Summary Report on the Performance of Open-Graded Friction Course Quieter Pavements

I-5 Lynnwood, SR-520 Medina, I-405 Bellevue

WA-RD 817.1

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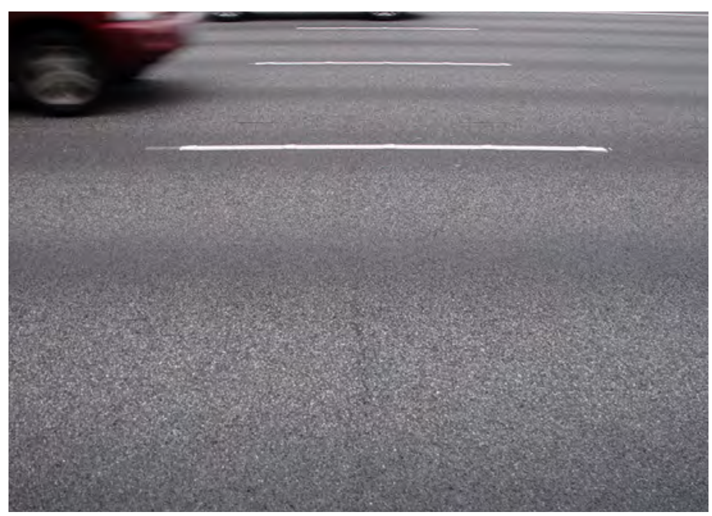
September 2013



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Summary Report
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I-405 Bellevue

Washington State Department of Transportation

Engineering and Regional Operations
Construction Division
State Materials Laboratory

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 817.1		

4. TITLE AND SUBTITLE Summary Report on the Performance of Open Graded Friction Course Quieter Pavements	5. REPORT DATE September 2013 6. PERFORMING ORGANIZATION CODE WA 05-06, 07-01, 08-02
7. AUTHOR(S) Keith W. Anderson, Jeff S. Uhlmeyer, Tim Sexton, Mark Russell, and Jim Weston	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Department of Transportation Materials Laboratory, MS-47365 Olympia, WA 98504-7365	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Project Manager: Kim Willoughby, 360-705-7978	13. TYPE OF REPORT AND PERIOD COVERED Summary Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This document summarizes the acoustic properties and pavement performance of three asphalt quieter pavement projects. Each of the projects included open graded friction course pavement built with sections of crumb rubber and polymer modified asphalt binders. Performance was compared to control sections of HMA Class 1/2 inch.

The open graded friction course sections were audibly quieter than the control section between one and fourteen months after construction. The rutting/wear on the open graded friction course sections was higher than the control section. On two of the projects the rutting/wear exceeded the depth of the overlay and reached a level that would require early replacement of the pavement.

The increases in noise and rutting/wear occurred primarily during the time periods when studded tires are legal in the state and are believed to be the primary cause of these increases.

Based on the results of the research, WSDOT has concluded that open graded friction course pavements are not a viable option as a noise mitigation strategy for the State of Washington.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
quieter pavements, rubber asphalt, open-graded friction courses, OBSI, styrene-butadiene-styrene	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	35	

DISCLAIMER

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Introduction

The Washington State Department of Transportation (WSDOT) evaluated the performance of open graded friction course pavements for their noise reduction properties and long-term performance. Three test projects were built between August 2006 and August 2009. The test sections used open graded friction course (OGFC) pavement with binders modified with crumb rubber from recycled tires and styrene butadiene styrene (SBS) additives. Control sections of conventional hot mix asphalt (HMA) pavement were included in the same project to facilitate side-by-side comparisons of noise and other pavement performance measurements.

Background

Open graded pavements are not new to the Washington State Department of Transportation. In fact, OGFC's were used extensively in the state in the early to middle 1980's, but their use was discontinued in 1995 because of problems with excessive rutting caused by studded tire wear. The renewed interest in open graded pavements was prompted by the successful use of this type of pavement to reduce noise in other states, principally Arizona. The use of rubberized OGFC pavements to make pavements quieter has been promoted in numerous road industry publications. News reports on rubberized open graded pavement being a solution to making pavements quieter has encouraged the public to request the use of these pavements to reduce noise in their neighborhoods.

Open graded pavements are also popular with drivers from reasons beyond noise reduction; including reduced splash-and-spray during rain storms as the open void structure can quickly drain away excess water. Faster drainage of water from the surface also improves the wet weather friction and decreases the potential for hydroplaning. At night, the increased drainage capability of OGFC's can improve visibility by reducing the glare from standing water on the pavement. Less standing water also makes it easier to see traffic and lane markings.

In Washington State, the lives of OGFC pavements have been cut short by the studded tire wear. In the 1980's, OGFCs lasted between three and ten years. Studded tire raveling and wear were cited as the main cause of the shortened pavement life. States where OGFCs have been used successfully (Florida, Texas, Arizona and California) do not experience extensive studded tire usage. Similarly, these states are southern, warm weather states; a clear advantage when placing a product like OGFC modified with crumb rubber. Arizona DOT, for example, requires the existing pavement to have a minimum surface temperature of 85°F at the time of placement. Paving in the Seattle urban areas must, by necessity to lessen traffic impacts, be done at night when pavement temperatures rarely approach 85°F, making successful placement of this type of pavement a challenge.

Project Descriptions

All three projects were located on high volume roadways in the Seattle urban area (Figure 1). The first project was located on the southbound lanes of Interstate 5 near Lynnwood which is located 14 miles north of Seattle. This is a four lane roadway with three general purpose lanes and a median-side HOV lane. This section of I-5 carries a high volume of traffic into Seattle from the north with an average annual daily traffic (AADT) of 173,000 (about 87,000 in the southbound direction) with seven percent trucks (2012 data). If the traffic was equally distributed over all four lanes the AADT per lane would be 21,750. An OGFC section with crumb rubber additive (OGFC-AR) about 3/4 of a mile in length was placed adjacent to a section of OGFC with SBS (OGFC-SBS) additive that was 1.09 miles in length. The OGFC sections were placed 3/4 of an inch in depth as an overlay on an existing HMA pavement in August 2006. The remainder of the project was paved with 1.8 inches of HMA Class 1/2 inch after the original pavement was milled an equivalent depth as the OGFC sections.

Figure 1. Location of the three projects.

The second project was located on SR 520, east to west highway connecting downtown Seattle with cities on the east side of Lake Washington. The project was located just east of the Evergreen Point Floating Bridge. The roadway has two general purpose lanes in each direction and an outside shoulder HOV lane in the westbound direction. The AADT on this section is 100,000 (both directions) with three percent trucks (2012 data). If the traffic were equally distributed over all five lanes the AADT per lane would be 20,000. The OGFC-AR section, HMA control section, and OGFC-SBS section were placed in that order from west to east. The open graded sections were 1/2 mile in length and 3/4 of an inch in thickness. The HMA Class 1/2 inch was placed 0.15 feet thick on all lanes with a taper section at each end to transition to the thinner open-graded sections.

The final project was located on the northbound lanes of I-405 where it crosses I-90 south of Bellevue. The roadway has three general purpose lanes and a median side HOV lane. The AADT on this section of I-405 is 165,457 (about 83,000 in the northbound direction) with 6.75 percent trucks (2012 data). An equal distribution of traffic over the four lanes would result in a 20,750 AADT per lane. An existing concrete pavement was rehabilitated by placing the OGFC-AR and OGFC-SBS sections in two parts, one south of I-90 and one north of I-90. The OGFC sections were also placed over a new concrete median-side HOV lane. The HMA control section was located south of the OGFC sections.

In summary, the projects were all on major commuter routes in the Seattle urban corridor with approximately the same average daily traffic per lane. Each project had an HOV lane located on the median side for the I-5 and I-405 projects an on the outside shoulder for the SR 520 project. The I-5 and SR 520 sections were overlays of existing asphalt pavements and the I-405 project was an overlay of a concrete pavement.

Mix Designs

The mix designs for the OGFC-AR and OGFC-SBS sections for the three projects were very similar providing a solid base for performance comparisons.

OGFC-AR

Arizona Department of Transportation (ADOT) is a leader in the use of crumb rubber modified pavements for noise mitigation and helped in the development of the mix design for the OGFC-AR on the Lynnwood project. The OGFC-AR mixes for the Medina project and Bellevue project were done in-house but patterned after the ADOT design used for Lynnwood. One big difference on the Bellevue project was the use of lime as the anti-stripping additive. ADOT specifies hydrated lime for all of their HMA mixes. Table 1 lists the percent of asphalt, grade of the asphalt binder, rubber content and anti-stripping additive used on the projects. Table 2 shows the gradations for the OGFC-AR mix designs.

