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A Comprehensive Review on the Effectiveness of Existing Noise Barriers commonly used in the Railway Industry

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Abstract. Nowadays, advanced development and sophisticated new technology have led to various types of environmental pollution such as water, air, land, thermal pollution and so on. Recently, however, noise pollution is becoming one of the major threats to the world especially in urban areas where it adversely affects the quality of life of the public. In Malaysia, the Department of Environment has identified that the average transportation noise levels in major cities in peninsular Malaysia are 71.6 dB (A) and 70.4 dB (A) during the day and night respectively. The noise is usually emitted by airplanes, trains, vehicles, motorcycles, trucks and etc. Even though rail transport requires less energy and emits less hazardous substances, it has contributed to noise pollution issues and several health hazards among urban inhabitants such as deafness, nervous breakdowns, mental disorder, heart troubles, high blood pressure, headaches, dizziness, inefficiency and insomnia. Therefore, many studies attempt to reduce noise pollution by applying noise barriers at noise polluted areas via various approaches. This paper aims to explore the effectiveness of noise barriers using noise absorption performance due to several factors such as type of absorbent materials, material thickness, density, porosity and design. This research has found that the thicker the specimen and the denser the absorbent material, the better the sound absorption performance. Besides that, barrier design also plays a major role in determining its effectiveness, where the effectiveness of noise barriers should be high and long enough to break the line-of-sight between the sound source and the receiver. There are several methods that can be used to measure the effectiveness of noise barriers such as the Adrienne Method (in-situ measurement method) and impedance tube method (laboratory measurement method) to measure the acoustic absorption. Nevertheless, the impedance tube measurement method provides the most precise results with the least measurement uncertainty as it only required small samples of the material.

1 Introduction

In a densely populated city with many high-rise buildings, noise pollution is one of the environmental problems that has been addressed with high priority [1]. A rapidly increasing population around the world accompanied by increasing consumption and a developing economy continue to generate noise pollution, where almost 80% of city traffic noises come from vehicles such as trains, cars, buses and motorcycles which are the major sources of noise in a modern environment. According to H. B. Huang et. al [2], there are various sources which contribute to vehicle noise which including axle-gear, tires, wind and engine. Meanwhile, Pultznerov and Izvolt [3] has identified railways as one of the most important modes of transportation for developed countries such as Korea, Japan and etc. Nowadays, rail transport has contributed to the biggest environmental noise issue even though it requires less energy and emits less hazardous substances [4]. Based on Comision & Energy [5], railways noise originates from the rolling noise, noise from traction, auxiliary system and aerodynamic noise. Noise is primarily defined as "disagreeable or undesired sound" or other disturbance. Bruneau [6] has indicated that noise and sound are constituted in the same phenomenon of atmospheric pressure fluctuations about the mean atmospheric pressure, where the differentiation is greatly subjective.

According to Hanidza et al. [7], the average level of sound pressure at night of 40 dB and 55 dB as an interim target should be the target to be achieved in order to prevent nocturnal noise deleterious health consequences which is recommended by the WHO regional office for Europe. In Malaysia, the Department of Environment has identified that the average transportation noise levels in major cities in peninsular Malaysia are 71.6 dB (A) and 70.4 dB (A) during the day and night respectively. However, a noise level above 55 dB (A) is considered as noise pollution [8]. If noise above this level lasts for an extended period of time, the efficiency and well-being of a person will be reduced [9].

Noise pollution issues have reduced the quality of life of human beings. Bistrup et al.[10] found that the

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exposure of noise to humans depends on the emission of sound, how the sound is received by the human body and the setting for the emission and perception of sound. Noise in the range of 65 to 75 dB (A) causes stress to the body, which can lead to arterial hypertension (high blood pressure), cardiovascular disease and myocardial infarction (heart attack) [11-13]. Besides that, the highest level of noise will also reduce gastric secretion and cause stomach ulcers [14].

