CHARACTERISTICS OF SOUND PRESSURE LEVEL IN EXTRA-LARGE SPACES

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A growth number of large spaces have been built in recent years and their sound fields are important for the acoustic design and crowed evacuation. The aim of this paper is to study the characteristics of Sound Pressure Level (SPL) in those spaces. The decreasing trend of total and reverberant SPL with source-receiver distance was studied by using the image method. The results showed that total SPL decreased in an exponential trend in extra-large spaces and the reason was not only the direct energy but also the exponentially decreasing reverberant energy, in which first-order reflections occupied a large part of reverberant energy. Furthermore, taking air absorption into account in extra-large space was necessary but it was difficult to become the main way of sound energy absorption except for extremely large spaces.

Keywords: SPL; large space; computer simulation; image method; air absorption;

1. Introduction

There is a growing number of large spaces and their sound fields are important for the acoustic design and crowed evacuation [1, 2]. Previous studies on the sound fields of large spaces have mainly focused on large churches and auditoriums. Anderson found that the variation of sound energy showed significant correlation with the source-receiver distance in St Paul's Cathedral (volume $152000\ m^3$) in London [3]. The variation of acoustic parameter was also found in many other churches [4, 5]. Coupling effect and interface reflection were considered as the main causes of the variations in sound energy and reverberation time.

Early reflections and air absorption were also important factors for the energy distribution in extra-large space. However, their effect was not studied systematically when the volume increases larger than ordinary size.

In this paper, the decreasing trend of total and reverberant SPL with source-receiver distance was studied by using the image method. The significance of first-order reflection and air absorption in extra-large spaces was also discussed.

2. method

Because of the difference in typology, shape, volume, acoustic interface performance, etc., it is difficult to obtain an accurate rule of energy distribution from measurements in different spaces. To control other variables and explore the influence of volume as a single factor on the sound field, sound energy variation in large spaces was studied by using computer simulation in a series of hypothetical cubic spaces at different volumes and interface absorptions. An image method[6] for rectangular spaces was developed because of its easy-implement algorithm and accuracy of reflection sequence[7, 8, 9]. A significant advantage of the image source model in the current paper is that the calculation accuracy and computational difficulty have no relation to the volume.

The above method was achieved using python language to avoid optimization of some commercial software developed for ordinary spaces. Furthermore, the new program shows more flexibility and total efficiency using the multi-processing method and customizable pre-processing than commercial software. Low-frequency resonance, diffraction and edge effects which are less of a concern in extra-large spaces, are not considered. The diffusion effect was also ignored for brevity.

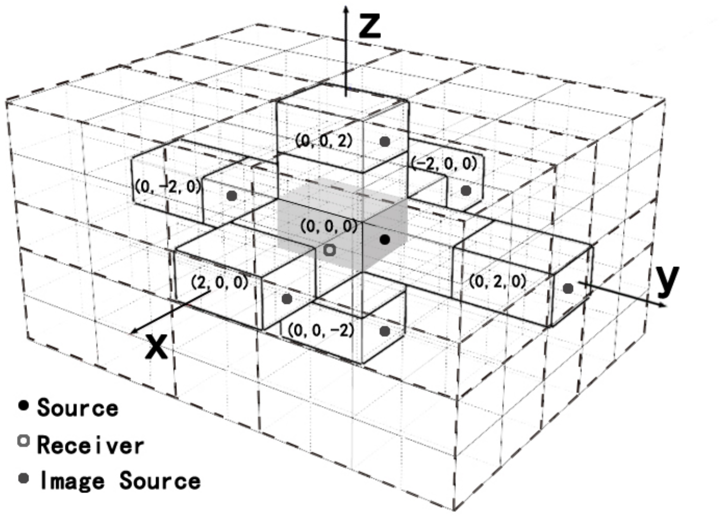

Figure 1: Image cells of a room including source and receiver locations.

In this paper, 20 quasi cubic models were chosen to be simulated which side length varied from $10\,m$ to $500\,m$ (namely which volume varied from $1000\,m^3$($10\,m$ x $10\,m$ x $10\,m$) to $125000000\,m^3$($500\,m$ x $500\,m$ x $500\,m$) which represent the different size of ordinary space, large space and even the space which is too large to exist) and 9 absorption coefficients varied from 0.1 to 0.9 were applied to each space respectively. Following ISO-3382 standard, the source points were arranged at the centre of the floor at a height of $1.5\,m$. 15 receiver points were arranged in every space evenly in the quarter of floor because of the symmetry at a height of $1.2\,m$.

3. Results

3.1 Energy distribution

As shown in Fig. 2, With the increasing of volume and interface absorption, reverberant energy decreased significantly as a whole. As a result, total energy decreased as well. In the area far from the source, the reverberant energy was nearly a fixed value, which is similar to the ordinary space.