Table 1. OGFC-AR mix design binder properties for the three projects.				
Project	**Asphalt Content (%)**	**Binder Grade**	**Rubber Content (%)**	**Anti-Stripping Additive and (%)**
Lynnwood	**9.2**	**PG64-22**	**22.0**	**ARR-MAZ 6500 (0.50)**
Medina	**8.8**	**PG64-22**	**23.5**	**ARR-MAZ 6500 (0.25)**
Bellevue	**9.4**	**PG64-22**	**20.0**	**Hydrated Lime (1.0)**
Average	**9.1**		**21.8**	

Table 2. OGFC-AR gradation properties for the three projects.				
Project - Pit Source	**Sieve Size**			
	3/8	**#4**	**#8**	**#200**
Lynnwood - B-335	**100**	**34**	**8**	**1.5**
Medina - B-335	**100**	**31**	**8**	**1.6**
Bellevue - A-189	**100**	**35**	**8**	**1.9**
Average	**100**	**33**	**8**	**1.7**

OGFC-SBS

All of the OGFC-SBS mixes were designed in-house using the drain down test to determine the optimum percent of asphalt. The first OGFC-SBS mix design for Lynnwood was done with guidance provided by the National Center for Asphalt Technology (NCAT), an asphalt industry supported research facility located on the campus of Auburn University in Auburn, Alabama. Fibers were added to help prevent drain down. Liquid anti-strip additives were used on Lynnwood and Medina with hydrated lime used on Bellevue. Tables 3 and 4 summarize the binder and gradation properties of the mix designs for the projects.

Table 3. OGFC-SBS mix design binder properties for the three projects.

Project	Asphalt Content (%)	Binder Grade	Rubber Content (%)	Anti-Strip Additive and (%)
Lynnwood	8.3	PG70-22	3.4±1	ARR-MAZ 6500 (0.25)
Medina	8.8	PG70-22	3.4±1	ARR-MAZ 6500 (0.25)
Bellevue	8.6	PG70-22	3.4±1	Hydrated Lime (1.0)
Average	8.6	PG70-22	3.4±1	-

Table 4. OGFC-SBS gradation properties for the three projects.

Project - Pit Source	Sieve Size			
	3/8	#4	#8	#200
Lynnwood - B-335	100	37	10	2.1
Medina - B-335	100	36	12	2.3
Bellevue - A-189	100	38	12	2.0
Average	100	37	11	2.1

In summary, the mix designs for the OGFC-AR and OGFC-SBS sections were very similar for the three projects with only slight variations in asphalt content, crumb rubber content and aggregate gradation. The largest dissimilarity was the use of hydrated lime on the I-405 project.

Construction

Construction of the three projects was very similar with all projects using dryer-drum asphalt plants and shear mixer to blend the crumb rubber into the asphalt binder for the OGFC-AR binder. The SBS rubber was added to the asphalt cement at the suppliers' facility. Dump trucks were used to transport the mix to the project site where it was loaded into a Roadtec Shuttle Buggy and remixed before being deposited into conventional pavers. Steel wheel rollers were used to compact the mix, which was monitored with infrared cameras to check for temperature differentials. The I-5 project was paved at night and the I-405 project during the day. The SR 520 was paved continuously over a weekend closure with the OGFC-AR paved during the day and the OGFC-SBS at night.

The major difference in the construction of the projects was that both OGFCs on the I-5 project and the OGFC-SBS section on the SR 520 were paved at night with all other sections paved during the day.

Performance Monitoring

Acoustic performance and pavement wear were the two main criteria used to judge the success of the OGFC quieter pavement test sections. For acoustic performance, the two questions to be answered were; (1) are the OGFC pavements audibly quieter than the HMA control section and, if so, (2) how long do they remain audibly quieter? For pavement wear, the question was; how long will the OGFC pavements stand up to studded tire wear and the environmental conditions common to Washington?

Noise

The first question to address regarding the performance of the OGFC sections is how long they were quieter than the HMA control sections constructed at the same time. Table 5 shows the relationship between the noise level change, the relative loudness, and the acoustic energy loss. Acoustic experts agree that noise levels must differ by more than three decibels for the difference to be noticeable to the human ear (audibly quieter). OGFC sections were considered "quieter" when the measured noise levels were three decibels or more lower than the noise level of the HMA control section. The three decibel level includes differences that are barely perceptible.

Table 5. Noise level changes, loudness and acoustic energy loss comparison.*		
Noise Level Change (A-weighted decibels)	Relative Loudness	Acoustic Energy Loss
0 dBA	Reference	0
-3 dBA	Barely Perceptible Change	50%
-5 dBA	Readily Perceptible Change	67%
-10 dBA	Half as Loud	90%
-20 dBA	1/4 as Loud	99%
-30 dBA	1/8 as Loud	99.9%

*** Information courtesy of Larry Scofield, American Concrete Paving Association (ACPA)**

I-5 Lynnwood

Figure 2 is the graph of the numerical difference between the average noise level of the HMA control section and the average noise level of each OGFC section. Data points above the black horizontal line are three decibels quieter than the HMA control section with the pavement judged to be audibly quieter than the control section. Data points below the line are not audibly quieter. The AR rubber section dropped below the black line at four months and continued a downward trend. The SBS section was initially not audibly quieter than the HMA but reached that level at three months, again at six months and between 11 and 14 months before it started a downward trend and was never again audibly quieter. The OGFC-AR becomes noisier than the HMA at 24 months (falls below the red line) and remains at that condition for almost the entire remainder of the four year monitoring period.

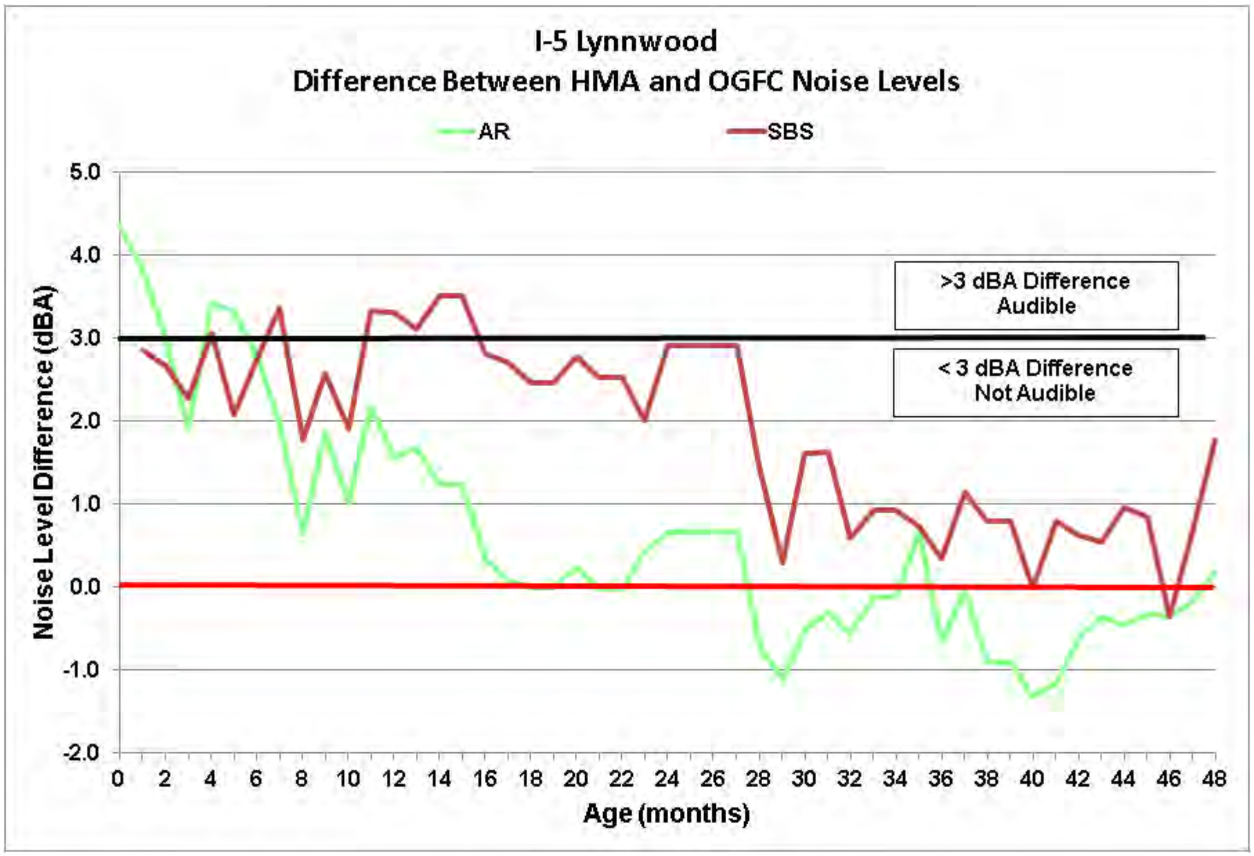

Figure 2. I-5 noise level difference.

