Comparative Analysis of Dynamic Responses of Different Types of High-Speed Railway Noise Barriers under the Influence of Fluctuating Wind Pressure

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Abstract: The fluctuating wind pressure generated when a high-speed train passes through the noise barrier will cause deformation and damage to the noise barrier, affecting the safety of train operation and causing serious economic losses. In this paper, a research method for the dynamic response of noise barriers is proposed, and a comparative study of vertical noise barriers and semi-enclosed noise barriers is carried out. The study shows that when trains pass through the noise barrier, the fluctuating wind pressure on the surface of the two different types of noise barriers both exhibit the characteristics of head and tail waves; the time course curve of fluctuating wind pressure has the same change rule, the wind pressure reaches the maximum value at the bottom measuring point, the maximum value of fluctuating wind positive pressure and negative pressure of the semi-closed noise barrier is larger than that of the vertical noise barrier. In terms of natural frequency, the natural frequency range of the vertical noise barrier is 16~85 Hz, and the natural frequency range of the semi-closed noise barrier is 3~13 Hz. The natural frequency of the semi-closed noise barrier partially coincides with the main frequency of fluctuating wind pressure, which may lead to resonance damage. When the train speed is raised from 200 km/h to 350 km/h, the maximum equivalent force of the semi-enclosed noise barrier reaches 17.21 Mpa, which is much larger than the maximum equivalent force of the vertical noise barrier. At the same time, the displacement of the two noise barriers increases with the height of the noise barrier, and the maximum displacement of the semi-closed noise barrier unit board reaches 3.63 mm, which is much larger than that of the vertical noise barrier unit board.

Keywords: high-speed railway; vertical noise barrier; semi-closed noise barrier; fluctuating wind pressure; natural frequency; equivalent stress

1. Introduction

High-speed railway has many advantages such as safety, comfort and reliability, and is one of the most convenient transportation modes. However, with the rapid development of high-speed railways, the noise generated by trains will continue to increase as the speed of the trains increases, which has a serious impact on the environment along the railway lines. Setting noise barriers along high-speed railway lines is one of the effective means to control train noise, and noise barriers have also been widely used in practical projects [1–4]. At present, traditional vertical noise barriers are mainly used in many regions, and have a high cost performance [5,6]. However, in many areas with stricter noise reduction requirements, semi-closed noise barriers usually provide better noise reduction [7]. Therefore, it is important to use different types of noise barriers together in the future.

At present, the research on noise barriers in related fields has made certain progress. In the field of acoustics, many researchers have verified the sound insulation effect of different structural types of noise barriers, and the overall research is relatively mature [8–11]. In
wind pressure and other related aspects, Walid Khier studied the flow field around high-speed trains under wind pressure and showed that noise barriers can effectively reduce the effects of wind pressure [12]. Long Liping analyzed the fluctuating wind pressure generated by a train passing through the noise barrier through CFX software, and the calculation results showed the feasibility of numerical simulation [13]. Xiong Xiaohui and Piao Ailing et al. studied the fluctuating wind pressure generated when a train passes through the noise barrier at high speed, and obtained the variation law characteristics of the fluctuating wind pressure [14–16]. Yang Mengqi studied the combined effect of fluctuating wind pressure and natural wind load on the noise barrier, and obtained the dynamic response of the folding-arm noise barrier [17]. He Xuhui studied the wind pressure generated by a train passing through the fully enclosed noise barrier by means of numerical simulation, which provided a reference for practical engineering applications [18]. Zhao Yungang analyzed the porosity of the deloading noise barrier and studied the energy saving effect of the noise barrier [19]. Han Xu conducted a wind tunnel test on the fully enclosed noise barrier, and obtained the aerodynamic characteristics of the fully enclosed noise barrier under the action of a cross wind [20]. Zhang Tian studied the wind barrier on a high-speed railway bridge, applied wind pressure on the wind barrier, and obtained the fatigue life of the wind barrier structure [21]. Yasushi Takei conducted measurement experiments, analyzed the wind pressure generated by high-speed trains passing through the station, and established relevant calculation equations to prevent the structure of the station from being affected [22]. Luigi Carassale studied the structure around the track and obtained the dynamic response of the structure around the track when the train passed [23].

