Simulation study on the noise reduction performance of enclosed noise barriers with different opening layouts

Jie Yang[1], Zhongxu Kang[1], Edgar Matas[2], Koen Vansant[2], Hailong Li[3], Fuliang Zhan[3]

[1]Beijing Municipal Institute of Labour Protection, Beijing, China
(yj@bmilp.com, zhongxukang@163.com)
[2]Siemens Digital Industry Software, Leuven, Belgium
(edgar.matas@siemens.com， koen.vansant@siemens.com)
[3]Siemens Digital Industry Software, Beijing, China
(hailong.li@siemens.com, fuliang.zhan@siemens.com)

Abstract
In order to meet the functional requirements such as fire protection etc., the enclosed noise barriers need to be equipped with smoke vents and other openings. The openings will destroy the sealing ability of the enclosed noise barriers and reduce the noise reduction performance. In order to study the influence of different opening layouts on the noise reduction performance of enclosed noise barriers, models of enclosed noise barriers used in rail transit were built and the noise reduction performance were simulated using Simcenter 3D Ray Acoustics software. The acoustic field results of enclosed noise barriers with continuous and periodic opening layouts were simulated and compared. The results show that this method can simulate the acoustics diffraction phenomenon at the openings, and the simulation data show that different opening layouts have a significant impact on the noise reduction effect of the enclosed noise barriers, so detailed designs are needed for the specific usage scenarios.

Keywords: enclosed noise barrier, noise reduction, acoustic simulation, opening layouts.

1 Introduction

Sound barrier is one of the most effective methods to control noise propagation. Especially for traffic noise, sound barrier has a wide range of applications. The common sound barrier is not closed. Noise control is realized by sound insulation, absorption and diffraction attenuation. A lot of literature has studied the influence of the height, width, absorption and sound insulation coefficient and top structure of the sound barrier on the performance of the sound barrier[1-4]. Compared with the vertical sound barrier, the fully enclosed sound barrier closes the sound source, and most of the sound waves are absorbed and reflected by the sound barrier in the process of propagation. There is no diffraction sound, which can achieve the best noise reduction effect. However, in practical application, in addition to the high cost, the completely closed sound barrier has obvious potential safety hazards. For example, in case of fire, it is unable to exhaust smoke effectively, which greatly limits the practical application of the closed sound barrier. Some researchers have studied the effects of the opening of the fully closed sound barrier on its acoustic, smoke exhaust, outlet pressure and other performance[5-7]. Liu Lei[8] and others have carried out simulation research on the influence of top opening on smoke exhaust. Zhang Chao[9] has analyzed the influence of fully enclosed sound barrier opening rate on outlet micro pressure wave. The results show that when the train speed is different, the influence of top opening rate on outlet micro pressure wave is obvious, there is an optimal parameter for the opening ratio of totally enclosed sound barrier. Zhang Lijuan[10] and others conducted a simulation study on the influence of different opening widths on the acoustic performance of the fully enclosed sound barrier. The results show that there is little difference between 1m and 2m opening widths, and the protective effect of the closed sound barrier with 4m opening width on the buildings with higher floors is obviously worse.

The noise reduction effect of fully enclosed noise barrier is high, and the general theoretical effect can reach more than 20dB. However, due to the requirements of fire protection, when the sound barrier reaches a certain length, it is necessary to set up natural ventilation and smoke outlet. Due to the setting of the opening, there is a certain difference between the actual noise reduction effect and the theoretical noise reduction effect. The opening is usually set at the top, and the opening area is related to the fire demand. There are also openings to one side, which is related to the distribution of sensitive buildings to be protected. There are also many long openings on the top of the sound barrier, or some openings are set periodically. There is no clear regulation on the setting of sound barrier openings, which mainly depends on the constraints in other fields or the site conditions. This paper also studies the influence of opening on the acoustic performance of sound barrier. However, different from Zhang Lijuan's paper[10], this paper intends to study the influence of different opening types on the acoustic performance of sound barrier with the same opening area. According to the common opening situation of sound barrier, the influence of continuous opening and periodic opening on the acoustic performance of sound barrier is studied on the premise of the same total opening area. Aiming at the periodic opening, the influence of different opening size parameters on the acoustic performance of sound barrier is studied, which provides guidance for the application of closed sound barrier.