SR 520 Medina

The noise level difference graph for the SR 520 Medina project is shown in Figure 3. The AR section was audibly quieter than the HMA for five months and one more time at month twelve. The SBS section was never audibly quieter than the HMA control section (no points above the black line). The OGFC-AR became noisier than the HMA at 23 months where it remained for the duration of the study. The OGFC-SBS was never measured to be noisier than the HMA (no points below the red line).

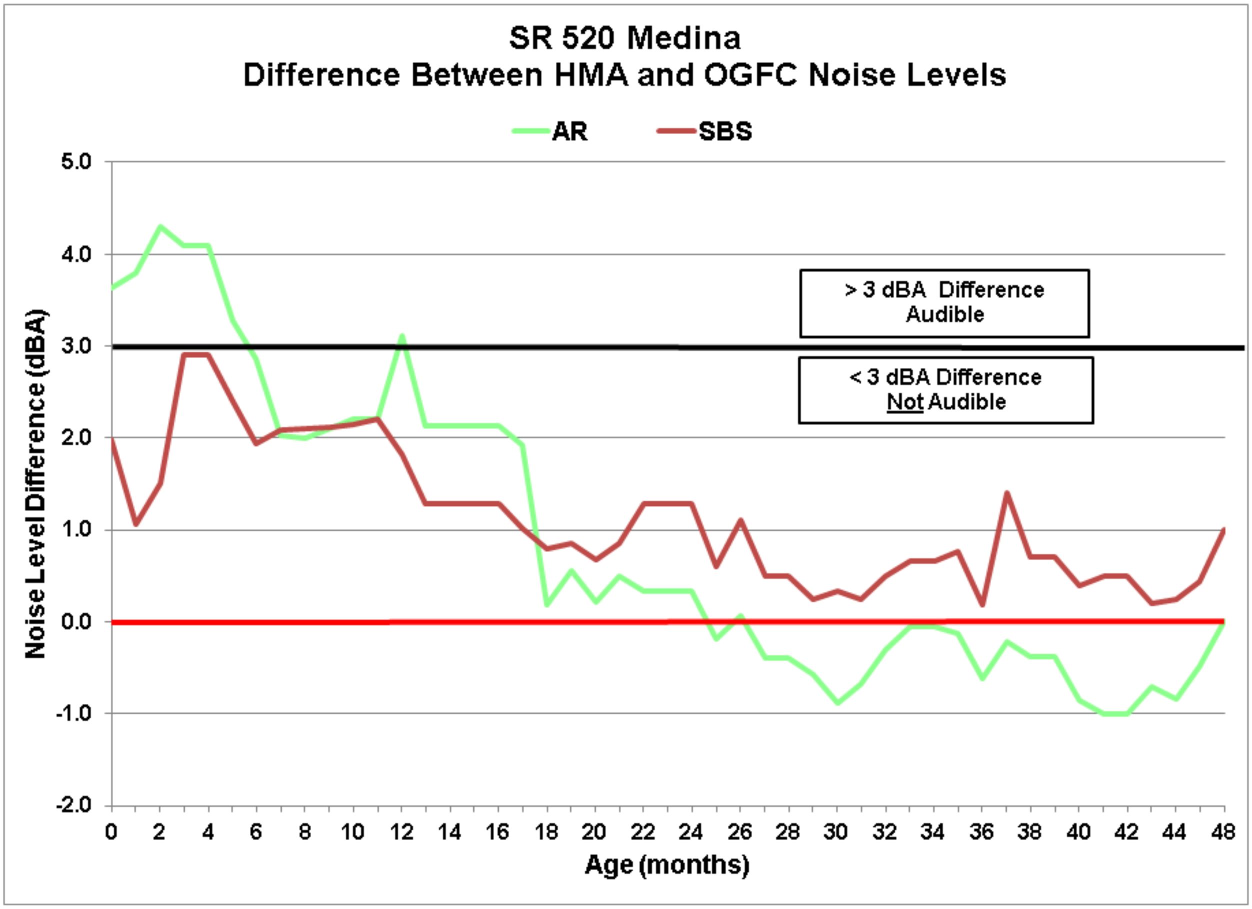

Figure 3. SR 520 noise level difference.

I-405 Bellevue

Figure 4 shows the noise level difference for the I-405 Bellevue project. The AR section was audibly quieter than the HMA for brief periods up to ten months. The SBS section was only audibly quieter than the HMA for the initial reading. Neither of the sections was audibly quieter than the HMA for the remainder of the study period (44 months).

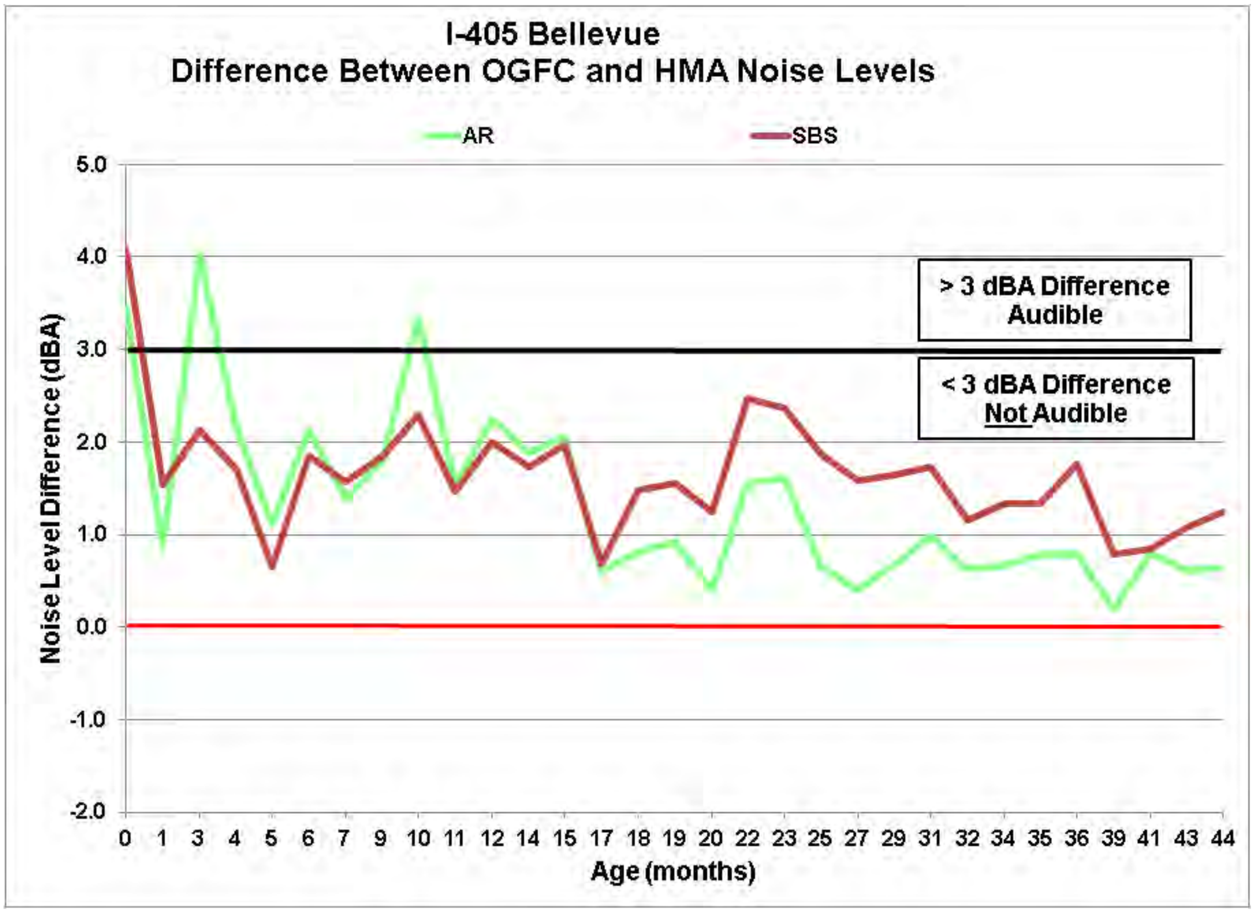

Figure 4. I-405 noise level difference.

