Research and Application of Noise Barriers in Highway Construction

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Abstract. In recent years, with the rapid development of highways, traffic noise has become a risk source in the environment, and noise control has attracted wide attention. As an economical and effective method, highway noise barriers were the best way to reduce traffic noise and protect residents' acoustic environment. At the same time, considering the various surroundings in selecting suitable materials (sound-reflective or sound-absorbing materials), types (such as concrete, organic glass, foam metal and photovoltaic noise barriers) and structures (such as vertical, T-shaped, Y-shaped, and inverted L-shaped) could greatly improve the sound reduction performance of barriers. This paper summarizes the current development of noise barriers from perspectives of the material, type and structure to introduce a variety of noise barriers and provides a reference for relevant research. With these analyses, it is possible to design more cost-effective and appropriate noise barriers for particular areas.

1 Introduction

Road construction is one of the important elements for economic and social development globally, which could greatly relieve traffic pressure, increase economic activities and improve accessibility at the region or urban level. Highways, as backbones of national traffic systems, are required to meet the need for efficient transportation. Until 2017, the length of expressways built was 136 thousand kilometers in China, 75 thousand kilometers in the United States, 30 thousand kilometers in Russia, 17 thousand kilometers in Canada, and so on. Although highways are greatly beneficial to the regional economy, they may inevitably bring about many negative effects by increasing the highway mileage, traffic volume and speed, such as air pollution, irrational use of land resources, noise pollution, and so forth. At present, traffic noise pollution has become a serious problem that cannot be ignored, which can cause detrimental health impacts[1, 2]. Generally, the acoustic spectrum of traffic noise originating from vehicles consists of multiple frequencies, and most of the spectrum falls in the frequency range of approximately 125 Hz-4000 Hz. Sounds within this frequency range can be easily heard by human ears and cause great discomfort. This is manifested as sleep disturbances, stress and annoyance in the short term[3], which are associated with long-term health problems such as hypertension[4], coronary heart disease[5] and others[6, 7]. Therefore, traffic noise reduction is an important area of public concern because nearly ten percent of the population is seriously affected by this type of noise[8]. At the same time, noise may also become an important factor for social instability under certain conditions. In view of highway noise pollution, studying low-noise automobiles, constructing low-noise pavement, planting green belts, installing noise barriers, etc., have been applied to noise control. To control the propagation of traffic noise, the common practice is to build noise barriers along highways to absorb sound waves and prevent them from spreading any significant distance.

According to incomplete statistics, the production of noise barriers reached approximately 370 million square meters in 2014, and demand increased to 357 million square meters, which indicated that the global market scale of noise barriers exhibited a rapid growth, and the design of noise barriers has been gradually maturing and widely being applied to engineering practice.

2 Highway noise barrier materials

Noise barriers are the most commonly used devices to reduce high-level noise. The materials for noise barriers can be divided into reflective types, absorptive types, earth landscape types and mixed types. For the purpose of designing efficient devices, sound absorbing materials are often used as the core of barriers. As illustrated in Table 1, two physical factors, the type and thickness of materials, have been discussed to investigate the acoustic properties measured by the impedance tube method, the transfer-function method, and the standing wave tube

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method. The results demonstrated that sound absorbing materials have a relatively high sound absorption coefficient (α) between approximately 1000 Hz-4000 Hz (αaverage = 0.50 (1000 Hz), αaverage = 0.80 (2000 Hz), and αaverage = 0.62 (4000 Hz)) and possess a lower absorption coefficient below 500 Hz (αaverage = 0.35 (125 Hz), αaverage = 0.18 (250 Hz), and αaverage = 0.35 (500 Hz)).