The negative effect of fluctuating wind on the rail infrastructure and vehicle is always a technical challenge in the railway community [24,25]. Relevant studies have shown that high-speed trains will disturb the surrounding air during the running process, and the fluctuating wind pressure generated will have an impact on the surrounding noise barriers, resulting in structural deformation and vibration damage of the noise barriers. Under the impact of long-term fluctuating wind pressure, it may also cause fatigue failure of the noise barrier. The German railway noise barrier was damaged by the impact of the fluctuating wind pressure of the train, which eventually caused huge economic losses [26].

In past studies, the main analysis was of the noise reduction performance of the noise barrier. There were very few studies on fluctuating wind pressure, and the noise barrier structure used was also very simple; most were vertical noise barriers. On the other hand, there was very little simulation analysis on the structural dynamic performance of noise barriers under the action of high-speed train fluctuating wind pressure; the use conditions of the noise barrier were not analyzed from the perspective of the structural dynamic response, and the research was not comprehensive. In this paper, the research carried out simulation analysis on vertical noise barriers and semi-enclosed noise barriers, respectively, and through the comparison between the two types of noise barriers, the effect of train fluctuating wind pressure on different types of noise barriers was investigated, and some suggestions were made on the use conditions of the two types of noise barriers.

In this study, the fluid analysis part was based on CFD models and calculated by SIMPLE algorithm, and the fluctuating wind pressure on the vertical noise barrier and semi-enclosed noise barrier was numerically simulated by fluent module. At the same time, finite element models of different types of noise barriers were established, and their natural frequencies were calculated. Finally, the fluctuating wind pressure data results were loaded into the transient dynamics module, and the structural dynamics calculation and analysis of different types of noise barriers under the action of fluctuating wind pressure were carried out. This research was carried out by the technical route shown in Figure 1.
where $\rho$ is the fluid density, $t$ is the time, $x; y; z$ is the three directions of the space coordinate system, $u; v; w$ is the velocity component. The conservation of momentum is presented in Equations (2)–(4) below.

$$\frac{\partial (\rho u)}{\partial t} + \text{div}(\rho uv) + \text{div}(\mu u \text{grad} u) - \rho c_p \frac{\partial T}{\partial z} + S_u = 0$$

$$\frac{\partial (\rho v)}{\partial t} + \text{div}(\rho vv) + \text{div}(\mu v \text{grad} v) - \rho c_p \frac{\partial T}{\partial y} + S_v = 0$$

$$\frac{\partial (\rho w)}{\partial t} + \text{div}(\rho vw) + \text{div}(\mu w \text{grad} w) - \rho c_p \frac{\partial T}{\partial x} + S_w = 0$$

where $\mu$ is the viscosity coefficient, $v$ is velocity vector, $S_u; S_v; S_w$ is the generalized source item. The conservation of energy is presented in Equation (5) below.

$$\frac{\partial (\rho T)}{\partial t} + \text{div}(\rho v T) = \text{div} \left( \frac{k}{c_p} \text{grad} T \right) + \frac{S_T}{c_p}$$
where $T$ is the temperature of flow field, $c_p$ is the specific heat capacity, $k$ is the thermal conductivity, $S_T$ is the viscous dissipation item.

To ensure the closure of the whole equation, in addition to the above equation, an additional equation of state is needed, presented in Equation (6) below.

$$\rho = f(\rho, T)$$  \hspace{1cm} (6)

2.2. Solid Control Principle

The conservation equation of solids is mainly based on Newton’s second law, presented in Equation (7) below.

$$\rho_s \ddot{\mathbf{d}_s} = \nabla \sigma_s + f_s$$  \hspace{1cm} (7)

where $\rho_s$ is the solid density, $\ddot{\mathbf{d}_s}$ is the solid acceleration vector, $\sigma_s$ is the Cauchy stress tensor, $f_s$ is the volume force vector.

In the calculation process, at the position of the interface between the fluid and the solid, it is necessary to ensure the equality and conservation of variables such as the stress, displacement, and temperature between the solid and the fluid.

3. Computational Model and Data Validation

3.1. Simulation Calculation Model

This calculation used the CRH380A train. In view of the complexity of the actual train model, which would increase the calculation difficulty and time, the model was simplified to a certain extent, ignoring the irregular protruding structures such as pantographs, train doors, and bogies, and the whole train was smoothed. At the same time, some space was left at the bottom of the train to ensure that the calculation was closer to the actual situation. On the other hand, in order to ensure the calculation efficiency, the calculation in this paper ignored the middle part of the carriage, and the total length of the train model was 78 m. The simplified train model is shown in Figure 2.

