Noise Reducing Asphalts
A Priority Issue for the Region of Waterloo

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ABSTRACT

Over the last 20 years, many highway jurisdictions have experimented with different asphalts that include blended recycled rubber particles as a way to re-use old tires as well as to monitor the effects of rubber in possibly reducing the aging effects in asphalt pavements. Anecdotal comments following these experiments were also being received noticing a reduction in traffic noise with these rubberized mixes when compared to conventional pavements. While there have been many claims of noise reduction from different agencies over the years, there was limited conclusive documentation and testing to support the claims.

In late 2003, the University of Waterloo's Centre for Pavement and Transportation Technologies (CPATT) and the Regional Municipality of Waterloo embarked on a partnership to first design and construct noise reducing pavement test sections and then secondly to conduct controlled noise testing on four different types of asphalt mixes to accurately determine the noise-reducing characteristics of different asphalt surface course mixes.

Four asphalt mixes were placed to conduct the noise testing:

Rubber-modified Open Friction Course (ROFC)
Rubber-modified Open Graded Course (ROGC)
Stone Mastic Asphalt (SMA)
Hot Mix HL-3 (standard Region of Waterloo surface course, ie. Control Section)

The test site location was selected from locations already committed for pavement rehabilitation within the Region's annual rural resurfacing program. The location chosen for the noise testing was on Regional Road 11 (William Hasting Line) between Manser Road and the western Regional boundary in the Township of Wellesley. This 5.5 km section of road was deemed conducive for use as a controlled test section because it provided a straight horizontal alignment with uniform vertical grades, consistent adjacent land use (predominantly agricultural) and little ambient noise activity.

The four different surface courses were placed in lengths of 600m. The overall 2.4 km test area was closed to traffic and four different test vehicles were driven through the test area at different control speeds with noise meters recording noise levels both at the tire/pavement interface as well as at monitoring stations off the roadway.

The purpose of the testing was to measure the noise characteristics of the different asphalt mixes in order to conclude whether there was a noise reduction benefit associated with the special mixes that would warrant their use in urban noise-sensitive areas to reduce or eliminate the need for other noise mitigation measures, including noise walls.

Noise level test results have indicated that the special premium pavement mixes do achieve a reduction in measured noise. The reduced noise levels are attributable to a reduction in the duration of exposure to noise observed with the special open-graded

mixes. The peak noise level observed with each premium pavement mix is the same as that observed with the conventional dense course mix. However, the overall noise impact over an 8 or 16 hour time period (as used in noise modeling programs) is reduced by using premium open-graded pavement mixes.

The paper will elaborate on the types of materials used, the testing protocol, the measured noise results and the conclusions which will be of use by other municipalities in assessing the merits of using premium surface course asphalts to reduce noise in urban, noise-sensitive environments.

Introduction

New and improved pavement technologies are developed through laboratory investigations, construction and maintenance, theoretical analyses and long term performance studies. This paper focuses on a study which examines the technical benefits of noise reducing pavements. The study described herein focuses on the evaluation of three types of noise reducing pavements which were constructed in the Summer of 2004. The Region of Waterloo and the University of Waterloo, Centre for Pavement and Transportation Technology are working together to examine how this pavement technology can be used as a possible noise mitigation tool.

This paper briefly summarizes the background to the study, noise policies in Ontario and the sources of traffic noise. The paper then concentrates on the design, construction and performance results from the field test sections. Particular emphasis is placed on the pavement materials (which included a conventional mix, a stone mastic and two types of rubber-modified open-graded courses) and the initial noise testing results which were obtained using both the close-proximity method and the pass-by method. Finally, the paper offers some initial conclusions and recommendations for future monitoring to further advance quiet pavement technologies.

Noise Policies in Ontario

Municipal governments are often faced with important decisions regarding the social effects of traffic noise on the enjoyment and well-being of its citizens. For example, policies are required to determine the acceptable level of traffic noise that residents can be subjected to before there is an obligation to mitigate that noise. In addition, any time a new residential development is proposed, decisions must be made on how that development must minimize the effects of traffic noise on its new residents.

There are a number of different noise modeling software programs in existence today in North America to predict noise levels associated with roadway traffic. In Ontario and much of Canada, most municipalities rely on the program "STAMSON" to predict traffic-generated noise levels.

The STAMSON program (original version entitled ORNAMENT) was developed in the 1980's by Ontario's Ministry of the Environment (MOE). The MOE conducted noise tests and collected tens of thousands of points of empirical data to create a model that would predict noise levels based on a set of input criteria. STAMSON input parameters include: total traffic volume; medium and heavy truck percentages; road grade; distance to the road; and the elevations of the traffic noise source and the noise receiver. The "receiver" is generally considered to be 1.5m above ground (ear height) and 3m off the back wall of a residence (backyard outdoor living area). For indoor living area calculations, the second floor window is considered the receiver [Schroterm 1989].

At the Region of Waterloo, a Noise Policy is enforced that predicts future noise levels using STAMSON. Developers wishing to construct homes adjacent to an existing road must construct noise walls if the expected noise levels (based on traffic 10 years in the future) exceed 60 dBA. When a road improvement is proposed adjacent to existing homes, Waterloo Region constructs noise walls if noise levels 10 years in the future exceed today's noise by more than 5dBA or exceed the threshold of 65 dBA [RW 1999].

Noise Mitigation

Noise walls are the mitigation method most often employed to reduce noise levels. Noise walls of at least 1.8m height can usually reduce noise by 5 dBA or more. Even though there have been advancements in the appearance of noise walls over the last 10 years, noise walls are still considered by most to be unappealing and to detract from a pleasing streetscape. In addition, noise walls are costly to construct and maintain and can cause personal security concerns since pedestrian visibility and accessibility is limited adjacent to a noise wall.

Accordingly, alternatives to noise walls are used where possible to mitigate or lessen noise levels to acceptable levels. These other alternative measures can include a change in the orientation of buildings and sites to increase the distance to outdoor living areas, use of earth berms to block the noise source, noise warning clauses in new home purchase agreements or the provision of air conditioning units to lessen indoor living area noise.

One other method to mitigate traffic noise is at the source, ie. where the tire meets the road.

Traffic Noise

Traffic noise is generated by three sources: engine noise, exhaust system noise and tire noise. Engine noise can only be controlled by vehicle manufacturers and through proper maintenance. Exhaust noise is controlled by mufflers and relies on proper maintenance and upkeep by vehicle owners. Tire noise is caused by the interaction between tire and pavement and the type of pavement surface can have a profound effect on tire noise.

Tire noise predominates over engine or exhaust noise at speeds in excess of 50 kph. Tire noise is therefore the prevalent vehicle noise source for all of the roads in Waterloo Region's arterial road system, all of which have posted speeds of 50 kph or more.

Therefore, modifications to the pavement surface material and texture where the tire contact occurs can have a dramatic effect on the noise emitted from traffic. It is known to most that concrete surfaced roads, especially those with a tined or grooved surface for traction, are far noisier that asphalt pavements. Older asphalt pavement that has surface deterioration and defects is also noisier than new asphalt pavement. In addition, many different types of asphalt pavements over the years have demonstrated noise reducing effects, most of which have been attributed to a greater volume of air voids at the surface which has provided the noise absorption [Garcia 2004, Jackson 2003, McDaniel 2004,].

Use of Rubber in Asphalt Pavements

Over the last 20 years, many highway jurisdictions have also experimented with different asphalts that include blended recycled rubber particles as a way to re-use old tires as well as to monitor the effects of rubber in possibly reducing the aging effects in asphalt pavements. Anecdotal comments following these experiments were also being received noticing a reduction in traffic noise with these rubberized mixes when compared to conventional pavements. While there have been many claims of noise reduction from different agencies over the years, there was limited conclusive documentation and testing to support the claims [Scofield 2005].

Noise Reducing Asphalt Testing Program

After researching the existing documentation without finding complete and conclusive information, the Region of Waterloo in conjunction with the University of Waterloo's Centre for Pavement and Transportation Technologies (CPATT) decided to embark on a partnership to study noise reducing asphalts including asphalts with added rubber. The study mandate was to design and construct noise reducing pavement test sections and then to conduct controlled noise testing on four different types of asphalt mixes to accurately determine the noise-reducing characteristics of different asphalt surface course mixes [CPATT 2004].

Mix Designs Selected for Testing

CPATT staff developed a list of candidate asphalt pavement mixes for inclusion in the controlled testing program. In addition to the open-graded mixes commonly used for noise mitigation in Europe and the rubber asphalt mixes used in the southern states, CPATT also suggested the use of Stone Mastic Asphalt (SMA) which had exhibited noise reducing characteristics in a number of jurisdictions.

The following four asphalt mixes were selected for placement for controlled noise testing:

Rubber-modified Open Friction Course (ROFC)

A conventional Open Friction Course mix using all-crushed premium fine and coarse aggregates with added rubber blended into the asphalt cement.