Table 1. Comparing with different sound absorbing materials

Materials	Measurements	Thickness (mm)	Sound adsorption coefficient (Hz)						Reference
			125	250	500	1000	2000	4000	
A high-temperature sintering porous ceramic material	The impedance tube method	20	—	0.05	0.09	0.40	0.98	0.94	[9]
Inorganic polymeric foam	The impedance tube method	—	0.47	0.54	0.69	0.74	0.78	0.87	[10]
The multi-layer needle-punching nonwoven	The impedance tube method	—	—	0.02	0.10	0.30	0.73	—	[11]
Sintering preparation of porous sound-absorbing materials from steel slag	The impedance tube method	25	—	0.07	0.57	0.42	0.55	—	[12]
Arengapinnata natural fiber	The impedance tube method	40	0.09	0.09	0.13	0.24	0.80	0.78	[13]
Coconut coir fiber sound absorber	Transfer-function method	20	0.09	0.11	0.27	0.54	0.91	0.81	[14]
Coal bottom ash-based sound absorbing concrete	The reverberation chamber method	300	0.04	0.37	0.6	0.83	0.84	0.97	[15]

3 Highway noise barrier type

From the perspective of the noise barriers type, barriers can be mainly divided into concrete, organic glass, foam metal, photovoltaic barriers, and so on.

3.1 Concrete noise barrier

Concrete has been used to construct noise barriers in various ways. One of the most common materials utilized in highway noise barriers is the combination of porous concrete with a hard backing of standard concrete. Porous concrete is generally applicable to construct pavements or noise barriers, thereby reducing the impact of expressway noise. Until now, concrete barriers have been widely used in global traffic noise barriers, possessing the advantages of reliability, low maintenance cost, etc. Meanwhile, concrete noise barriers usually maintain a sufficient mechanical strength to withstand vehicle impact damage. Alternatively, concrete profile barriers could be used to form the lower portion of the noise barrier.

3.2 Organic glass noise barrier

Generally, the organic glass noise barrier is a transparent noise barrier that could greatly reduce the driver's sense of depression, possesses a beautiful appearance and has suitable safety and durability advantages. Compared with the concrete noise barrier, its landscape effect is greatly improved. A glass noise barrier was made from PC with two spacing layers of 120 mm by the Shanghai Shenhua Acoustic Equipment Co Ltd. and Tongji University, which had been applied in a Shanghai inner ring elevated road and Yanan viaduct road, and the average sound insulation could reach 23.5 dB[16]. Xu et al. studied a double glass noise barrier in the Tongji road of the Shanghai outer ring road and demonstrated that the average sound transmission loss was higher than 30 dB, and the noise could be reduced by approximately 5 dB-10 dB after using a noise barrier[17].

3.3 Foam metal noise barrier

In recent years, foam metal is a new material used for sound absorption, including foam aluminum, foam magnesium, foam lead, etc. Foam metal noise barriers have been widely used for being lightweight, transparent, easily installed and possessing sound insulation preponderances, thereby fulfilling the requirements of sustainable development. Considering the economic factors and the properties of foam, foam aluminum has become one of the most widely used materials in noise absorption and noise reduction[18, 19].

3.4 Photovolatic noise barrier

With the popularization of solar photovoltaic (PV) power generation systems, the application field of PV power generation is also expanding. Photovoltaic modules are installed on both sides of the highway, which can generate electricity and reduce noise but also reduce the cost of photovoltaic power generation. Therefore, the research and application of photovoltaic noise barrier (PVNB) have great potential for development of the environment and society.

4 The structure of highway noise barrier

Usually, increasing the height can improve the noise reduction effect of a noise barrier but will greatly increase the cost and destroy the visual environment.

Recently, using various designs of the top edge and innovatively revamping the geometry have become very important aspects to achieve greater acoustic reduction efficiency and help solve problems related to the construction of noise barriers. For highways, the application of an effective superstructure is the best choice to solve noise pollution, so studying a noise barrier's structure has become a hot spot. Several different types of novel barriers have been developed to increase their performance without increasing their height, such as vertically shaped, T-shaped, Y-shaped, inverted L-shaped barriers.

