Study on Wind Resistance of New Type Rail Transit Concrete Noise Barrier

Shiyong Wang

The First Management Center of Jinan Rail Transit Group Construction Investment Co., Ltd. 250000, China.

1739830747@qq.com

Abstract

Setting up a new type of rail transit concrete noise barrier is a very effective method to solve the noise pollution of urban rail transit. The new type of rail transit concrete noise barrier has good wind resistance and can ensure the normal operation of the noise barrier, which is the key to sound absorption and noise reduction. Referring to the latest calculation methods at home and abroad, the aerodynamic wind pressure fluctuation values of the sound barrier under normal working conditions are determined. The finite element analysis of wind pressure resistance of sound barrier is carried out by means of finite element software ANSYS. The simulation results show that the maximum tensile stress of concrete is 6.225 kPa, the maximum deflection of unit plate is 4.98 mm, and the maximum tensile stress of concrete is 8.387 MPa and the maximum tensile stress of steel bar is 22.789 MPa under 3.5 kPa wind load. The maximum mid-span deflection of the element plate is 6.95mm. The calculated values are less than the standard values, which fully meet the requirements of practical engineering application.

Keywords

Rail transit, Sound barrier, Wind resistance, Finite element analysis.

1. Introduction

High-speed railway brings people a convenient, fast and comfortable way to travel, but at the same time, its noise also brings serious impact on the surrounding environment. When the high-speed train is running at high speed, it causes strong disturbance to the surrounding air. The disturbance becomes more serious when the train carriage passes through the sound barrier. At the same time, the sudden air pressure acts on the surface of the sound barrier, causing instantaneous pressure impact, and the maximum positive and negative pressure occurs successively within tens of milliseconds. This instantaneous pressure impact is generated when the train passes through the sound barrier. Aerodynamic wind pressure pulse power of train [1].

The wind impulse driving force consists of three parts: the head wave of positive pressure before negative pressure, the interval wave produced by the interval between carriages in the middle, and the wake wave of negative pressure before positive pressure. The positive pressure of the head wave is greater than the negative pressure, and the negative pressure of the tail wave is greater than the positive pressure. The distribution of wind impulse power is related to train speed, distance from track center line to noise barrier, headway coefficient and height of noise barrier. The impulse wave generated by the train passing through the noise barrier is composed of different frequencies. Relevant studies at home and abroad show that when the train travels at 350 km/h speed, the energy generated by the train passing through the noise barrier mainly concentrates in the range of 4-6 Hz. Because the starting wind pressure impulse force of train is the dynamic load, when the main energy concentration frequency of the impulse force is the same as the natural frequency of the sound barrier, the resonance will occur and the structure of the sound barrier will be seriously damaged. In the construction of high-speed railway, noise barrier is an effective measure to reduce the noise outside the vehicle.

As an important measure to reduce noise in high-speed railway, noise barrier has higher requirements on its strength and fatigue resistance under the environment of high-speed train running. The vibration response of the noise barrier will cause fatigue of the connecting parts, which will affect the service cycle and even threaten the safety of train operation. Vibration response of fully enclosed sound barrier on Viaduct under dynamic loads of EMUs and freight wheels and rails is studied by numerical analysis, which can provide reference for the design of fully enclosed sound barrier on viaduct.

Because the vertical or semi-enclosed sound barrier is "open", there are still a lot of direct sound, and the phenomenon of diffraction is serious, so the noise reduction effect is limited. A fully enclosed sound barrier can "close" the sound source. Compared with a vertical or semi-enclosed sound barrier, part of the noise is absorbed and reflected in the transmission process, and there is no diffracted sound. On the premise of good sealing performance, only a small amount of sound wave will pass through the fully enclosed sound barrier to reach the sensitive target point. Therefore, the fully enclosed sound barrier can achieve the best noise reduction effect.

In addition, during the service period, the number of trains designed to pass is as high as 200 pairs per day. The aerodynamic wind pressure pulsation of trains may also cause fatigue damage to the noise barrier. Therefore, it is necessary to study the wind resistance of the concrete noise barrier in rail transit.