However, both of the reverberant and total energy showed more exponential trend in the near-source area, rather than as a fixed value in the diffuse hypothesis. Reverberant energy showed more distance sensitivity in the near-source field with the increasing of volume which was mainly due to the spatial unevenness of early reflections. If the interface absorption coefficient is a fixed value, for example 0.1 and 0.5 as in Fig. 2, the difference between the total and direct energy had a little variation with the increasing of volume. When the interface absorption coefficient was 0.3 the difference varied from $7.6\,dB$ to $9.6\,dB$ and when the interface absorption coefficient was 0.7, this difference range varied from $2.7\,dB$ to $4.0\,dB$.

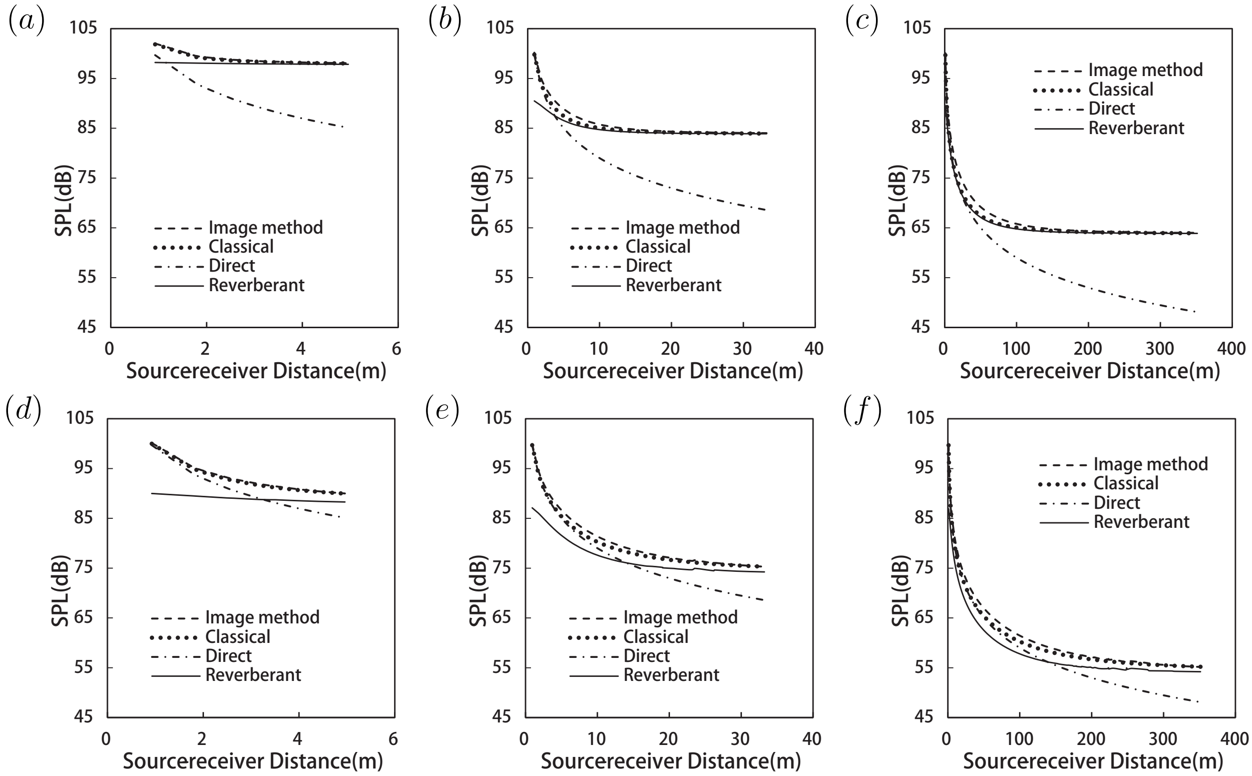

Figure 2: Sound energy distribution in different volume and interface absorption coefficient: (a), (b) and (c) were in the space which volume were $1000m^3$, $125000m^3$ and $125000000m^3$ respectively when the interface coefficient was 0.1. (d), (e) and (f) were in the space which volume were $1000m^3$, $125000m^3$ and $125000000m^3$ respectively when the interface coefficient was 0.5.

The differences of sound energy distribution in ordinary and extra-large rooms were presented in FIG. 3. In ordinary large rooms, such as auditoriums and small indoor stadiums, the reverberant energy attenuates slightly with the increase of source-receiver distance. This was also verified in the current paper. In the rectangular space, whose volume is $1000\ m^3$, the range of reverberant SPL was $1.1\ dB$ and $2.5\ dB$ while the absorption coefficient was 0.3 and 0.7, as shown in FIG. 3.