4.1 Vertical type barriers

Among many structural noise barriers, the vertical type noise barrier is simple, but the noise reduction effect is weak. In general, when the height of the vertical barrier is approximately 3 m-6 m, the noise reduction (insertion loss) in the acoustic shadow will range from approximately 5 dB to 12 dB.. Generally, the demands of barrier design in several countries are increasingly high, and the characteristics of vertical barriers are improved only by increasing the height. Although the insertion loss can be improved by 1.5 dB through increasing the height by 1 m, the adverse effects cannot be ignored: (1) the light in the residential area on both sides of road becomes insufficient, (2) the driver's sight is obstructed, which could easily cause visual fatigue, and (3) the increased height of the barrier results in a weight increase, foundation reinforcement and cost increase. Additionally, studies have shown that the ratio of performance and price of steel barriers could reach a maximum value when the height of the vertical barrier is 4 m. As a consequence, it is not advisable to satisfy the noise reduction requirement only by increasing the height of the noise barrier.

4.2 T-shaped barriers

In 1980, May and Osman et al. first proposed that the acoustic performance of a T-shaped barrier was better than an ordinary barrier.Moreover, Hothersall et al. used experimental modeling and field measurement to study the insertion loss (ΔIL) of T-, Y- and arrow-profile noise barriers. The results showed that the ΔIL of T-shaped barriers had increased by approximately 2 dB-3 dB compared with those of other barriers with the same height.

4.3 Y-shaped barriers

Compared with the vertical structure, the Y-shaped barrier possessed an improved noise reduction effect. When the barrier employed rigid materials and sound-absorbing materials, the insertion loss (ΔIL) reached 2.9 dB and 3.4 dB, respectively.

4.4 Inversed L-shaped barriers

The inverted L-shaped noise barrier contains an additional part on top of the common vertical barrier to achieve a certain angle between the upper and lower part (usually 60° or 90°). Because the acoustic characteristics of a vertical barrier can be improved only by increasing the height of the noise barrier, increasing the height can bring about many disadvantages. When the barrier height is the same, the insertion loss of the inverse L-shaped barrier can be enhanced by approximately 1 dB-2 dB compared with the vertical noise barrier. Therefore, if the height of the barrier does not increase and the top of the barrier employs an L-shaped structure, the noise reduction can be significantly improved.

5 Conclusions and outlook

With the rapid development of countries' highways, traffic noise pollution has become a key point in environmental governance. Noise barriers act as the main measures to control noise pollution, and the number of existing noise barriers is vast. Although the material, type and structure of noise barriers vary, they are only different in appearance, and there is no essential change in function and mechanism. Therefore, noise pollution treatment measures in highway projects should not only be based on the actual situation but also adopt measures to protect the surrounding environment of the highway to achieve the ideal noise reduction effect. At the same time, the noise barrier material must also be able to resist corrosion, moisture and age, be dustproof and fire-resistant, and not cause secondary pollution. For the purpose of achieving environmental and social benefits, how to effectively design noise barriers and fully take advantage of their function will be the focus of future research.

5.1 Pay attention to the coordinated design of noise barrier and landscape

In many countries, a variety of novel and beautiful noise barriers stand on both sides of the road, which are popular with people. Although noise barriers have environmental benefits of reducing noise, they also cause a certain level of negative influence. A high and monotonous wall installed alongside the road can result in people experiencing psychological effects and block the visibility of people, thereby affecting the safety of drivers. To overcome these shortcomings, despite satisfactory acoustic requirements, several countries have paid special attention to structure, color and design in the construction of noise barriers.

5.2 Use low-cost materials to build acoustic barriers

Noise barrier materials can be divided into several categories: soil embankment, wood, reinforced concrete, metal and so forth. In general, from the perspective of lower investment and ease of maintenance, many

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countries have considered the use of ordinary and lightweight concrete for the construction of sound absorption and nonsound-absorption barriers. Facing a shortage of resources and construction funds globally, the study of economic, practical and durable acoustic materials has become necessary. Based on the development of a circular economy, the utilization of industrial waste residues and waste materials should be the trend of barrier materials.

