Design and optimization of noise barrier based on mechanical analysis of ANSYS

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Abstract. In order to ensure the structural strength of the noise barrier and optimize its design, in this paper, the Finite Element Analysis software ANSYS is used to model the noise barrier, and the mechanical properties are analyzed. The effects of different numbers of reinforcing ribs on the deformation and stress of the noise barrier under natural wind are studied. From the perspective of wind load, load bearing and bolt strength, the number of reinforcing ribs of the noise barrier is optimized. The results show that the structural strength of our self-developed noise barrier can meet the requirements. This design method provides guarantee for the future engineering design and application.

1. Introduction

Road noise and environmental noise caused by industrial have seriously affected the normal life of residents [1]. Therefore, effective measures must be taken to prevent and control noise pollution. At present, urban environmental noise is mainly reduced by planting noise-reduction green belts [2], developing low-noise equipment [3], setting up noise barriers [4], and regionalizing environmental noise function [5]. Among them, the noise barrier technology is to set a barrier between the sound source and the receiving point to hinder the propagation of sound wave [6]. Compared with other noise reduction technologies, noise barrier technology is widely used due to its obvious noise reduction effect, convenient installation, small footprint and low maintenance costs [7].

Since most of the noise barriers are located outdoors, they are easily affected by wind loads due to their large windward area and light weight. When designing noise barriers, in addition to ensuring the good acoustic effect, it is also necessary to consider its structural stability (capable of withstanding wind loads), durability and fatigue resistance. At present, the wind load of noise barriers under natural wind is mainly studied through wind tunnel experiments and simulations [8]. Yu Haihong et al. [9] used the numerical simulation method to establish a calculation model of an upright noise barrier, and studied the distribution of the wind load on the noise barrier under different conditions. Han Xu et al. [10] tested the surface wind pressure of closed noise barriers by wind tunnel tests with section models, and the influences of wind speed, Reynolds number effect, wind attack angle and section position on the aerodynamic characteristics were analyzed. Based on RANS and κ-ε equation models, Wang Hongchao [11] run a numerical simulation on the noise barrier of high-speed railway under the action of train-induced impulsive wind pressure and natural wind load by the CFD software Fluent.
At present, the research on the sound barrier load is mainly focused on its columns, while the research on the soundproof board is ignored. As the main component to withstand wind pressure, it is necessary to supplement its research on wind load. In this paper, the Finite Element Analysis software ANSYS is used to model the self-developed noise barrier, and the mechanical properties are analyzed. The effects of different numbers of reinforcing ribs on the deformation and stress of the noise barrier under natural wind are studied, and then the optimal design structure is obtained.

2. Materials and Methods

The experimental material in this study is a self-designed noise barrier. The structure of the soundproof board is shown in Figure 1.

![Fig. 1 Schematic diagram of soundproof board](image1)

The soundproof board is mainly composed of metal frame, 5 or 3 reinforcing ribs, a board material, and a filling sound absorbing material. There are four small holes on each side of the soundproof board for bolting. The schematic diagram of the reinforcing rib is shown in Figure 2.

![Fig. 2 Model of reinforcing rib for soundproof board](image2)

The soundproof board material is made of SGCC hot-dip Zinc galvanized steel. The bolts used for fixing on both sides are made of Q235 carbon steel. The parameters of materials are shown in Table 1.

| Materials | Elastic Modulus (GPa) | Poisson's ratio | Yield Strength (MPa) | Tensile Strength (MPa) | Elongation (%) | Density (kg/m³) |
|-----------|-----------------------|----------------|----------------------|------------------------|----------------|-----------------|
| SGCC      | 202                   | 0.3            | 205                  | 270                    | 20             | 7853            |
| Q235      | 206                   | 0.3            | 235                  | 370                    | /              | 7850            |
3. Simplified calculation of noise barrier
For smooth calculation and analysis of the model, the following assumptions and simplifications are made in this article:

1) Simplify the holes of the noise barrier. Since the soundproof board is fixed by the bolts on the rigid column, constraint boundaries are applied only at the bolts.

2) Ignore the filling material of the soundproof board during the simulation. As the filling materials are mostly low-density sound-absorbing materials such as polyurethane, the low-order vibration frequency of the model is low when performing dynamic analysis. And the vibration shape of the model is mainly reflected in the filling material, which cannot accurately reflect the overall vibration shape of the soundproof board.

Figure 3 shows a simplified model of soundproof board.

4. Results analysis and discussion

4.1. Modal analysis
When designing the model of noise barrier, the difference between the natural frequency and the frequency of the impulsive wind load in the environment should be taken into account, and the structural damage caused by the resonance effect of the two should be avoided. So, when using the Block Lanczos method in ANSYS to perform modal analysis, the out-of-plane vibration of the soundproof board (including high-order local vibration in the area that separated by the reinforcing ribs) should be set, and the inherent vibration characteristics of the soundproof board should be studied.

