NEW RESEARCH IN NOISE REDUCTION AND SAFETY

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ABSTRACT

Noise is defined as a loud sound of any sort that is disagreeable or unwanted. Throughout the ages of civilized history, noise has been an annoying irritant to mankind. In recent years the noise level of freeways in urban and suburban areas in the United States has increased perceptibly as freeway traffic has increased and more people are living closer to freeways. To reduce such a noisy irritant generated by traffic on concrete or asphalt pavements Arizona has employed either a 12.5 or 25 mm asphalt-rubber open graded friction course hot mix surfacing. This paper reviews the experience and research in Arizona and California with using asphalt-rubber open graded friction course pavements to reduce the noise by 3-12 decibels. These findings have led to Arizona developing a large scale program of covering over 2000 lane kilometers of concrete pavement with a 25 mm asphalt-rubber open graded friction hot mix surface course to substantially reduce noise. This program started in 2002 and is referred to in Arizona as the Quiet Pavements Program and has been very successful. In addition Texas has noted an improvement in safety due to the use of open graded permeable surface courses.

1 BACKGROUND ON NOISE AND HIGHWAY NOISE MEASUREMENT

Noise is defined as a loud sound of any sort that is disagreeable or unwanted. Through the ages of civilized history noise has been an annoying irritant to mankind. The Roman Emperor Caesar decreed in 20 BC that carts could only move through the city of Rome during the night, since their noisy din during the day interfered with the daily business of Rome. Carts moving through Rome at night were acceptable since Caesar and his court lived in the mountains far from the noise of the carts in the city. As the centuries passed by mankind has tried to live in a peaceful world. Horse drawn wagons and coaches with wooden wheels and iron rims generated plenty of noise in the 1800's. In the late 1800's in England road builders used wood blocks and even rubber blocks to deaden the wagon wheel noise. In the 1900's with the advent of automobiles and rubber pneumatic tires it appeared the tire/pavement noise had finally ended for all time. However, as more automobiles and trucks took to the highways, freeway noise gradually crept back into the city.

To measure the tire pavement noise several measurement instruments were developed. The noise measurement instrument, which is most commonly used, is an electro-acoustical device with a microphone that converts sound pressure (a scale value) into an electronic or voltage signal, or vice versa. The instrument has a variety of names such as noise meter, sound meter, or sound level meter. When placed near a sound source, it will display or readout a single number of the corresponding decibel level in dB or dBA. The

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dB level refers to the sound or noise level in general, whereas the dBA value is a sound or noise measurement adjusted to the level of sensitivity of human hearing. The value of sound or noise is a function of frequency typically it is obtained by averaging the sound pressure over a pre-set frequency band of about 100 Hz to as high as 20,000 Hz. Figure 1 shows common sources of noise and the associated noise level.

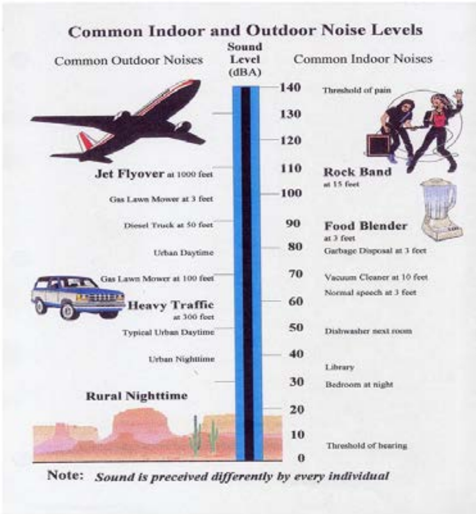

Figure 1. Noise levels from quiet to very loud (Courtesy of Arizona DOT)

There are several noise measurement methods for measuring the traffic related level of noise. The most common method is the wayside method which generally is conducted by measuring the noise with a typical noise meter placed approximately 15 m from the center of the roadway to be tested and a typical height of 1.5 m, Figure 2. Although the USA has used the wayside method of measuring noise there is presently no AASHTO or ASTM standard, albeit work is underway by both groups to develop a wayside standard. There is a European standard for this testing (ISO 11819-1 1997).