Rubber-modified Open Graded Course (ROGC)

An open-graded mix with the same gradation as an Open Friction Course mix but using locally available fine and coarse aggregates. Rubber was also blended into the asphalt cement.

Stone Mastic Asphalt (SMA)

A durable, gap-graded mix (no medium aggregates) with high asphalt cement binder content.

HL-3 Hot Mix Asphalt (HL-3)

HL-3 is the standard Region of Waterloo surface course and was placed adjacent to the other three specialty mixes for use as a Control Section.

It is important to note that there were some construction issues associated with the placement of the SMA section. Due to some difficulties at the contractor's plant, several areas of SMA exhibited "fat spots". Some follow-up testing also indicated that the SMA section did not meet a number of the mix design and compaction requirements. Consequently, there are some concerns that the performance expectations in terms of service life and noise reduction of the SMA test section may not be fully achieved.

A copy of the gradation tables for the four test mixes follows.

Contractor:	Steed and Evans Limited	Job Number:	2004-065B
Contract:	2004-013	Date Completed	July 22, 2004

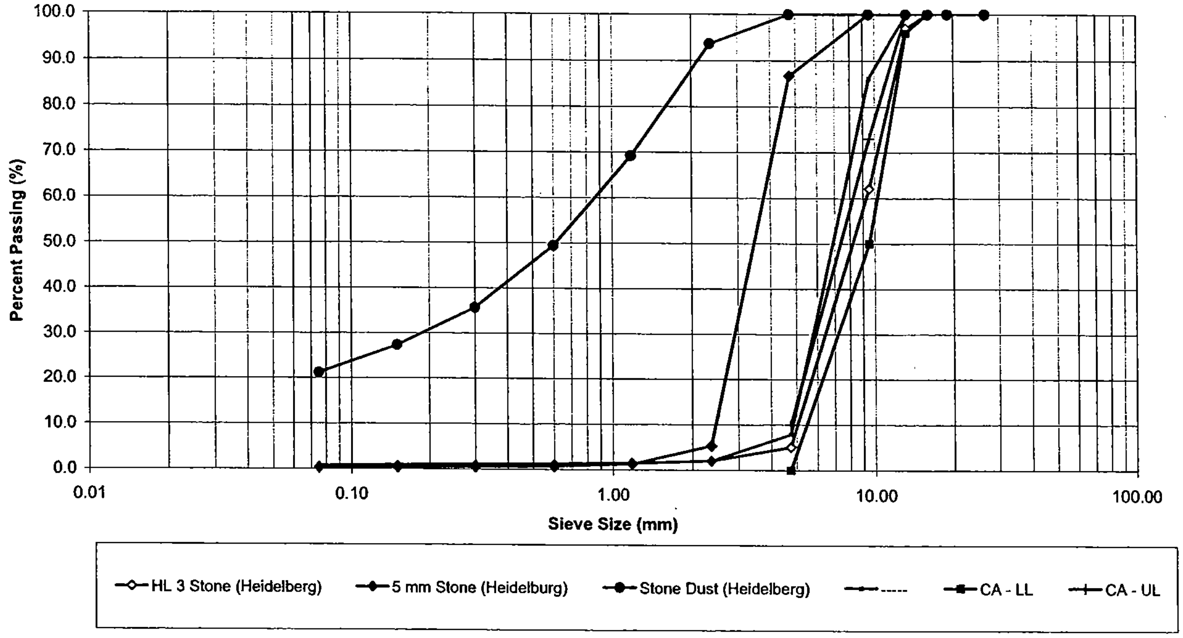

FIGURE 1: AGGREGATE GRADATIONS

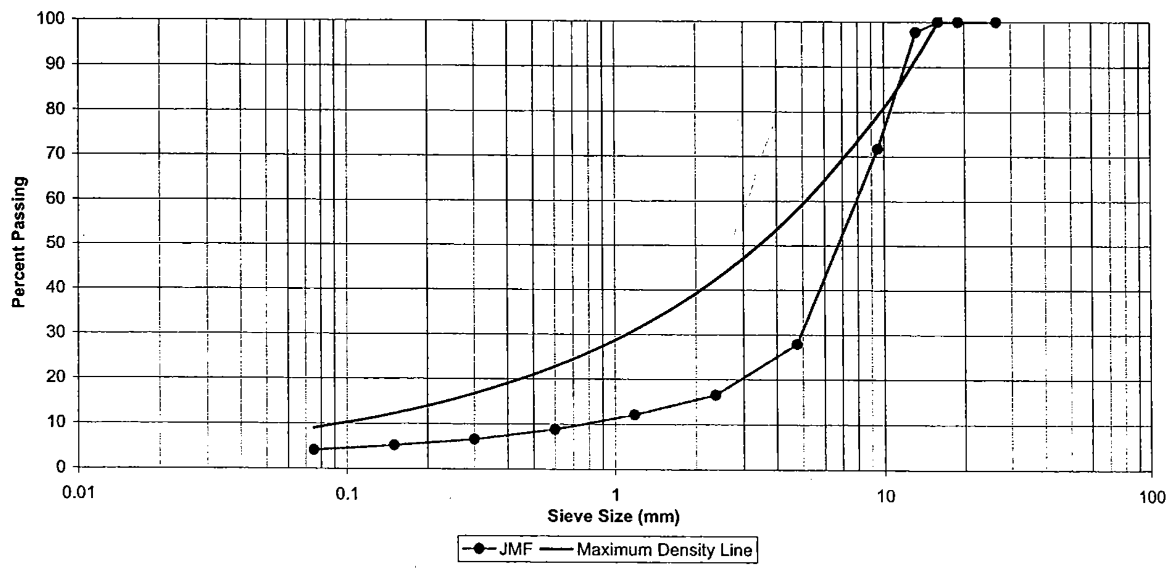

FIGURE 2: JOB MIX FORMULA

Rubber-Modified Open Graded Course (ROGC)

Contractor:	Steed and Evans Limited	Job Number:	2004-065C
Contract:	2004-013	Date Completed	July 23, 2004

