Rubberized asphalt mixtures: a novel approach to pavement noise reduction

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Abstract

Noise, which is defined as unwanted sound, is present everywhere whether at home, in an office, or on the road. When noise reaches a certain level, it becomes annoying or uncomfortable to the human ear. Highway noise is one such noise that has become a serious issue in many cities in the United States. Highway noise eminates from three main sources of a vehicle: the interaction between the tires and the pavement, engine and exhaust noise, and noise resulting from the aerodynamic effects of the vehicle. In an effort to mitigate highway noise, local, state, and/or federal agencies typically construct noise barriers adjacent to the highway. These barriers effectively reduce the noise heard by those located behind the barrier, but this method of noise reduction can come at a cost of up to $290/m^2 in some cases. In addition, some sound barriers are not aesthetically pleasing to the public. An alternative to constructing noise barriers is to address the highway noise problem at the source with the use of rubberized asphalt concrete as a surface course on the highways. Such rubberized asphalt mixtures have been proven to reduce the noise generated by the interaction between the vehicle and the pavement resulting in perceived noise reductions of 50% in some cases. Not only does the rubberized asphalt reduce noise generation, but it also provides more durable pavements that are less susceptible to the effects of temperature.
Keywords: highway noise, asphalt, rubberized asphalt, asphalt-rubber, noise pollution, open graded friction course.

1 Introduction

Throughout the United States, as with many other countries, once suburban areas are beginning to show signs of the urban areas they surround. One of these signs is the noise associated with the increased traffic traveling on the expanding highway infrastructure each year. In the US, there are more than 4 million km of paved roads, 1.36 million km of which are in urban areas [1]. Of these paved roads, approximately 97% are bituminous in nature (e.g., dense graded asphalt concrete, gap graded asphalt concrete, open graded friction course, stone matrix asphalt, etc.), while the remaining 3% consist of Portland cement concrete (PCC) pavements.

Traffic noise issues have become more pronounced in the past decade or so with the increase in size of the vehicles on the road. Today, the popularity of the sport utility vehicle (SUV), and larger vehicles in general, is responsible for much of the increase traffic noise in urban areas (Figure 1) [2]. Also, there is more truck traffic today as compared to a decade ago.

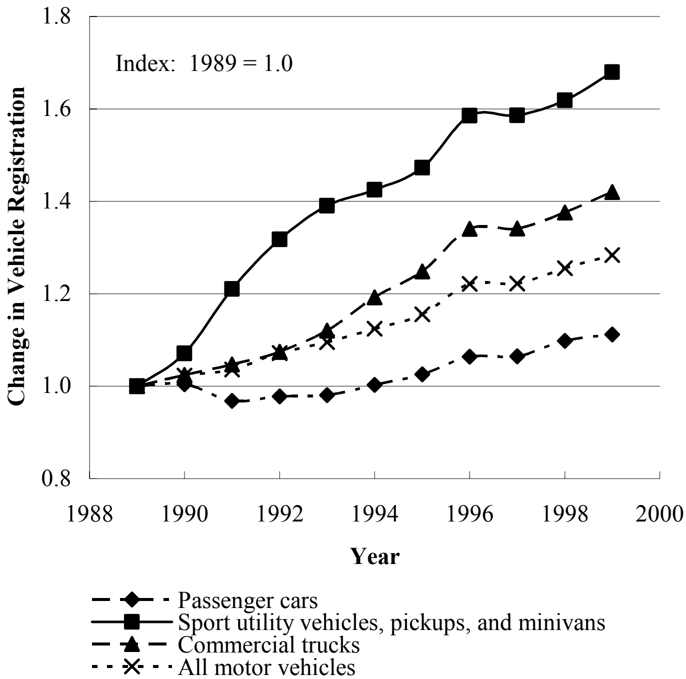

Figure 1: Vehicles registered from 1989 to 1999 [2].

In response to highway noise, highway departments have traditionally constructed large and sometimes unsightly noise barriers to dampen the intensity of the noise before reaching citizens in residential areas. These barriers, while relatively effective in decreasing the noise heard by residents local to the highway where the noise is generated, do not provide any reprieve to the motorists or the public not protected by a noise barrier. It was not until the 1990s that several investigations into such pavement noise issues commenced.