Fig.1 Several cases of enclosed sound barrier openings

2 Simulation method

2.1 Theory of simulation

When the length of acoustic wave is much smaller than the geometric size of the model, We assume that sound waves will travel in a straight line like a beam of light. Based on this assumption, the ray acoustic method is gradually developed and more and more used in various acoustic simulation. There is no any requirement for the size of acoustic mesh in the ray acoustics method, acoustics mesh discretization only needs to capture geometry detail and is independent on frequency, so surface modelling is sufficient. This yield small model sizes and fast computations, typically and order or two in magnitude smaller compared to typical FEM or BEM computations. So the acoustic ray method is very suitable for high frequency or large-scale acoustic simulation, such as environmental acoustics, architectural acoustics, urban rail noise, etc.
In this paper, we will use Simcenter 3D Ray Acoustics to do the acoustics simulation of enclosed noise barrier. In Simcenter 3D Ray Acoustics, acoustics rays will shoot from a point source location and reflect or absorb when they meet the wall, we can simulate sound through tracing the number and strength of the beams rays cross the receiver microphone using triangular beam tracing technology. Through using triangular beam tracing technology, results are obtained per frequency line and include phase interference effects from all contributing beams. Simcenter 3D Ray Acoustics can simulate the real physical environment of the acoustics wave traveling process, including absorption in air, reflections on surfaces, diffractions on edges and surfaces and so on.

2.2 Simulation model

This paper is mainly to simulate the radiated noise of overhead subway. The subway is 120m in length, 2.8m in width, 3.8m in height and 1.435m in rail moment. The plane of the rail is 15m above the ground. The noise barrier is 300 m in length, 9.2 m in width, and the maximum height is 8.5 m. There is one tall building in the middle of the noise barrier. The inner side of the building is 45m away from center line of the rail, and the building dimensions are 90m in length, 20m in width and 100m in height. The schematic diagram of the overhead subway is shown in the below picture.

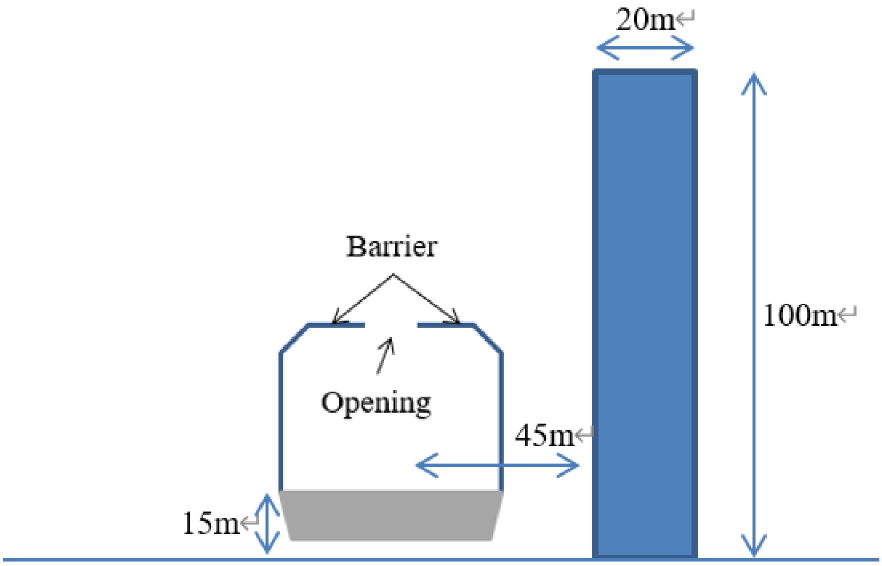

Fig.2 The schematic diagram of the overhead subway

2.2.1 Structure of the enclosed noise barrier

The enclosed noise barriers need to be equipped with smoke vents and other openings to meet fire protection demand. This pater will study how three designing of the smoke vents affect the environmental noise.

Case I: a continuous long opening, 0.5m in width and 300m in long.
Case II: uniform distribute 5 rectangular opening, 2m in width and 15 in long.
Case III: uniform distribute 5 rectangular opening, 6m in width and 5 in long.