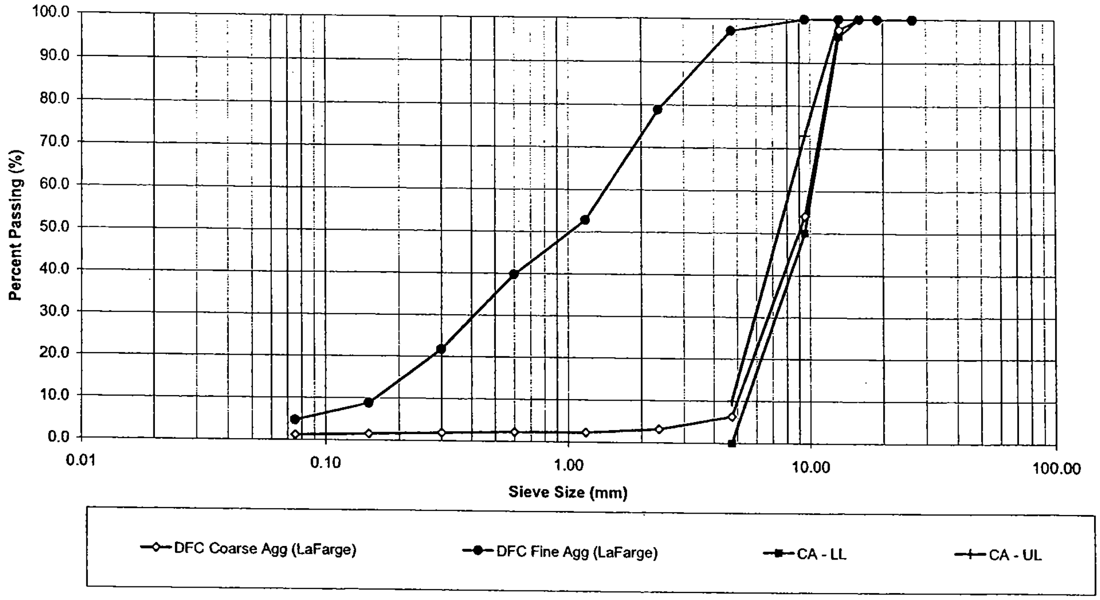

FIGURE 1: AGGREGATE GRADATIONS

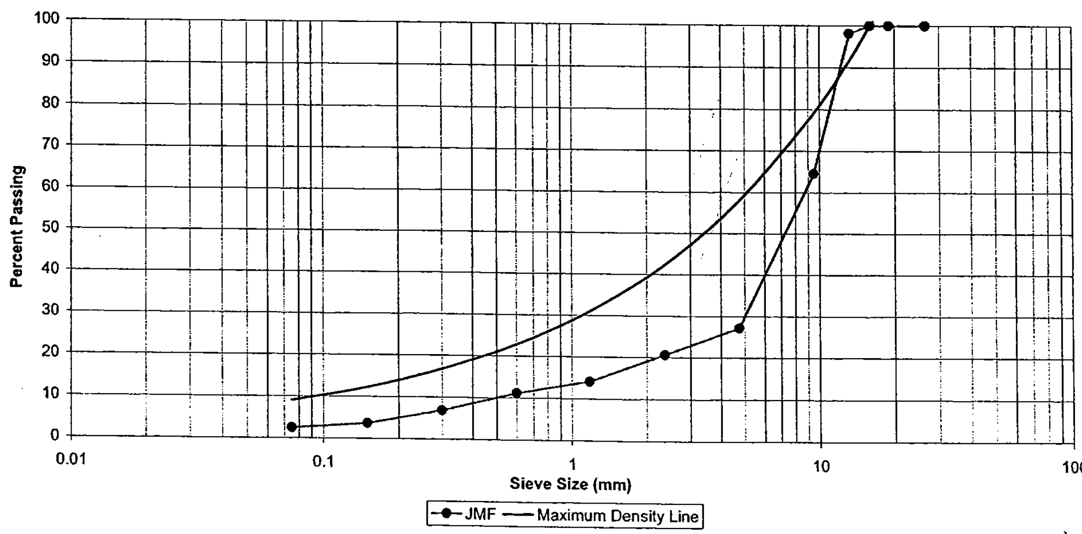

FIGURE 2: JOB MIX FORMULA

Rubber-Modified Open Friction Course (ROFC)

CONTRACTOR:	Steed and Evans Limited	McA JOB NO.	2004-065A
Contract:	2004-013	Highway	Test Section

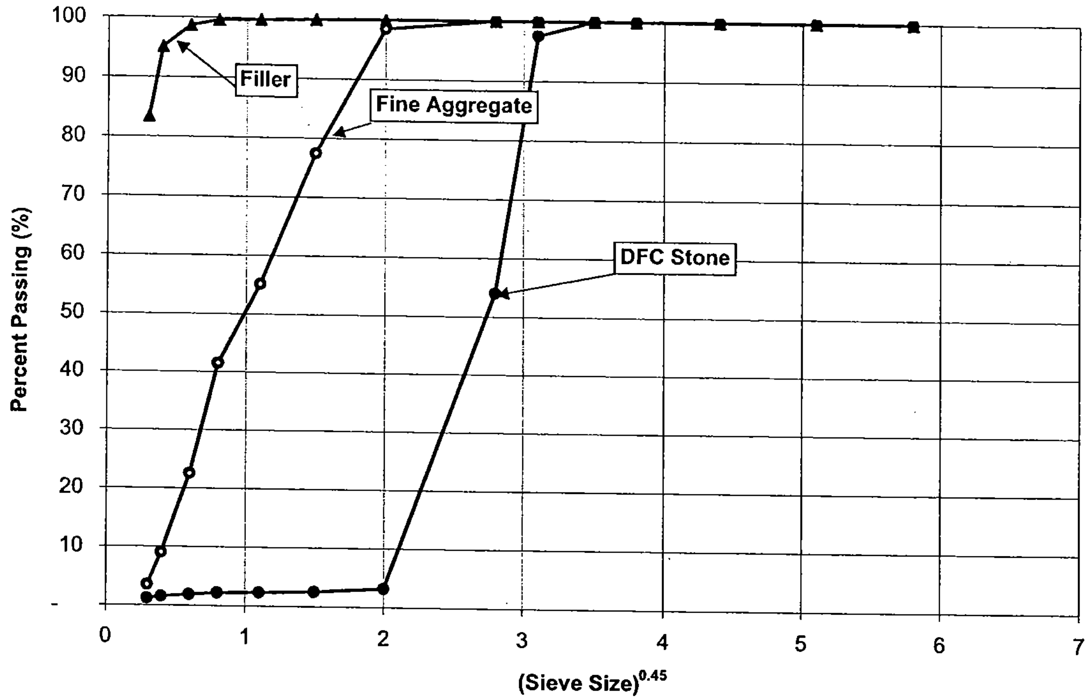

Figure 1: Aggregate Gradations

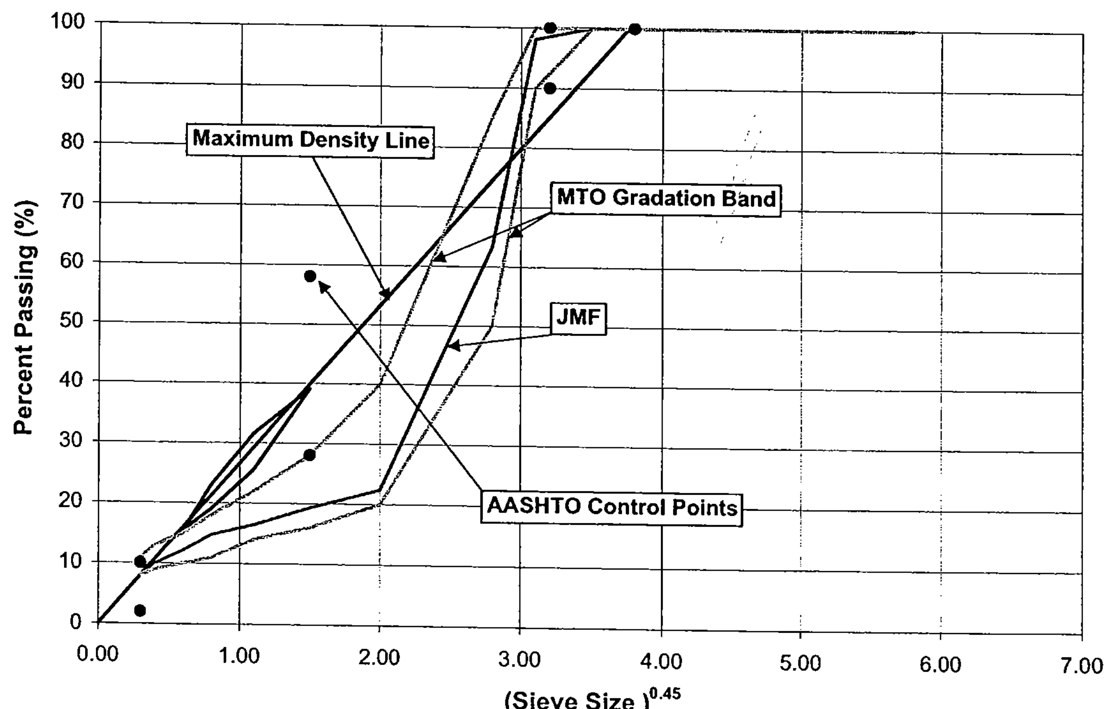

Figure 2: Job Mix Formula.

Stone Mastic Asphalt (SMA)

Contractor:	Steed and Evans	McA Job Number:	3002-B
Contract:	----	Date Completed	March 24, 2003

