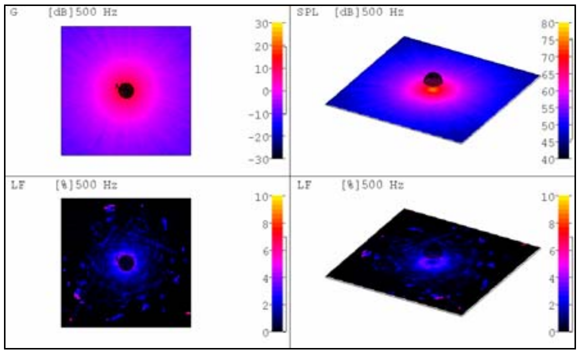
On the contrary, it can be seen from Figure 30 that the influence range of SPL, LF, G, D_{50} and C_{80} of the sound field of the stage covered with a caisson ceiling, whether the shape is round or square, remains almost unchanged when the sound absorption coefficient of the caisson ceiling is increased, while maintaining the same scattering coefficient of the caisson ceiling. This is because keeping the scattering coefficient constant means that the capacity of scattering sound of the surface of the caisson ceiling stays the same. Accordingly, the range of coverage area of sound reflected from the caisson ceiling also remains unchanged. However, with increasing absorption the difference between maximal and minimal values of various acoustic indices mentioned above becomes small or even disappears, as shown in Figure 31. Furthermore, it can be seen from Figure 30 that the actor envelopment of the stage also gradually becomes worse when increasing the absorption coefficient of the caisson ceiling, whereas the value of C_{80} and D_{50} increases. The reason for this phenomenon is that the amount of sound energy reflected from the caisson ceiling was affected a lot by changing the absorption coefficient.



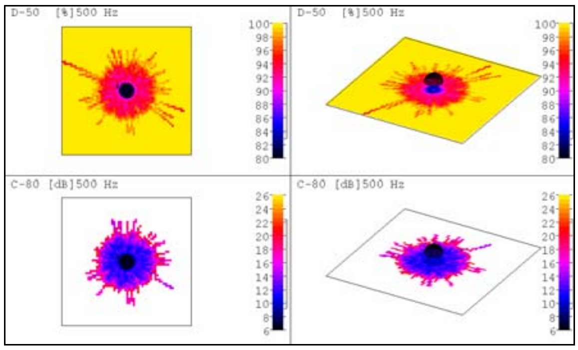
(a1)



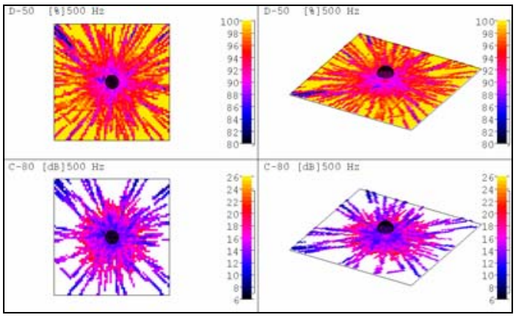
(b1)



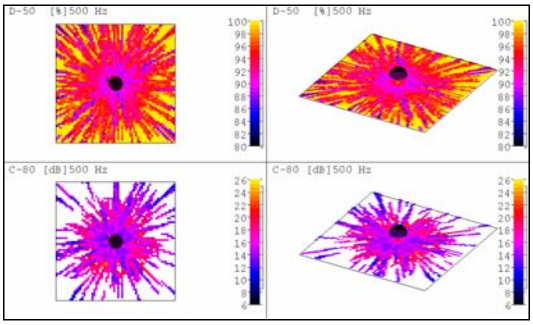
(c1)



(a2)



(b2)



(c2)

Figure 28. Sound fields with the scattering coefficient of the caisson ceiling set as 0 (a1;a2), 50 (b1;b2) and 100 (c1;c2)

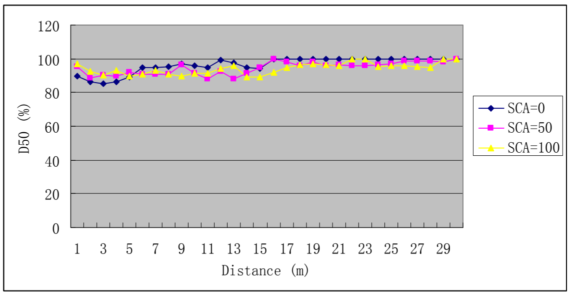
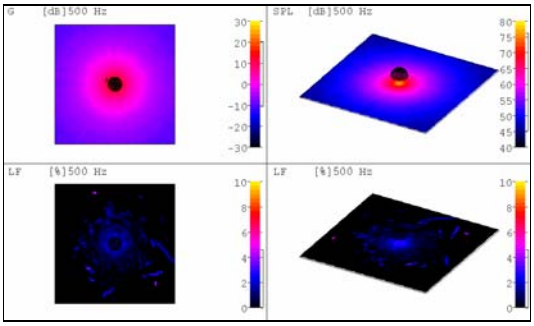
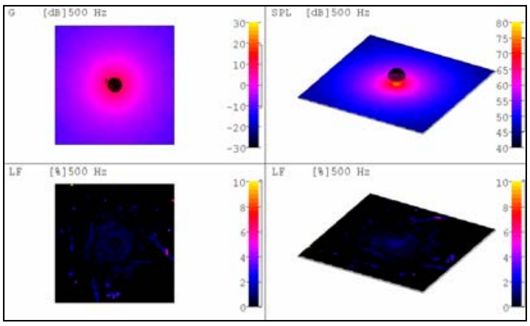


