Mechanical and Acoustic Performance Test of New Designed Metal Noise Barrier Unit Plate with No-Riveted Connection

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Abstract: The modern transportation system is increasingly developed during recent years. It is an effective solution to set the noise barriers to reduce the traffic noise pollution caused by different kinds of transportation systems. Many deficiencies on concrete noise barriers and metal noise barriers with rivet structure can be eliminated by a new kind of noise barrier with no-riveted structure. The mechanical performance examination and acoustic performance test are conducted on the new-designed noise barrier with no-riveted structure. The results indicate that the maximum stress is 1.74 MPa and the maximum deformation is 1.04 mm with load acting on the unit plate. The noise reduction coefficient of this kind of no-riveted noise barrier unit plate is 0.75 and its noise insulation is 40 dB, which were conform to or superior to the standard requirements. Therefore, this new designed noise barrier meets the field application requirements of mechanical and acoustic performance, which demonstrates the noise barriers can be widely promoted.

Key words: noise barrier unit plate; no-riveted connection; structure design; mechanical performance; acoustic performance

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0 Introduction

During the last few decades, urbanization has been developed rapidly, and the total mileages of urban rail transportation have increased sharply with an annual growth rate of 25% on average. Until the end of 2015, the operating mileages of high-speed railway totaled 19 915 km in China[1]. According to China Mid-to-Long-Term Railway Network Plan, the high-speed railway operating mileages will reach 25 000 km, and the total high-speed railway operating mileages will be more than 30 000 km by the year of 2020. In Japan, the Tokaido Shinkansen railway operating kilometers reached 552.6 km, and the total lines under the management of the Central Japan Railway Company was more than 1 970.8 km[2].

Much convenience and efficiency were brought to urban residents with the large-scaled construction of elevated lines, subways and high-speed railways. However, the traffic noise pollution problem has been increasingly serious. Residents would suffer a lot when exposed to the traffic noise for a long time. But few emphasis has been put on the issue[3]. The solution to transportation noise pollution has become one of the research topics of pollution reduction and environmental protection.

Current solutions to traffic noises are to set noise barriers along road pavements and railways,

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and concrete- and metal- riveted noise barriers are widely applied. However, concrete noise barriers could affect the integral aesthetics of environment. And the components of metal noise barriers are connected by rivet structures where rivets often loose and fall out, endangering the barrier structure and normal road traffic. In this paper, the noise barrier unit plate with no-riveted connection is presented. Its mechanical and acoustic performance are examined and tested. The results can be references to its application in practice.

1 Structure Design and Performance Test on Noise Barrier Unit Plate

1.1 Acoustic principle of noise barriers

A noise barrier is a kind of acoustic material specially designed to hinder the noise propagation, which is placed between the noise source and the receiving point. The noise wave will have a significant attenuation during the propagation process, so that the noise received by the receiving point can be attenuated obviously. Once the noise source generates a noise wave, it will propagate in all directions.

When the noise wave encounters the noise barriers during the propagation process, it will propagate in three main routes: Reflection, diffraction and transmission. The propagation routes sketch is shown in Fig.1. If the three phenomena occur at the same time, the noise wave will be weakened and the noise level will be decreased, thus the noise received by the receiving point will be attenuated, and the effect of noise absorption and reduction can be achieved[4].