Figure 2. Wayside method of measuring noise

Recently a mobile trailer form of measuring tire/pavement interface noise has been developed. This method is called the Close Proximity method or CPX method, (a.k.a. "The trailer method"). There is no AASHTO or ASTM standard. As described by a paper presented at Inter-Noise 2007 (Leeuwen 2007) there is a European standard for this testing now in draft form (ISO 11819-2 2011). Figure 3 presents a picture of the trailer as used in the USA. The CPX trailer method was used to accomplish much of the original work described in this report. As used in the USA the test tire is mounted in a trailer, which is towed by a towing vehicle. Close to the test tire, generally within 0.1-0.5 m, one or more micro- phones are located. The noise level is measured as an average over a certain time interval, usually 4-60 seconds. Most trailers have an enclosure around the microphone and test tire in order to provide screening from wind and traffic noise. Such enclosures are lined on the inside with sound absorbing material. Some trailers may utilize more than one test tire. The method may also utilize especially designed self-powered vehicles. This method is less sensitive to noise generated by other traffic. This equipment is essentially designed for comparing road surfaces.

Figure 3. CPX trailer method of measuring noise

The newest form of measuring the tire pavement interface noise is the noise intensity method, now referred to as the On Board Noise Intensity (OBSI) method of tire pavement noise measurement. The American Association of State Highway and Transportation Officials (AASHTO) has developed an OBSI standard test method (AASHTO TP 76-10 2010) and the American Society of Testing Materials (ASTM) is developing an international OBSI standard noise measurement. The sound intensity measuring hardware consists of a probe (microphone pair) held next to the tire/pavement contact patch by a fixture attached to the wheel studs of the test tire/wheel. The microphone is cabled to the interior of the vehicle where the signals are simultaneously captured on a recorder and processed by a real time-analyzer. The specially tuned microphone only picks up the noise of the tire pavement interface and virtually no other noises from wind or other vehicles or any other sound. Figure 4 shows a an early typical installation.

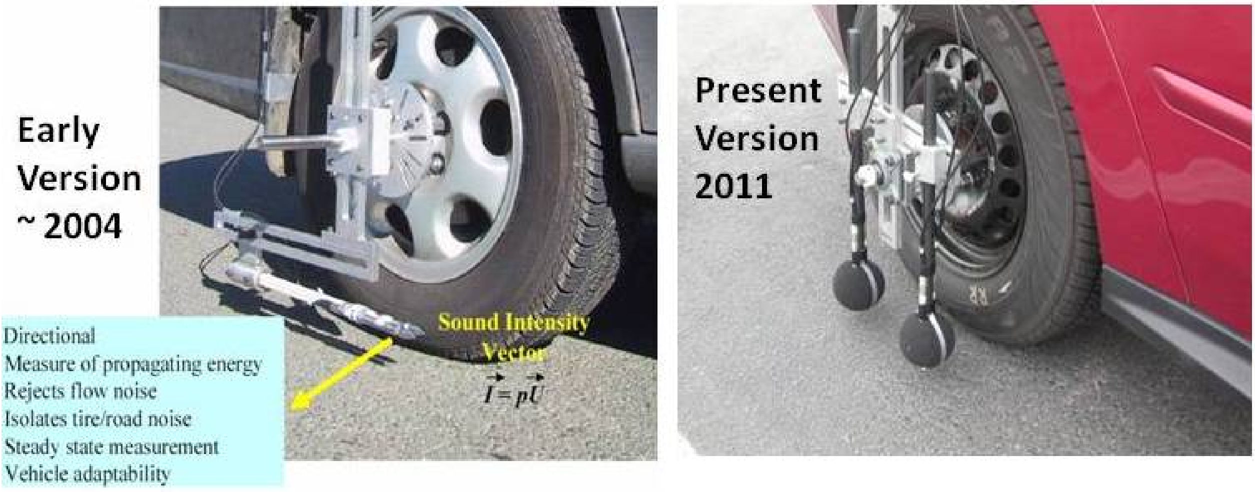

Figure 4. Early version of the OBSI equipment of measuring noise

2 ASPHALT-RUBBER OPEN GRADED SURFACE

To reduce such a noisy irritant generated by traffic on concrete or asphalt pavements both California and Arizona have employed a 25 mm asphalt-rubber open graded hot mix surface course referred in this report as ARFC. Asphalt-rubber binder is a mixture of 80 percent hot paving grade asphalt with 20 percent ground tire rubber produced from waste tires (Way 2001 and Zareh 2009). The resultant asphalt-rubber binder mixture is added hot, to a hot open graded mineral aggregate to produce an ARFC as the final wearing course of the pavement structure. This paper reviews the experience in both California and Arizona with using an ARFC mix to reduce the noise by 3-12 decibels. Research has been conducted in both states to determine the nature of the noise and how best to measure it and to compare the results of such tests to various pavement surfaces to reduce the noise to an acceptable level. Findings from this research include the following observations, namely that wayside measurements have shown that an ARFC can achieve 3 to 5 dBA noise level reduction when compared to traditional asphalt dense graded surfaces and 6 to 12 dBA noise level reduction when compared to concrete surfaces. In addition sound intensity measurements by CPX or OBSI have shown that an ARFC is effective in reducing noise by 4 to 6 dBA compared with traditional dense graded asphalt concrete and by 6 to 12 dBA when compared to concrete surfaces. These findings have led to Arizona developing a large scale program of covering over 1500 lane kilometers of relatively new concrete with a 25 mm ARFC surface to substantially reduce noise. This program is referred to as the Quiet Pavements program and has been very successful (Zareh 2009).

