“quiet

Asphalt Pavements Mitigate Tire/Pavement Noise

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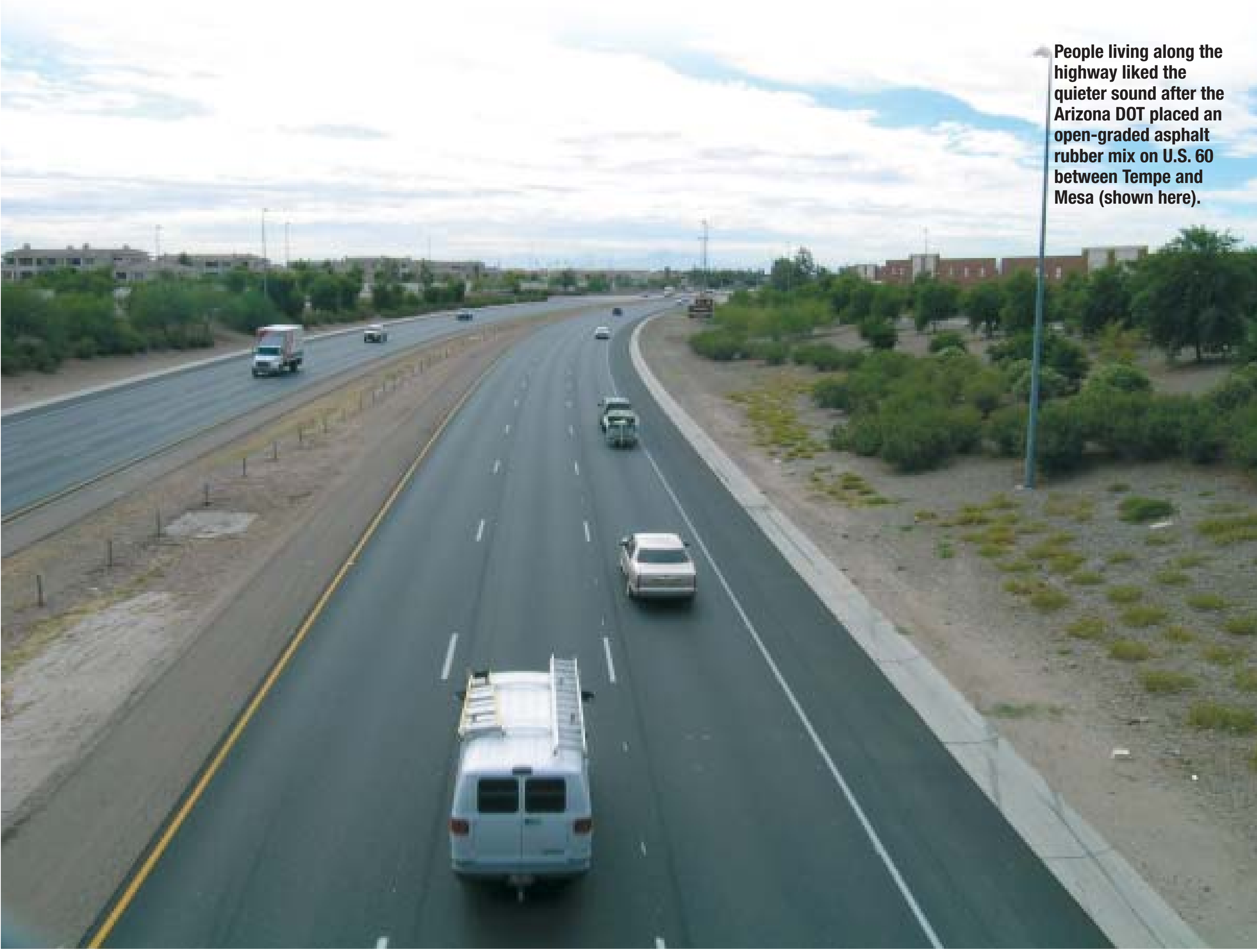
Roadside noise as experienced by people living near highways has become one of the major environmental concerns in the past decade. This environmental pollution does affect the public’s comfort, health, and general standard of living. The impact of roadside noise is acute at night when the other background noises are minimal. The traffic noise from the adjacent highway which is experienced as a “roar” during the day changes to successive individual sounds—the “gunshot” effect—at night. The problem of roadside noise is becoming increasingly severe as the traffic is increasing on highways, especially in urban areas.