Popović et al. [15] have listed several health problems caused by noise such as uneasiness, irritability, tendency towards depression, insomnia, digestive problems, cardio-vascular diseases and deafness. Even though noise can be classified as a slow and subtle killer, it could also be so severe that it may lead to permanent loss of memory or a psychiatric disorder [16-18]. Therefore, many studies on noise pollution using different approaches are actively being conducted at the moment [19][20].

In order to reduce noise pollution caused by noise from rail transport and to protect the health and the quality of life of people living close to railroads, noise barriers could be used as it is considered as one of the best noise reduction devices. Maffei and Luigi [21] also stated that noise barriers are the main solution for noise mitigation and very often provides a good insulation. All related devices that act on airborne sound propagation (road/rail covers, claddings and added devices) are collectively called Noise Reducing Devices (NRDs) [22].

Noise barrier is a structure that is built between a noise source and a receiver which may be living or non-living. However, there are several types of materials that could be used for noise barriers such as wood, concrete, masonry, metal, gabion and transparent materials [23], where the materials used for barriers must be of an impervious material with a minimum surface density of 4lb/sq. ft to ensure that the noise barrier is effective for reducing noise levels. The effectiveness of certain noise barriers is determined by its dimensions and material used, where the noise barrier should have a transmission loss of at least 10 dB (A) greater than desired noise reduction[24]. Though the noise barrier could mitigate or reduce the noise level, it cannot block the noise from the source to the receiver completely. However, the evaluation of effectiveness of noise barriers could be determined by using the insertion loss method which is defined as differences between the measured sound pressure levels behind existing barriers and without barriers [25]. However, little emphasis has been placed on the evaluation of the effectiveness of noise barriers. This, this paper aims to determine the effectiveness of different types of existing noise barriers in the industry in terms of materials used, parameters and shapes identified by using the insertion loss method.

2 Methodology

According to P. Guidorzi and M. Garai [26], several methods can be used to determine the effectiveness of noise barriers. The Adrienne method is one of the methods that can be used to measure in-situ sound reflection, diffraction and airborne sound insulation. N. D Jambrosic [27] has indicated that the Adreienne method (in-situ measurement method) has been developed to measure the acoustic absorption or reflection coefficients in-situ, where this method uses one single-driver loudspeaker and one microphone in a fixed position from the loudspeaker. However, this method also has two measurements systems; in-situ measurement absorption coefficient and the second method which is basically similar to the first method, but it is used with the multiplication of impulse responses with the ratio between the estimated time of the arrival of the direct incoming sound impulse and the estimated time of the reflected incoming sound impulse (used in some commercial acoustic measurement application) such as Easera software [27] as shown in Figure 1 and Figure 2. Both systems introduce significant harmonic distortion but the Adrienne method produces less harmonic distortion than second method.

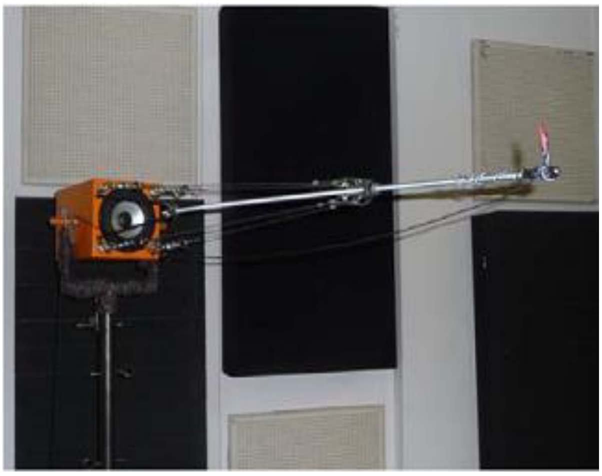

Figure 1: Configuration of the Adrienne method for in-situ measurement of the absorption coefficient.

Figure 2: Configuration of the second method

Sound sources emitted the sound wave in both methods that travel past the microphone position to the device under the test and are then reflected on it [27]. The surface undergoing the test can be an absorbing material such as noise barrier material to determine its absorption coefficient. A hard surface with a absorption coefficient of less than 0.05 is selected as a reference to be compared with the tested material. Figure 3 shows the measurement set up. The source and the microphone are 125 cm apart

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and the microphone is placed 25 cm away from the measured surface.