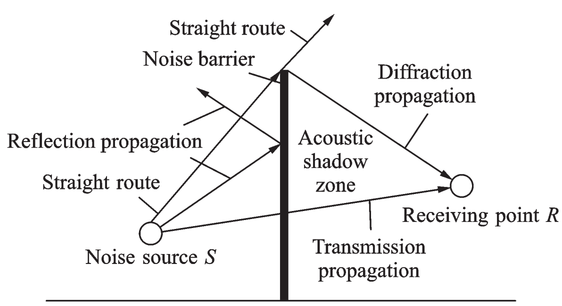


Fig.1 Noise propagation process sketch

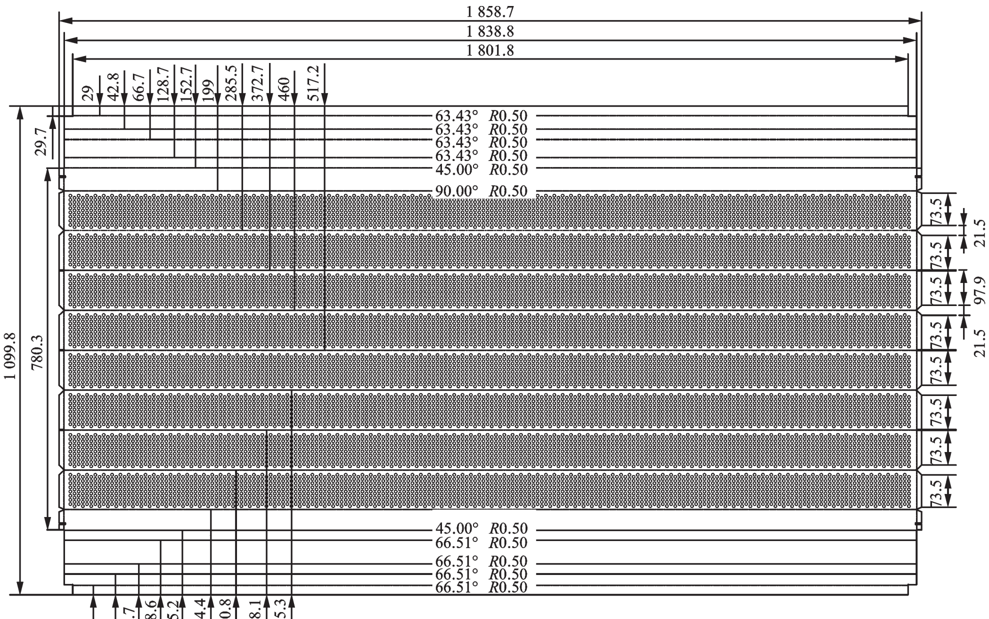
1.2 Structure design of no-riveted noise barrier unit plates

The no-riveted noise barrier unit plates must meet national standards before being applied to practical projects, thus it must meet the requirements of mechanical performance, acoustic performance and security performance for high-speed railway projects[5]. Despite their own light structure weight, the noise barrier unit plates set at the special surroundings along the two sides of the roads or tracks must stand against strong wind load brought about by the passing vehicles or trains, and even bear loads caused by vehicle collisions , earthquakes, or natural disasters such as typhoons, heavy rains and storm snows. Plus, they should not endanger passing persons and vehicles at the same time.

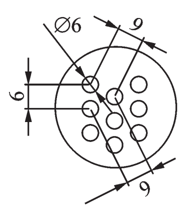
The acoustic technology of this new kind of no-riveted noise barrier unit plates is the combination of "micro-perforated sound-absorbing plate" and "acoustic wedge". Occlusion process technology, a well-developed manufacturing process, is adopted during the manufacture procedure. The back board and the face board are buckled and connected through the side board. Special designed concave and convex grooves are preseted on the back board and the face board, and their dimensions are shown in Figs.2—4, where 45°, R0.50 are the bending angle and the bending radius of the noise barrier unit plate, respectively. The buckling between concave convex grooves guarantee the effective connection between the back board and the face board.

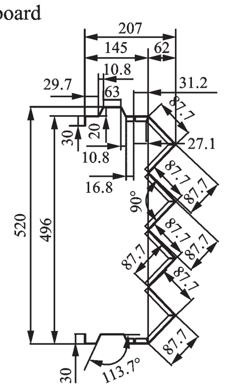
Due to the application of the acoustic wedge, this new kind of no-riveted noise barrier unit plates would have a good noise absorption performance, especially at the medium and low frequency noise. The acoustic wedges on the face board and the side board of the noise barrier unit plate are made from a 1 mm aluminum alloy plate 5754, and the back board from a 1.5 mm aluminum alloy plate 5754. The basic mechanical properties of the aluminum alloy plate 5754 are listed in Table 1.