2. Value of Aerodynamic Wind Pressure Load

Because there are some differences between the above values, the design values of aerodynamic pressure pulsation of trains are determined by comparing the calculated values with the measured values. The installation of noise barrier is generally 3.5-4.2m away from the center line of the near track. The closer the noise barrier is to the track train, the greater the aerodynamic wind pressure pulsation dynamic value. According to the following calculation method, the aerodynamic wind pressure pulsation dynamic value of the train at different locations from the center line of the track is calculated [2]. Aerodynamic force is stipulated in the literature of domestic calculation methods: when a train passes, the aerodynamic pressure and suction generated can be regarded as the moving surface load of 5m long + q and the moving surface load -q of 5m long. Aerodynamic force consists of horizontal aerodynamic force q_h and vertical aerodynamic force q_v. The maximum height of horizontal aerodynamic force q_h acting on the prescribed height is 5 m, which can be obtained from the curve in Fig. 1. The vertical aerodynamic q_v formula is:

$$q_v = 2q_h \frac{7D + 30}{100}$$

In the formula: q_h is horizontal aerodynamic force; D is the distance from the action line to the center of the line.

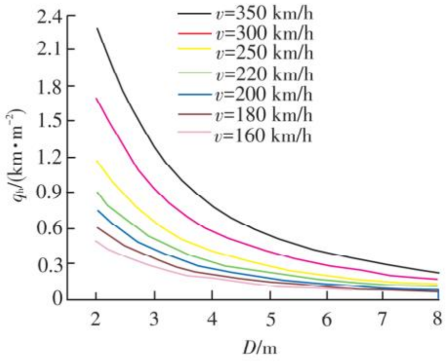

Fig. 1 Aerodynamic forces generated by passing trains on buildings or components

For the components or buildings under the top cover of the sound barrier, the blocking coefficient of q_h and q_v groups should be multiplied by 1.5. Surface loads q_h and q_v need to be superimposed on the wind loads of vehicles. For structural vibration caused by aerodynamic force, the dynamic amplification factor should also be considered, which is determined by research. Fig. 1 shows that when D = 4m and u_v= 350km/h, train horizontal aerodynamic force $q_h \approx 0.78\ km/m^2$ and D = 4m and $u_v = 250\ km/h$, train horizontal aerodynamic force $u_v \approx 0.4 km/m^2$.

3. Finite Element Modeling of Novel Nonmetallic Noise Barrier Element Plate

3.1 Structure of noise barrier unit plate

The sound barrier column foot is bolted to the flange base of the box girder roof. Under the action of wheel-rail dynamic load, the vibration energy acting on the box girder is transmitted to the sound barrier through the column foot. Taking 32 m simply supported box girder of high-speed railway as an example, concrete box is analyzed .The size of the mid-span section of the beam is shown in Figure 2. It is assumed that the sound barrier steel arch is fixed to the flange of the concrete box girder. In order to simplify the calculation model, according to the structural characteristics of the two kinds of noise barriers, the stiffness contribution of the metal element plate and the high toughness concrete cover plate to the steel arch is neglected, and the additional mass is applied to the steel arch [3].

The size of the sound barrier unit board is 3960 mm x 500 mm x 140 mm. In order to ensure the sound absorption effect, the structure design of the sound barrier unit board is a rectangular hollow structure with sound absorption holes on the surface. The porosity of the sound absorption hole is 30%, and the size of the hole is $20mm \times 150mm$. Steel fiber powder concrete is used to make noise barrier. Its compressive strength can reach more than 100 MPa, and its tensile strength can reach more than 9 MPa. The steel bar is made of ordinary steel bar. The simplified model of concrete sound barrier unit plate and finite element is shown in Fig. 2, A and B.

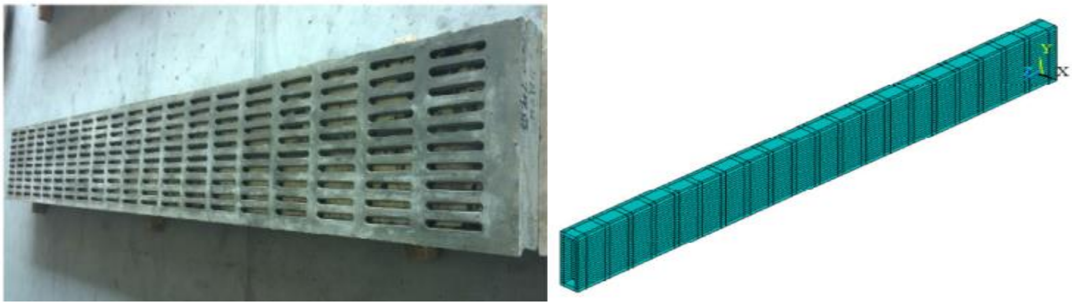

Fig. 2 A Concrete Noise Barrier Unit Plate B Simplified finite element model

According to the above calculation results, the maximum tensile stress of concrete of each section unit slab is less than the set tensile strength of concrete 9KPa when the surface load is 7KPa. The results show that no cracks occur in the above section unit slabs when the surface load is 7KPa, which meets the requirement of bearing bending fracture load.