3 ARIZONA QUIET PAVEMENTS PROGRAM

Phoenix, Arizona and its surrounding suburban sister cities have experienced a tremendous growth in population in the last 50 years. Phoenix is one of fastest growing cities in all of the country and now is the fifth largest city in population in the USA. With growth in population has come the growth in automobile traffic and the need for more freeways in the Phoenix Metropolitan area. In 1985 the citizens of Maricopa County, which includes Phoenix and numerous sister cities, voted in favor of a 0.5 cents sales tax to fund the design and construction of over 200 kilometers of new freeways. Since the funding only addressed design and construction of the freeways and not maintenance or rehabilitation it was decided that the freeways would be built with concrete pavements. Starting in 1986 construction of the freeways began and with time more miles were completed and more people bought homes built near the freeway, and they began to notice the annoying noise of the freeways. Even though sound walls were constructed to mitigate the noise, complaints about noise continued. In the year 2000 the Arizona Department of Transportation (ADOT) began construction of the widening of 17 km of Superstition Freeway which is in the Phoenix Metropolitan area. The freeway construction included widening the concrete pavement from three lanes to six lanes in each direction to accommodate the over 150,000 vehicles a day that use the freeway, Figure 5. As part of this major construction ADOT decided to overlay all the lanes full width with an ARFC. The ARFC surface was selected to provide a new surface with a smooth ride, good skid resistance for safety, a new surface that could be plainly re-striped and to reduce the tire/pavement noise.

Figure 5. Superstition Freeway in 2003 with ARFC surface (Courtesy of Arizona DOT)

As construction the ARFC drew to a close people began to notice the new ARFC riding surface was very quiet. Unexpectedly, they began writing to newspapers and calling local radio talk shows in praise of the ARFC. From this action groups sprang up to petition government to cover all the concrete freeway miles with an ARFC. The local governments and state government heard the voice of the people and developed a Quiet Pavements Program in December 2002, (Carlson 2003 ; Scofield 2003). Then Governor Jane D. Hull and ADOT Director Victor Mendez informed the public that over the next three to four years ADOT in cooperation the Maricopa Association of Governments (MAG) would overlay the concrete freeway system with an ARFC. The cost of this Program was estimated to be 34 million dollars ($3.50/Sq. meter) and it is considered a Quality of Life issue for the people of the Phoenix Metropolitan area. Figure 6 shows how much the ARFC reduce noise.

Figure 6. Superstition Freeway 2002 noise reduction due to asphalt-rubber open graded mix, courtesy Rubber Pavements Association, noise measured in dBA

4 TIRE/PAVEMENT INTERFACE NOISE MEASUREMENTS FOR VARIOUS SURFACES

California and Arizona tested many different surface types for their tire/pavement noise using both the CPX and OBSI test methods. As shown in Table 1 the ARFC is less noisy in absolute terms than concrete surfaces with different surface textures.

Table 1. CPX noise measurements at the tire/pavement interface and estimated wayside noise 15 m away from tire in dBA

Surface Type	CPX Noise	Noise 15 m Wayside
Concrete Random Transverse Tining	104.9	80.9
Concrete Transverse Tining	102.5	78.5
Concrete Longitudinal Tining	99.1	75.1
Concrete Whisper Grind	95.5	71.5
ARFC	91.8	67.8

In addition to what is shown in Table 1 there is the second part of the story. When an ARFC is placed over a concrete freeway section the noise level reduction to the human ear seems even more dramatic. From noise testing done by the ADOT and California DOT it was possible to record the noise spectrum over a wide range of frequencies. The human ear can hear sounds from about 500 Hz to about 20,000 Hz. Sounds in the 1,000 to 2,000 Hz range tend to be of an annoying type to the human ear. By recording the frequency spectrum of the concrete pavements it was observed that transverse textured concrete has a tonal spike in the 1,000 to 2,000 Hz range (Scofield, 2003) that is particularly annoying to human hearing as shown in Figure 7. The longitudinal and whisper texture concrete has less of a spike, however the ARFC actually has a dip in the 1,000 to 2,000 Hz range which means to human hearing there is very much less annoying noise being heard. In effect the ARFC is both reducing the overall noise over all frequencies and the irritating tonal spike noise in the 1,000 to 2,000 Hz range.