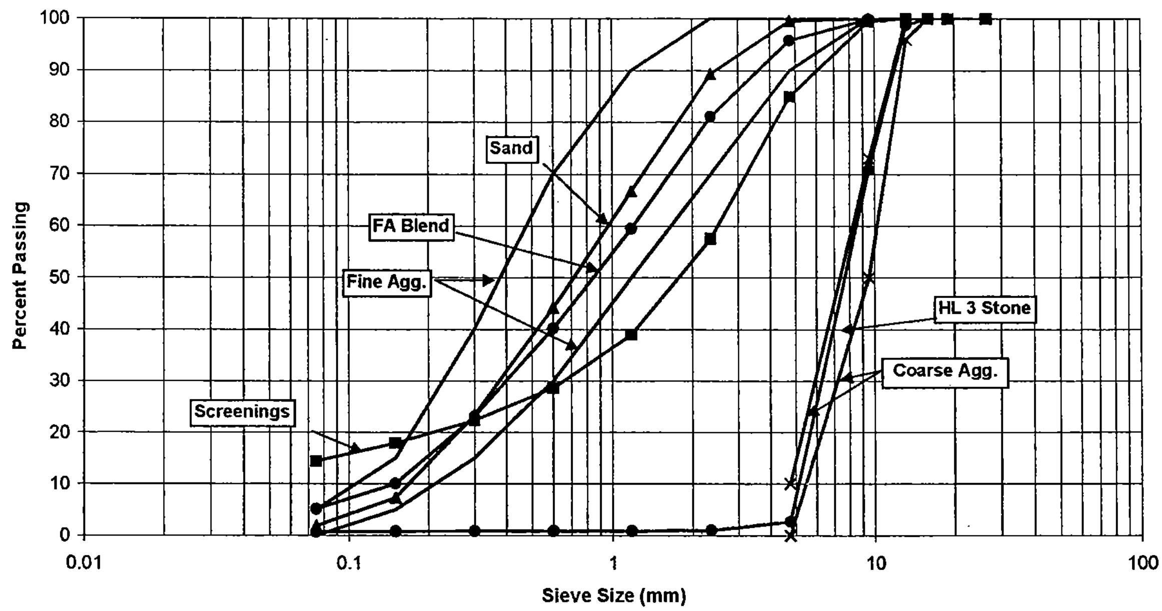

FIGURE 1: AGGREGATE GRADATIONS

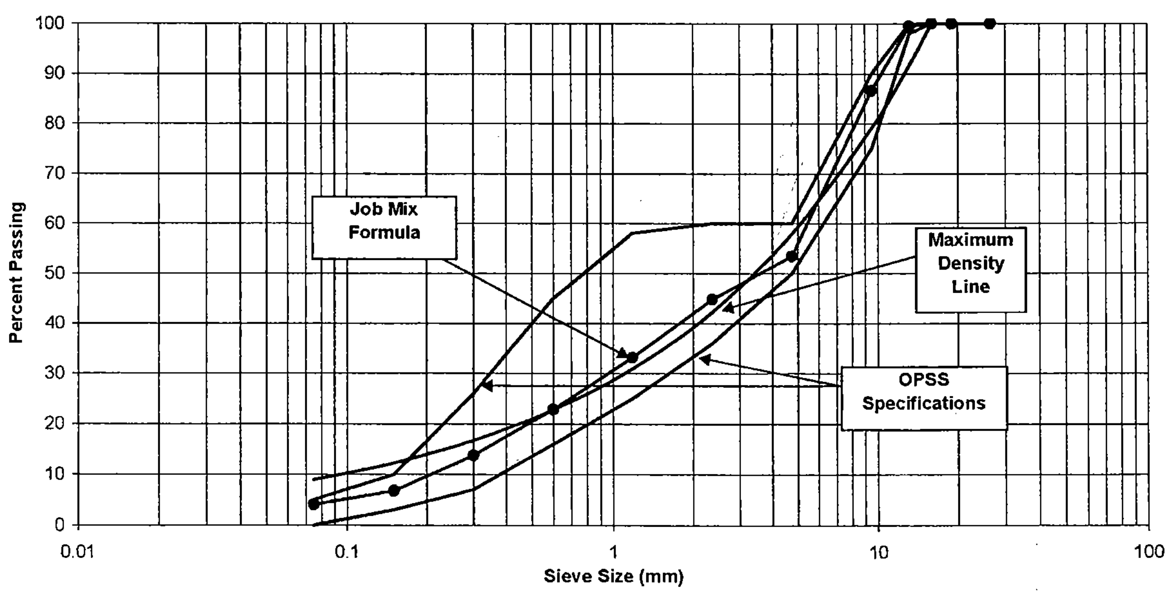

FIGURE 2: JOB MIX FORMULA

HL-3 Hot Mix Asphalt (HL-3)

Notes on Different Types of Rubber-modified Asphalt

Over the years, there have been a number of different types of rubber-modified asphalts used by different jurisdictions in efforts to re-use discarded rubber tires and divert tire waste from landfills. Introduction of the rubber into the asphalt has been accomplished by heating and blending liquified chipped rubber into the asphalt cement (called the "wet" process) or by adding the crumb rubber particles directly into the mix as part of the aggregate make-up (called the "dry" process). Based on a number of experiments over the years, the "dry" process has been shown to be deficient in that the dry crumb rubber under moderate to heavy traffic loadings can tend to segregate and pop out of the asphalt matrix causing premature failure at the surface of the mat.

The two rubber-modified mixes (ROFC and ROGC) used in the Region/CPATT testing program were introduced into the asphalt using the "wet" process. The ground tire rubber particles were introduced into the asphalt cement at the refinery terminal where is it heated to become homogeneous with the liquid asphalt cement binder. The liquid asphalt cement included 10 % tire rubber and was then shipped to the asphalt plant where it was mixed with the fine and coarse aggregates to form the final asphalt product. This process is called the “terminal blend” process.

Another rubber-modified process that is used in the southern United States involves the addition of the rubber particles at the asphalt plant where the rubber is added into the asphalt cement in larger quantities immediately prior to mixing with the aggregates. This “field blend” process requires a separate reaction chamber at the asphalt plant to continuously mix and suspend the rubber particles in the asphalt cement mix to avoid segregation of the rubber. A “field blend” process can include up to 20 % rubber in the asphalt cement but can only be produced with the reaction chamber at the asphalt plant. The reaction chamber units cost over $1 Million and are therefore only feasible if sufficient quantities of rubber-modified mixes are being produced. Accordingly, the Region/CPATT test area included only the “terminal blend” rubber-modified asphalts to test the noise reduction characteristics of rubber mixes.

Noise Reducing Asphalt Program - Test Site

The Region of Waterloo / CPATT test site location was selected from locations already committed for pavement rehabilitation within the Region’s annual rural resurfacing program. The location chosen for the noise testing was on Regional Road 11 (William Hasting Line) between Manser Road and the western Regional boundary in the Township of Wellesley. This 5.5 km section of road was deemed conducive for use as a controlled test section because it provided a straight horizontal alignment with uniform vertical grades, consistent adjacent land use (predominantly agricultural) and little ambient noise activity [CPATT 2004].

Noise Measurement Testing

The four different surface courses were placed in lengths of 600m over a four day period in August, 2004. On September 13 and 14, 2004, William Hastings Line was closed to traffic and controlled noise testing was undertaken under contract with the noise specialist consultant Rowan Williams Davies and Irwin Inc. (RWDI). Noise measurement stations were set up at the midpoint of the four test areas at a consistent distance and elevation from the road in accordance with the Pass-By Method. In addition, a boom microphone was placed on each test vehicle suspended 50 cm from the tire/pavement contact point, to record noise at the tire/pavement interface.

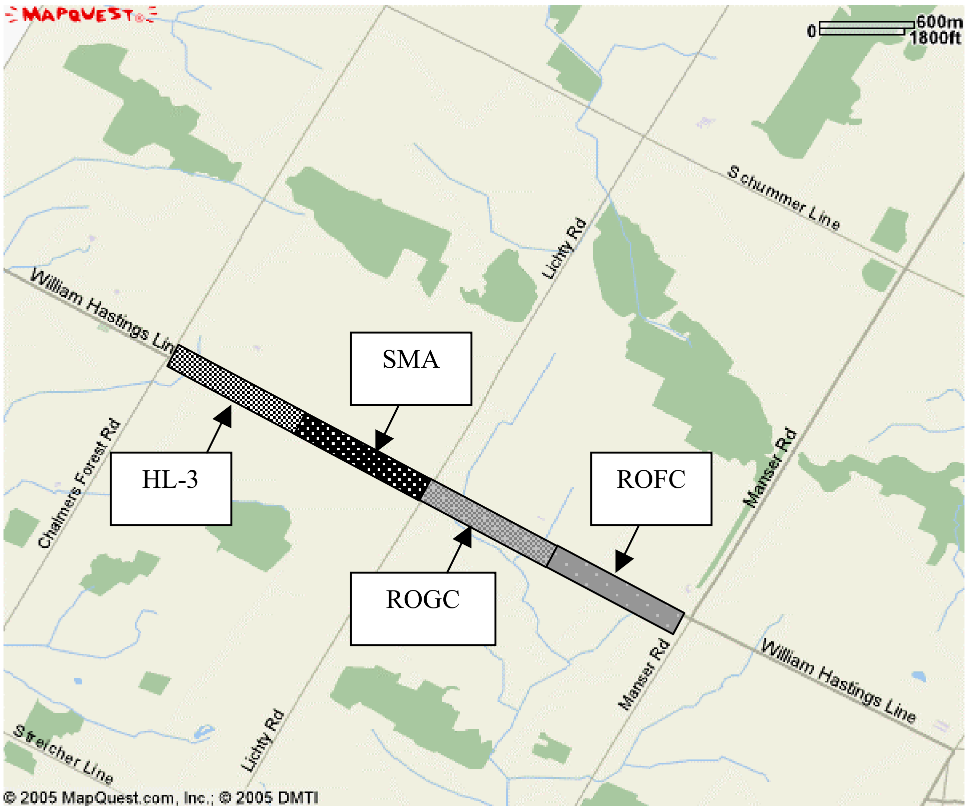

Figure 1: Site Map (Adapted from www.mapquest.ca)

Testing Methodology

Thirteen test vehicles were used to conduct the noise testing, divided into three categories: light (5 vehicles); medium (5 vehicles); and heavy (3 vehicles). Vehicle sizes and types are described in Table 1.

Table 1 Description of Test Vehicles

Vehicle Size	Vehicles Type	Specifications
Car/Light Truck	2 cars, 1 mini van, 2 light trucks	2-axle, 4 wheels, ≤ 9 passengers, ≤ 4500 kg
Medium Truck	2 Region buses, 3 Region Works trucks	2-axle, 6 wheels, 4500 to 12000 kg
Heavy Truck	3 snow plow trucks	≥ 3-axle, design for hauling cargo, ≥ 12000 kg

Noise measurements were recorded for each test vehicle passing through the test site. Test vehicles were driven through the test site at constant speeds of 60, 70, 80 and 90 km/h from east to west and then made a return trip. Thus two measurements for each of four speeds were taken for each of the thirteen vehicles. With noise levels being recorded from both the fixed noise measurement stations and the mobile microphone during each run, the testing program provided 832 noise measurements over the two-day testing period [RWDI 2004].