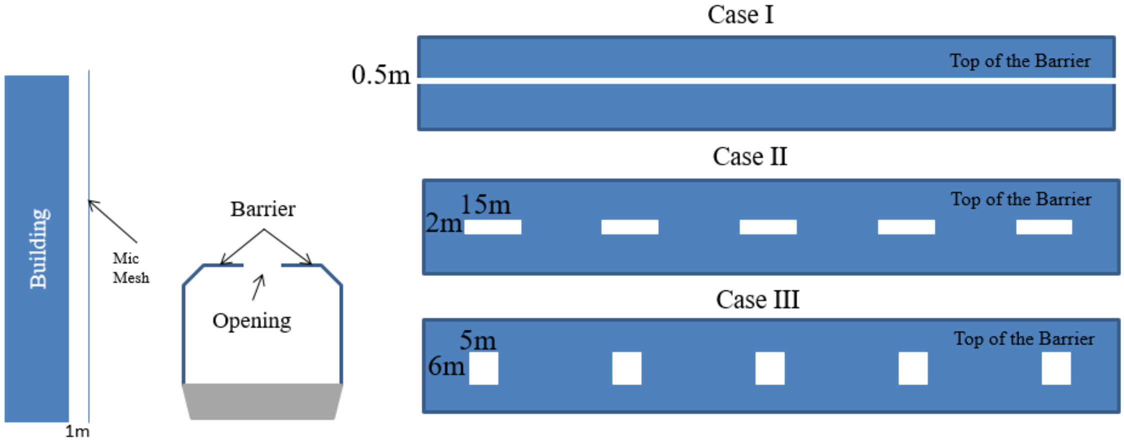

Fig.3 Schematic diagram of three types of openings

2.2.2 Building the simulation model

Base on the designing of the vents and the barrier, using Simcenter 3D to establish the geometric model, including the barrier, the building, and the train, below picture showing the smoke vents fully opened case.

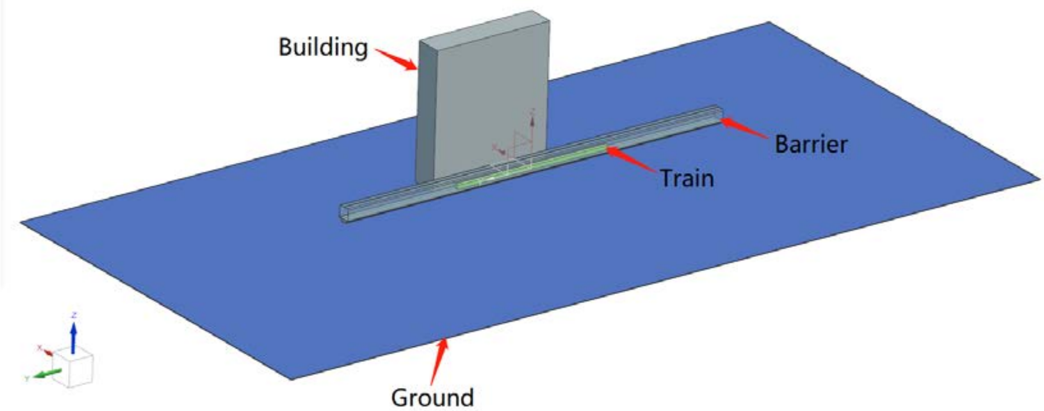

Fig.4 CAD Model of smoke vents fully opened barrier

Then doing the acoustics meshing, due to the acoustics mesh discretization only needs to capture geometry detail, so all the acoustics mesh using shell element, as shown in the below picture.