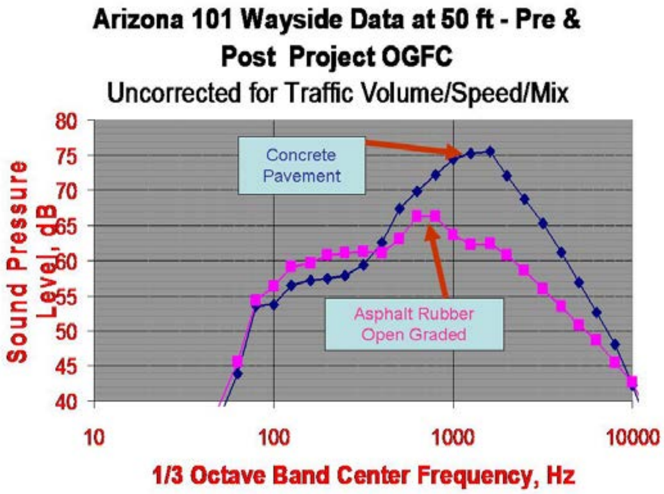

Figure 7. Noise reduction in the 1,000 to 2,000 Hz range due to an ARFC surface, (Scofield 2003)

As further documentation of an ARFC noise tests from many different surfaces were compared and combined into a single illustration (Donovan, 2003), shown in Figure 8. As can be seen the least noisy surface measured to date is an ARFC. The ARFC produces less noise as documented in numerous reports and by literally millions of people driving over the freeway pavement surfaces in the Phoenix Metropolitan area or living next to a freeway overlaid with an ARFC. The ARFC is less noisy because it contains air pockets, air voids that reduce the pressure change. Also, because of its very smooth riding due to the small aggregate size and because it is a layer of low modulus elastic soft material due to the high percentage of asphalt binder and crumb rubber. The ADOT expects at least a 4-decibel reduction with the use of an ARFC and this reduction has led to a significant improvement in the quality of life of home owners living near the freeway and people driving on the freeway.

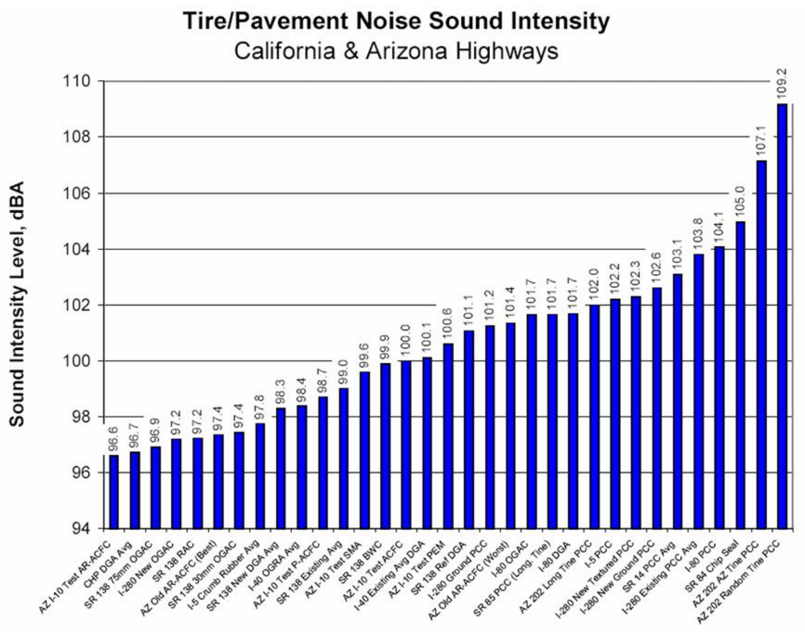

Figure 8. Comparison of the CPX (near the tire) tire/pavement noise for different surfaces, (Donovan, 2003)