From FIG. 3, it can also be seen that the SPL attenuate curve became closer to the direct sound straight line, since logarithmic abscissa axis was used. This means that with the increase in volume and absorption coefficient, reverberant SPL showed a significant exponential decreasing trend.

When an exponential pattern of curves appeared with the increase in volume, the attenuate curves shown in these two figures could be divided into three parts. The first part was the linear attenuate curve near the source and in different spaces those curves were always within about $6\ m$ from the source. Then the second part showed an exponential trend in the remaining near-source area. The first two parts made up convex curves, and the reason will be discussed below.

With the increase of volume more exponential trends appeared in the two figures. The reverberant SPL attenuate curves in different spaces moved down and gradually approached a critical curve. Theoretically, this critical curve should be hypothetical, however, as shown in FIG. 3, the FRFF (which means first reflection from the floor) curve could be regarded as the critical one in practice because of the high degree of coincidence between the two curves.

The last part backed to the linear attenuate trend again in the area far from the source. This linear pattern was due to the domination of other reflection energies, which still have a slight attenuation with distance because the first reflection energy from the floor decreased with the source-receiver distance. This three-part phenomenon in a large space was different from the hypothesis of classical model or other models [10, 4].

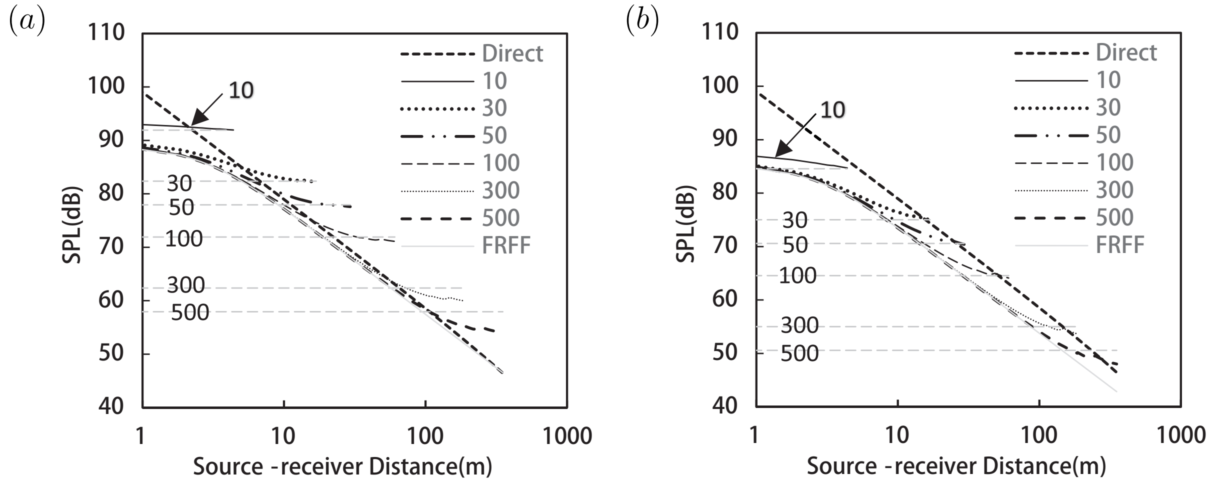

Figure 3: Reverberant SPL variation in the space of different volumes and the same absorption coefficient, which is 0.3 in panel(a) and 0.7 in panel(b). FRFF means first reflection from the floor, and the flat dotted lines mean the reverberant SPL from classical models in different spaces.

In terms of effect of interface absorption, according to the relative relationship between the dash straight line and other curves in FIG. 3, a larger absorption coefficient reduced the ratio of the reverberant energy to the direct energy, which means that direct energy occupied a greater proportion and showed more exponential trends. Moreover, as shown in the comparison of two figures, larger absorption aggravated the non-diffusion of the sound field, and the reverberant energy appeared to be an exponential trend, which is more evident in a large space. In this way, more exponential characteristics appeared in the space with the increase in volume and absorption.

Early reflections made reverberant energy more sensitive to the source-receiver distance. To study the effect on the total sound pressure level, first-order reflections were considered first. The first-order reflections and the direct sound were added and then compared with the total sound pressure level to get the difference, as shown in Fig. 4.

As shown in Fig. 4, when the average absorption coefficient is 0.7, only the first order reflection can meet the tolerance of $1.5dB$. When the absorption coefficient is 0.3, spaces with smaller volume did not meet the tolerance, while the larger ones still met. This showed the significance of first-order reflection in extra-large space.

3.2 Air absorption

Air absorption was always an important part of sound pressure level prediction, which value grows with the increasing of volume. However, the magnitude of total sound pressure level also affects the effect of air absorption. As shown in Fig. 5, the air absorption had a small percentage of total absorption which including the effect of air and interface when the volume is smaller than $125000m^3$.