2 Highway noise

Noise is defined as unwanted sound and is measured in decibels (dBA). To put this unit of measure in perspective, the lowest sound that a person with perfect hearing can hear is 0 dBA, normal human breathing measures 10 dBA, and typical highway noise measures about 70 dBA (Figure 2) [3], which is considered to be in the uncomfortable range for most people. It is because of this discomfort that the Federal Highway Administration (FHWA) has selected 67 dBA as the point where federal and state agencies must consider reducing the noise level [4].

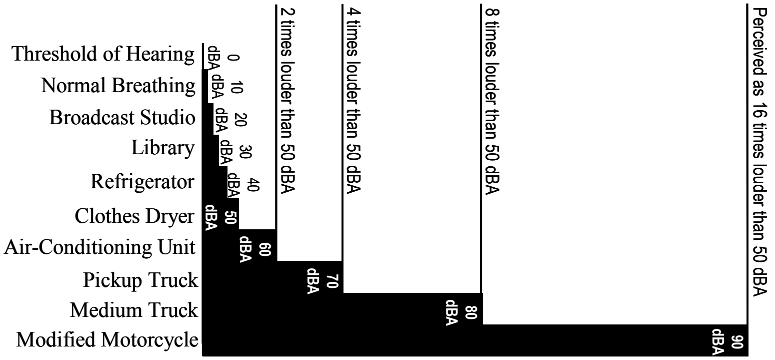

Figure 2: Illustration of typical sound levels (in dBA) and perceived loudness [2].

There are several factors that have contributed to pavement noise throughout the years: interaction of the tires and the pavement (78%), engine and exhaust noise (12%), and aerodynamic effects (10%) [4]. To help minimize highway noise, automobile manufacturers have developed quieter exhaust systems and engines, more efficient aerodynamic designs, "quieter" materials with which to manufacture vehicles, and tires having tread designs that reduce the noise generated by the rolling tire in contact with the pavement [5]. With the automotive industry leading the way in reducing pavement noise, the highway community is beginning to follow suit and investigate methods of reducing pavement noise from the pavement end of the spectrum.

Pavement noise studies have evolved in the past 15 years with a better understanding of pavement noise and the development of equipment well suited to accurately record pertinent data. Two main categories of highway noise measurement include pass-by methods and on-board measurements (e.g., close-proximity (CPX) and sound intensity methods). The pass-by methods employ the use of a sound meter located at some distance from the traffic being measured. This method captures the noise resulting from all factors of highway noise. The on-board methods provide the ability to isolate the noise generated only from the tire-pavement interaction. As this interaction is the most prolific source of highway noise, these methods are the preferred methods for determining the effects of pavement type on highway noise.

3 Rubberized pavements

The first use of scrap tire rubber in asphalt pavements in the United States occurred in the 1940s as a dry process was introduced by the US Rubber Reclaiming Company. The dry process requires that the crumb rubber is added to the aggregate (or dry components) prior to mixing with the asphalt binder. The wet process of utilizing crumb rubber in asphalt concrete was conceived in the 1960s and is still the most widely used method of incorporating crumb rubber into asphalt mixtures. In the wet process, crumb rubber finer than that used in the dry process is blended, or digested, with the asphalt binder (or wet component) and then mixed with the aggregate.

The use of rubberized asphalt concrete has provided more durable pavements that are less temperature susceptible. Rubberized asphalt pavements have increased viscosity, or stiffness, at high pavement temperatures to reduce permanent deformation. The increased flexibility of rubberized asphalt at lower pavement temperatures minimizes cracking as a result of low temperatures. Increased durability of rubberized asphalt pavements comes from an increase in the asphalt film thickness surrounding the aggregate particles as a result of an increase in the viscosity of the rubber modified asphalt binder. Such film thickness reduces the ageing of the asphalt binder due to oxidation over time, therefore, extending the life of the pavement.

The use of rubberized asphalt has spread from its early uses as patching material, to use in dense graded asphalt concrete, to use in open graded friction courses used as a primary wearing course in several states.