5 ARFC AND PERMEABLE SURFACE COURSES FOR SAFETY

For most people, driving is the most dangerous activity that they encounter in their daily lives. Statistics in the USA indicate that the average person will be in almost six auto accidents in their lifetime. By 1950, more Americans were killed in auto accidents then were killed in both world wars. A high percentage of accidents happen in intersections and in horizontal or vertical curves. Wet weather accidents account for a high percentage of highway fatalities. Almost all accidents are avoidable. Studies show that speed kills and differential speed kills. The common attitude: “people just need to slow down and adapt to the conditions to avoid accidents.” Fortunately engineers design highways for those people that do not always do what they should to avoid accidents. Examples of engineering redundant design features that give all of us a second chance include: bridge rail, guard rail, rumble strips, shoulders, median barriers, crash cushions and safety end treatments for culverts. How can ARFC and permeable surface course mixes improve safety? They can reduces the risk of hydroplaning, drain the water off the roadway quicker, reduce spray, reduce glare, improve visibility of traffic markings and coarse macro-texture improves frictional characteristics. Question: can it be proven that an ARFC or permeable surface actually reduce the occurrence of wet weather accidents? The Texas Department of Transportation has provided proof of the safety value of ARFC's and permeable surface course (Rand 2007 and RPA 2008) from accident records before and after the placement of an ARFC permeable surface on a concrete freeway on IH 35 in San Antonio, Texas. As shown in Figure 9 the number of wet weather accidents and fatalities were reduced substantially after the placement of the ARFC. As an outgrowth of this study the Texas DOT is making greater use of permeable surfaces with and without asphalt rubber to reduce wet weather accidents (Rand 2011).

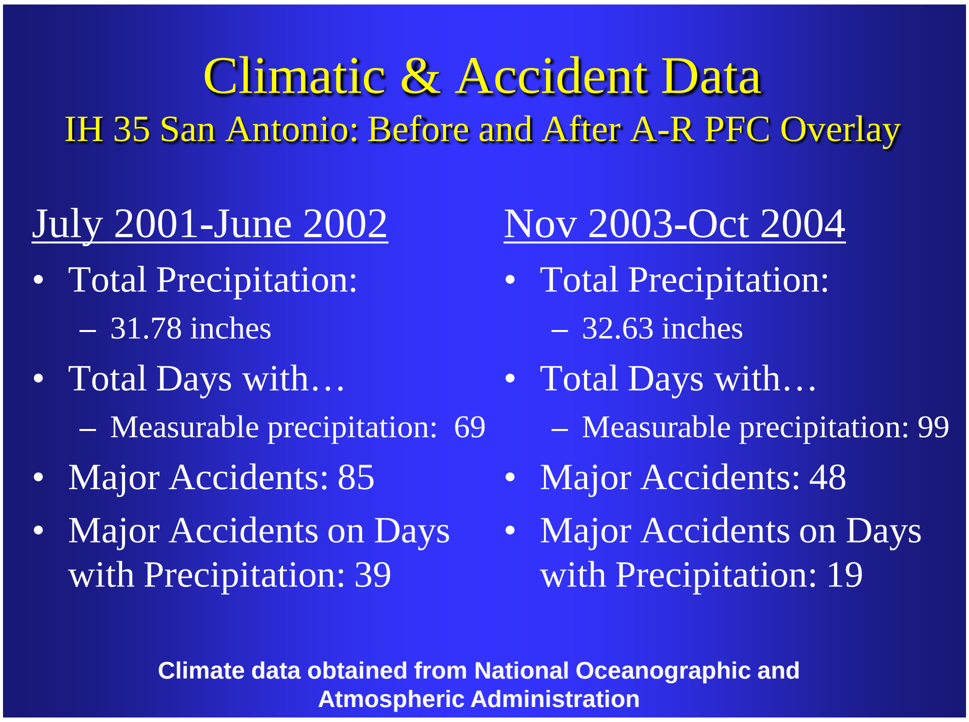

Figure 9 - Wet weather accidents before and after placement of AR-PFC similar to an ARFC

6 CONCLUSIONS

From the compilation of the data and analysis of the data obtained in the study the following conclusions can be derived:

- Roadside measurements have shown that an ARFC can achieve 3 to 5 dB noise level reduction when compared to traditional asphalt dense graded surfaces and 6 to 12 dBA noise level reduction when compared to concrete surfaces.
- Sound intensity measurements such as CPX and OBSI have shown that asphalt rubber surfaces are effective in reducing noise by 4 to 6 dBA compared with traditional dense graded asphalt concrete and by 6 to 12 dBA when compared to concrete surfaces.
- The Texas DOT found that the use of an ARFC and related permeable surfaces also contribute to accident safety and can reduce wet weather accidents.

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