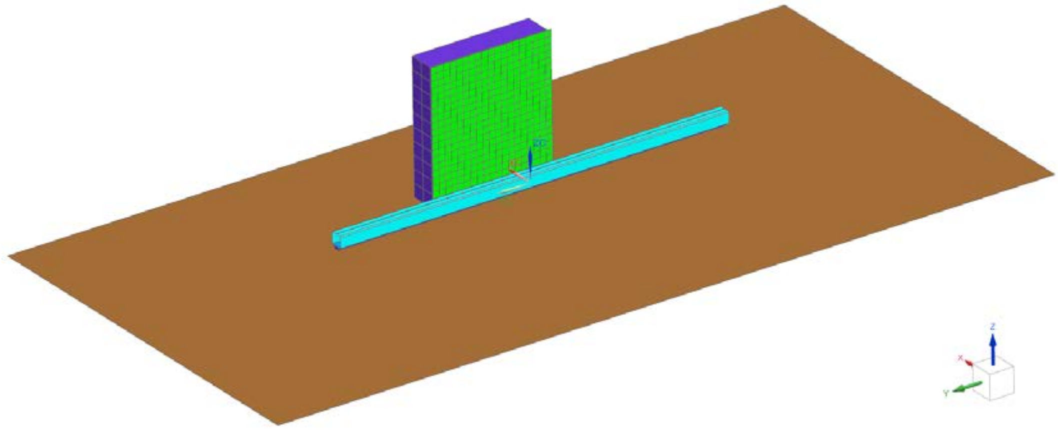

Fig.5 Acoustics Mesh of the Barrier

2.2.3 Noise source

This noise barrier is mainly used to shield noise when the train passing, so the noise source is at the wheel-rail position. The following table shows the measurement results of the wheel-rail noise. The measuring point is 2m away from the outer rail.

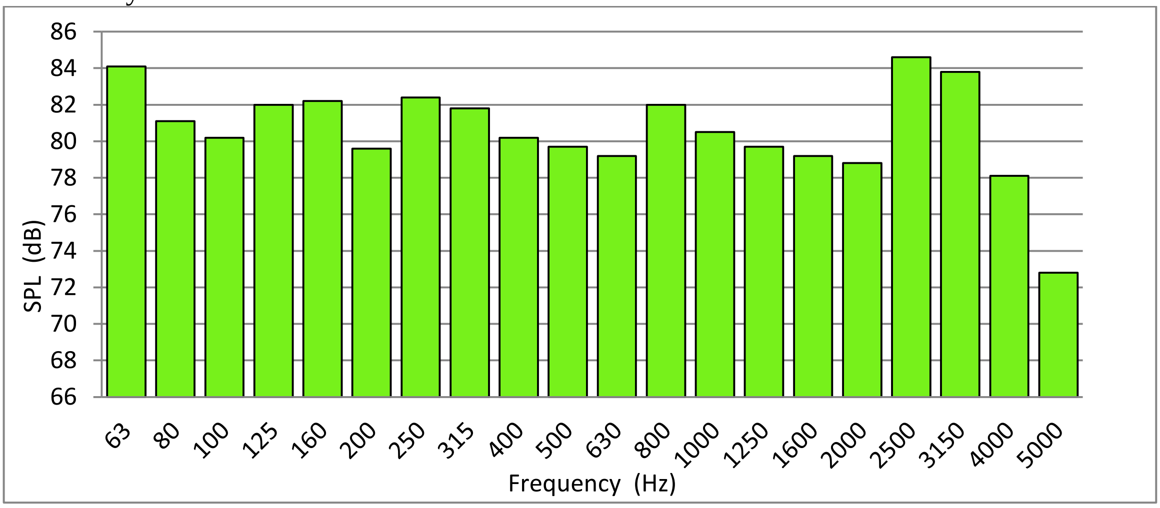

Fig.6 Sound source parameters

In the bottom of the train, through defining two panel ray sources to simulate the wheel-rail noise, as shown in the below picture.