3.2 Finite element simulation of novel noise barrier element plate

With the help of the finite element analysis program ANSYS, a three-dimensional finite element analysis model is established to simulate the wind resistance of the sound barrier panel. In order to facilitate modeling, reduce calculation and save calculation time, the shape of panel opening and the section of unit plate are simplified, and the section is simplified to rectangle for ANSYS modeling.

Therefore, the difference between the two dynamic analysis models of noise barrier is reflected in the additional mass of steel arch. The finite element model of fully enclosed sound barrier-box girder coupling is shown in the figure. In this model, steel arch and longitudinal connection system adopt two-node space beam element, concrete box girder adopt four-node plate element, steel arch column foot joint and box girder flange joint adopt common joint treatment [4]. The second stage dead load is 165 kN/m, which is evenly applied to the roof of box girder in the form of surface load.

In the most disadvantageous case, the maximum deflection of the unit plate in the mid-span of 7KPa under the surface load is 6.93 mm, which is less than the design limit of $\frac{1}{200} = 19.8mm$ in the standard, and meets the requirements. In the most disadvantageous case, the maximum tensile stress of the reinforcing bar is 22.798 MPa when the unit plate is subjected to 7 KPa of surface load, which is far less than the design value of the reinforcing bar's tensile strength of 270 MPa and meets the requirements.

In this paper, two kinds of fully enclosed sound barriers, metal sound absorber and concrete, are studied. The metal composite sound absorber is 2 m long and 0.45 m wide. The panel is perforated aluminium plate, the back is 1.5 m m thick aluminium alloy plate, and the inside is filled with glass wool felt. The thickness of the high toughness concrete cover is 5 cm, the arc length of the cover is 2.3 m~2.6 m, and the width is 2 m. Vibration response of a fully enclosed sound barrier on an elevated bridge under dynamic loads on the wheels and rails of EMUs is studied by numerical analysis [5]. In addition, based on full-scale model test, the noise reduction characteristics of fully enclosed metal composite sound absorption board and fully enclosed concrete sound barrier for high-speed railway are studied.

4. ANSYS Calculation Result Analysis

The concrete is simulated by Solid65 element and the steel bar is simulated by pipe16 element. In the program ANSYS, the symmetrical model is built, that is, only half of the model is built. Simply supported at both ends, no sound absorption holes on the back plate. The surface load is directly applied on the back, including pressure and suction. The natural wind load and aerodynamic wind pressure are simulated. The program automatically adds self-weight and given material density. In the simulation, the uniform force applied is analyzed as shown in Figure 3. The elastic modulus E of concrete is 5.1×104MPa, Poisson's ratio is 0.25, the shear transfer coefficient of crack opening is 0.45, the shear transfer coefficient of crack closure is 0.9, and the tensile strength is 9.0 MPa. Without considering the compressive failure of concrete, the uniaxial crushing stress of concrete is 0; the elastic modulus E_s of steel bar is $E_s = 2 \times 10^5$MPa, Poisson's ratio is 0.3, and the ultimate tensile strength is 420 MPa. The non-metallic sound barrier unit plate is restrained by H-shaped steel columns on both sides.