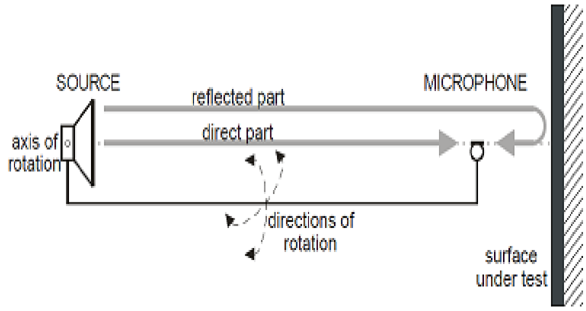

Figure 3: Measurement set up

The signal subtraction technique is used to separate the direct component and the reflected component by extracting the reflected component from the overall impulse response after the direct component is removed by subtracting the identical signal. For the Adrienne method, the reflected part of the impulse is being multiplied with time due to the longer time taken compared to the direct part. Meanwhile, for the second method, the correction factor is obtained by dividing the arrival time of the reflected component with the arrival time of the direct component [27]. Figure 4 shows the direct comparison of measurement between the two methods which is between the Adrienne method and the Easera software. It is obvious that the absorption coefficient is higher when the sound travels at a greater angle due to the thicker area of absorption material.

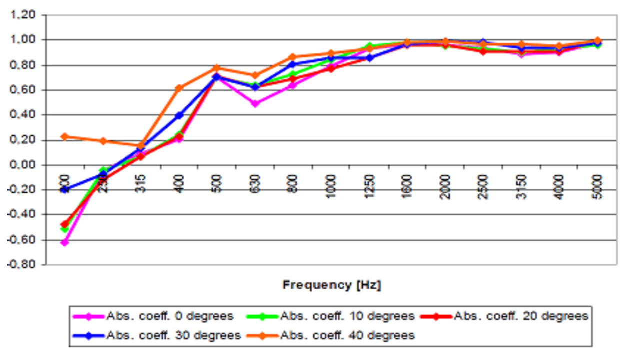

Figure 4: Absorption coefficient measured for various angles of incidence

Both methods are compared and they show a good agreement if the measured absorption coefficient is very high, but it shows disagreement for the lower values [27]. Besides that, laboratory measurement method also can been conducted in order to determine accurate measurement of the normal incident acoustic impedance and requires just a small sample of absorbing material to be tested, which used a standing wave tube or called as the impedance tube method (as shown in Figure 5). Using this method, acoustic waves produced by a loud speaker travel down a pipe and are reflected from the test sample. The standing wave pattern in the pipe is formed by the phase interference between the waves which are incident upon and reflected from the test sample material. The incident and reflected waves are considered to have the same amplitude if 100% of the incident wave is reflected. The incident and reflected wave have different amplitudes when some of the incident wave energy is absorbed by the test material. During the test, the sound source is moved towards the specimen and the first sound pressure level minimum is detected and the corresponding voltage is read off the measurement amplifier.

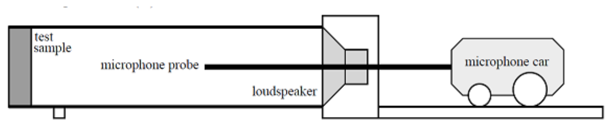

Figure 5: Standing wave impedance tube

According to C. Heed [28], the incidence sound absorption coefficient can be determined based on the ratio of the maximum and the minimum voltage corresponding to the measurements of the maximum to minimum sound pressure levels used to calculate the incidence sound. Therefore, it can be concluded that all methods listed are accurate measurements that have been used to measure the effectiveness of noise barriers. Nonetheless, the in-situ measurements of the absorption coefficient like the first and second method are not easy to carry out due to unfavourable measurement conditions. In addition, the main limitation of all systems based on the pass-by method and Adrienne method is the geometry of the measuring space [27], even though it is more economical in terms of measurement equipment and easy to be implemented. So, it can be concluded that the impedance tube measurement method provides the most precise results with the least measurement uncertainty where it only requires small samples of the materials to be measured either by using the standing wave ratio for discrete frequencies or by using transfer functions between two fixed points inside the tube where the pressure is measured using equalized microphones.