4 Noise reduction: noise barriers

On existing roads, or on roads that are being rebuilt, there are many noise reduction measures including: creating buffer zones, constructing barriers, planting vegetation, installing noise insulation in buildings, and managing traffic. Buffer zones are undeveloped open spaces which border a highway and the buildings, either residential or commercial, which occupy people. One of the advantages of the buffer zones is that they often improve the roadside appearance; however, in many cases because of the tremendous amount of land that must be purchased it makes it uneconomical alternative.

In addition to the buffer zones, some agencies use noise barriers, solid obstructions built between the highway and the homes along the highway, to reduce the noise level. In some cases, effective noise barriers have reduced noise levels by 10 to 15 decibels. These barriers are either earth mounds along the road (usually called earth berms) or high, vertical walls. In general, earth berms have a natural appearance and are usually attractive; however, they require a lot of land if it is very high. This type of noise barrier has not been used extensively for the last 15 years in the United States. For example, Arizona used over

46,000 m^2 of berms before 1992 and only 2200 m^2 since then. In contrast, walls take less space and are usually limited to 8 m in height for structural and aesthetic reasons. These noise walls can be built of many materials including wood, stucco, concrete, masonry, metal, and other materials. Most of the barriers in the United States are made of concrete and masonry block. Many cities attempt to construct noise barriers that are visually pleasing and that blend in with their surroundings [6].

In the United States, from 1963 to 1980, there were approximately 360 linear kilometers of noise barriers costing $187 million (2001 dollars) to construct. In addition, from 1981 to 1991 there were over 960 km of noise barriers constructed with a total cost of $810 million. From 1991 to 2001, over 1230 km of noise barriers were constructed costing over 1.56 billion dollars. California has the largest volume (over 770 km) of sound walls in the nation. The cost of construction of the sound walls depends on many factors (e.g., location, materials used, size of the project, etc.). For instance, concrete sound walls constructed in Colorado, on average, from 1997 to 2001 would cost approximately $290/$m^2$ compared to only 120 in Nevada [6].

Since 1960s, the federal, state, and local officials have been concerned about highway noise. The first noise barrier was built in 1963 in Washington State. Federal Highway Administration (FHWA), in 1976, published *Highway Noise Barrier Design Handbook* to help state, local, and highway engineers to address all issues involved with noise barrier design. Since then, many changes have occurred in all aspects of barrier design. Furthermore, there are more pressures from various communities and motorist interested in having less expensive and more aesthetically pleasing and environmentally friendly barrier designs [6].

5 Noise reduction: rubberized pavements

As an alternative solution to sound walls for mitigating highway noise, pavement surface type is beginning to find its place. In the past few decades, new pavement types have been used in the United States (e.g., open graded friction course (OGFC) and stone matrix asphalt (SMA)). These types of asphalt mixtures provide quieter pavements through a more interconnected void structure having the ability to absorb more noise. Also, these pavements are made with polymer modified asphalt binders, which create a larger film thickness and essentially insulate the hard, reflective aggregate particles, thereby, potentially reducing highway noise.

Other pavement solutions to highway noise have included the surface preparation of PCC pavements. The process of tining PCC pavements involves the creation of grooves in the surface of the pavement. The purpose of tining is twofold: increase pavement friction and decrease pavement noise. There are several tining patterns used in the US that provide some reduction of pavement noise when compared to smooth concrete (e.g., uniform transverse, random transverse, uniform longitudinal, and random longitudinal).

In 1990, the first evaluation of rubberized asphalt pavements as a noise reduction paving option was conducted in Tucson, AZ. Following this first study, Arizona led the way in the utilization of rubberized asphalt for sound reduction purposes, followed by California, Texas, and several other states since.

5.1 Phoenix, Arizona 2002

In 2002, one of the more recent pavement noise studies was conducted in Phoenix, AZ with the overlaying of existing Portland cement concrete (PCC) pavement with asphalt-rubber open-graded friction course (AR OGFC) [5]. This construction also included the addition of an additional travel lane in both directions. Noise measurements were recorded on the PCC pavement prior to construction in May 2002, while measurements were recorded less than a month later on the new AR OGFC pavement. It should be noted that environmental conditions were similar for both readings. The traffic volume and speed, however, were higher for the readings on the AR OGFC after the widening of the highway.