The outer part of the noise barrier is metal shell that has an empty cavity inside. Noise absorption materials could be filled into the empty cavity, and



(a) Dimension sketch of unfolded face board

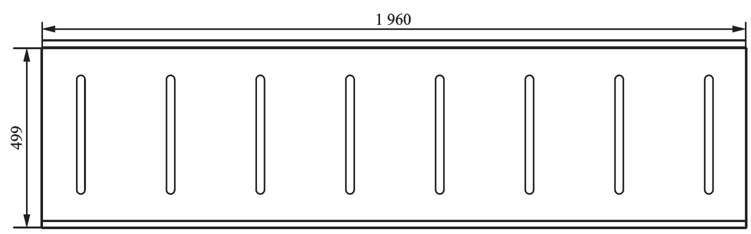


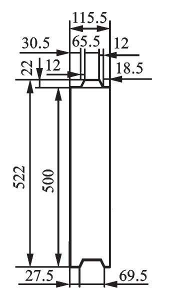


(b) Detailed dimension sketch of the perforated holes

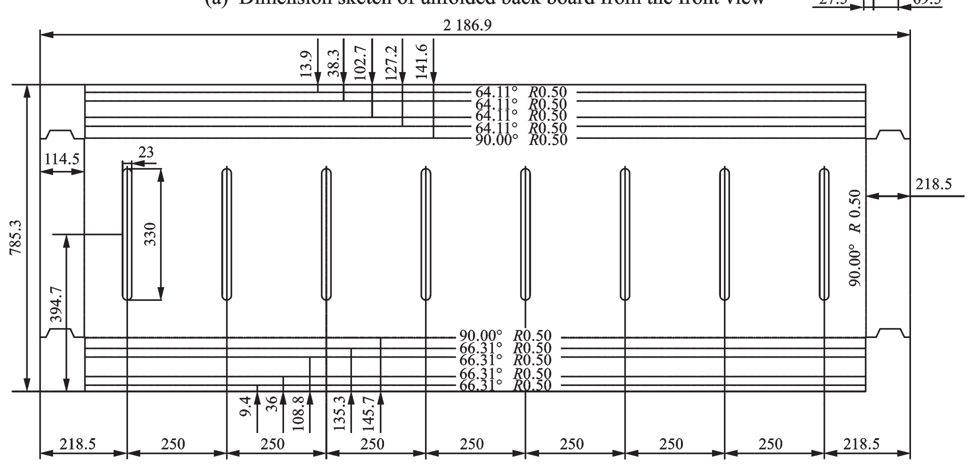
(c) Dimension sketch of unfolded face board from the lateral view

Fig.2 Dimension sketch of the face board of no-riveted noise barrier unit plates



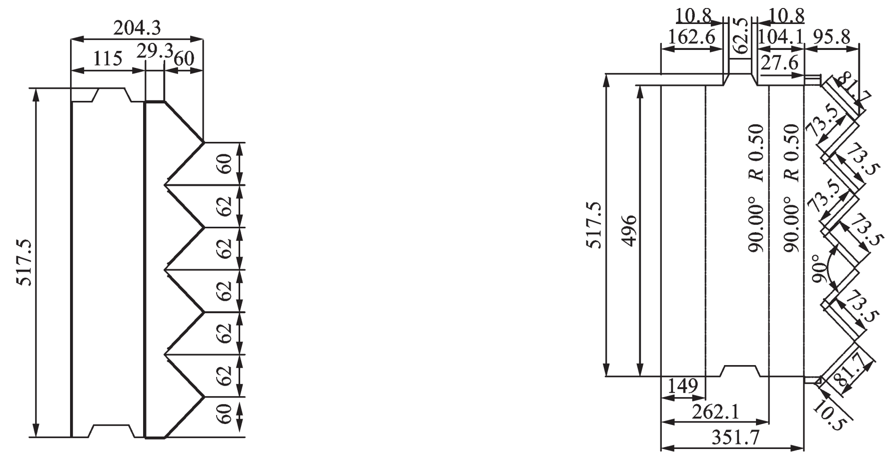


(a) Dimension sketch of unfolded back board from the front view



(b) Dimension sketch of unfolded back board from the back view

Fig.3 Dimension sketch of the back board of no-riveted noise barrier unit plates



(a) Dimension sketch of side board from the lateral view (b) Dimension sketch of unfolded side board