5.3 Construct ecological acoustic barriers

Paying attention to the environmental effects of noise barriers, the design concept and implemented measure should be in accordance with local conditions. For example, the planting of different plant varieties in noise barriers before and after is advocated. If possible, the noise barrier should be designed to be able to be planted with flowers and plants so that the barrier would be evergreen, which would reduce noise pollution and beautify the environment.

References

1. Babisch W. (2006) Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased. Noise & Health. 8: 1-29.
2. Morley D.W., De H.K., Fecht D., et al. (2015) International scale implementation of the CNOSSOS-EU road traffic noise prediction model for epidemiological studies. Environ. Pollut., 206: 332-341.
3. Bj Rk J., Ard J., Stroh E., et al. (2006) Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities and health. Scand. J. Work. Env. Hea., 32: 392-401.
4. Pirrera S., Valck E.D. and Cluydts R. (2010) Nocturnal road traffic noise: a review on its assessment and consequences on sleep and health. Environ. Int., 2010, 36: 492-498.
5. S Rensen M., Hvidberg M., Andersen Z.J., et al. (2011) Road traffic noise and stroke: a prospective cohort study. Eur. Heart J., 32: 737-744.
6. Stansfeld S.A. and Matheson M.P. (2002) Noise pollution: non-auditory effects on health. Brit. Med. Bull., 68: 243-257.
7. Ising H and Kruppa B. (2004) Health effects caused by noise: evidence in the literature from the past 25 years. Noise & Health, 6: 5-13.
8. Watts G. (2002) Barrier designs to reduce road traffic noise. Transport, 153: 79-86.
9. Duan C, Cui G, Xu X, et al. (2012) Sound Absorption Characteristics of a High-Temperature Sintering Porous Ceramic Material. Appl. Acoust., 73: 865-871.
10. Hung T.C., Huang J.S., Wang Y.W., et al. (2014) Inorganic polymeric foam as a sound absorbing and insulating material. Constr. Build. Mater., 50: 328-334.
11. Tai K.C., Chen P., Lin C.W., et al. (2010) Evaluation on the Sound Absorption and Mechanical Property of the Multi-Layer Needle-Punching Nonwoven. Adv. Mater. Res., 123-125: 475-478.
12. Sun P. and Guo Z.C. (2014) Sintering preparation of porous sound-absorbing materials from steel slag. Chinese J. Environ. Eng., 25: 2230-2240.
13. Ismail L., Ghazali M.I., Mahzan S., et al. (2013) Sound absorption of Arenga Pinnata natural fiber. World Acad. of Sci. Eng. Tech., 4: 438-440.
14. Rozli Z., Name Z.L. and Nor M.J.M. (2010) Noise Control Using Coconut Coir Fiber Sound Absorber with Porous Layer Backing and Perforated Panel. Am. J. Appl. Sci., 7: 260-264.
15. Arenas C., Leiva C., Vilches L.F., et al. (2015) Technical specifications for highway noise barriers made of coal bottom ash-based sound absorbing concrete. Constr. Build. Mater.,, 95: 585-591.
16. He X., Wang L., Chen Y., et al. (2015) Research Progress of Highway Noise Barrier at Home and Abroad. Sci. Technol. Inno., 21: 63-64.
17. Li X.D., Hui G., Xu B.H. (2009) Noise-barrier design practice for tongji road interchange of shanghai outer ring road. The acoustic academic conference.
18. Liang L.S., Yao G.C., Yong-Liang M.U., et al. (2011) Design of Closed-Cell Aluminum Foam Sound Barriers. Noise Vib. Control, 31: 71-74.
19. Liang L.S., Yao G.C., Yong-Liang M.U., et al. (2011) Study on Denoising Effect of Sound Barriers Made from Closed-Cell Aluminum Foam. J. Northeastern Univ., 32: 274-276.