Noise Discussion

The OGFC-AR sections on the three projects were audibly quieter than the HMA control section for between four and twelve months with an average of nine months. The SBS sections were audibly quieter from zero to fourteen months with an average of five months.

Total increases in noise level over the study period for each project are shown in Table 6. The OGFC-AR sections increased the most with a range from 7.2 to 9.0 dBA and average of 8.1 dBA; followed by the OGFC-SBS sections with a range of 6.2 to 7.2 dBA and an average of 6.6 dBA. The HMA section had the lowest increase in noise levels with a range of 4.1 to 4.8 and average of 4.4 dBA. The next section of the report will investigate the cause of these increases.

Table 6. Study period increases in average noise level.				
Project	**Reading**	**Average Noise Level**		
		AR (dBA)	**SBS (dBA)**	**HMA (dBA)**
I-5 Lynnwood	**Initial**	95.1	96.0	99.4
	Final	103.3	102.2	103.5
	Increase over 48 months	**8.2**	**6.2**	**4.1**
SR 520 Medina	**Initial**	96.1	97.8	99.8
	Final	105.1	104.1	104.6
	Increase over 48 months	**9.0**	**6.3**	**4.8**
I-405 Bellevue	**Initial**	97.4	96.8	100.9
	Final	104.6	104.0	105.3
	Increase over 44 months	**7.2**	**7.2**	**4.4**
Average Increase for All Projects		**8.1**	**6.6**	**4.4**

Seasonal Changes in Noise Levels

In general, the OGFC sections show significant increases in noise levels the first few months after construction. Beyond that period, the increases were confined almost exclusively to the winter months. Figures 5-7 illustrate the change in average noise level during each of the winter and summer periods for the three projects. The peaks mark the winter season and the valleys the summer periods. The high peaks for the Winter 2008-09 data points on the I-5 and SR 520 projects were caused by a severe winter storm that resulted in the increased use of studded tires and chains on these two roadways. The I-405 project, built in 2009, was not subject to any abnormal weather conditions, which was reflected by more moderate peaks and valleys in the data.

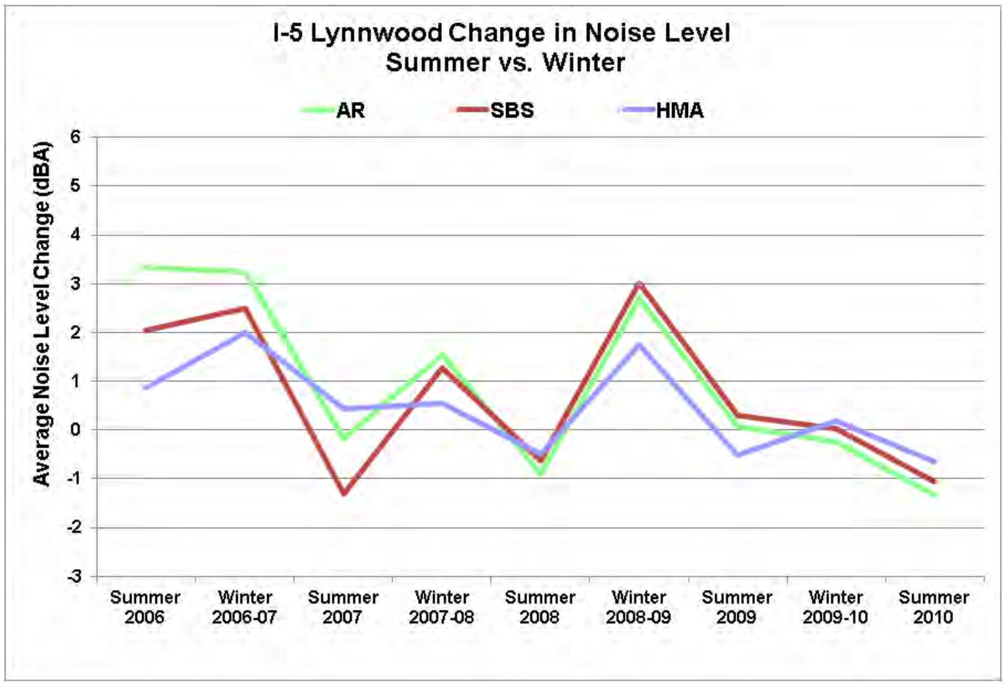

Figure 5. I-5 Lynnwood seasonal change in noise levels.

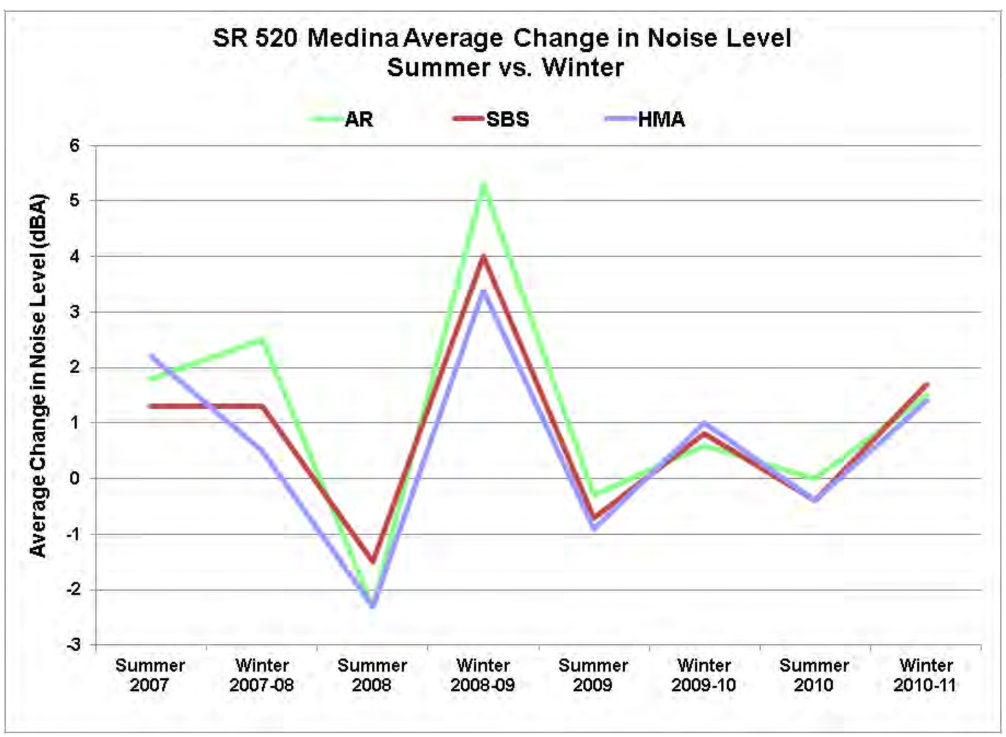

Figure 6. SR 520 Medina seasonal changes in noise levels.

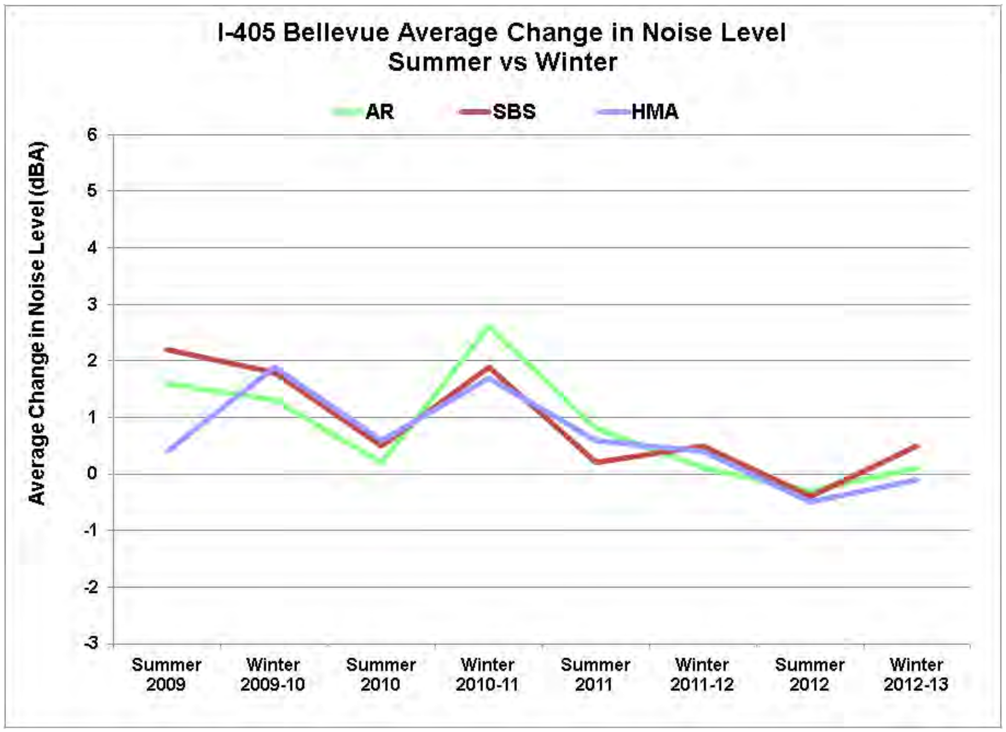

Figure 7. I-405 Bellevue seasonal changes in noise levels.