Fig.4 Dimensional sketch of the side board of no-riveted noise barrier unit plates

Table 1 Basic mechanical properties of 5754 aluminum alloy plate

Material parameter	Value
Modulus of elasticity/MPa	6.9×10^4
Poisson's ratio	0.3
Density/(kg·m^{-3})	2 700
Yield strength/MPa	160
Ultimate strength/MPa	245
Fatigue strength/MPa	130
Elongation after fracture/%	10—14

acoustic rock wool is taken as the noise absorption material placed at the inner cavity of the noise barrier. The face board facing the noise source is perforated, thus air current can flow through the holes on the face board. Such that the fluctuating pressure acting on the noise barrier unit plate can be reduced effectively[6-7]. The perforating rate is curial to the mechanical and acoustic performance of the no-riveted noise barrier unit plates. As illustrated in Fig.2, the radium of the holes on the face board is 6 mm and their spacing is 9 mm after referring to the investigation results from other scholars[6].

The opposite board need not to be perforated. The back board and the face board are buckled and connected through the side board. Figs. 5—6 illustrate the details of the structure. The convex groove at the upper part and the concave groove at the lower part are special designed on the back board. Rubber strips are glued to the two sides of upper convex groove. In site engineering, the unit plates are upper-and-down assembled and installed. The friction can be eliminated between the unit plates at the upper and the down, and their installation stability can also be guaranteed by rubber stripes on the unit plates. H-section steels are vertically installed at both sides along the roads and tracks, and the distance between two H-section steels is adjusted to ensure the two ends of the unit plate can be nested in H-section steel.

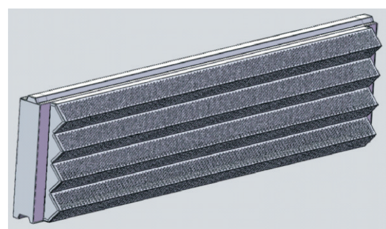


Fig.5 Sketch of a no-riveted noise barrier unit plate

Fig.6 Photo of a no-riveted noise barrier unit plate

1.3 Mechanical examination for no-riveted noise barrier unit plates

Under service conditions, wind load and train aerodynamic wind pressure act on the unit plates together. The unit plate is a flexural member, suffering the moment and shear force at the same time. As the long span and short heights of the noise barrier unit plate, the moment is taken into consideration, while the shear force is ignored after referring to the actual condition. The anti-bending fracture load is taken the value of 7.0 kPa according to the standard requirements[5]. The load acting on the unit plate is transformed into line load[8], the simplified sketches are shown in Figs.7—8.

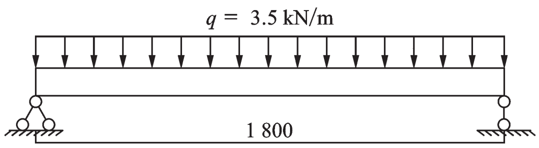


Fig.7 Simplified stress calculation model

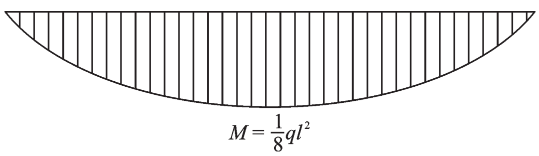


Fig.8 Diagram of the bending moment

The cross-section of noise barrier unit plate is at the elastic stage under the practical condition. It has an empty cavity inside, and the unit plate cross-section could be simplified into a I-shaped cross-section composed of an upper flange, an intermediate web and a lower flange. The sketch of simplified section is shown in Fig. 9. The extent of the cross section can be maintained as flat state before or after deformation. The maximum stress σ_t at its cross section and the maximum deformation ω on the noise barrier unit plate can be figured out

$$\sigma_t = \frac{My_0}{I_0} \tag{1}$$

$$M = \frac{1}{8} ql^2 \tag{2}$$

$$\omega = \frac{5ql^2}{384EI_0} \tag{3}$$

where q is the uniform line load acting on the unit plate; M the maximum bending moment on the unit plate; I_0 the simplified cross-sectional inertia moment at the unit plate; y_0 the distance from the edge at simplified cross-sectional tension zone to the neutral axis; l the length of the unit plate; ω the maximum deflection on the unit plate; and E the elasticity modulus of the alloy plate.