The two sound level measurement techniques used in the testing program are commonly referred to as the Pass-By Method and the Close-Proximity Method [Bernhard 2004].

Each Pass-By station was monitored by a technician and was located 15 m from the centreline of the road at a height of 1.5m above the road to replicate a typical receiver location in the STAMSON model. The maximum sound level (L_{max}) and equivalent sound level (L_{eq}) were recorded at the Pass-By stations [Schroterm 1989].

The Close-Proximity microphone recorded the continuous sound from a single tire (at 50cm distance) producing equivalent sound level (L_{eq}) measurements at the vehicle.

Test Results

Using the data that was collected, various types of analysis were carried out. The following section briefly summarizes recorded performance to date. Graphical plots for the three types of vehicles showing sound level versus vehicle speed are provided in the following figures [Leung 2005].

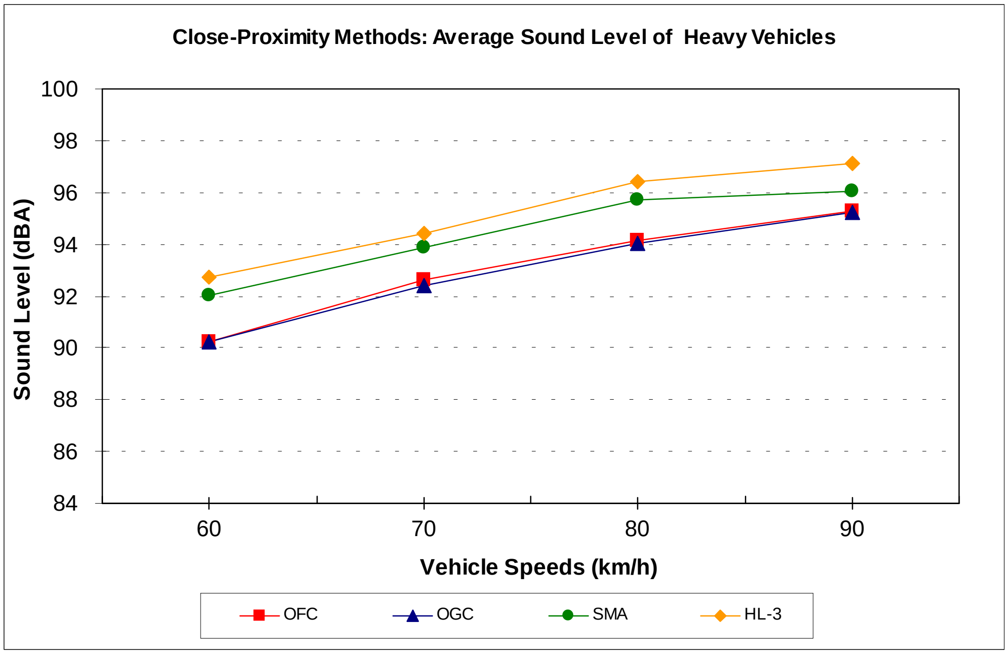

Figure 2: CPM Sound Level Measurements for Heavy Vehicles at Various Operating Speeds

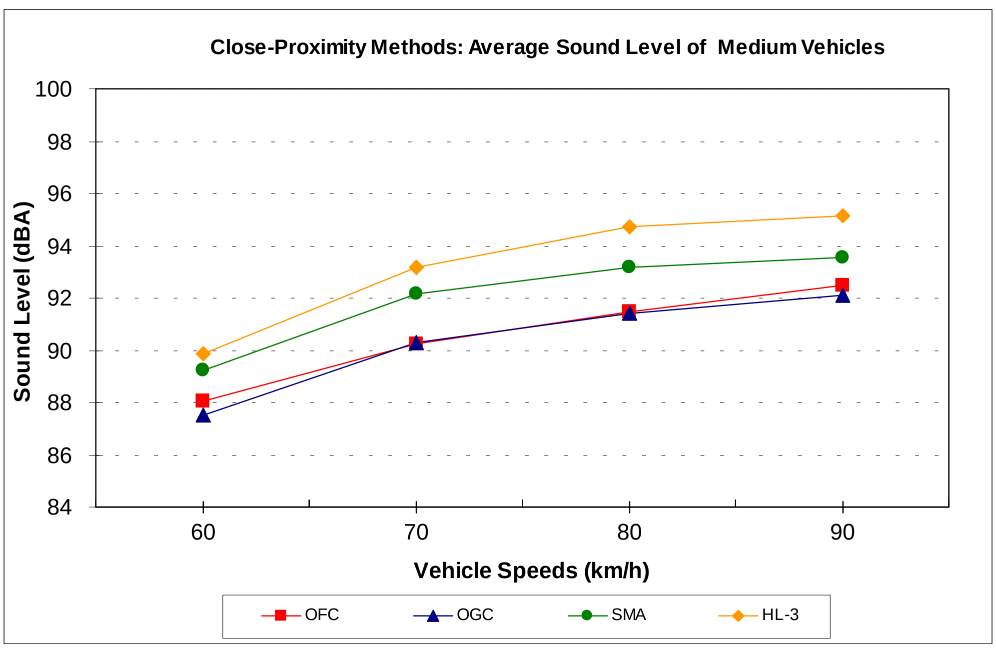

Figure 3: CPM Sound Level Measurements for Medium Vehicles at Various Operating Speeds

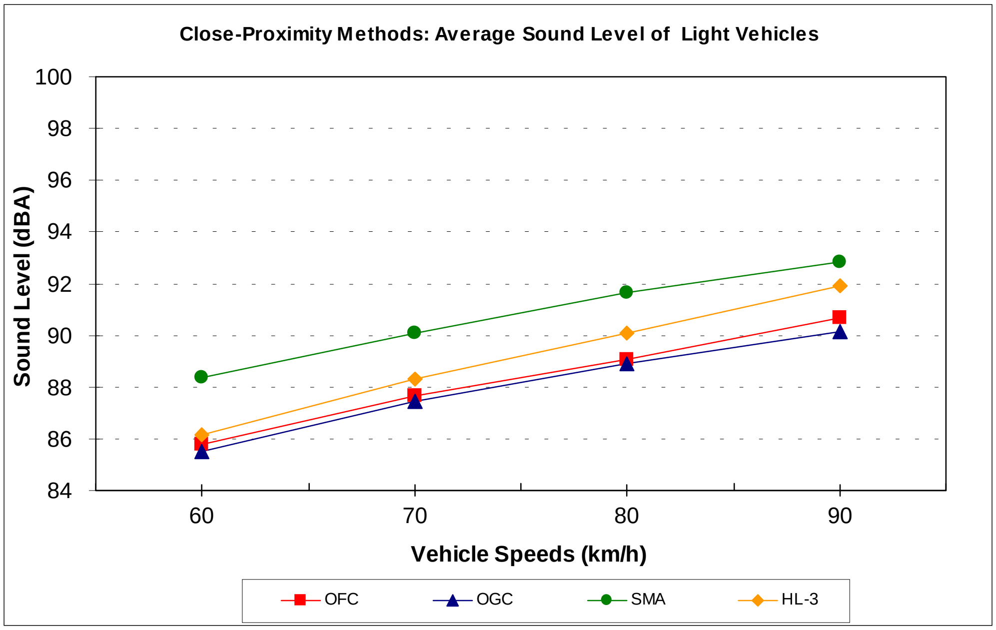

Figure 4: CPM Sound Level Measurements for Light Vehicles at Various Operating Speeds

For all four types of pavements and all types of vehicles, the sound level increases with vehicle speed. The sound measurement results show that HL-3 has the highest sound level measurement for heavy and medium vehicles for all four of the test speeds. SMA was shown to exhibit the highest sound level measurement for the light vehicle category for all speeds. Both the ROFC and ROGC have the lowest sound level measurement for all three vehicle speeds. The amount of noise reduction compared to the HL-3 control section is show in the following Figures 5 and 6.