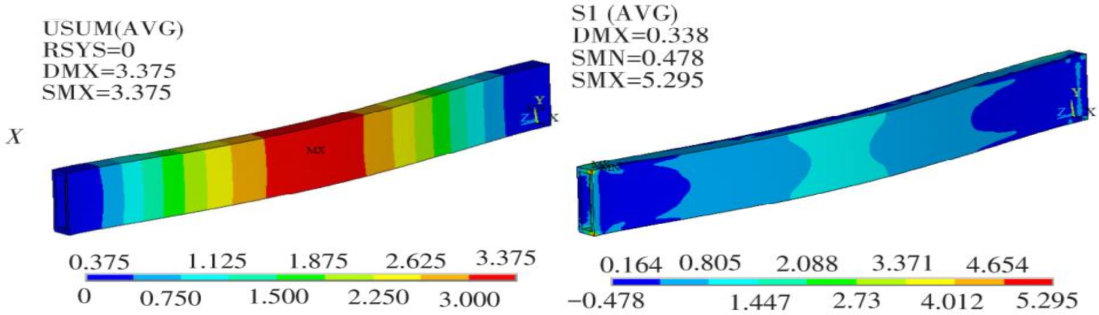

Fig. 3 a Unit Plate Displacement b Principal stress of concrete

Therefore, fixed end constraints are set on one side and simple support constraints are set on the other side. The uniform loads of 3.5 and 7.0 KPa are applied on the panels and backplanes of the sound barrier panel respectively to simulate the fluctuating wind pressure on the sound barrier panel in practical engineering applications. Fig. 3 shows the insertion loss spectrum and total displacement stress diagram at the distance from the line. It can be seen that under the condition of train sound source, the sound barrier of fully enclosed metal sound absorption board and the sound barrier of fully enclosed concrete can be used. That is to say, the displacement effect of the fully enclosed sound screen can reach the standard. The reverberation effect of the sound field inside the concrete sound barrier is more remarkable, which weakens its noise reduction effect to a certain extent.

Considering the combined effects of self-mass, live load, aerodynamic force and wheel-rail force on the vibration of the noise barrier, the maximum average stress of the sound barrier column is 88 MPa, which meets the strength requirements. Through the fatigue test of column foot section, the results show that the stress-thrust relationship of each measuring point has no obvious change during 2 million times of loading, no cracks occur in the place where the structural stress is large, and the bolts of column foot have not loosened. The strength and fatigue properties of the sound barrier column itself and its foot connections meet the requirements. Under the action of EMU, the peak value of dynamic displacement of each inspection point is smaller than that of the truck, while the maximum value of vibration acceleration is larger than that of the truck. Under the two kinds of noise barrier schemes, the dynamic response and spectrum characteristics of each inspection point are consistent under the action of two types of vehicles, but the magnitude is different.

Table 1 Calculations

working condition /Kpa	Maximum deflection /mm	Maximum Tensile Stress of Reinforcement Bar /Mpa	Maximum Tensile Stress of Concrete /Mpa
Panel pressure 3.5	3.38	8.64	5.296
Backplane compression 3.5	4.98	17.036	6.225
Panel pressure 7.0	6.95	17.268	7.489
Backplane compression 7.0	6.78	22.789	8.387

Based on the RANS method, the relative motion between the train and the noise barrier is simulated by using the dynamic laying technique, and the fluctuating wind pressure produced by the train running is calculated. Semi-enclosed noise barrier and high-speed train model, the surface of semi-enclosed noise barrier is smoothed, and only bridge deck and noise barrier plate are established [6]. Simplified marshalling is used for numerical simulation of fluctuating wind loads to save calculation time. In order to ensure that the boundary of the air flow field will not affect the calculation results when the train is running at high speed, the initial position of the train is 50 m away from the measuring section and the speed of the train is 350 km/h. The finite element model of semi-enclosed noise barrier is established by using simulation software to calculate the vibration response under fluctuating wind. The time history of fluctuating wind load is applied to the sound insulation board at the corresponding position through the form of surface pressure.

5. Conclusion

When 3.5KPa load is applied to the slab and the back slab respectively in the general wind speed area, the calculation results show that the maximum tensile stress of the steel bar and the concrete is far less than the design value of the tensile strength of the steel bar and the concrete. In typhoon area, the maximum tensile stress of steel bar and concrete is less than the design value of the tensile strength of steel bar and concrete under the most disadvantageous conditions when 7 KPa loads are applied on the slab and back slab respectively, which meets the requirements. In the most complex case, when the panel is subjected to 7KPa, the maximum mid-span deflection of the unit plate is 3.93mm, which is far less than the design limit of the code and meets the deformation requirements. In summary, the stress and deformation of the new type of sound barrier unit plate under 3.5KPa wind load in general wind speed area and 7KPa wind load in typhoon area are lower than the national standards and industry specifications, which meet the requirements of Engineering practicability. The sound source is "closed" by a fully enclosed sound barrier. Most sound waves are absorbed and reflected by the sound barrier in the process of propagation, and there is no diffracted sound. Therefore, the best noise reduction effect can be achieved by fully enclosed noise barrier.

The vertical and transverse displacements of the two kinds of noise barriers under wheel-rail dynamic loads are very small, both within 2 mm. Under the two kinds of noise barrier schemes, the dynamic response of each observation point is consistent with the spectrum characteristics under the action of the two types of vehicles, but the magnitude is different.

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