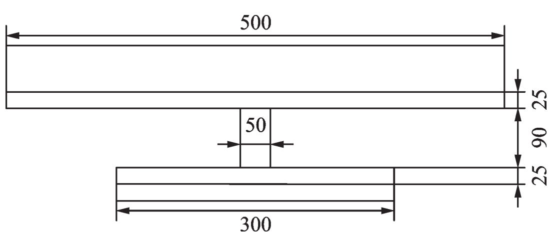


Fig.9 Sketch of simplified section

1.4 Mechanical performance test on no-riveted noise barrier unit plates

After equivalent conversion, the uniform surface load acting on the sound barrier unit board is converted into two concentrated forces. Then the concentrated forces are loaded to the tripartite points on the back plate of the noise barrier during the test. The four point bending test method is adopted. The bending moment could be evenly distributed on the component, and the test result can be relatively close to the practical service condition. The sketch of the experiment program is shown in Fig.10.

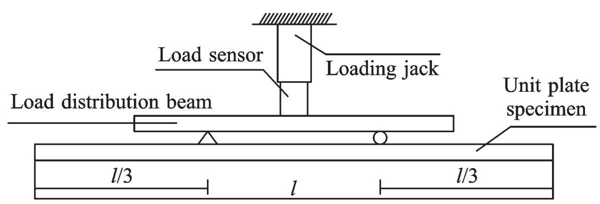


Fig.10 Sketch of load on the specimen

This test is to examine the bending resistance of unit plate when the load reaches 7 kPa[5]. The mid-span deformation of the unit plate can be examined according to the data from the displacement meters, which are placed on the specimen at the support position and the mid-span position, and flexural fracture load of unit plate could be read on the load devices.

1.5 Acoustic experiment test on no-riveted noise barrier unit plates

The noise-absorption performance is related to the internal structure of the noise barrier unit plate, the noise absorbing material and some other factors. Experiment tests on noise absorption coefficient and noise insulation of the noise barrier unit plate are conducted in a reverberation chamber, referring to the standards and requirements[9-10].

The tests are conducted on six no-riveted noise barrier unit plates manufactured by Shanghai Zhong Chi Group Co. Ltd. The outer dimension is 1 960 mm×520 mm×140 mm, and the cover area is 6.12 m^2. The experiment equipment consists of a standard reverberation chamber, four free field microphones, an acoustic measurement platform, a data acquisition computer, all directional sound sources, a power amplifier, and sound level monitor. The connection sketch between equipmental devices is shown in Figs.11—12. Fig.13 displays the acoustic reverberation chamber in the test.

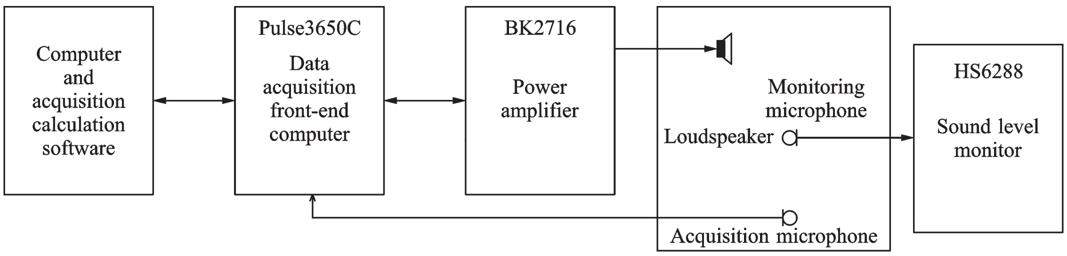


Fig.11 Experiment equipment connection of the noise absorption coefficient measurement