The average increase in noise level during the winter and summer for each pavement type for the three projects is summarized in Table 7. The average increase during the winter periods was 1.8 (AR), 1.3 (SBS) and 1.2 dBA (HMA). The average increase for the summer periods was 0.2 (AR), 0.1 (SBS), and -0.1 dBA (HMA).

Table 7. Change in average noise intensity levels for winter and summer.

Project	Season	Average Noise Level Change AR (dBA)	SBS (dBA)	HMA (dBA)
I-5 Lynnwood	Summer	0.2	-0.1	-0.1
	Winter	1.8	1.7	1.1
SR 520 Medina	Summer	-0.2	-0.3	-0.4
	Winter	2.5	2.0	1.6
I-405 Bellevue	Summer	0.6	0.6	0.3
	Winter	1.0	1.2	1.0
Average Summer		0.2	0.1	-0.1
Average Winter		1.8	1.3	1.2

Compared to the HMA section, the larger increase in average noise levels for the OGFC sections during the winter seasons suggests that winter conditions (studded tires, tires with chains, or colder temperatures and increased moisture) have a greater negative effect on the acoustic performance of the OGFC pavement than for the HMA pavement. This is not surprising since open graded pavements are known to have less strength than dense graded pavements due to their higher void content. OGFC's lower strength makes them more susceptible to damage from studded tires or tires equipped with chains. Their higher content of voids also makes them more susceptible to damage from moisture, freezing, and thawing. The OGFC-AR sections are more susceptible to damage from studded tires because of their higher content of rubber which also weakens the pavement. It is not clear which factor, climate or studded tires, is the main contributor to the increases in noise levels exhibited by the OGFC sections. The next section of the report will look at additional noise measurements taken to determine if the cause of the increases in noise levels for the OGFC pavements are due to traffic or the environment.

Center of Lane Noise Measurements

Special noise readings were taken in the center of the lanes between wheel paths on both the I-5 Lynnwood and SR 520 projects. The center of the lanes should have much less traffic than the wheel paths and therefore the readings should be a measure of how the environmental factor such as temperature, moisture, freezing and thawing affect the noise properties of the pavements.

I-5 Lynnwood

The center of lane measurements on I-5 was taken in September of 2007, 13 months after construction. The between wheel paths noise measurements are compared to the normal wheel path measurements taken at the same time and the initial measurements made after construction (Figure 8).

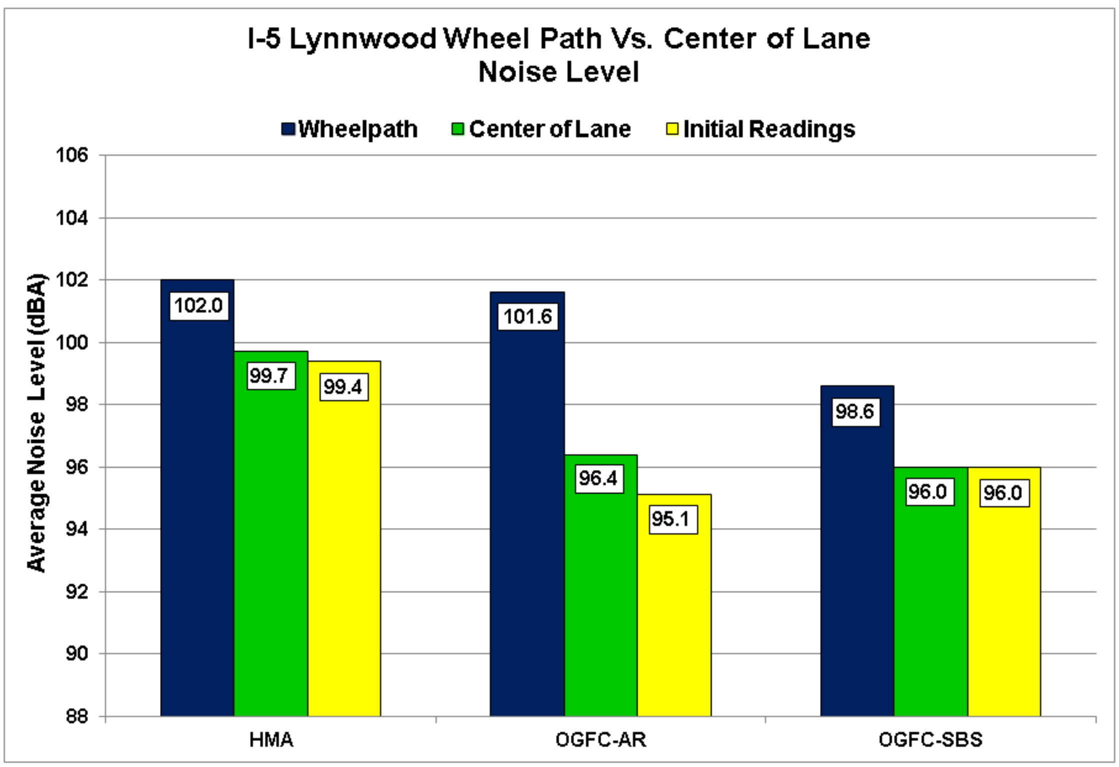

Figure 8. I-5 Lynnwood average noise levels in the center of the lane and in the wheel path versus initial readings after construction.

For all three pavements the noise levels in the less trafficked center of lane were very similar to the initial post-construction wheel path measurements with none of the pavements differing by more than the 1.3 dBA (the AR section). This absence of a difference in noise levels is significant since the 13 month period of time between the two readings includes a winter studded tire season. This suggests that environmental factors have less effect on the noise levels of the sections and that traffic is the major contributor to changes in noise level. In contrast, the comparison of wheel path measurements during the same time period showed increased noise levels of 6.5 dBA for the AR, 2.6 dBA for the SBS, and 2.6 dBA for the HMA. This data shows that noise levels are being negatively affected by traffic with the AR pavement more affected than the SBS or HMA.

SR 520 Medina

Center of the lane measurements for the SR 520 project are shown in Figure 9. These measurements were made 10 months after construction. The measurements were similar to the initial wheel path results for both OGFC sections differing by only 0.6 dBA for the AR section and 1.3 dBA for the SBS. The difference for the HMA section was 2.0 dBA. In contrast, the comparison of wheel path measurements during the same time period showed noise levels of 3.6 dBA for the AR, 2.2 dBA for the SBS, and 1.8 dBA for the HMA. Center of lane data for SR 520 mimics the data from the I-5 project with wheel path noise levels increasing as a result of traffic and not the environment. The AR pavement was more affected than the SBS or HMA.