![Figure 2. High-speed train model.](image)

In the fluid calculation part, the detailed structure of the noise barrier did not affect the law of the fluctuating wind pressure generated by the high-speed train, so the components such as columns, unit boards, and beams were ignored, and the surface of the noise barrier was smoothed. This calculation only considered noise barriers on the side close to the train;
the thickness of the vertical noise barrier and the semi-closed noise barrier were both set to 0.14 m and the length to 300 m, and a section was set at the middle of both types of noise barrier. The vertical noise barrier selected six measurement points at different heights along the inner surface of the noise barrier at equal distances, and recorded them as Z1~Z6 in order; the semi-enclosed noise barrier also selected six measurement points at different heights along the inner surface of the noise barrier at equal distances, and recorded them as B1~B6 in order, and the heights of Z1 and B1 were the same, which was convenient for subsequent calculation and analysis. The arrangement of noise barrier measurement points is shown in Figure 3.

![Noise barrier arrangement and measurement points](image)

**Figure 3.** Noise barrier arrangement and measurement points. (a) Vertical noise barrier arrangement and measurement points. (b) Semi-enclosed noise barrier arrangement and measurement points.

This paper adapted the sliding mesh method to simulate the relative motion between high-speed trains and noise barriers. At the same time, the entire computational domain was divided into static zone and slip zone, and the size of the computational domain was set reasonably while ensuring computational efficiency and accuracy. The size of the static area was set to 140 m × 140 m × 320 m, and the size of the slip area was set to 4.5 m × 4.5 m × 560 m. In the computational domain, the front and rear surfaces in the travel direction were set as pressure outlets, and the contact surfaces in the slip region and stationary region were set as interface intersections. The train speeds considered in the calculation were 200 km/h, 250 km/h, 300 km/h and 350 km/h; all the above four speed conditions were less than Mach 0.3, so the flow of air in the flow field during the calculation was considered as three-dimensional incompressible and solved based on pressure.

Mesh delineation is one of the most important steps in the process of numerical simulation, and its quality and quantity control will directly affect the results of the numerical simulation. The model was meshed by the mesh module in ANSYS, and a more adaptable unstructured mesh was used in the process of meshing. At the same time, in order to improve the mesh accuracy, mesh refinement was performed on the two parts of the car body and the noise barrier, the mesh size of car body and noise barrier were set to 0.1 m and 0.2 m respectively, and the mesh between the car body and the noise barrier and the external flow field was smoothly transitioned according to a certain ratio. Ultimately,
it ensured that the overall number of meshes was kept within a reasonable range. The computational domain model and mesh division results are shown in Figure 4.

Figure 4. Computational domain model and mesh division results. (a) The computational domain model. (b) Mesh division results and dimensions.

In the structural dynamics calculation section, the finite element models of the ten-span single-sided vertical noise barrier and the ten-span single-sided semi-enclosed noise barrier were established [27]; the length of each unit board of both noise barriers was 2 m, and the transverse width of the top transverse unit board of the semi-enclosed noise barrier was 1.2 m, and the model mainly consisted of H-shaped steel columns, aluminum alloy unit boards, and rubber damping strips and other structures. In the dynamics calculation, the bolts between the steel column and the bottom concrete foundation were ignored, and the bottom end of the noise barrier steel column was set as a fixed full restraint in order to suppress the degrees of freedom. The finite element model of the noise barrier is shown in Figure 5.

Figure 5. Finite element model of noise barrier. (a) Finite element model of vertical noise barrier. (b) Finite element model of semi-enclosed noise barrier.
3.2. Simulation Results and Actual Measurement Results

The German Railway has conducted field tests on the fluctuating wind pressure generated by trains passing through noise barriers, and has given the corresponding calculation formula [28,29]. Therefore, the actual measured data of German railways are compared with this simulated data. The vehicle speed used in both the German railway test and this simulation was 330 km/h; on the other hand, the measured and simulated noise barrier structure type was a vertical noise barrier, and the height was 4 m, the distance from the center of the track to the noise barrier was 3.8 m, and the location of the measurement points were all located at the bottom unit board position, so as to verify the feasibility of this simulation method. Figure 6 shows the results of the measured fluctuating wind pressure and the simulated fluctuating wind pressure. In the head wave position, the measured value is basically consistent with the simulated value. In the middle part, the simulated value does not fluctuate slightly, because during the simulation, the structures such as pantograph and bogie were omitted, and the simulated train was smoothed, which weakened the fluctuation of the middle part. There is a certain difference between the two datums in the tail wave position, mainly due to the different models used in the measurement and simulation, while the measurement is a multi-group train, and the model length used in this simulation is shorter in order to ensure calculation efficiency, which leads to a larger air disturbance caused by the tail of the train. In summary, the method used in this paper can effectively calculate the fluctuating wind pressure.