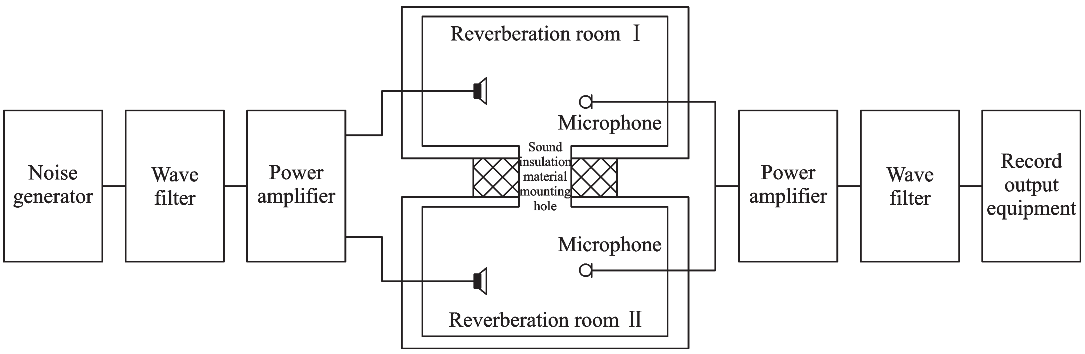


Fig.12 Experiment equipment connection of noise insulation measurement

Fig.13 Acoustic reverberation chamber in the test

Table 2 Calculation results

Parameter	Result
$q/(\mathrm{N \cdot mm^{-1}})$	3.5
$M/(\mathrm{N \cdot mm})$	1 417 500
y_0/mm	81.73
I_0/mm^4	66 830 443
σ_t/MPa	1.74
ω/mm	1.04

2 Results and Discussion

2.1 Mechanical performance examination and test results

The maximum deformation ω on the unit plate of the noise barrier unit plate is 1.04 mm, which is complied with the requirements regulated in the national standard. The limited maximum elastic deformation value is 19.6 mm (l/100=1 960/100=19.6 mm)[5]. And the calculation results are listed in Table 2.

The results indicate that the maximum stress is 1.74 MPa, which is far less than the fatigue strength and the yield strength of the aluminum alloy plate. The results of mechanical performance test on the no-riveted noise barrier unit plate totally satisfy the standard, and there is much enough security redundancy.

When the experimental load is 7 kPa, the displacement is 0.90 mm on the unit plate from the meter, which is very close to the theoretical calculation result. When the load is increased to 8 kPa, the wedge panel of the noise barrier unit plate bends. However, the surface is intact and the deformation is small at the middle span of the unit plate. The results of mid-span deflections on the unit plates are shown in Table 3.

Table 3 Bending test results

Specimen	Flexural load /kPa	Deflection/mm
1	8.9	2.5
2	8.7	3.1
3	8.3	2.8

The results indicate that the middle span deformations are smaller than the standard limited value when load acting on the unit plates is 7 kPa. The average value of the load can reach 8.63 kPa, which is 23% more than the regulation requirement. And the average deflection on the unit plate is 2.8 mm, which is much less than the limited value. Because of the favorable structure design and the effective connection of the components, the bending resistance performance of the noise barrier unit plate is conform to the standard[5].

2.2 Noise absorption coefficient of no-riveted noise barrier unit plates

The no-riveted noise barrier unit plate could attain different noise absorption effects under various noise frequencies. The noise frequencies used in the experiment are determined according to the standard requirements and research results from site projects[11-12]. The test results are given in Table 4, and the noise absorption performance graph is shown in Fig. 14. The noise reduction coefficient is the arithmetic mean value of the noise absorption coefficient under the frequencies of 250, 500, 1 000, and 2 000 Hz. The noise reduction coefficient is a comprehensive evaluation indicator on noise absorption performance of this no-riveted noise barrier unit plate. Only when the noise reduction coefficient reach or more than 0.5, the noise could be reduced obviously[7].