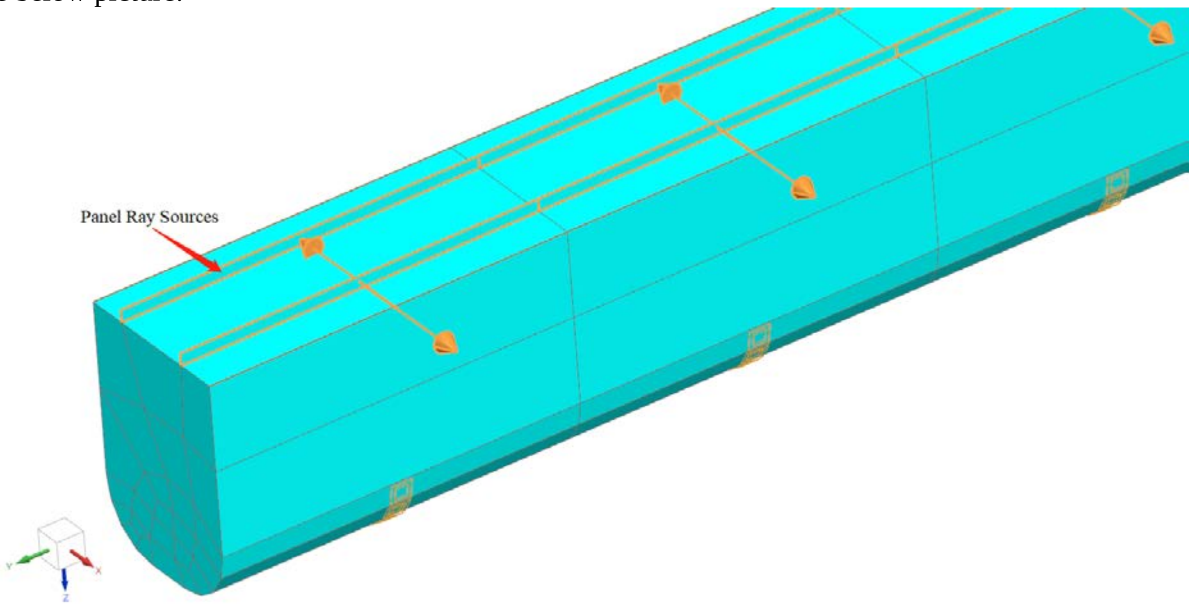

Fig.7 Panel ray sources

2.2.4 Boundary conditions

The Rays travelling from the bottom of the train and will diffract at the edge of train. Then the rays will reflect at the internal of the barrier, especially will emerge complex surface reflection at the curved surface of the train. So in order to realistically capture the rays at the edge and curved surfaces, so we need define the edge diffraction at the bottom of the train and define smooth surface reflection at the curved surface of the train, as shown in the below picture.

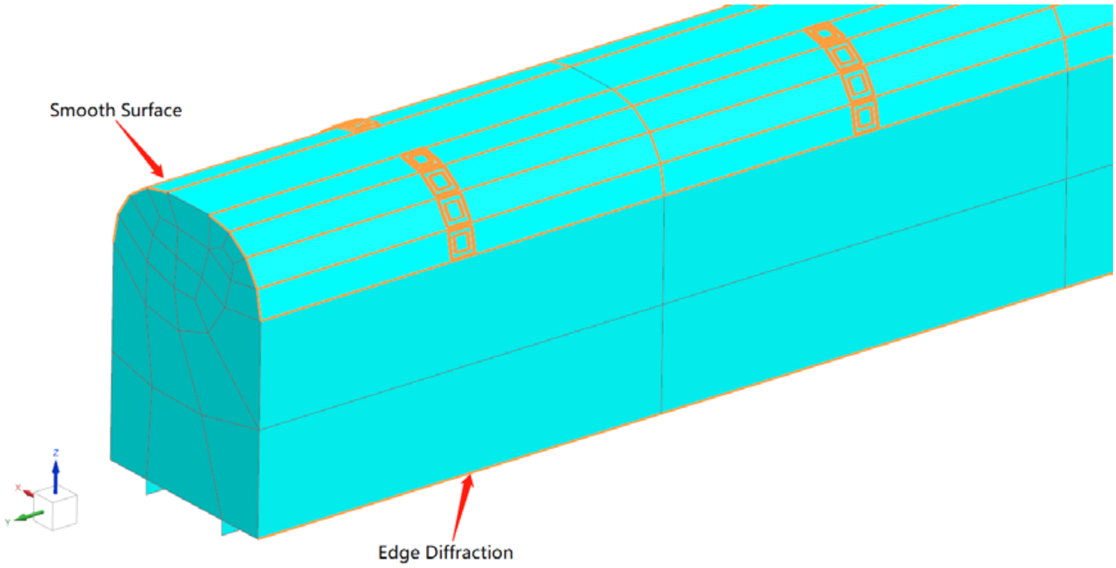

Fig.8 Schematic diagram of train surface and edge setting

When the rays travelling to the opening of the barriers, there will have diffraction phenomenon at the edge of the barrier. Then the acoustics wave will travel forward in the form of creeping waves along the surface of the barriers. And these also have surface reflection at the curved surfaces of the barriers. Then we through define edge diffraction, surface diffraction and smooth surface reflection to capture at the rays travelling along the surface of the barrier.
Simcenter 3D also can simulate the transmission loss of the barrier, through defining panel absorption on the vertical part of the barrier to simulate absorption and shield noise affection.