![Figure 6. Comparison of measured and simulated results. (a) Measured results. (b) Simulated results.](image)

4. Results and Analysis

4.1. Fluctuating Wind Pressure Simulation Results

Based on the model established in the previous paper, the fluctuating wind pressure generated by high-speed trains passing through the noise barrier at different speeds was simulated and analyzed. Because the fluctuating wind pressure cloud chart is basically the same for each velocity phase, only a single velocity case is shown. Figure 7 shows the fluctuating wind pressure clouds for 350 km/h vehicle speed passing through two types of noise barriers. When the train passes through the noise barrier, the fluctuating wind pressure on the inner surface of both the vertical noise barrier and the semi-enclosed noise barrier shows the characteristics of head and tail waves, and a pair of negative area and positive pressure area will be constituted in the head and tail positions, the wind pressure area shows the rule of diffusion from the center of pressure to the outside, where the negative pressure area is larger than the positive pressure area, and the wind pressure in the middle of the train does not change significantly.
area shows the rule of diffusion from the center of pressure to the outside, where the negative pressure area is larger than the positive pressure area, and the negative pressure area shows the rule of diffusion from the center of pressure to the outside, where the negative pressure area is larger than the positive pressure area, and the negative pressure area is larger than the positive pressure area.

Figure 7 shows the fluctuating wind pressure cloud chart. (a) Fluctuating wind pressure cloud chart of a vertical noise barrier. (b) Fluctuating wind pressure cloud chart of a semi-enclosed noise barrier.

Figure 8 shows the time course curves of fluctuating wind pressure for a vertical noise barrier and semi-enclosed noise barrier at the speed of 350 km/h, with the measurement points at the same height position at the bottom. In the whole process of fluctuating wind pressure change, when the head of the train gradually approaches the measurement point, the wind pressure on the surface of the noise barrier gradually increases to the peak of the head wave of positive pressure, then the wind pressure plummets to the peak of the first wave of negative pressure, after which it experiences a relatively stable negative pressure phase. As the rear of the train approaches and passes, the wind pressure drops and rises again, finally, the wind pressure returns to its original state after the train leaves. In general, the time course curve pattern of fluctuating wind pressure for the vertical noise barrier and semi-enclosed noise barrier is basically the same, showing obvious peaks and valleys, where the head wave positive pressure peak and negative pressure peak of both barriers are larger than the tail wave, and the time course curve of semi-enclosed noise barriers is larger than that of the vertical noise barriers in the whole process.

Figure 8. Time course curve of fluctuating wind pressure of noise barrier.
The peak positive and negative pressures at each measurement point when passing the noise barrier at different speeds are shown in Figure 9. Under the four train speed conditions, the peak wind pressure of both the vertical noise barrier and the semi-enclosed noise barrier decreases with the increase of the height of the noise barrier measurement point, and the wind pressure amplitude variation of semi-enclosed noise barriers is more obvious than that of the vertical noise barrier, which is influenced by the different distance between the adjacent measurement points of the two types of noise barriers; the positive and negative pressures of both types of noise barriers reach a maximum value at the bottom point and a minimum value at the top point. Meanwhile, for the same type of noise barrier at the same speed, the rate of decline of the positive pressure with the rise of height is greater than the rate of decline of the negative pressure, which is due to the negative pressure area formed by fluctuating wind pressure being larger than that of the positive pressure area, resulting in the positive pressure fallback amplitude being larger than that of negative pressure when the height of the noise barrier measurement point increases. On the other hand, in the process of rising with the height of the measurement point, the decreasing rate of both positive and negative pressure of the vertical noise barrier is accelerating, and the positive pressure at the top position of the vertical noise barrier has a rapid fall-back due to the size of the positive pressure area. For the semi-enclosed noise barrier, the decreasing rate of positive and negative pressure is accelerated and then slowed down in the process of increasing the height of the measurement point, because the transverse unit board on the top of the semi-enclosed noise barrier plays a certain buffer role in the dissipation of wind pressure.