Table 4 Noise absorption coefficient under different testing frequencies

Frequency/Hz	Frequency range	The noise absorption coefficient	Frequency/Hz	Frequency range	Noise absorption coefficient
100	Low	0.21	800	Medium	0.81
125	Low	0.25	1 000	Medium-high	0.77
160	Low	0.26	1 250	Medium-high	0.77
200	Medium	0.31	1 600	Medium-high	0.83
250	Medium	0.55	2 000	Medium-high	0.92
315	Medium	0.65	2 500	Medium-high	0.93
400	Medium	0.72	3 150	Medium-high	0.95
500	Medium	0.76	4 000	Medium-high	0.89
630	Medium	0.80	5 000	Medium-high	0.84

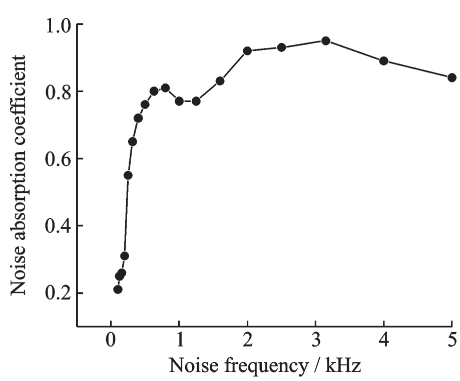


Fig.14 Noise absorption performance measurement result

The noise absorption coefficient measurement results are given in Table 4 and Fig. 14. Due to the holes pre-set on the face board and the inner rock wool, the noise absorption coefficients of the noise barrier are close to 0.9 or more than 0.9 under the frequencies of 2 000, 2 500, 3 150, and 4 000, which reveals its excellent noise reduction effect at medium-high noise frequencies. And meanwhile, the noise barrier performs well at the low and medium frequencies, especially below 1 000 Hz, which is close to the real traffic noise frequencies[9-10]. Because of the acoustics wedge structure application on the face board and the acoustic rock wool at the internal of the unit plate, its noise absorption coefficient reach 0.55 when the noise frequencies are 250 Hz. Within the range of 500—1 000 Hz, the noise absorption coefficients are all more than 0.75. These results all prove its good acoustics performance. The noise reduction coefficient of the no-riveted noise barrier unit plate is 0.75, which fully meet the requirement that the noise reduction coefficient must be greater than 0.7[5].

2.3 Weighted noise insulation of no-riveted noise barrier unit plates

The weighted noise insulation can be examined based on the experiment data and the basic principle of reverberation chamber method. The noise insulation results of the noise barrier at different frequencies are listed in Table 5, and the weighted noise insulation performance graph is shown in Fig.15.

Table 5 Weighted sound insulation under different testing frequencies

Frequency/Hz	Frequency range	Noise insulation/dB	Frequency/Hz	Frequency range	Noise insulation/dB
100	Low	15	800	Medium	37.1
125	Low	24.1	1 000	Medium-high	37.7
160	Low	26.6	1 250	Medium-high	41.9
200	Medium	27.8	1 600	Medium-high	41.7
250	Medium	32.3	2 000	Medium-high	38.5
315	Medium	36.5	2 500	Medium-high	42
400	Medium	41	3 150	Medium-high	46.9
500	Medium	40.5	4 000	Medium-high	49.8
630	Medium	40.8	5 000	Medium-high	51.1