NOISE AND ITS CONTROL: SOME BASICS

Noise is defined as “unwanted sound.” Like all other sounds, noise is a form of acoustic energy. An understanding of the physics of sound and how humans respond to it is required to understand noise.

Sound is an acoustic energy or pressure that is measured in decibels. It is not appropriate to use a linear scale to measure sound because human hearing covers a large range of sounds. If a linear scale of 0 to 1 were used to measure sounds, most sounds occurring in daily life p a v e m e n t s"



People living along the highway liked the quieter sound after the Arizona DOT placed an open-graded asphalt rubber mix on U.S. 60 between Tempe and Mesa (shown here).

would be recorded between 0.0 and 0.1. Thus, it would be difficult to discriminate between sound levels encountered in our daily lives using a linear scale.

Therefore, a logarithmic scale is used to represent sound levels in decibels or dB. The term dB(A) is most commonly used to represent the noise level perceived by a human ear. In other words, the inclusion of A after dB indicates the scale has been adjusted or "fine-tuned" for hearing by humans.

Since dB(A) is used with a logarithmic scale, a doubling of the sound is represented by a ten dB(A) increase. For example, a dB(A) of 90 is twice as loud as a dB(A) of 80. Similarly, if we combine two sounds of equal loudness we increase the total noise by only 3 dB(A). As shown in Figure 1, adding two freeway noise levels of 65 dB(A) each results in a total noise level of only 68 dB(A). This indicates that an increase of only 3 dB(A) in noise level is very significant since this is the equivalent of doubling the traffic volume. Both national and international noise test data, reported later in this article, have shown the noise level of portland cement concrete (PCC) pavements generally to be about 3 dB(A) higher than that of dense-graded Hot Mix Asphalt (HMA) pavements. Again, this is equivalent to doubling the traffic volume. In addition, in some instances asphalt overlays of concrete pavements have shown a noise differential as high as 8 dB(A). Therefore, we see that a proper selection of pavement surface type can minimize the noise problem.

The decibel scale ranges from 0 dB(A), which is the threshold of human hearing, to 140 dB(A), which can cause serious hearing damage. Table 1 gives dB(A) values for some common noises.

The noise level alongside a freeway might be in the range of 70 to 80 dB(A). Once the exterior continuous noise levels reach 65-70 dB(A), people inside a building have to close windows to hold a conversation. Ideally, noise levels in homes should not exceed 40-45 dB(A), levels that are often exceeded by traffic noise with the windows closed.

How do we control the noise? For roadside noise, we have to think of noise in terms of a source, a path, and a receiver. Typically, a source would consist of a passenger car or a truck. The path is the area between the vehicle creating the noise and any location where noise is objectionable. The receiver would be the facility or home where noise is objectionable.

Although trucks are louder as sources of noise, traffic that is primarily comprised of cars can sometimes be more annoying due to the constant "whining." At high speeds, the noise from tire/pavement interaction stands out over the noise from the vehicles' exhaust and engines. Again, a proper selection of pavement surface type is important to mitigate tire/pavement noise.

Generally, noise control is attempted in the path in two ways: increasing the distance between the source and receiver or inserting an obstruction (such as a noise barrier wall). Both methods will reduce noise levels.

Distance is a natural way of controlling the noise because geometric spreading reduces the level of sound. A vehicle in motion and bumper-to-bumper with other vehicles behaves like an endless train and is considered as a line source of noise rather than a stationary point source. Line source noise expands in a cylindrical shape and will decrease approximately 3 dB(A) each time the distance from the line source is doubled. For example, if the noise level from a stream of vehicles (a line source) at 100 feet is 67 dB(A), it would be 64 dB(A) at 200 feet. This can be restated in terms of pavement surface types, which have a difference of 3 dB(A) in noise generation at the pavement/tire interface. With the same amount of traffic, the noise level at 100 feet from an HMA pavement can be equal to the noise level at 200 feet from a PCC pavement.