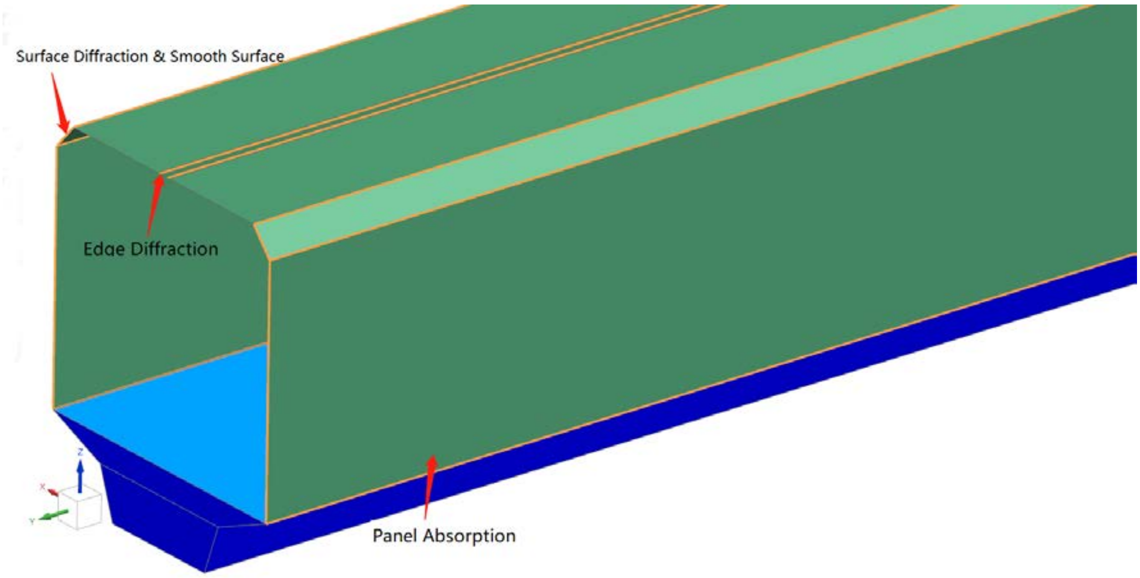

Fig.9 Schematic diagram of sound barrier surface and edge setting

3 Simulation results and analysis

The predicted results of SPL at 1m of building surface for three types of totally enclosed sound barrier openings are shown in figure 10 to 12.