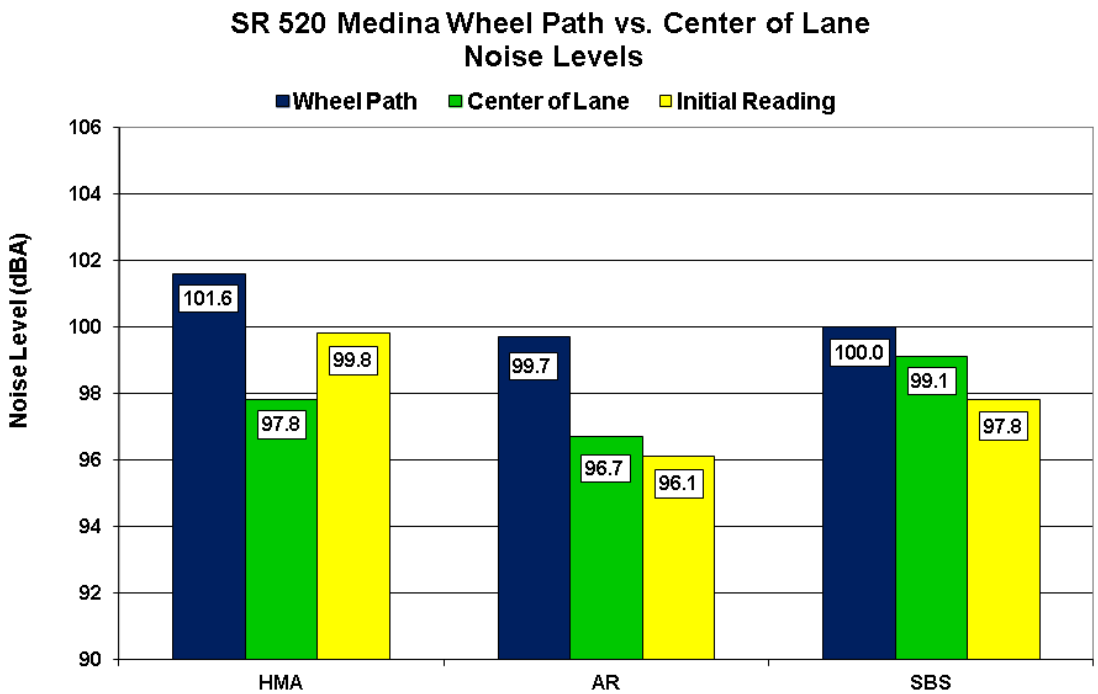

Figure 9. SR 520 Medina average noise levels in the center of the lane and in the wheel path versus the initial readings after construction.

The measurements taken in the center of the lane, which is not exposed to the same traffic as the wheel paths, showed that the noise levels on the OGFC sections were increasing as a result of traffic. The greater change in noise in the wheel paths as compared to the center of the lane measurements indicates that traffic and especially studded tires are the major factor in the increase in noise levels on both the I-5 Lynnwood and SR 520 Medina projects. Center of lane measurements were not taken on the I-405 Bellevue project.

Noise Summary

The results of the testing of the noise characteristics of the OGFC sections can be summarized as follows:

- The OGFC sections were audibly quieter than the HMA control sections for only a brief period of time following construction.
- Noise increases on the OGFC pavements occurred primarily during the winter studded tire seasons.
- Noise measurements outside of the wheel paths proved that the increase in noise was not due to environmental factors.
- Large increases in noise levels on two of the projects were due to the increased use of studded tires and chains during a winter storm.

The next section of the report will investigate the rutting/wear that occurred on the projects to see if there is a link between increases in noise and the pavement wear.

Wear/Rutting Results

Rutting/wear measurements were made on each project in the fall and spring of each year bracketing the legal studded tire season. HMA pavements are subject to both rutting due to additional compaction of the pavement from traffic and wear due to the removal of material from the pavement surface (raveling). Therefore, the rutting/wear from this point on will be confined to discussions of the rut depth which takes into account both types of distress. Figures 10-13 show the average rut depth for each of the three pavement types on each project. The bar graphs for the I-5 and SR 520 projects show gradual increases in the rut depth up to the Winter 2009 reading when a large increase is noted as a result of the severe winter storm mentioned previously. In contrast, the bar graph for the I-405 Bellevue project, constructed after the winter of 2009, shows no large jumps in rut depth. The rut depths on the AR pavements (green bars) for all three projects, and especially the I-5 and SR 520 projects, are greater than the rut depths for either the SBS (brown bars) or the HMA (blue bars) sections.

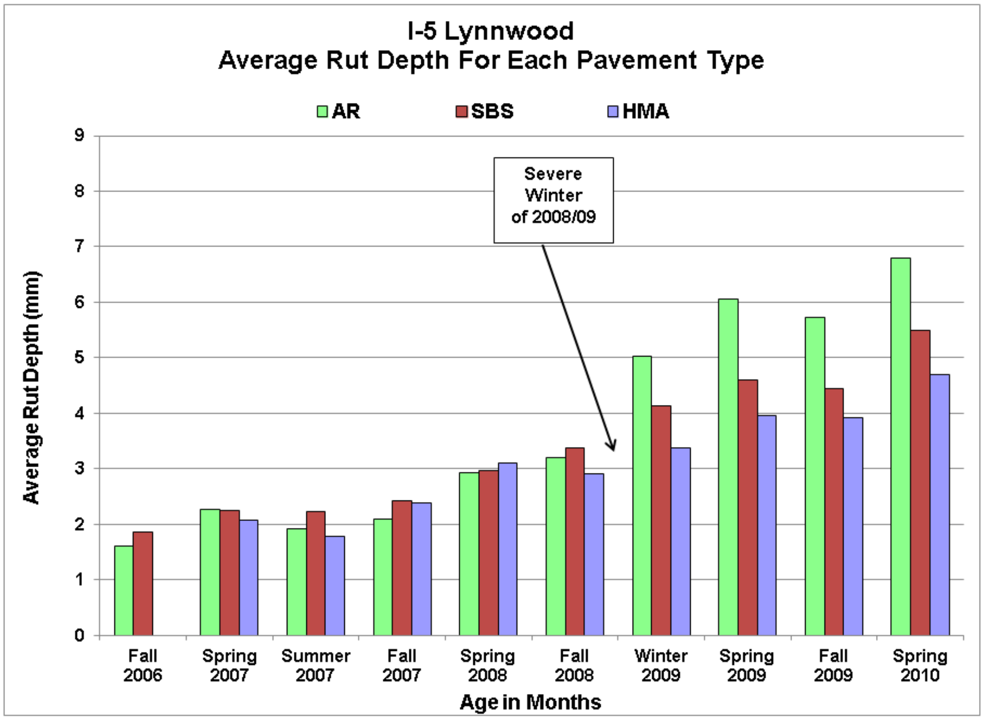

Figure 10. I-5 Lynnwood average rut depth for each pavement type.

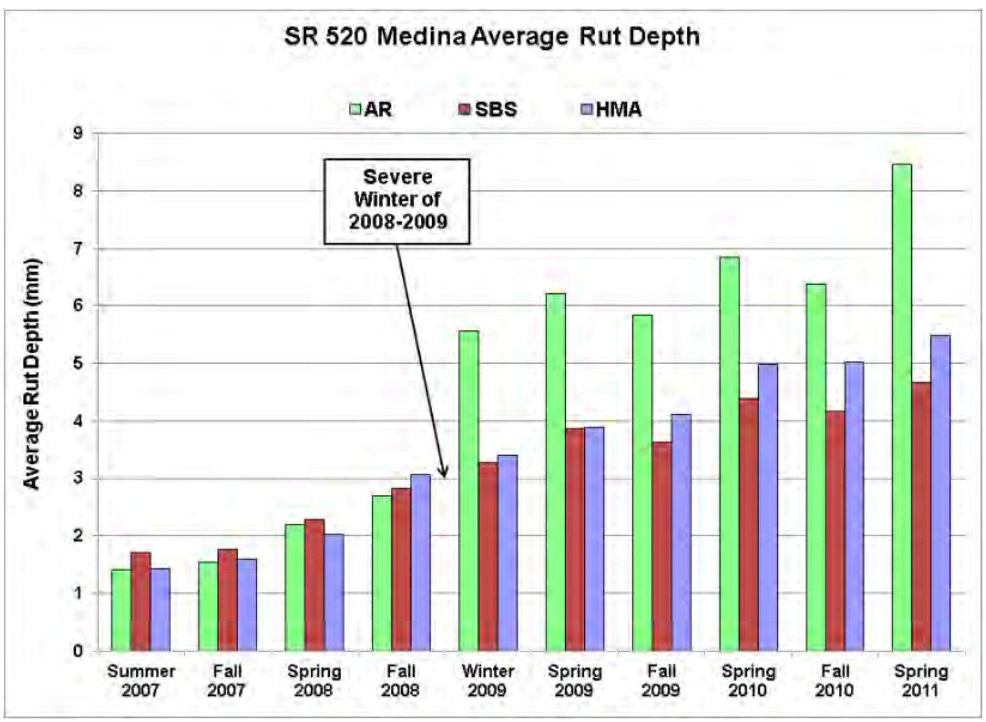

Figure 11. SR 520 Medina average rut depth for each section.