The second option of noise control in the path is to construct noise barrier walls or berms to intercept the noise. Walls need to be at least as high as the line of sight from the vehicle to the building for effective mitigation of noise. Once the wall height intercepts the line of sight, a good rule of thumb is: increase the height by an additional 2 feet for each 1 dB(A) reduction in noise levels. For example, after a wall is constructed to intercept the line of sight and the resultant noise level at the roadside residence is 67 dB(A), it would require an increase of approximately 6 feet of wall height to obtain a noise level of 64 dB(A) at the residence.

There are two major disadvantages in using noise barrier walls for mitigating highway noise. First, noise barriers are very expensive. A study by the University of Louisiana showed that the national average cost of noise barriers is $1.25 million per mile. Second, noise barriers are not completely effective. Sound not only diffracts over the top of walls, it also diffracts around the end of walls. This typically requires the noise barrier to extend 400 feet beyond the last building for each one hundred feet behind the wall it is located. Therefore, noise walls are not effective on arterial streets due to the many driveways and side streets that allow noise to bend around the ends of walls.

Depending on the level of noise to be mitigated, it is possible to eliminate the noise barrier walls/berms by a proper selection of pavement surface type such as dense-graded hot mix asphalt (HMA), stone matrix asphalt (SMA), or open-graded asphalt friction course (OGFC). In other words, reduce the noise at the source rather than by erecting a barrier as shown in Table 3.

PAVEMENT SURFACE TYPES AND NOISE GENERATION

European countries have been very proactive in using pavement surface type as a noise mitigation strategy. Numerous studies were conducted in Europe in the 1980s and 1990s to determine comparative noise levels of dense-graded HMA, OGFC, and PCC pavements. General conclusions from some studies are given in Table 2. The World Road Association (PIARC) has reported

TABLE 1. COMMON INDOOR AND OUTDOOR NOISE LEVELS

Noises	Sound Level dB(A)
Threshold of pain	140
Jet flyover at 1000 feet	110
Gas lawn mower at 3 feet	100
Diesel truck at 50 feet	90
Food blender at 3 feet	90
Garbage disposal at 3 feet	80
Vacuum cleaner at 10 feet	70
Heavy traffic at 300 feet	60
Dishwasher next room	50
Library	35
Threshold of hearing	0

TABLE 2. NOISE FROM DIFFERENT PAVEMENT SURFACE TYPES: INTERNATIONAL STUDIES

Country/Agency (Year Reported)	Surface Types Evaluated*	General Conclusions
World Road Association (1993)	HMA, OGFC, PCC, Chip Seal	The following ranges of noise levels have been reported in this extensive report (see Figure 4): OGFC 69-77 dB(A); HMA 72-79.5 dB(A); and PCC 76-85 dB(A). This indicates the HMA is at least 4 dB(A) quieter than the PCC.
Belgium (1994)	HMA, OGFC, PCC	HMA was quieter than PCC (old pavement) by 3.4 dB(A). OGFC was quieter than PCC by 7.5 dB(A). OGFC was quieter than transverse grooved PCC by 10.5 dB(A).
United Kingdom (1993)	Rolled Asphalt	OGFC was quieter than Rolled Asphalt surface (used in U.K.) OGFC, PCC by 4 decibels. OGFC was quieter than PCC by 6-7 decibels.
British Columbia, Canada (1999)	HMA, OGFC	After three years in service, the OGFC is quieter than the HMA by 3.5 to 4.0 dB(A).
Italy (1990)	HMA, OGFC	OGFC was quieter than HMA by 3 dB(A).
Germany (1990)	HMA, OGFC	OGFC was quieter than HMA by 4 to 5 dB(A).
Sweden (1990)	HMA, OGFC	OGFC was quieter than HMA by 3.5 to 4.5 dB(A).
France (1990)	HMA, OGFC	OGFC was quieter than HMA by 3 to 5 dB(A).
Netherlands (1990)	HMA, OGFC	OGFC was quieter than HMA by about 3 dB(A).
Nordic Countries (1994)	HMA, OGFC	A joint Nordic project determined OGFC to be quieter than HMA by 3 to 5 dB(A).
Danish Road Institute (1992)	HMA, OGFC	OGFC was quieter than HMA by 4 dB(A).
Italy (1998)	HMA, SMA	As much as 7.0 dB(A) reduction in noise level has been reported at 110 km/h when SMA compared to HMA
Germany (1991 and 1998)	HMA, SMA	SMA was 2.5 and 2.0 dB(A) quieter than HMA