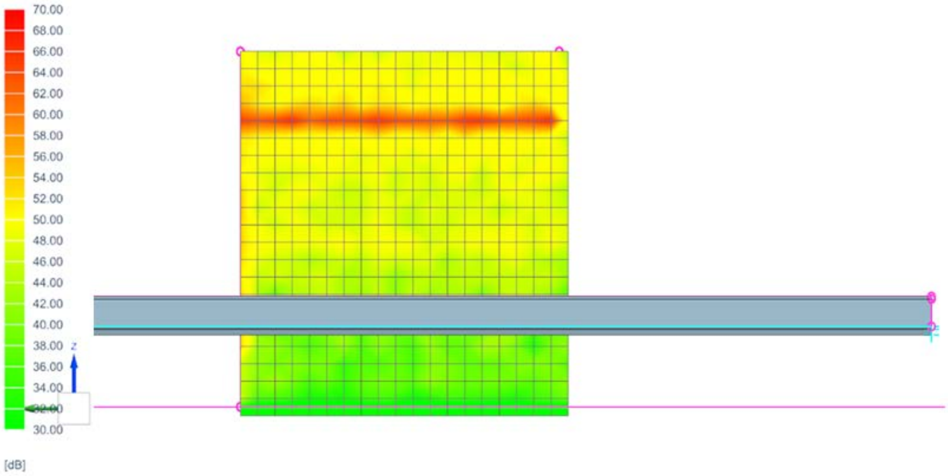

Fig.10 Distribution of total SPL in case I

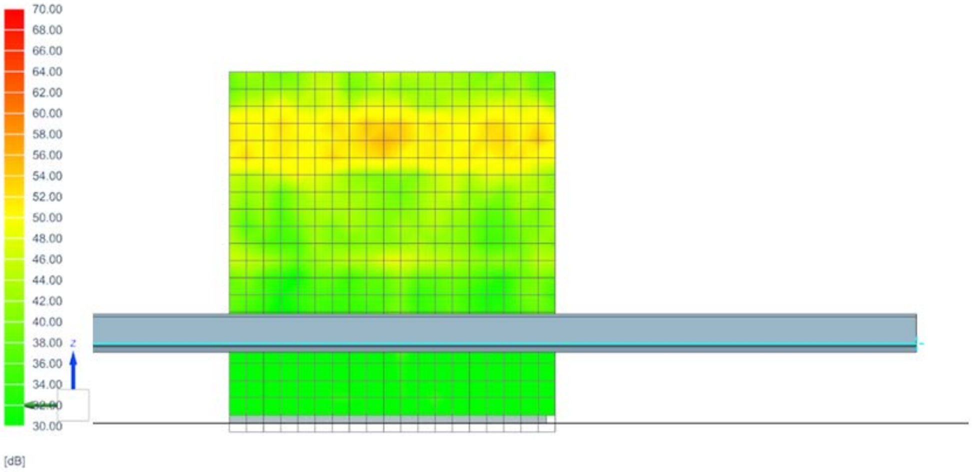

Fig.11 Distribution of total SPL in case II

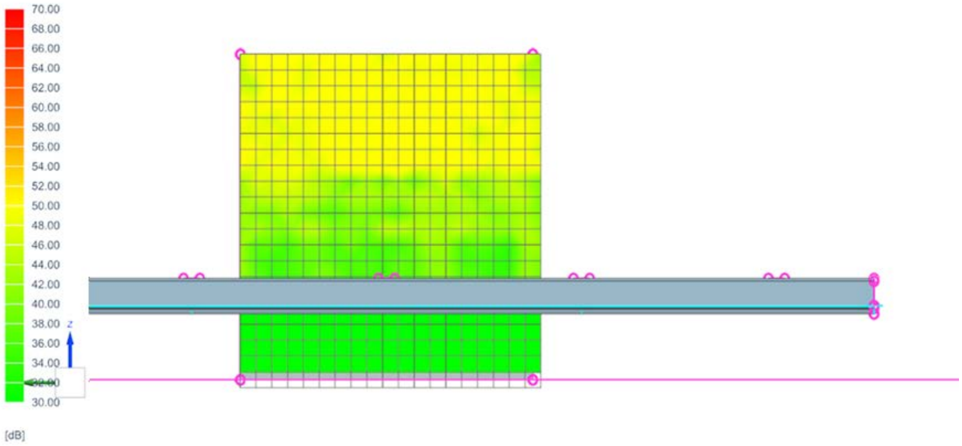

Fig.12 Distribution of total SPL in case III

From the above prediction results, it can be seen that in case I, the SPL of the high-rise building about 80m above the ground increases significantly, and the SPL of the higher or lower position decreases significantly.

The high SPL area is more concentrated, and the SPL intensity along the track direction is consistent. The maximum SPL is about 65.0 dBA, the SPL decreases gradually in the area below 80m, but the attenuation is not obvious. In case 2, the SPL of the high-rise building about 70 ~ 90m above the ground increases obviously, and the SPL of the higher or lower position decreases obviously. The high SPL area is wider, and the SPL of the opening position is higher along the track direction, and the rest decreases slightly. The maximum SPL is about 58.0 dBA; The SPL is decreased from 70m to 0m, especially in the open area. In case 3, the SPL of the building above 65m from the ground is slightly higher than that of the area below, but there is no obvious high noise area, and the position facing the opening is slightly higher than that of other areas. The maximum SPL is about 54.0 dBA. The SPL is attenuated below 60m, and it is in the low SPL area along the track direction.
In view of the three working conditions, the frequency is also analyzed. The prediction results of 63Hz, 200Hz, 1000Hz, 2500Hz and 5000Hz under three working conditions are extracted respectively from figures 13 to 15. It can be found that under the three conditions, the contribution of 63Hz is the highest, and the noise contribution decreases with the increase of frequency. It is special at 2500Hz, and the SPL is higher than that in the adjacent frequency band.