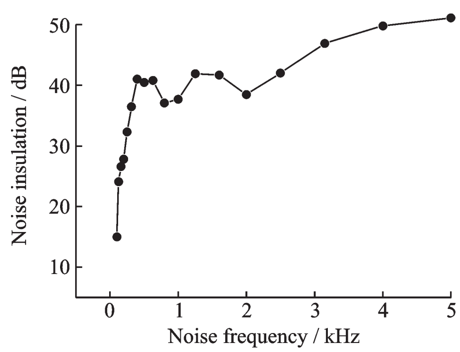


Fig.15 Weighted noise insulation performance measurement result

From Table 5 and Fig.15, it can be seen that the noise insulation is greater than 30 dB when the noise frequency reach 250 Hz. The noise insulations are more than 37 dB under each of the traffic noise frequency range of 500—800 Hz, which would reduce the traffic noise evidently[12-13]. It is attributed to the combination of acoustics wedge on the face board and the noise absorption material inside the noise barrier unit plate. Even though a small reduction occur when the noise frequency is within the range of 800—1 000 Hz, the noise insulation is kept almost increasing after then. At the noise frequency of 5 000 Hz, the noise insulation can reach 51.1 dB, revealing the excellent noise reduction effect of the no-riveted noise barrier unit plate. Its weighted noise insulation is 40 dB, which fully meet the requirement that weighted noise insulation must be greater than 30 dB.

3 Conclusions

A new kind of no-riveted noise barrier is designed for practical traffic projects such as high-speed railways, urban rail traffic and city express ways. On the premise of excellent mechanical performance, the acoustic performance of the no-riveted noise barrier unit plate should also be guaranteed. The mechanical and acoustic experiments are conducted on the unit plates, and some conclusions can be drawn.

(1)The maximum stress is 1.74 MPa and the maximum deflection is 1.04 mm when the load 7 kPa is acting on the unit plate. The stress is far less than the unit plate manufacture material strength. And the average value of the load acting on the plate can reach 8.63 kPa, while the deformation is far less than the limited value, so that the security and mechanical performance can be guaranteed.

(2)The noise absorption coefficients of the noise barrier are excellent under the medium-high noise frequencies. In addition, when the traffic noise frequency is below 1 000 Hz, its noise absorption coefficients are all more than 0.55, which leads to obvious noise reduction. Its noise reduction coefficient is 0.75, greater than standard requirement value of 0.7, indicating the unit plate of good noise absorption performance.

(3)The noise insulation of the noise barrier unit plate is greater than 30 dB at the medium frequencies more than 250 Hz. And its weighted noise insulation is 40 dB, which well meet the standard requirements.

The experimental results prove excellent mechanical performance and acoustics performance of the no-riveted noise barrier unit plate . In addition, the defects of the concrete noise barriers and the current metal noise barriers with rivet structure can be alleviated. Therefore, this kind of no-riveted noise barrier can be widely applied to the traffic noise abatement projects.

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Author contributions Mr. **LUAN Haoxiang** drafted and wrote the manuscript. Prof. **ZHU Wanxu** and Prof. **WU Jin** conceived, directed and supervised all aspects of the study. Ms. **PAN Jiayu** contributed to the writing of the manuscript. Ms. **ZHOU Hongmei** and Mr. **PENG Hanze** contributed to technical support and experiment setup assistance. All authors discussed results, plotted figures, edited the manuscript and approved the submission.

Competing interests The authors declare no competing interests.

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新型无铆型声屏障单元板结构设计及力学与声学性能分析

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摘要:近些年来,各种现代化的交通体系日益发展成熟。在道路和轨道两旁设置声屏障是降低交通运输系统产生的噪声污染的有效途径。目前广泛应用的主要是混凝土声屏障和金属有铆型声屏障,新型的无铆型声屏障单元板可以有效缓解现有声屏障单元板上存在的问题和缺陷。本文对新型无铆型声屏障单元板的力学性能和声学性能分别进行了检验校核和试验测试。试验结果表明,当声屏障单元板受到7 kPa的均布荷载时,声屏障单元板上产生的最大应力是1.74 MPa,发生的最大变形是1.04 mm,和校核计算结果相一致,产生的应力远小于单元板制作原材料铝合金板的屈服强度和疲劳强度,产生的变形也远小于规范限值。声学性能试验结果表明声屏障单元板的降噪系数为0.75,单元板的隔声量可以达到40 dB,均超过国家标准要求。因此,此种无铆型声屏障单元板符合实际工程应用要求,可以进行大规模推广使用。

关键词:声屏障单元板;无铆连接;结构设计;力学性能;声学性能