* HMA = dense-graded hot mix asphalt / OGFC = open-graded asphalt friction course / PCC = portland cement concrete / SMA = stone matrix asphalt

noise data from different pavement surfaces. The ranges of noise levels are given in Table 2 and are illustrated in Table 4. Many countries have guidelines for selecting pavement surface type based on the comparative noise levels. In the United Kingdom, for example, the Roads Agency's strategy for mitigating noise pollution is to overlay all major highways with asphalt by 2010.

The Danish government has planned to reduce the number of dwellings exposed to noise levels above 65 dB(A) by 66 percent by year 2010. In extreme cases, two-layer OGFC or porous asphalt is being used as a noise-reducing strategy in lieu of noise barrier walls.

This system incorporates a large stone mix (16 or 22 mm) in the lower layer and a smaller stone mix (5 or 8 mm) in the upper layer. This configuration not only dampens the noise, it also prevents the OGFC from clogging during service. The Alabama DOT has plans to construct a similar system in an urban area.

As summarized in Table 3, noise level studies have also been conducted in the U.S. for pavement surfaces comprised of HMA, OGFC, PCC, and SMA. The most extensive study was conducted by the Volpe National Transportation Center of the U.S. Department of Transportation in multiple states to collect data for developing FHWA's noise model. This extensive study showed PCC pavements were louder than dense-graded HMA by about 3 dB(A) for automobiles. At the present time, the FHWA noise model used for designing noise barrier walls does not take the surface type into account. The difference in noise levels of HMA and PCC surfaces increases further when PCC is grooved or tined transversely to improve skid resistance. In the case of HMA, if further reduction in noise level is desired, one can use SMA, one-layer OGFC, and two-layer OGFC in that order. Not only is the noise level reduced with these surface types, the skid resistance is also increased and hydroplaning is minimized.

Based on the international and national studies (Tables 2 and 3), the average comparative noise levels given in Table 4 are recommended at the present time for selecting pavement surface type as a noise mitigation strategy. The dense-graded HMA has been considered as a base reference.

Conventional HMA pavements have a surface texture which is **isotropic**; that is, the texture is similar in all directions. The opposite is **anisotropic**, which has an orientated texture; that is, the texture is mostly periodic and is in one direction. Common types of anisotropic textures are found in PCC pavements, which have been transversely or longitudinally grooved or have been brushed, usually in the transverse direction. Studies have shown that tire/road noise generation on an anisotropic surface is extra high if the texture is orientated in a transverse direction.

Some old PCC pavements may have faulted transverse joints, which make a "clap" sound when the tires pass over them. Most noise studies do not report these annoying "peak" sounds at the joints, even though they are certainly important to the people nearby. One study in Japan (1998) reported the peak "clap" noise to be 5 dB(A) higher than the "constant" noise from the surrounding road surface. For the drivers of the vehicles or the residents in proximity, these high noise levels at the joints are a major annoyance that should be mitigated.

RECENT SUCCESS STORIES

Federal guidelines require noise levels of 67 dB(A) or less at roadside residences. However, pavement surface type has not been allowed as a noise mitigation strategy by the FHWA. This has resulted in a mushrooming of noise barrier walls that often border highways, especially in urban areas. According to the FHWA, 1,630 miles of sound barriers were built in the U.S. between 1970 and 1998 at a cost of $1.9 billion.

Things are changing now. Some states such as Arizona, California, and Texas have become proactive by initiating field research projects to investigate the use of pavement surface type as a noise mitigation strategy.