Although the sound absorption energy of the air in a space has little spatial variation, the ratio of air absorption to total sound absorption varied with the source-receiver distance, as shown in Fig. 5. This was mainly due to the exponential decrease of total SPL with the source-receiver distance.

However, air absorption was difficult to become the main way of sound energy absorption. For example, when interface absorption coefficient was 0.3 and the volume of space reached $27000000m^3$ (that is, of which cube root was equal to $300m$). When the average sound absorption coefficient is 0.7, the volume reached $125,000,000m^3$ (that is, of which cube root was equal to $500m$).

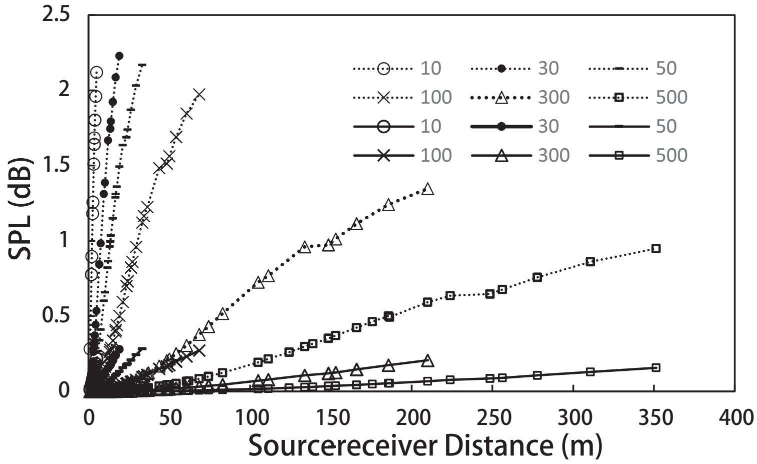

Figure 4: The difference between total energy and the sum of direct and first-order reflections. The dotted curves represented the difference in the spaces which the absorption is 0.3 and the solid curves represented the difference in the spaces which the absorption is 0.7.

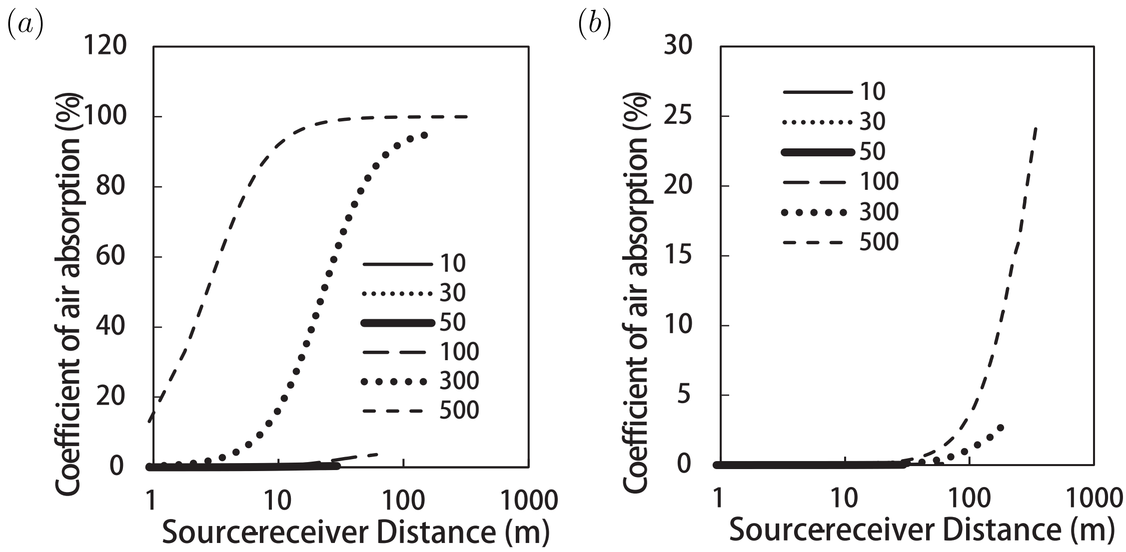

Figure 5: Air absorption as a percentage of total absorption, when the interface absorption coefficient was 0.3(a) and 0.7(b) and the air absorption coefficient was $0.00466 dB/m (1000 Hz$, $20°C$, 50%humidity).

4. Conclusion

The basic characteristics of sound fields in large spaces have been revealed by using the image method. Because of the unevenly distributed early reflections, Both reverberant and total energy showed more exponential trend in the near-source area and the difference between the total and direct energy had a little variation with the increasing of volume. First-order reflection had an important role on the SPL prediction in extra-large space and its role was also affected by the interface absorption. Taking air absorption into account in extra-large space was necessary but it was difficult to become the main way of sound energy absorption except for some extreme situation, such as large enough with low interface absorption.

5. Acknowledge

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