Figure 9. Peak fluctuating wind pressure of noise barrier under different measurement points. (a) Peak positive pressure of vertical noise barrier. (b) Peak negative pressure of vertical noise barrier. (c) Peak positive pressure of semi-enclosed noise barrier. (d) Peak negative pressure of semi-enclosed noise barrier.
According to the results of the above analysis, the fluctuating wind pressure impact on both vertical noise barriers and semi-enclosed noise barriers reaches the maximum at the bottom position. Therefore, the analysis is carried out for the maximum value of the fluctuating wind pressure on the noise barrier. Figure 10 shows the maximum value of positive and negative pressure on the noise barrier when driving through at different speeds. In the process of speeding up from 200 km/h to 350 km/h, the positive pressure maximum and negative pressure maximum of the semi-enclosed noise barrier are larger than that of the vertical noise barrier; with the increasing of vehicle velocity, the growth rate of wind pressure maximum of semi-enclosed noise barrier is also faster than that of vertical noise barrier.

![Fluctuating Wind Pressure](image)

**Figure 10.** Maximum fluctuating wind pressure of noise barrier at different speeds.

### 4.2. Noise Barrier Modal Analysis

The finite element model of the noise barrier has been completed in the previous section. This section includes a modal analysis of the noise barriers, at the same time considering the accuracy and efficiency of the calculation; the mesh was reasonably divided, and the top ten natural frequencies of the two types of noise barriers were finally calculated [30,31]. Figure 11 shows the first order and second order mode of the vertical noise barriers and semi-enclosed noise barriers, where the first order mode is the lateral deformation of the noise barrier, and the second order mode is the torsional deformation of the noise barrier. Table 1 shows the top ten natural frequencies of the two types of noise barriers, the natural frequency range of the vertical noise barrier is mainly concentrated between 16–85 Hz, and the natural frequency range of the semi-enclosed noise barrier is mainly concentrated between 3–13 Hz. Relevant information shows that the dominant frequency range of train fluctuating wind pressure is 2–4 Hz [32]; the natural frequency of the vertical noise barrier is much higher than the dominant frequency of the fluctuating wind, so the noise barrier will not be damaged by resonance. However, the natural frequency of the semi-enclosed noise barrier overlaps with the dominant frequency of the fluctuating wind, and there is a possibility of resonance damage. Therefore, during the initial design of semi-enclosed noise barriers, it is necessary to control the range of natural frequencies to avoid overlapping with the dominant frequencies of fluctuating winds, and to prevent resonance damage to the noise barriers.

| Natural Frequency Range (Hz) | Vertical Noise Barrier | Semi-Enclosed Noise Barrier |
|------------------------------|-----------------------|-----------------------------|
| 16–85                        | 16–85                 | 3–13                        |
| 2–4                          | 2–4                   | 2–4                         |

Table 1: Natural Frequency Range of Noise Barriers
Figure 11. Modal analysis of noise barrier. (a) The first order mode of vertical noise barrier. (b) The second order mode of vertical noise barrier. (c) The first order mode of semi-enclosed noise barrier. (d) The second order mode of semi-enclosed noise barrier.

Table 1. The top ten natural frequencies of the noise barriers (Hz).

| Modal Order | Vertical Noise Barrier | Semi-Enclosed Noise Barrier |
|-------------|------------------------|-----------------------------|
| 1           | 16.96                  | 3.15                        |
| 2           | 18.70                  | 3.30                        |
| 3           | 23.13                  | 4.87                        |
| 4           | 29.31                  | 8.94                        |
| 5           | 36.68                  | 9.16                        |
| 6           | 44.96                  | 9.64                        |
| 7           | 54.04                  | 10.42                       |
| 8           | 63.84                  | 11.41                       |
| 9           | 74.10                  | 11.73                       |
| 10          | 84.03                  | 12.54                       |