After the Arizona DOT placed an asphalt rubber OGFC on the Superstition Freeway (U.S. 60) between Tempe and Mesa, drivers and people living along the highway liked the quiet roadway. Although the DOT had been using asphalt rubber OGFC for a number of years, the Superstition Freeway was the first to set off a public movement to demand more of the same. Arizona's state and local governments soon responded with a $34 million plan to resurface 115 miles of existing urban concrete freeways in the Phoenix metropolitan area with asphalt rubber OGFC.

The California Department of Transportation (Caltrans) has also used asphalt rubber OGFC successfully as a noise mitigation measure on Interstate 80 near Davis, Calif. Caltrans is beginning additional research on different pavement surface types. Construction of test sections will begin this year. The U.S. Department of Transportation's Volpe Research Center will measure noise levels for five years.

Noise Pollution:
It's Been Around for a Long Time

The roadside noise problem is not new. It has always been associated with the type of pavement surface. More than 2000 years ago, the clickety-clank of iron wheels on cobblestone pavement surfaces was a problem. This probably resulted in the first documented noise regulation. In 44 BC, Julius Caesar declared: "Hence-forward, no wheeled vehicle whatsoever will be allowed within the precincts of the city, from sunrise until the hour before dusk... Those which shall have entered during the night, and are still within the city at dawn, must halt and stand empty until the appointed hour."

It is apparent from the regulation Caesar preferred noise at night instead of during the daytime for unknown reasons. This contrasts with what Roman author Martial wrote: "the noise on the streets at night sounded as if the whole of Rome was traveling through my bedroom."

The same roadside noise problem still existed almost two thousand years later. In 1869, the British physician, Sir Norman Moore, wrote the following concerning London streets paved with granite blocks: "Most of the streets were paved with granite set (blocks) and on them the wagons with iron-tyred wheels made a din that prevented conversation while they passed by. The roar of London by day was almost terrible—a never varying deep rumble that made a background to all other sounds." This description of the noise is similar to aforementioned "roar" during the day and "gun shots" at night experienced by people living near highways at the present time.

Although macadam roads became popular in the US for rural road construction during the 1830s and 40s, the cities reverted to the use of block and brick street construction similar to what existed in Europe. Obviously, the public in US cities began experiencing the noise problem similar to what the British physician described. This led most major cities in the US during the 1870s to start using wooden blocks for street pavements in lieu of granite blocks. This was the first time a pavement surface type was used as a noise mitigation strategy. The noise issue was so important during the late 1800s that communities were willing to accept the significantly shorter service life of wooden blocks compared to granite blocks. Wood blocks also presented a fire hazard, as experienced in the Chicago fire of 1871.

The early 1900s saw the advent of hot mix asphalt along with the development of motorized vehicles. The asphalt pavements were smooth and quiet. During the 1900s, the use of motorized vehicles became increasingly common, resulting in ever-increasing noise levels. However, during the 1900s pavement surface types were not generally used to mitigate noise as was commonly done at the end of the 1800s. It is still uncommon today as a policy, which is a complete turnabout in just 100 years.