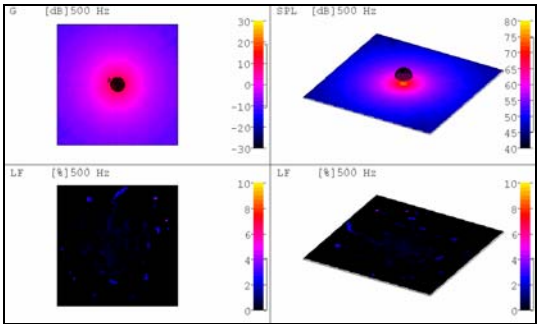
Figure 29. The value of D50 of the caisson ceiling with different scattering coefficients



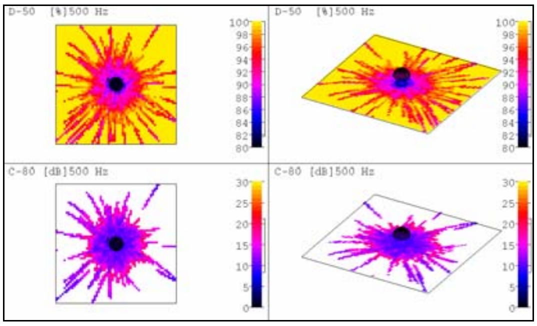
(a1)



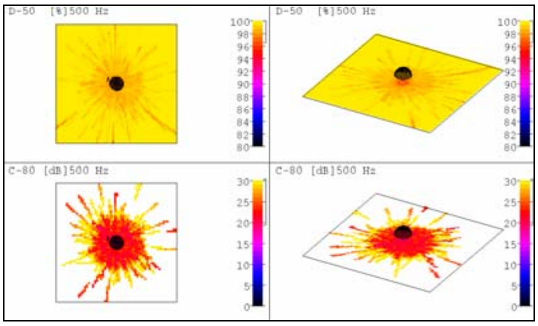
(b1)



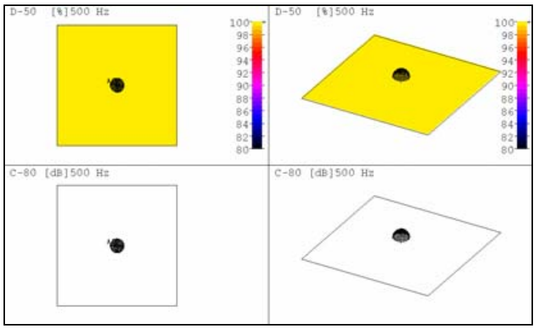
(c1)



(a2)



(b2)



(c2)

Figure 30. Sound fields with the absorption coefficient of the caisson ceiling set as 0 (a1;a2), 50 (b1;b2) and 100 (c1;c2)

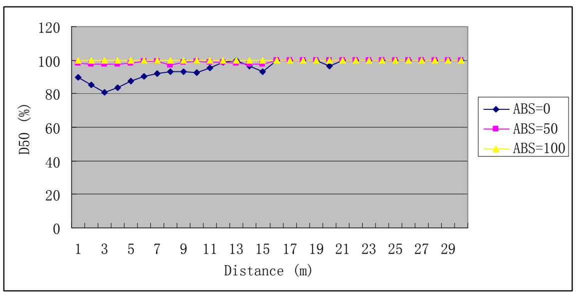


Figure 31. The value of D50 of the caisson ceiling with different absorption coefficients

CONCLUSIONS

To conclude the above, the caisson ceiling, regardless of whether the shape was circular or polygonal, did have the function of concentrating sounds. Additionally, in the case of the single-caisson ceiling, the larger the size, the greater the depth, the lower the height, the smaller the absorption coefficient and the smaller the scattering coefficient which the octagonal caisson ceiling possesses, the better the actor envelopment (as discussed on page 3) it provides on the stage. Moreover, the larger the size, the shallower the depth, the higher the height, the smaller the absorption coefficient and the greater the scattering coefficient which the octagonal caisson ceiling possesses, the better the acoustic effect it provides for the audience area. Therefore, in order to improve the actor's self awareness as well as the audience's acoustic feeling, the traditional Chinese opera play should be put on the stage covered with a one-caisson ceiling which is constructed with an octagonal shape, a large size, a moderate depth, a moderate height, a moderate scattering coefficient and a small absorption coefficient. In the case of the multi-caisson ceiling, in order to improve the actor's self awareness as well as the audience's acoustic feeling, the opera play should be put on to the stage covered with a three-caisson ceiling. Furthermore, the shape of the caisson ceiling directly over the stage should be octagon.

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