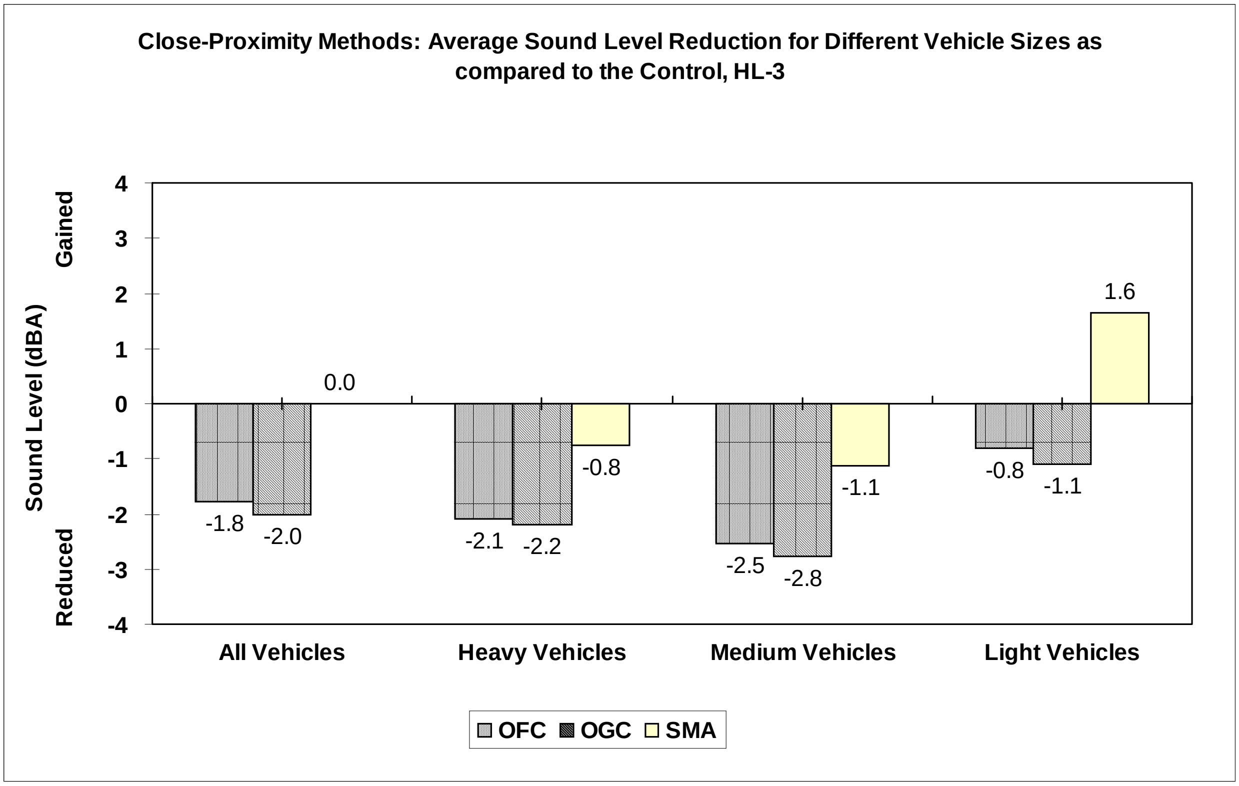

Figure 5: CPM – Average Sound Level Reduction for Different Vehicle Sizes as compared to the HL-3 Control Section

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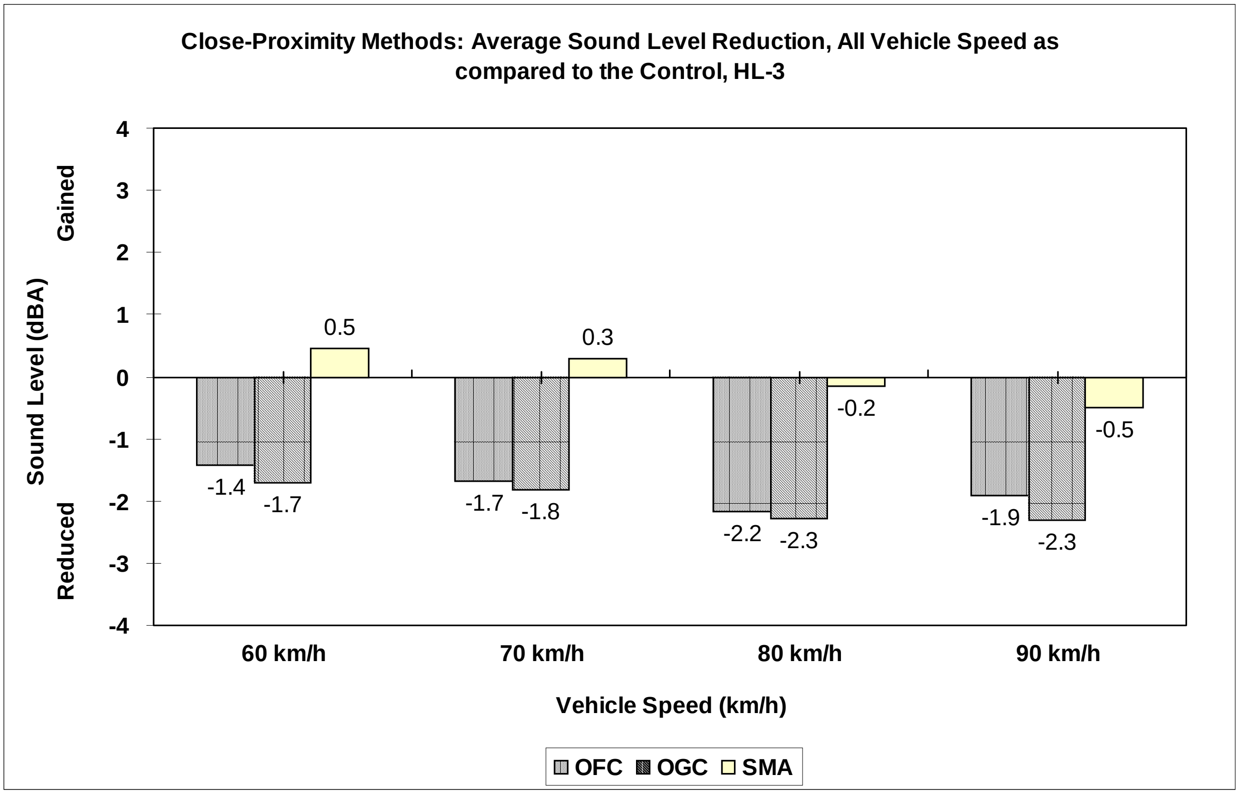

Figure 6: CPM – Average Sound Level Reduction for Different Vehicle Speeds as compared to the HL-3 Control Section

The averaged noise results in this initial study for the SMA section showed noise levels both greater and less than the HL-3 control section, depending on type of vehicle and speed. The greatest reduction in noise on the SMA section was a reduction of only 1.1 dBA for medium sized vehicles (all speeds combined) compared to the HL-3 control section.

Both the ROFC and ROGC exhibited the greatest noise reduction effect for the averaged results compared with the HL-3 control section. For the ROFC pavement, the greatest noise reduction values were a 2.5 dBA reduction (observed for medium vehicles, all speeds combined) and a 2.2 dBA reduction (observed at 80 km/h, all speeds combined). For the ROGC pavement, the greatest noise reduction values were a 2.8 dBA reduction (observed for medium vehicles, all speeds combined) and a 2.3 dBA reduction (observed at 80 km/h, all speeds combined). The smallest noise reduction values for ROFC and ROGC were recorded at 0.8 dBA and 1.1 dBA in the light sized vehicle category.

Pass-By Method

The sound level measurements from the Pass-By Method are presented as the Maximum Sound Level (L_{max}) for the three vehicle sizes: heavy, medium, and light vehicle and are shown in Figures 7, 8 and 9.

The following analysis examines changes in Sound Level as a function of vehicle type and operating speed.

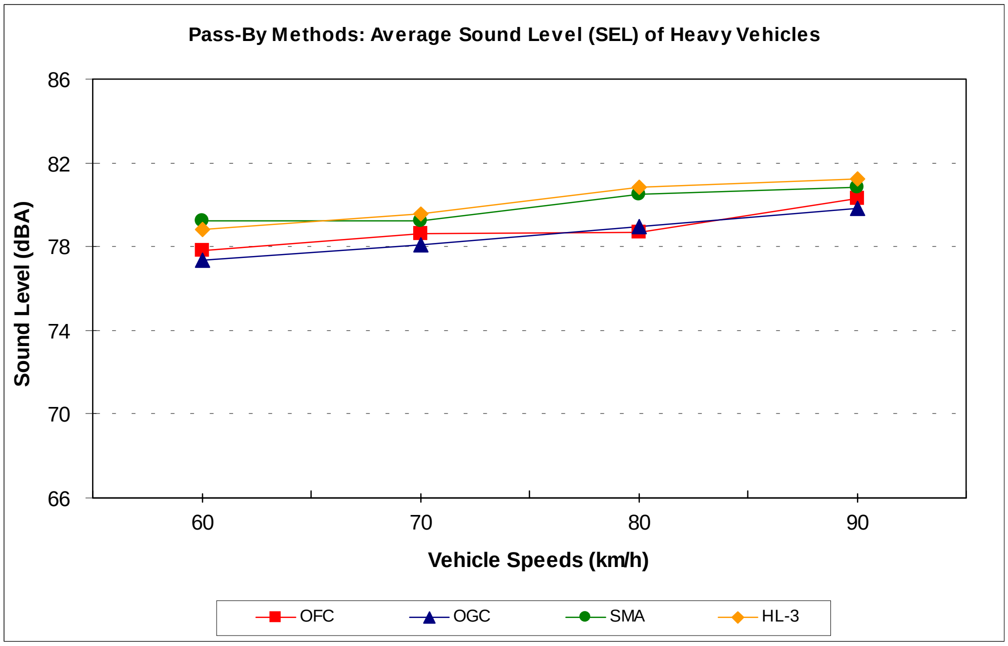

Figure 7: PBM Sound Level Measurements for Heavy Vehicles at Various Operating Speeds