The diagram of first-order mode is shown in Figure 4, and the first ten natural frequencies is shown in Table 2. It can be seen from Table 2 that the first-order frequency is 45.109 Hz, which is much higher than the excitation frequency (2-8 Hz) of the impulsive wind load. Therefore, the resonance response is difficult to be excited, and the calculation model has high reliability.
**Table 2.** The first ten natural frequencies of the soundproof board

| Model | Frequency /HZ | Model | Frequency /HZ |
|-------|---------------|-------|---------------|
| 1     | 45.109        | 6     | 59.926        |
| 2     | 48.405        | 7     | 63.111        |
| 3     | 49.126        | 8     | 64.359        |
| 4     | 49.155        | 9     | 64.752        |
| 5     | 50.234        | 10    | 64.507        |

4.2. Analysis of wind load and weight load

The noise barrier in this study is mainly used to reduce noise in urban substations and residential areas, so natural wind loads and self-weight loads are the main loads. Among them, the natural wind load calculation formula in the standard state is as follows:

\[
W = 0.5 \cdot r \cdot v^2 \cdot k / g
\]

In the formula:
- \(W\) -- wind pressure, kPa;
- \(R\) -- air severity, 0.01225 kN/m³;
- \(V\) -- wind speed, m/s;
- \(K\) -- wind vibration coefficient, 2;
- \(G\) -- gravitational acceleration, 9.8 m/s²

In this study, the maximum design wind resistance level of the soundproof board is 11, so the maximum design wind speed is 33 m/s, and the wind pressure loaded on the model is calculated to be 1361 Pa. The external weight on the top beam is assumed to be uniformly distributed on the top skin (0.1 MPa), that is, the resultant force is about 24.5 kN. Figure 5 shows the loading and constraints of the model. Figures 6 and 7 are the deformation and stress cloud diagrams of the model, respectively.
Fig. 7 Stress cloud diagram of the model (upper: windward side, lower: leeward side)

It can be seen from Fig. 6 that there is an area with a large displacement in the upper part of the middle, and the maximum deformation is 7.4 mm, which is difficult to identified with the naked eye. It can be seen from Fig. 7 that the stress of the middle five reinforcing ribs are very low. This is because there are no small holes in the middle five reinforcing ribs, so there is no stress concentration. However, on the edge of soundproof board, due to the presence of bolt holes, the stress concentration at the small holes on both sides is very obvious. It can be known from Table 1 that the yield strength of the soundproof board is 205 MPa, and the allowable stress is 137 MPa when the safety factor is 1.5. Except for the small holes, the maximum stress of the other parts of the soundproof board did not exceed 80 MPa (far less than the allowable stress), which meets the requirement that the general location stress level of the structure should be less than the allowable stress.

In the vicinity of small holes, it is generally required that the stress should not exceed three times the allowable stress. Figure 8 shows the stress cloud near the small hole. As can be seen from Figure 8, the stress near the small hole is about 160 MPa, which meets the requirements.

Fig. 8 Stress near the small hole

From the perspective of the overall model, the displacement and stress levels of the upper load-bearing beams are relatively high, and special attention should be paid. It can be seen from Figure 9 that the middle part of the beam has a large displacement. At the same time, due to the stress concentration caused by the restraint of the reinforcing ribs, Figure 10 shows the locally enlarged stress map of the middle part of the beam. The maximum stress from Figure 10 is about 220 MPa, which also meets the requirements.
4.3. Check of bolt strength

From Section 4.2 “Analysis of wind load and weight load”, the force applied in the vertical direction is approximately 24.5 kN. Assuming it is evenly distributed to eight bolts, the force on each bolt is 3062.5 N. For ordinary bolts of type M8×30, the tensile stress area is 36.6 mm$^2$. If the parameters are calculated according to bolt strength grade of 4.8, the tensile strength is 170 MPa, the shear strength is 140 MPa, the maximum design tensile load capacity is 6222 N, and the maximum shear load capacity is 5124 N. If the parameters are calculated according to bolt strength grade of 5.6, the tensile strength is 210 MPa, the shear strength is 190 MPa, the maximum design tensile load capacity is 7686 N, and the maximum shear load capacity is 6954 N. If the safety factor is 1.5, both bolt strength grades meet the requirements of strength design.

5. Optimal design of sound barrier

It can be known from the results that the maximum deformation of the soundproof board with 5 reinforcing ribs is 7.4 mm. The stress of the soundproof board and bolt strength meet the design requirements. In order to meet the requirements of mechanical strength and minimize the loss of raw materials, this article studied the effect on the mechanical properties of noise barriers by changing the number of reinforcing ribs.

Fig. 11 is the model of soundproof board with three reinforcing ribs. The stress and deformation diagrams under the same conditions as the five reinforcing ribs are shown in Fig. 12 and Fig. 13, respectively. It can be seen from Fig. 12 and Fig. 13 that the maximum stress of the soundproof board with three reinforcing ribs is about 104.22 MPa, and the maximum deformation is about 11.6 mm.
Fig. 12 Stress diagram of the soundproof board with three reinforcing ribs

Fig. 13 Deformation diagram of the soundproof board with three reinforcing ribs

Fig. 14 is a model of a soundproof board with two reinforcing ribs. The stress and deformation diagrams under the same conditions as the five reinforcing ribs are shown in Figs. 15 and 16, respectively. As can be seen from Fig. 15 and Fig. 16, when the reinforcing ribs of the soundproof board are reduced to two, the maximum deformation has reached 25 mm and the stress has reached 120 MPa (close to the allowable stress). Therefore, for practical application, the mechanical properties of the soundproof board with two reinforcing ribs cannot meet the actual needs.

Fig. 14 The model of soundproof board with two reinforcing ribs

Fig. 15 Stress diagram of the soundproof board with two reinforcing ribs
6. Conclusion

In this paper, the Finite Element Analysis software ANSYS is used to analyze the mechanical properties of the noise barrier. It was found that under natural wind and weight loads, the stress, deformation and bolt strength of self-developed noise barrier meet the requirements. The optimal design of the soundproof board showed that it is most suitable when the number of reinforcing ribs is three.

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