TABLE 3. NOISE FROM DIFFERENT PAVEMENT SURFACE TYPES: NATIONAL STUDIES

State/Agency (Year Reported)	Surface Types Evaluated*	General Conclusions
U.S. Department of Transportation (1995)	HMA, OGFC, PCC	Volpe National Transportation Center of the U.S. Department of Transportation made numerous noise measurements in multiple states to collect data for FHWA's noise model. For automobiles, PCC pavements were about 3 dB(A) louder than dense-graded HMA. OGFC was about 1.5 dB(A) quieter than dense-graded HMA. (Note: These OGFCs do not represent European type new-generation OGFCs which are used now in the US and are significantly quieter.)
Wisconsin (1997)	HMA, PCC	The noise from HMA pavements was about 2 to 5 dB(A) less than PCC pavements.
Michigan (2002)	HMA, SMA, PCC	A limited number of pavements were tested by close proximity method. Considering the noise data obtained at 60 mph with an aggressive tire pattern the following noise levels were recorded in dB(A): SMA=98.3, HMA=98.8, and PCC=98.9 to 100.8. For PCC, the quietest surface was the diamond ground with 98.9 dB(A), which was about equal to HMA.
Oregon (1994)	OGFC, PCC	Compared to PCC pavements, the OGFC pavements were 5.7 to 7.8 dB(A) quieter.
Maryland (1990)	OGFC, PCC	The OGFC was quieter by 2.3 to 3.6 dB(A) than the PCC pavement.
New Jersey (1994)	HMA, SMA, PCC	One PCC pavement and one HMA pavement were overlaid with SMA. Noise levels were determined before and after overlays. Measurements during the afternoon rush hours showed SMA to be quieter than PCC by 4.1 dB(A), and quieter than HMA by 2.1 dB(A). The HMA pavement was quieter than PCC by 2.0 dB(A) before overlays.
Minnesota (1979, 1987, and 1995)	HMA, OGFC, PCC	OGFC was found to be quieter than HMA in the 1979 study. HMA was found to be quieter than PCC in all three studies.
FHWA (1975)	HMA, OGFC, PCC	Noise level studies were conducted in Arizona, California, and Nevada. Based on average dB(A) values, OGFC was quieter than HMA by 2 dB(A), and HMA was quieter than PCC by 1 dB(A). Again, old design OGFC were tested.
Texas (2003)	OGFC, PCC	An existing continuously reinforced concrete pavement (CRCP) was overlaid with asphalt-rubber OGFC. On average, the roadside noise was reduced from 85 to 71 decibels. The reduction of 14 decibels is very high and is possibly the largest noise reduction ever recorded on a Texas DOT project.
Michigan (2000, 2001)	HMA, SMA, PCC	The first study (2000) was conducted on Interstate 275, west of Detroit. It indicated Superpave HMA was 4-5 dB(A) quieter than PCC. The second study (2001) conducted on Interstate 94, west of Ann Arbor, indicated a 12.5 mm SMA was approximately 4 dB(A) quieter than 12.5 mm Superpave HMA.
California (2002)	HMA, OGFC	After four years in service on Interstate 80 near Davis, the OGFC is quieter than the HMA by 4 to 6 dB(A).
Maryland (1994)	HMA, SMA	Average noise level of SMA was 1 dB(A) lower than HMA.
Wisconsin (1993)	HMA, SMA	Similar to Maryland, average noise level of SMA was 1 dB(A) lower than HMA.

* HMA = dense-graded hot mix asphalt
OGFC = open-graded asphalt friction course
PCC = portland cement concrete
SMA = stone matrix asphalt

The Texas DOT has also experienced outstanding success with the use of asphalt rubber OGFC as an overlay over the existing continuously reinforced concrete pavement (CRCP) on a project in San Antonio. The OGFC reduced the noise levels by an average of 8 decibels and improved the surface friction by more than 200 percent. Numerous positive comments were received related to noise reduction from local business owners and residents.

The Institute for Safe, Quiet and Durable Highways (SQDH) at Purdue University is the only center in the U.S. dedicated to research aimed at mitigating highway noise while still maintaining the safety and durability of the pavement. Created by the Transportation Equity Act for the 21st century (TEA-21), the SQDH Center has built a huge tire/pavement test apparatus which looks like a giant drum with different types of pavement mounted on its perimeter. Tires roll over the pavement and the resulting noise is measured. After a year of research, the SQDH researchers report that different types of tires do not mitigate the noise very much—but different types of pavement can.

Now, the FHWA is also supporting research that tests how different pavement surfaces reduce highway noise, by initiating pilot programs in Arizona and California.

The first attempt to use pavement surface type for noise mitigation was made in the U.S. during the 1870s by substituting wooden blocks in lieu of granite blocks for street pavements. It appears that, after a lapse of some 130 years, we are going to make a second attempt.

Acknowledgment

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TABLE 4. AVERAGE COMPARATIVE NOISE LEVELS OF DIFFERENT PAVEMENT SURFACE TYPES

Pavement Surface Type	dB(A)
Open-graded asphalt friction course (OGFC)	-4
Stone matrix asphalt (SMA)	-2
Dense-graded hot mix asphalt (HMA)	0 (reference)
Portland cement concrete (PCC)*	+3

* Noise level is likely to be significantly higher if PCC has transverse grooves or tining