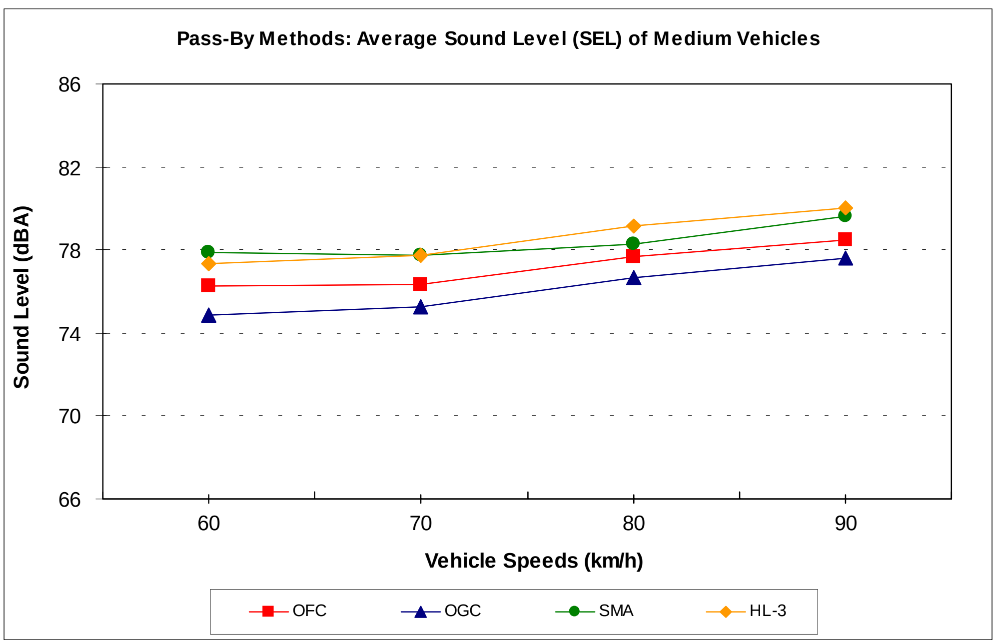

Figure 8: PBM Sound Level Measurements for Medium Vehicles at Various Operating Speeds

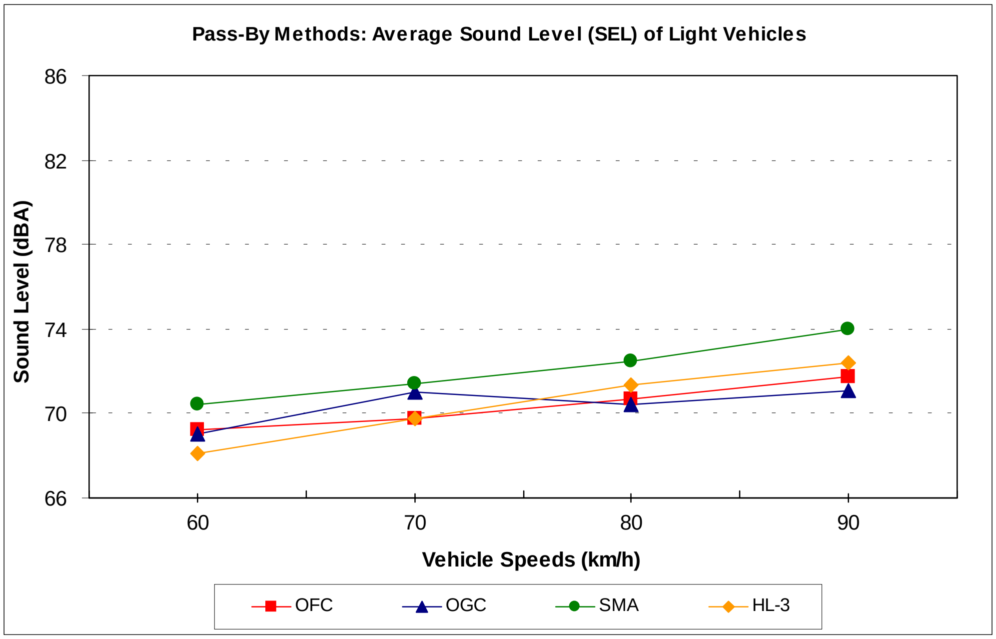

Figure9: PBM Sound Level Measurements for Light Vehicles at Various Operating Speeds

Heavy and medium size vehicles on the HL-3 control section show the highest pass-by sound level when their speeds are above 70 km/h. However, SMA shows the highest pass-by sound level for light vehicles. Again, as shown earlier with the close-proximity method, the ROFC and ROGC produce lower sound levels compared to the control section. The amount of pass-by noise reduction compared to the HL-3 control section is shown in the following Figures 10 and 11.

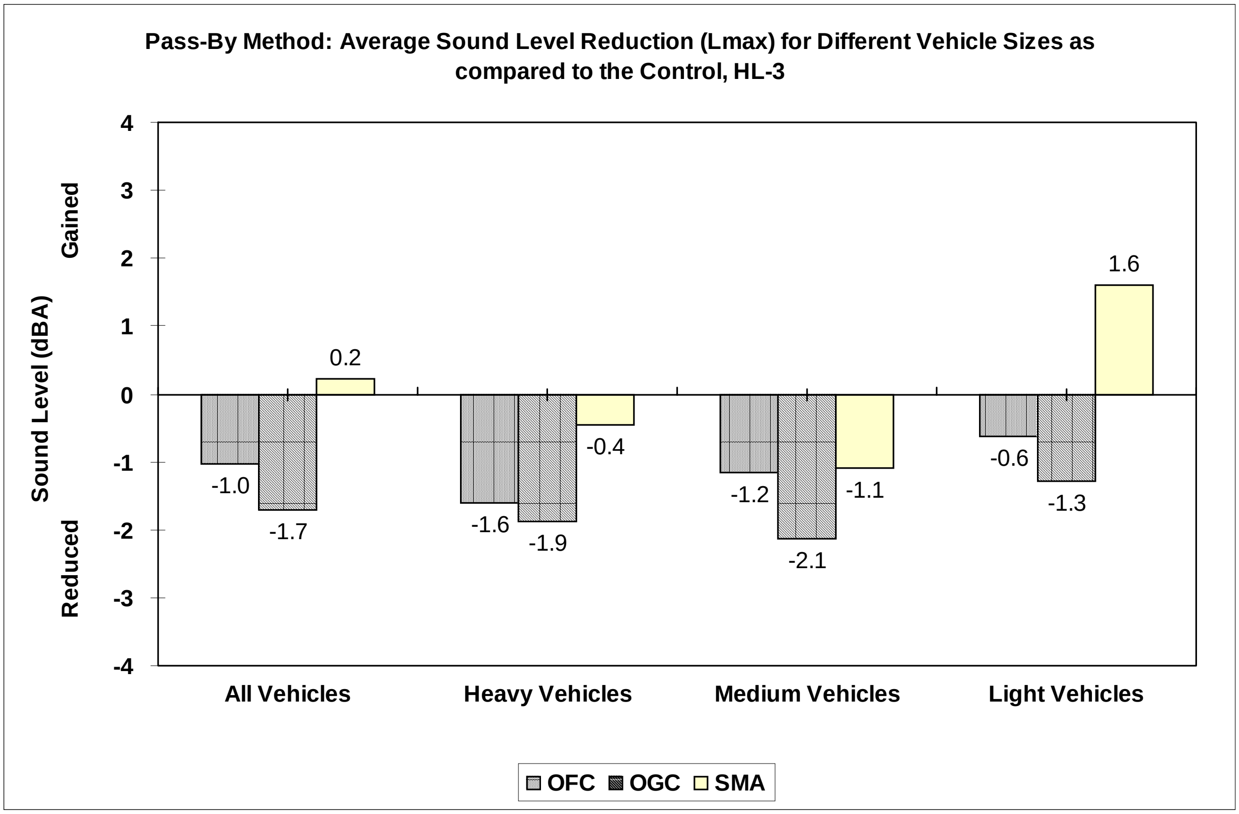

Figure10: PBM – Average Sound Level Reduction in Different Vehicle Sizes as compared to the HL-3 Control Section