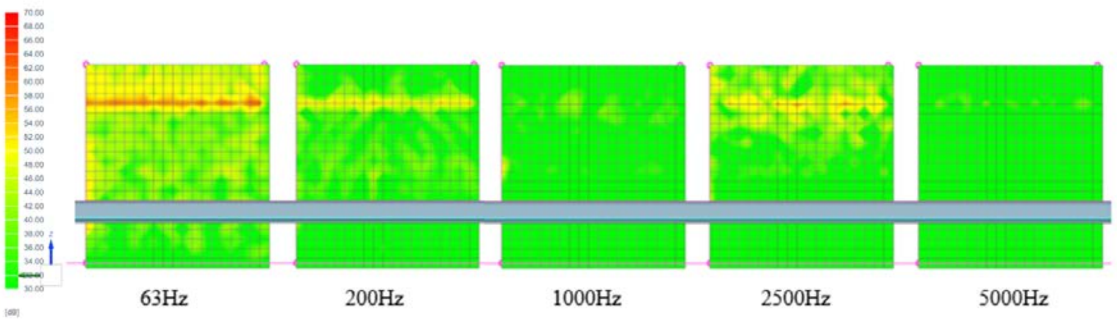

Fig.13 Multiple frequency prediction results of condition I

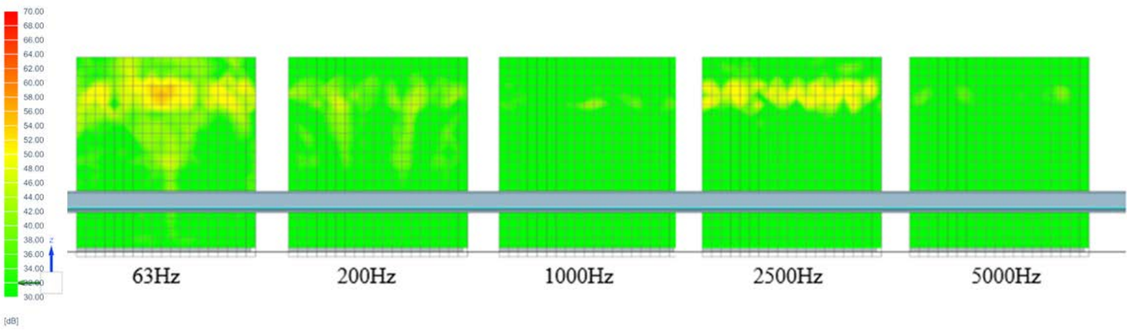

Fig.14 Multiple frequency prediction results of case II

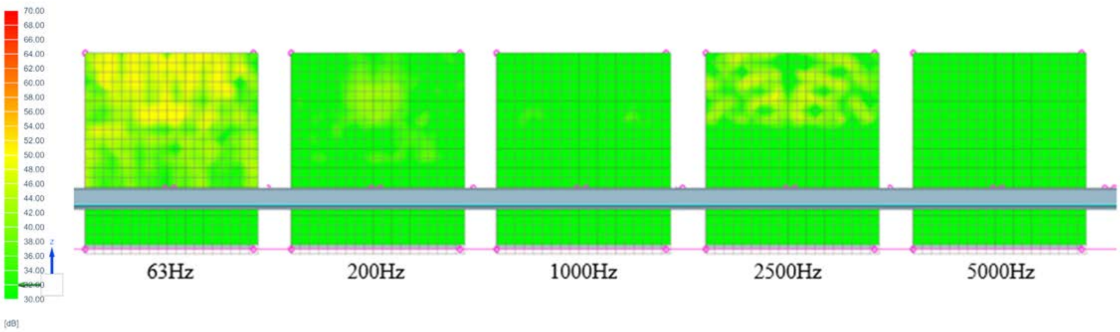

Fig.15 Multiple frequency prediction results of case III

4 Conclusions

In this paper, Simcenter 3D Ray Acoustics is used to analyze the noise impact on the surrounding high-rise buildings when the fully enclosed noise barrier of urban rail transit viaduct adopts different types of openings, such as normal openings, periodic openings of different sizes, etc., under the condition of a certain opening area. Through the analysis of the total SPL, 1/3 octave band SPL and the distribution on the building surface, the following conclusions are obtained.

- The opening type has obvious influence on the prediction results. The larger the opening along the line, the greater the SPL. The larger the size perpendicular to the line direction, the greater the impact on buildings.
- The influence of low frequency is the biggest, and it decreases gradually with the increase of frequency. Some of the frequencies were abnormal, whether the abnormal frequency is fixed needs further study.
- Using 3D simulation method, the optimal design of fully enclosed sound barrier can be better realized.

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