4.3. Structural Dynamics Analysis of Noise Barriers

Based on the previous calculation results, the fluctuating wind pressure data are imported into the transient dynamics module and loaded into the finite element model of the noise barrier, and the structural dynamics analysis is carried out for the vertical noise barrier and semi-enclosed noise barrier under different working conditions. Taking the
noise barrier as a whole as the object of study, Figure 12 shows the maximum value of the equivalent stress when a high-speed train passes through the noise barrier at different speeds. The equivalent stress of the semi-enclosed noise barrier at each speed stage in the figure is higher than that of the vertical noise barrier. Although the equivalent stress of the two types of noise barriers is increasing with the acceleration of the vehicle speed, the growth rate of the equivalent stress of the semi-enclosed noise barrier is faster. During the acceleration of the train’s speed from 200 km/h to 350 km/h, the equivalent stress of the vertical noise barrier increases from 1.69 Mpa to 5.37 Mpa, while the equivalent stress of the semi-enclosed noise barrier increases from 3.58 Mpa to 17.21 Mpa. The main reason for these results is that the height and structural form of the two types of barriers are different, and the semi-enclosed noise barrier will provide a more closed flow environment, resulting in a greater impact of fluctuating wind pressure on the semi-enclosed noise barrier. Therefore, the process of semi-enclosed noise barrier construction should pay more attention to the solidity of the overall steel frame and the rationality of the structural design, and ensure the structural safety of the noise barrier.

Since the stiffness of the noise barrier unit board is small compared with that of the steel column, the displacement analysis is mainly for the noise barrier unit board. In the vertical noise barrier, six heights of 0.5 m, 1 m, 1.5 m, 2 m, 2.5 m and 3 m are selected, respectively, which are recorded as N1~N6 in turn, and the displacement peak value of the unit board at each height is selected; the semi-enclosed noise barrier selects six heights of 0.9 m, 2.25 m, 3.95 m, 5.35 m, 7.35 m, and 8.15 m, respectively, which are recorded as M1~M6 in turn, and the displacement peak value of the unit board at each height is also selected for the convenience of subsequent research. Figure 13 shows the displacement peaks at different heights of the two types of noise barriers under the influence of four train speeds, the displacement of the unit board at the bottom position of both the vertical noise barrier and semi-enclosed noise barrier is very slight, mainly due to the fact that the bottom of the noise barrier steel column is set to a fixed full restraint. When trains pass at different speeds, the displacements of both types of noise barrier unit panels show a growing pattern with the increase of height. In summary, the maximum displacement of the unit boards for both types of noise barriers occurs at the top height position.

![Figure 12. Maximum equivalent stress of noise barrier.](image-url)
According to the content of the previous research, the height position of the maximum displacement of the top of the noise barrier unit board is analyzed. Figure 14 shows the maximum displacement produced by the two types of noise barriers when the train passes by at different speeds. With the increasing speed of the train, the maximum displacement of the unit boards of both the vertical noise barrier and the semi-enclosed noise barrier show an approximately linear growth pattern. In each speed stage, the maximum displacement of the semi-enclosed noise barrier unit board is significantly larger than that of the vertical noise barrier. In the process of increasing the train speed from 200 km/h to 350 km/h, for the vertical noise barrier, the maximum displacement has a larger increase of 0.29 mm, and the maximum displacement reaches 0.42 mm at the speed of 350 km/h. For the semi-closed noise barrier, the maximum displacement has a larger increase of 2.56 mm, and the maximum displacement reaches 3.63 mm at the speed of 350 km/h. At the same time, as the train speed increases, the maximum displacement difference between the two types of noise barriers gradually increases, and the gap increases from the initial 0.94 mm to the final 3.21 mm.
To sum up, the unit board of the semi-enclosed noise barrier is much more affected by the fluctuating wind pressure of the train than the vertical noise barrier, and the larger displacement of the unit board of the semi-enclosed noise barrier is a hidden safety problem that cannot be ignored. In the design process of the noise barrier, more attention should be paid to the safety and reliability of the semi-enclosed noise barrier unit board, and the displacement of the unit board can be restrained by improving the steel column, so as to prevent the unit board from being displaced too much and thus causing the overall failure of the noise barrier.

5. Discussion

As an effective noise control method, the noise barrier is widely used in life, and semi-enclosed noise barriers with better noise reduction effect are also used in many areas. However, while the noise barrier provides good noise reduction effect, the structural safety of the noise barrier is also an important issue that cannot be ignored, which seriously endangers the stability of trains and the safety of surrounding areas. In the past studies, many studies were limited to noise reduction analysis of noise barriers, and the structural performance tests of noise barriers relied mainly on actual field measurements, without considering the dynamic response of semi-enclosed noise barriers, and the scope of the studies were not comprehensive.