Figure 3 illustrates the recorded noise data at different locations along the highway as well as inside a vehicle. The noise data collected shows a significant reduction in noise with the AR OGFC as compared to the PCC pavement. With a reduction of 9.5 dBA at the location 30-m from traffic, the AR OGFC reduced the traffic noise by almost 50% (Figure 2). Vehicle occupants also experienced a reduction in noise by 5.2 dBA when driving on the AR OGFC pavement surface.

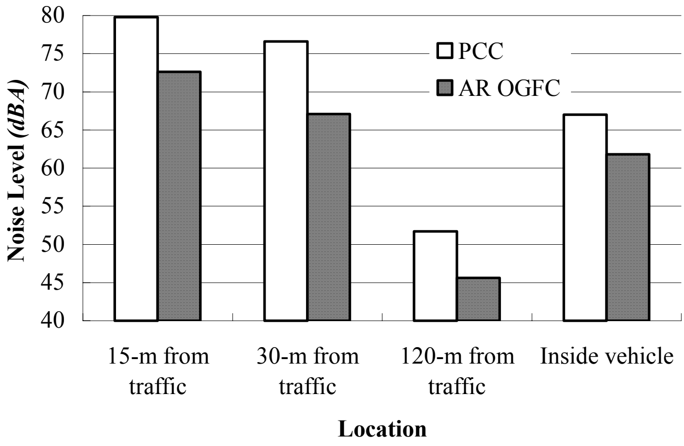

Figure 3: Average noise data from Phoenix, AZ study in 2002.

5.2 Sacramento County, California 1993 – 1999

In the mid 1990s, Sacramento County set forth to determine the effectiveness of rubberized asphalt in reducing highway noise with the evaluation of a resurfacing project in 1993 using an AR OGFC and a widening project in 1995 where the surface mixture was a rubberized dense graded asphalt course (DGAC) [7]. Another section included in the noise study, which used a conventional asphalt course (non-rubberized), was included as a control segment with which to compare the rubberized mixtures.

Figure 4 shows the reduction in noise from the 1993 section using AR OGFC. A 5 dBA reduction was maintained for six years after the resurfacing occurred. Again, this is a significant reduction in the highway noise as perceived by the public. The noise reduction of the rubberized DGAC was maintained at 3 dBA over a five year period (Figure 5). A reduction of 3 dBA is equivalent to doubling the distance from the noise source – a significant difference. Finally, the conventional asphalt overlay did not provide any appreciable noise reduction after four years of service (2 dBA reduction after one month and no reduction after four years).

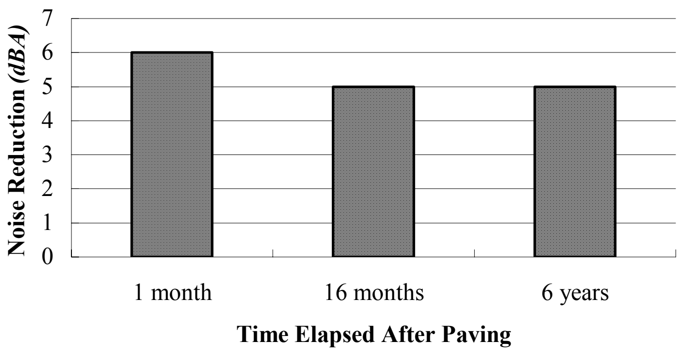

Figure 4: Noise reduction of AR OGFC in Sacramento County, CA.

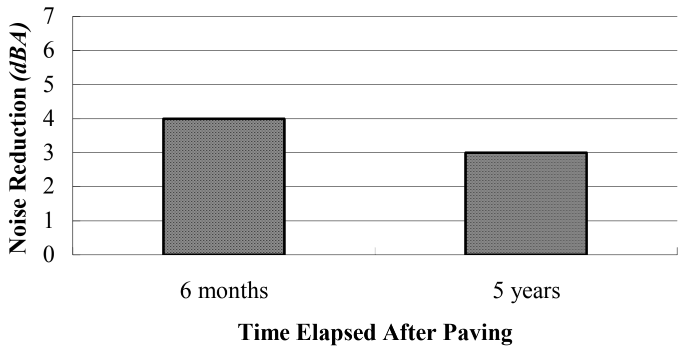

Figure 5: Noise reduction of rubberized DGAC in Sacramento County, CA.