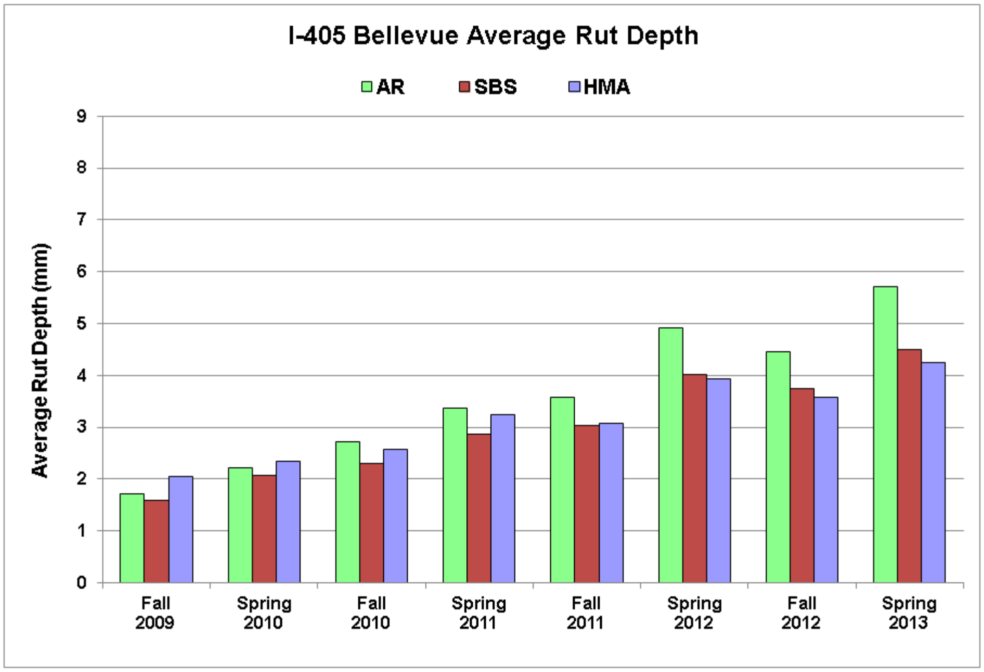

Figure 12. I-405 Bellevue average rut depth for each section.

In summary, the rutting depths mimic the noise level measurements with the OGFC-AR experiencing the greatest increases followed by the SBS and HMA sections.

Seasonal Variations in Wear/Rutting

The change in the depth of the rut in the wheel paths from winter to summer shows a pattern similar to the noise level readings with the increases in rut depth confined mainly to the winter studded tire season. The changes in rut depths for the summer and winter periods for each pavement type and project are shown in Figures 13-15. Negative or zero changes in rut depth are possible due to the transverse profile measurements which can vary a few millimeters due to inherent variations in the method used to measure rutting and the fact that wear can occur across the entire lane, not just the wheel path, thus reducing the depth of the rut from one measurement to the next. Note the peaks for the winter 2008-09 measurements on the I-5 Lynnwood and SR 520 Medina projects which correspond to the severe winter storm.

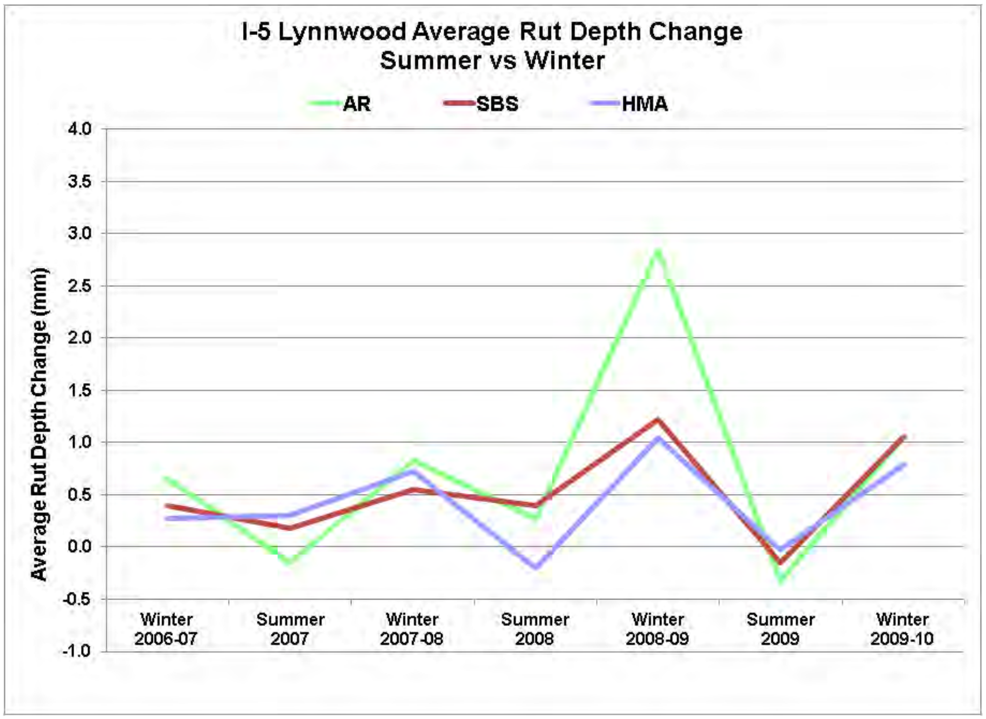

Figure 13. I-5 Lynnwood seasonal change in rut depth.

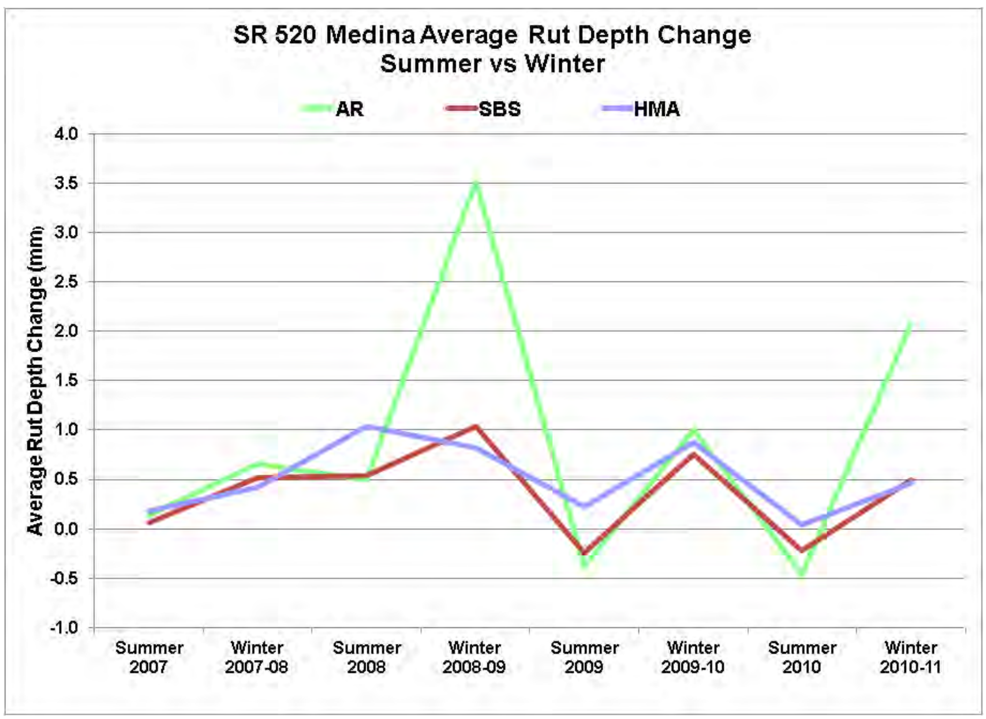

Figure 14. SR 520 Medina seasonal change in rut depth.