In this paper, a research method of the structural dynamics of noise barriers was proposed. Firstly, the study effectively calculated the fluctuating wind pressure on the surface of vertical noise barriers and semi-enclosed noise barriers, and obtained the natural frequency of the noise barrier by modal analysis. Then, in the transient dynamics module, the fluctuating wind pressure was applied to the noise barrier, and the structural dynamic response characteristics of the two types of noise barrier were obtained. This method largely improves the calculation efficiency, while the research results have great significance for the sustainable development of noise barriers in the future. Based on the above research, some suggestions on the safe use of vertical noise barriers and semi-enclosed noise barriers are proposed:

1. When trains pass through the area where noise barriers are installed, regardless of whether the noise barrier is a vertical noise barrier or semi-enclosed noise barrier, the driving speed of trains should be reduced to reduce the impact effect of fluctuating wind pressure on the noise barrier, and prevent the noise barrier from damage and fatigue failure under the influence of long-term fluctuating wind pressure.

2. During the noise barrier design and construction, there should be a focus on the natural frequency of the semi-enclosed noise barrier to prevent overlap with the fluctuating wind dominant frequency, which could lead to resonance damage.

3. When the surrounding environment does not have high noise requirements, it is recommended to use vertical noise barriers. Since vertical noise barriers are less affected by fluctuating wind pressure of trains, they can effectively ensure traffic safety and save construction costs.

4. In the future, with the continuous speed increase of high-speed trains, the requirements for noise barriers will also continue to improve, so it is necessary to regularly maintain and repair the noise barriers, especially with regard to the safety of semi-enclosed noise barrier structures, and to strengthen and improve important structures, so that the noise barrier is always in normal working condition, which will help the sustainable development of the noise barrier.

6. Conclusions

This paper established a high-speed train model, simulated the fluctuating wind pressure generated on the surface of the vertical noise barrier and semi-enclosed noise barrier when the train passed through with different speeds, analyzed the fluctuating wind pressure distribution law and the peak value, established finite element models of the two types of noise barriers, and simulated the natural frequencies of the vertical
noise barrier and semi-enclosed noise barrier. At the same time, the fluctuating wind pressure was loaded into the finite element model of noise barrier, and the variation law of equivalent stress and unit board displacement of the noise barrier was obtained. The following conclusions can be made:

1. When high-speed trains pass through the vertical noise barrier and semi-enclosed noise barrier, the fluctuating wind pressure cloud chart on the inner surface of the two types of noise barriers show the characteristics of head and tail waves, and form a pair of positive and negative pressure areas, and the wind pressure time course curves of the two types of noise barriers change in a similar pattern.

2. The fluctuating wind pressure of the vertical noise barrier and the semi-enclosed noise barrier both reach the minimum value at the top position and the maximum value at the bottom position. In terms of the maximum fluctuating wind pressure, the fluctuating wind pressure of the semi-enclosed noise barrier is greater than that of the vertical noise barrier.

3. The top ten natural frequencies of the vertical noise barrier are 16–85 Hz, which is outside the dominant frequency range of the fluctuating wind, so resonance damage will not occur, while the natural frequency range of the semi-enclosed noise barrier is 3–13 Hz, which partially overlaps with the dominant frequency range of the fluctuating wind, so resonance damage may occur.

4. In terms of equivalent stress, the semi-enclosed noise barrier is larger than the vertical noise barrier in terms of maximum equivalent stress. When the train speed is accelerated to 350 km/h, the equivalent stress of the vertical noise barrier finally reaches 5.37 Mpa, while the equivalent stress of the semi-enclosed noise barrier reaches 17.21 Mpa.

5. The displacement of the unit board of the vertical noise barrier and semi-enclosed noise barrier increases with the increase in height, and both produce the maximum value at the top position. In the process of the train speed increasing from 200 km/h to 350 km/h, the top displacement growth of the vertical noise barrier reaches 0.42 mm, while the top displacement growth of the semi-enclosed noise barrier reaches 3.63 mm, and the semi-enclosed noise barrier unit board is more affected by the fluctuating wind pressure.

This study analyzes the noise barrier from multiple perspectives, which provides help for the design of vertical noise barriers and semi-enclosed noise barriers. In the subsequent work, in order to further promote the sustainable development of noise barriers, the research will take into account the complex wind field environment, targeted at various shapes and types of noise barriers, such as fully enclosed noise barriers, and improve the research on the dynamic performance of noise barriers.

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