3 Noise Barrier Material and Design

3.1. Sound absorption material

For the last few decades, sound absorption materials have been used for reducing noise and reducing echoes in enclosed spaces [29]. Usually, absorptive materials such as porous materials are always used to reduce the reflection of sound by controlling airborne sounds. Besides that, there are several types of material which have the potential to absorb sound from several sources such as porous absorptive materials, fibrous materials and lightweight materials. Generally, porous materials are classified as fibrous medium or porous foam which is produced using various types of materials. On the other hand, fibrous media consists of high acoustics absorption and fire proof properties for several materials such as glass or rock wool [30-33]. According to T. Morimoto [34], more than 90% of air on porous absorbing materials leads to the dissipation of sound propagation through the small pores on the porous material. The performance of conventional absorbers depends on the pores and fibre structure. Conventional sound absorption materials can be expensive. However, nowadays many researchers are interested to take a similar approach in the development of sustainable sound absorbers by using waste material which has created environmental pollution.

Due to the abundance of waste materials, many researchers have taken innovative steps by exploring the potential of a variety of material as sound barriers. A. Amanda et al. [35] have investigated the potential of sugarcane bagasse for sound absorption application. Here, the comparison was done between three types of panels with and without sugarcane bagasse. The potential of coir as agriculture waste has also been investigated [36]. It was found that coir with the addition of recycled rubber is capable of absorbing sound with an average of 0.6 (sound absorption coefficient) which is caused by filler content. S. Ersoy and H. Küçük [37] have also investigated the sound absorption performance by using tea-leaf fibre and found the comparison between the different configuration of tea-leaf fibre with and without backing provided by a single layer of woven textile cloth. Meanwhile, H. K. Kim and H. K. Lee [38] have investigated the influence of lightweight aggregates on the acoustics properties of porous concrete due to different layers. The result has shown that the sound absorption coefficient for porous concrete has achieved the maximum value which is approximately 1.00. The minimum absorption coefficient of the 'double-layered porous concrete' structure is shown to be more than 0.60 with a frequency of 400 Hz or above, considering the tolerant error.

Therefore, acoustical material plays an important role in acoustics engineering in reducing the noise levels in various field. Usually, sound absorptive material is used to overcome unwanted effects of sound reflection and is also helpful in reducing the reverberation noise level [39]. Hence, the selection of sound absorbing materials was done based on several factors that will be discussed in this paper.

3.2 Factors influencing acoustics performance

Many researchers have conducted studies on the acoustics performance of noise barriers by using various types of sound absorptive materials. They have found several factors that will influence the absorption performance of noise barriers such as the types of materials, thickness, density, placement or position of the sound absorptive medium (noise barriers), compression, porosity and etc [29]. However, in this paper only six physical factors that have the greatest potential to influence the acoustics performance of noise barriers which are choice of materials, size of materials, porosity, thickness, density and design will be discussed.

3.3 Choice of materials

Noise barriers can be divided into reflective types, absorptive types, earth landscape and mixed types. Table 1 shows the details of each type mentioned.

TABLE 1: Types of noise barriers [24]

Types	Descriptions
Reflective type	Transparent and non-transparent
Absorptive type	Sound absorbent materials and possible finishes of absorptive panels
Earth landscape	Nature landscaped mound and retaining structures
Mixed type	A combination of all types

Despite the categorization in Table 1, the noise barriers are often divided into two groups which are either reflective or absorptive. The Environmental Impact Assessment (EIA) and Noise Impact Assessment (NIA) already determined the types of noise barriers such as reflective noise barriers, absorptive noise barriers or a combination of both.