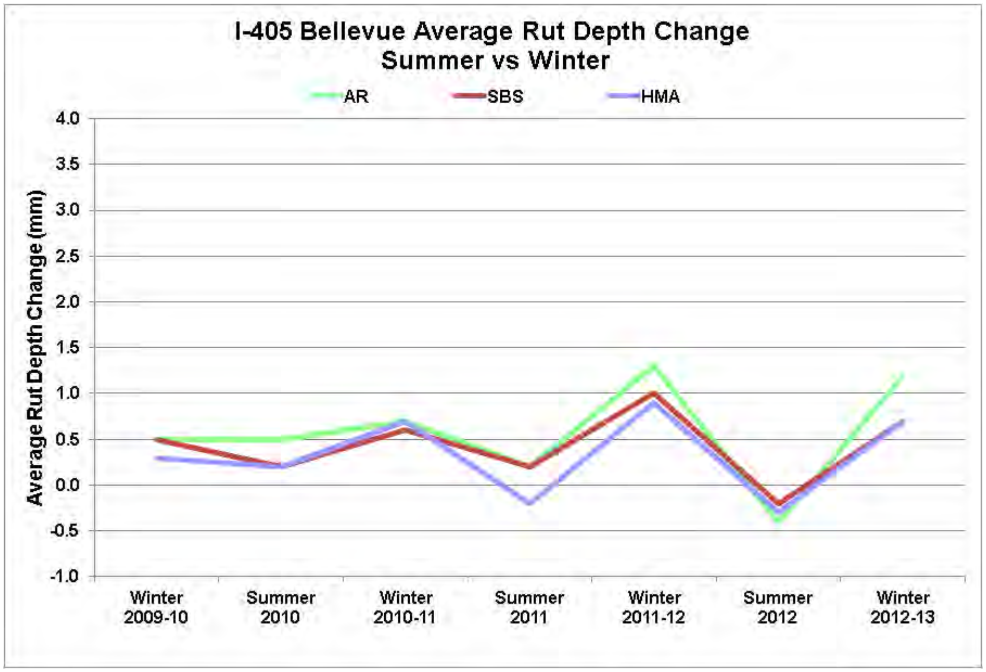

Figure 15. I-405 Bellevue seasonal change in rut depth.

Table 8 lists the average rut depths for the winter and summer periods for each pavement type and each project. The data shows that all of the increases in rut depth are occurring during the winter studded tire season. This explains why OGFC quieter pavements are more successful in states like Arizona, California, Texas and Florida which do not have high volumes of vehicles with studded tires.

Table 8. I-5 Lynnwood seasonal change in average rut depth.

Project	Season	AR (mm)	SBS (mm)	HMA (mm)
I-5 Lynnwood	Summer	-0.1	0.1	0.0
	Winter	1.4	0.8	0.7
SR 520 Medina	Summer	-0.1	0.0	0.4
	Winter	1.8	0.7	0.7
I-405 Bellevue	Summer	0.1	0.0	-0.1
	Winter	0.9	0.7	0.7
Average Summer		0.0	0.0	0.1
Average Winter		1.4	0.7	0.7

Pavement Condition

The pavement condition of the OGFC sections at the end of the monitoring period supported both the noise and wear performance data with the OGFC-AR sections performing much worse than either the OGFC-SBS sections or the HMA control sections.

I-5 Lynnwood

The OGFC-AR test section on the Lynnwood project was removed in the fall of 2010 after only four years of service due to safety concerns with vehicles having to cross the deep ruts during shifts of traffic necessary for the construction of new ramps for the Alderwood Mall interchange. The rutting in the OGFC-AR (Figure 16) was a result of wear and raveling and not the result of deformation of the pavement due to compaction or shoving as evidenced by the accumulation of aggregate on the shoulder (Figure 17).

Figure 16. Wear in OGFC-AR near Lynnwood. (Photo date 2010.)

Figure 17. Accumulation of aggregate on the shoulder in the OGFC-AR section. (Photo date 2010.)

SR 520 Bellevue

The performance of the OGFC-AR section on the Bellevue project matched that of the Lynnwood project with wear and raveling exceeding the depth of the overlay in the wheel paths as shown in Figure 18.

Figure 18. Rutting in EB Lane 1 (far left lane in photo) of OGFC-AR test section on SR 520. (Photo date February 2011.)

I-405 Bellevue

The wear/rutting on the Bellevue sections have not exceeded the depth of the pavement which is 1 inch as compared to the other two projects that were only 3/4 inch in thickness. However, the 2012 pavement condition data for the project shows that the OGFC-AR section is not performing as well as the OGFC-SBS section. Table 9 shows the type and extent of the distress for both sections. The distress noted for the OGFC-AR includes a minor amount of low severity alligator and longitudinal cracking but a significant number of low severity transverse cracks and sealed transverse cracks. In contrast, the data for the OGFC-SBS section shows only a few low severity transverse cracks (Figure 19). The 82 transverse cracks reflecting through the OGFC-AR overlay from the underlying concrete pavement accounts for 33 percent of the possible cracks as contrasted with the 5 cracks in the OGFC-SBS overlay which equates to 5 percent. The underlying concrete pavement ranged in age from 42 to 50 years with a length weighted average of 44 years. This would indicate that all of the transverse cracks throughout both the AR and SBS sections would be wide and worn by traffic and very prone to reflect through an HMA overlay. The amount of cracking in the OGFC-AR as compared to the OGFC-

SBS section indicates a weaker pavement that is less resistance to this type of cracking. Pavement condition data for the HMA control section is not presented because it is not underlain by concrete pavement.

Table 9. Pavement condition data for the OGFC-AR and OGFC-SBS (2012)

Section	Low Severity Alligator Cracks (ft)	Low Severity Longitudinal Cracks (ft)	Low Severity Transverse Cracks (Number)	Sealed Transverse Cracks (Number)	Transverse Cracks in Underlying Concrete (Number)
OGFC-AR	7	81	46	36	246
OGFC-SBS	0	0	5	0	235

Figure 19. Transverse reflection crack in OGFC-AR section. (Photo date February 2011.)

Life Cycle Cost Analysis

WSDOT uses life cycle cost analysis (LCCA) to compare the cost of different pavement options. LCCA is a method of economic analysis that takes into account the initial as well as future costs. In the case of the OGFC and the HMA control section, the future cost is the cost of repaving the roadway at the end of the pavements life. The life cycle cost is a function of how much it costs to pave the road and the time between each cycle of repaving.

Audible Noise Reduction

Table 10 shows the life of the audible noise reduction and the annual cost for that length of pavement life for the I-5 Lynnwood and SR 520 Medina projects (no life cycle costs were computed for the I-405 project due to the lack of construction cost data). The life of the OGFC-AR and OGFC-SBS were based on replacement as soon as they were no longer audibly quieter than the HMA control section. Cost has been converted to uniform annual cost in order to directly compare the different pavement types. Although the audible noise reduction capability of the OGFC's were less than six months, for simplicity, one year was used in the calculation as the OGFC's pavement life with respect to audible noise reduction. The LCCA for the HMA control section based on performance data is also included for comparison.

Table 10. Life cycle cost data for audible noise reduction.

Pavement Type	Audible Noise Reduction Life		Noise Reduction Annual Cost	
	I-5 Lynnwood (yr.)	SR 520 Medina (yr.)	I-5 Lynnwood	SR 520 Medina
HMA	13	11	16,048	30,218
OGFC-AR	1	1	178,061	355,396
OGFC-SBS	1	1	142,598	252,833

The short duration of audible noise reduction for the OGFC's leads to a high life cycle cost. Current performance data for the HMA control section indicates that it will need to be replaced between 11 and 13 years for the SR 520 and I-5 projects, respectively. The OGFC-AR life cycle cost is 11-12 times the life cycle cost of the HMA for both projects. The OGFC-SBS life cycle cost is 8-9 times the life cycle cost of the HMA.

Pavement Performance

An LCCA analysis based strictly on pavement performance was also performed (Table 11). Data from the Washington State Pavement Management System (WSPMS) indicates that the OGFC-AR would have needed replacement at five years due to rutting from studded tires for both projects. The OGFC-SBS would have lasted 9-14 years for the I-5 and SR 520 projects, respectively, with rutting also dragging down its performance.

Table 11. Life cycle cost data for pavement performance.

Pavement Type	Pavement Life		Pavement Life Annual Cost	
	I-5 Lynnwood (yr.)	SR 520 Medina (yr.)	I-5 Lynnwood	SR 520 Medina
HMA	13	11	16,048	30,218
OGFC-AR	5	5	38,459	76,761
OGFC-SBS	9	14	18,441	23,015

The annual cost of the OGFC-AR is over twice that of the HMA and the OGFC-SBS for both projects and the OGFC-SBS about 15 percent higher than the HMA for the I-5 project and 24 percent lower for the SR-520 project.

In summary, the life cycle costs of the OGFC pavements with respect to noise reduction were 8-12 times higher than the HMA making them unrealistic choices. The life cycle costs with respect to pavement performance were double for the OGFC-AR and slightly higher to somewhat lower for the OGFC-SBS pavements.

Conclusions

It can be concluded that rubber modified open-graded friction course “quieter pavements” have not worked in the state of Washington as cost effective pavement choices. This conclusion is based on both the acoustical performance and the wear performance of the three test sections.

References

Anderson, K., Uhlmeyer, J., Sexton, T., Russell, M., Weston, J., **Evaluation of Long-Term Performance and Noise Characteristics of Open-Graded Friction Courses – Project 1: Final Report**, Washington State Department of Transportation, WA-RD 683.2, June 2012.

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