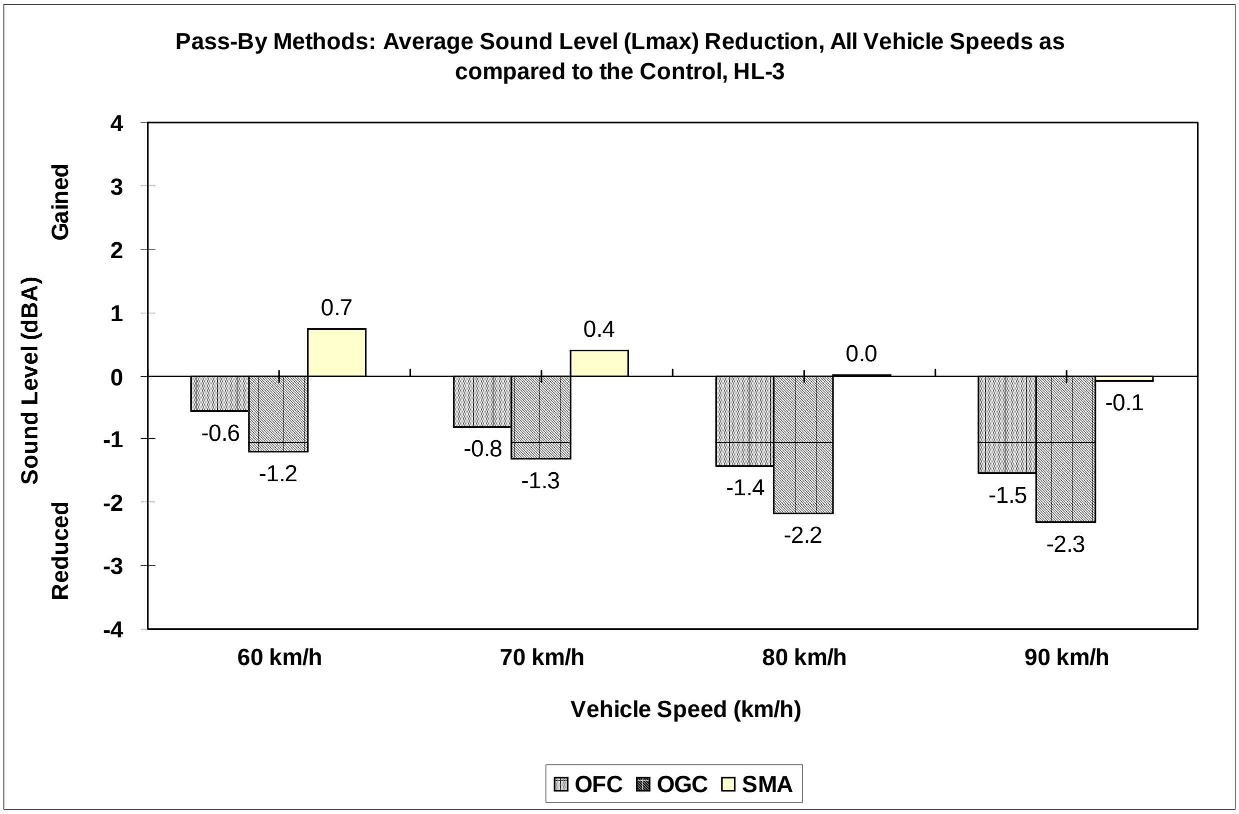

Figure 11: PBM – Average Sound Level Reduction in Different Vehicle Speeds as compared to the Control, HL-3

The pass-by noise reduction results are similar to the CPM noise reduction results for the OFC and OGC. The highest noise reduction values observed were 2.2 dBA and 2.3 dBA for the medium sized vehicles and vehicle speeds of 90 km/h in the OGC pavement. The lowest noise reduction values for OGC were approximately 1.2 dBA for light size vehicle and the vehicle speed is at 60 km/h.

Conclusions

This paper provides a brief description of an initiative which examines the technical effectiveness of three specialized asphalt mixes with respect to noise reduction. The three specialty mixes are each compared to the typical control mix used by the Region of Waterloo. Two primary methods of noise measurement are used in this study to examine performance. These methods include the Close-Proximity Method and the Pass-By Method. Although the results are very preliminary, it is demonstrating that some noise reduction has been achieved.

The Close-Proximity Method results show that ROFC and ROGC pavements provide approximately 2-3 dBA Leq attenuation, when compared to conventional HL-3 pavement. The SMA does also show some reduction in noise for medium and heavy vehicles. However, for light vehicles it appears to be slightly louder. It is noteworthy that the SMA does exhibit several construction deficiencies associated with problems that the contractor encountered during construction. This in part could be contributing to the limited noise reduction results at this point in time for the SMA test section.

The By-Pass Method results show that Lmax is generally similar for the ROFC and ROGC pavements, when compared to conventional HL-3 pavement. However, the Leq results show that the ROFC and ROGC pavements are both quieter than the HL-3 control section by approximately 2.5 dBA.

Although these results are preliminary, some reduction in noise was observed. Overall, the results observed on the first set of measurements are conservative. However, this was somewhat expected as the research team developed the mix designs in a prudent manner. In short, the use of open-graded courses has been limited in Ontario and the team was concerned about drainage and general performance over the winter period. Also, based on the literature, there have been some issues related to use of rubber in asphalt mixes, particularly in cold climates which experience freeze/thaw cycles. For both of these reasons, there was some concern about long term performance. Thus, a conservative approach was taken in the selection of design mixes. It is anticipated that future placements will re-examine these initial mixes and slight modifications will be made to further enhance knowledge in this area.

<u>Results from Other Jursidictions</u>

As noted earlier in this report, the testing undertaken by the Region of Waterloo and CPATT used “terminal-blend” rubber-modified asphalt. The jurisdictions that have been producing significant quantities of “field blend” rubber-modified asphalts include Arizona, Texas, California and Florida. In addition, Alberta Transportation has just recently made arrangements to use a reaction chamber over the next few years for its experimental rubber pavement testing program. Alberta has not done any controlled testing but based on 24 hour noise measurements, Alberta is also reporting a 2-3 dBA reduction in noise after 2 years of service for the “field-blend” rubber pavement.

Texas, California and Florida have not conducted any controlled noise testing programs since rubber mixes are primarily used in these states to reduce tire waste, reduce reflective cracking and to improve traction and visibility during wet weather. Based on its limited noise testing program, Arizona DOT has agreed to incorporate a noise reduction factor for rubber-modified pavements when proposed for use in highway corridors that would otherwise be constructed with concrete pavement. Arizona DOT allows a 4 dBA reduction factor in some noise analyses when rubber-modified pavements are modeled in lieu of concrete pavement. No similar reduction is applied when comparing noise reducing pavement to conventional dense-graded asphalt pavements. The US federal highway transportation agency (FHWA) has not yet agreed to unilaterally allow any noise reduction factor for the use of rubber pavements as FHWA insists that the long term degradation of rubber pavements must be further studied before any conclusions on the noise reduction benefits can be drawn.

Recommendations and Next Steps

It is generally accepted that the human ear can only perceive a change in average sound level of 3dBA or greater. The 2-3 dBA reduction measured in the Region/CPATT noise testing program is therefore only marginally perceptible and not considered significant. It is also expected that the noise reduction benefit of these special mixes will degrade over time with surface wear and filling of the voids. The Region of Waterloo and CPATT are committed to long-term monitoring of the test area constructed on William Hastings Line to assess these possible degradation effects as well as to monitor the performance of these special pavement mixes over time. Other possible benefits could be realized through further testing and analysis of these special mixes. In the interim however, results from the noise reducing asphalt testing program have shown that there is no appreciable reduction in noise associated with the ROFC or ROGC asphalt pavements that warrants their consideration for use in noise attenuation on Region of Waterloo roads.

References

[Bernhard 2004] Bernhard, R., and R. McDaniel, “Basics of Noise Generation for Pavement Engineers, Indiana, 2004

[CPATT 2004] Centre for Pavement and Transportation Technology, “Construction Notes Noise Reducing Pavement Project”, University of Waterloo, 2004

[Garcia 2004] Garcia, A and A. Merida, “Urban Traffic Noise Reduction by Quiet Pavements: Experimental Result”, Spain, 2004

[McDaniel 2004] McDaniel, R, and W. Thornton, “Field Evaluation of a Porous Friction Course for Noise Control”, Indiana, 2004

[RW 1999] Region of Waterloo, “Implementation Guidelines for Noise Policies”, Waterloo, Ontario, 1999

[Schroterm 1989] Schroterm, V., and C. Chiu, “Ontario Road Noise Analysis Method for Environmental and Transportation (Ornament)” Ontario Canada, 1989

[Scofield 2005] Scofield, L and P. Donavan, “The Road to Neighborhoods in Arizona”, Arizona Department of Transportation, 2005