3.4 Size of materials

The diameter of materials is one of the most important factors that need to be considered as it will influence the absorption coefficient during the test. According to Kouzumi et al.[40], the increase in fiber diameter tend to increase the coefficient of sound absorption as the movement of sound waves in thinner fibres occur more easily compared to thicker fibre. Meanwhile, P. R. Tahir et al, [36] used 5mm to 10 mm of recycled rubber particles as additional material and 10 to 20 mm of coir fibre in the mixture of composite boards with different percentages of fillers. It was found that the increase in the percentage of coconut coir up to 20% is suitable to be made as sound absorbing material due to the good properties of coconut coir which are cellular, light and porous. A. Putra et al. [41] conducted a study on sugarcane wasted fibres as a sustainable acoustic absorber with a diameter of 5 to 10 mm in length and it was found that sugarcane absorbers that possess ½ inch in thickness affects the acoustical performance which is better than commercial sound absorptive material. Moreover, the size of materials will also influence the acoustic absorption. H. K. Kim and H. K. Lee [38] discovered that 4 to 19 mm of aggregates have resulted in low absorption coefficients. This was due to a decrease in airflow resistance by means of friction of viscosity through the vibration of the air.

3.5 Thickness

Stein and Reynolds [42] concluded that the thickness of absorbent material is one of the important parameters that will affect the acoustic properties. A study on the acoustical performance of oyster shells has been conducted by E. Setyowati and G. Hardiman [43], with various dimensions of the samples which were tested to determine the absorption coefficient or sound transmission loss at 500 Hz to 1000 Hz. From the studies, it was found that the mixture with a thickness of 1 cm containing oyster shells and white cement has the largest potential to absorb sound. Meanwhile, A. Putra et al. [41] also investigated the effect of the thickness of an innovative absorbent made from tea leaf fibre and it was found that the sound absorption coefficient of tea leaf fibre with a thickness of 10mm is similar when compared with traditional absorbers such as polyester. The increase in sound absorption was due to the increase in sample thickness. Thicker samples will absorb more sound due to a longer travel distance by the impinged wave which causes it to lose more energy [44]. Besides that, H. K. Kim and H. K. Lee [45] discovered that the arrangement of material such as aggregates as absorbent material will affect the thickness of air gaps in panels. A decrease in frequency occurred due to the increasing thickness of the specimen. However, according to E. M. Samsudin et al. [29], the amount of absorption is not always proportional to the thickness of the absorbent material. It also depends on the type of materials and method of installation.

3.6 Density

The best sound absorption behavior depends on the density of the material which it is an important factor that needs to be considered in a research. According to A. Putra et al. [46], increasing amounts of sound absorber material added into a mixture will increase its density and subsequently improve the absorption at a higher frequency. Besides that, the density of absorptive material has shown an effect on flow resistivity. By adding the amount of absorption material into a mixture, the pores will become closer to each other which ultimately reduce the absorption capability. Meanwhile, L. Peng et al. [30] found that when the density of composite decreases, the acoustic wave reflection will be reduced due to the presence of larger voids (pores) inside the material.

Therefore, the acoustic waves in a less dense material will propagate more easily compared to denser material. In addition, the frictional and viscous resistance among the air particles and fibers inside the composite will also decrease due to the internal surface area [47-49]. Thus, most denser materials absorb more sound energy compared to less dense materials. However, in some cases, materials with higher density will absorb less sound energy due to non-fibrous characteristics of the materials. Materials that are more compact and dense are low in porosity which significantly affects its sound absorption performance

3.7 Porosity

Porosity is also an important factor that should be considered in this research. E. M. Samsudin et al. [29] has defined porosity as the ratio of the volume of voids to the total volume of the samples. By knowing the density of absorbent material, several methods can be used to identified the porosity of a particular absorbent material; dynamic method, static method and also by simple calculation [50]. Z. Hong et al. [51] have studied porosity by using several types of polymer perforated panels with different pore size and found that a panel containing rubber particles with a thickness of 3mm and pore size of 5 mm has a porosity of 4.75%. From the research, it is obvious that the porosity eventually affects the sound absorption performance of samples. The rubber particles have improved the sound absorption ability just like traditional porous materials such as PU foam or glass wool. According to S. Mahzan et al. [52], the absorbency of 60% recycled rubber will increase the porosity value up to 98.62% while a specimen with 100% recycled rubber has shown a reduction in porosity which is 86.59%. Therefore, it can be said that a higher content of absorbent material in a sample will fill up more voids and decrease the porosity of samples. In terms of absorption capability, when the porosity value is more than 70%, the value of absorption will usually remain constant. H. S. Seddeq [53] suggests that enough pores on the surface of material will allow sound waves to penetrate the porous material for maximum energy dissipation by friction.