5.3 San Antonio, Texas 2002

In 2002, the Texas Department of Transportation (TxDOT) overlaid more than 3-km of PCC pavement with an asphalt-rubber permeable friction course (AR

PFC) with the goal of reducing highway noise, among others [8]. Constructed in the early 1980s, the PCC pavement had only minor distresses, but had a history of wet weather accidents. In addition to the safety concerns, the pavement was also very rough resulting in excessive noise.

The 38-mm AR PFC, having a void content of more than 18% enabled TxDOT to achieve its goal of reducing noise on this section of highway (Figure 6). The average noise level of the PCC pavement prior to overlay was 85 dBA, which is considered very uncomfortable for most people. Following the overlay with the AR PFC, the noise level was reduced 14 dBA. This means that the use of the AR PFC, in this case, reduced the perceived noise level by more than half. In addition to measuring noise levels, TxDOT also measured the roughness of the pavement before and after the overlay (Figure 7). The significant reduction in pavement roughness, as measured by the International Roughness Index (IRI), is a major reason for the reduction in pavement noise by the AR PFC.

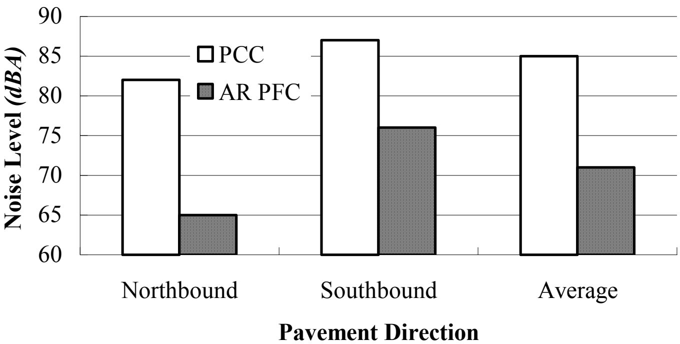

Figure 6: Noise data collected in San Antonio, TX in 2002.

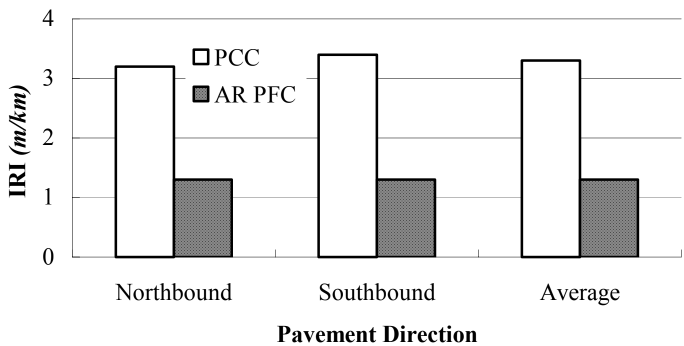

Figure 7: Roughness data collected in San Antonio, TX in 2002.

6 Conclusions

Highway noise is not a new issue in urban areas. Population growth in urban areas has led to increases in traffic volume generating more highway noise. Also, the size of vehicles has become larger in the past 15 years with the popularity of the sport utility vehicle (SUV), which generates more noise than the smaller passenger cars they are replacing.

Highway agencies have typically dealt with highway noise by constructing large noise barriers alongside of the highway. These barriers, while effective in dampening the noise heard by the citizens behind the barrier, are expensive and sometimes not aesthetically pleasing. Also, the noise barrier does not reduce the noise heard by the vehicle occupants using the highway. The only feasible method that will reduce the noise heard by vehicle occupants and neighboring citizens is to reduce the noise generated by the interaction between the vehicle and the pavement.

One method of reducing the noise of the vehicle/tire interaction is to utilize rubberized asphalt concrete as a surface course on the highway. Several test cases in the U.S. have shown marked reductions in pavement noise when compared to Portland cement concrete pavements, and even conventional asphalt concrete pavements without rubber. In many cases, a reduction in highway noise was evident even after widening of the roadway, resulting in higher traffic volumes and speeds. This noise reducing capability, as well as the increased durability and performance at both high and low temperatures make rubberized asphalt mixtures a novel approach to pavement noise reduction.

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