3.8 Noise barrier design

H. Berger et al. [2] also stated that there are various factors that need to be considered in the production of noise such as traffic noise, construction noise, underwater noise as well as environmental and structural factors. The existing noise pollution mitigation methods could be improved by improving materials, parameters and shapes of existing noise barriers. Therefore, the designs of barriers also play a major role in determining its effectiveness [23][24]. Many designs have been proposed including classic wall type barrier and gabions [8]. Covering a T-shape barrier with a layer of mineral wool type absorbent material (flow resistivity r = 20,000 Nsm and thickness T = 0.1 m) could improve the performance of a single rigid barrier by 2.5 dB which is better than the performance of purely absorptive barriers [25]. The barrier must be high enough and long enough to break the line-of-sight between the sound source and the receiver [19]. Modification of the top edges of the noise barriers has been shown to be capable of increasing noise attenuation over that of a simple barrier of the same height [28]. However, the height of a noise barrier does not necessarily have to be too high but it can be as high as 3m or 4 m [20][23]. Nevertheless, noise barriers which are too long and too high cause other problems such as loss of sunlight and visual impact [26]. Therefore, the low height of noise barriers is mostly suitable for trains as the noise produced mainly originates from the rail tracks and bogie areas, which are close to the ground.

4 Conclusions

Effective noise barriers are usually able to reduce noise levels by 5 to 10 dB(A) and heavily depend on its dimensions as well as the location of the noise sources and the noise receivers [54-56] The ability of environmental noise barriers to reduce A-weighted noise levels depends on its design, materials, density of absorbent material, porosity and thickness [23]. A reduction as much as 5 dB(A) in noise level produced can be achieved if the noise barrier surface density exceeds 20kg/m2 and possesses a height tall enough to break the line of sight from the road to the receiver. An additional 1.5 dB (A) reduction can be achieved for each additional meter of height[23]. Therefore, some important remarks on this literature review for this research are:

1. The materials used to build certain noise barriers play a major role in reducing noise levels existing in a real situation. Different types of sound absorbent materials would result in different absorption coefficients.
2. The decrease in thickness and size of the absorbent material will affect the increase in the sound absorption coefficient.
3. Most of the findings show that denser materials will absorb more sound energy compared to less dense materials. However, when the density of the absorbent material is higher with low porosity, it will usually absorb less sound energy. Therefore, it can be concluded that density and porosity are related to each other.
4. Porosity influences the sound absorption performance of samples. Porosity decreases due to a high content of absorbent material which fills up more voids in a particular sample. However, some research has indicated that the absorption coefficient will remain constant when the porosity value is more than 70%.
5. Barrier design also play a major role where effective noise barriers should be high and long enough to break the line-of-sight between the sound source and the receiver
6. Most of the previous studies believe that the choice of materials, size of materials, porosity, thickness, density and design will influence the acoustic performance of noise barriers.
7. Various methods can be used to measure the effectiveness of noise barriers such as the Adrienne Method (in-situ measurement method) and the impedance tube method (laboratory measurement method). These methods can be used to measure acoustic absorption. However, the Adrienne method is not easy to carry out due to unfavourable measurement conditions.
8. Therefore, the impedance tube measurement method provides the most precise results with the least measurement uncertainty where it only requires small samples of the material.

To sum up, very little research focuses on the application of noise barriers for the railway industry even though it is one of the biggest contributors to noise pollution. Therefore, this warrants further research on this matter.

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