SPECIAL NOISE BARRIER APPLICATIONS
Phase III

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Final Report

SPECIAL NOISE BARRIER APPLICATIONS

Phase III

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THE EXECUTIVE SUMMARY

This report presents the results of an acoustical scale modeling research effort in which the performance of special noise barrier shapes are compared to the performance of conventional noise barriers. This effort is a follow-up to previous work (*Phases I and II*) in which various barrier shapes were examined for increased performance and cost-saving potential.

The results of this study provide generally good agreement with the results predicted by the *Phase II* project. While not exactly reproducing the theoretical performance of the special barrier shapes, this scale modeling effort has demonstrated that an increase in performance can be expected by implementation of these special barrier shapes. The results demonstrate that application of an absorptive T-top or treatment of a conventional single reflective wall with absorptive material can provide similar performance to a taller conventional noise barrier. For example, *Phase II* results indicated that barrier heights could be reduced by 5 to 8 feet by constructing a T-top barrier instead of a conventional vertical wall. The scale model results demonstrated that the actual insertion loss was about 2.3 dB less than expected, but was still in the acceptable range for abatement goals. Similarly, *Phase II* results indicated that conventional barriers heights could be reduced by 3 to 5 feet by substituting single-wall absorptive barriers. About 1.5 dB less insertion loss than expected was realized, but again the results were in the acceptable range for abatement goals.

The report concludes that while these special barrier shapes did not provide the magnitude of insertion loss expected, the results do indicate an increased barrier performance using them. A recommendation for implementation of the special noise barrier shapes on specific actual projects is then made. The construction of these barriers is an important next step in finalizing and quantifying the real benefits of these special shapes.

PROBLEM STATEMENT

During the last 20 years, state highway agencies have constructed more than 500 linear miles of noise barriers in the United States. Most of these barriers have been vertical, reflective walls made of concrete, wood, or steel with a "knife-edged" barrier top, providing a single diffraction edge with a reflective diffraction zone. Clearly, many other options are available for noise barrier shapes and treatments, including earth berms, absorptive or partially absorptive barriers, barriers with slanted sections at their tops to provide horizontal displacement of the diffraction zone, and barriers with T-tops or Y-tops to provide a double-diffraction zone.

In two previous studies for WSDOT, *Special Noise Barrier Applications: Phase I and Phase II*, potential special barriers shapes and treatments were identified and recommended for potential future implementation on four actual highway projects in Washington State. The recommended treatments were: absorptive T-top barriers, single-wall absorptive barriers, and absorptive parallel barriers.

This *Phase III* study examined the predicted performance of Phase II results by constructing a scale model of each of the four WSDOT highway sites and testing them in an acoustic laboratory. The final *Phase II* barrier recommendations for each highway project were tested and the results statistically analyzed. These results allow verification of the performance of the special treatments prior to WSDOT actually constructing any of the special shaped barriers in the field.

OBJECTIVE

A previous study, *Special Noise Barrier Applications: Phase II*, recommended that each of the selected WSDOT highway projects could benefit from the construction of a special noise barrier shape. The special barriers were shown to have several advantages over conventional barriers of the same height. Several rules of thumb were presented in *Phase II* relating to the generalized performance of the special noise barriers. The objective of *Phase III* research is to reproduce and test actual scale models representing sections of the four WSDOT Highway projects. Results from this testing will be used to verify the predicted increased performance of the recommended special barrier shapes.

INTRODUCTION

This study examined the predicted performance of Phase II results by constructing a scale model of the four actual WSDOT sites and testing them in an acoustic loboratory. Three of these highway projects are located in Seattle: Fourth Avenue S.E. and Magnolia Road, both located on SR-405 in King Co. and south Snohomish Co; and Kent Commons Play Field, located on SR-167. The other project is the Spokane Community College Area, located on the Market/Greene alternative of the planned North Spokane Freeway route.

A section of each site was selected and modeled at a scale factor of 50 to 1. Each modeled site represented a range of 1000-2000 feet of actual roadway. One (1) or two (2) receiver locations were selected and tested for each site. An artificial noise source was used for all of the testing and data was collected using sensitive microphones. A desktop computer was used to store and analyze the information collected for each site.

Acoustical scale modeling requires the careful selection and preparation of a variety of equipment and materials. Therefore a literature review was performed to examine past modeling efforts and provide the necessary specifications to accurately model the physical and acoustical components of the WSDOT sites. The primary source of information used to determine these specifications was a 1979 FHWA report entitled "Acoustical Scale Modeling of Roadway Traffic Noise: Final Report, Vol. 2", report no. FHWA/RD-81/021. A second source, "Mathematical Modeling of Absorbent Highway Noise Barriers" (1990) by S.I. Hayek was used in selecting the absorbent materials for the ground cover and barriers. A complete listing of all references is contained in the Appendices of this report.

This report is further organized into three sections. The first section explains the reason for using a scale factor and discusses the selection of the 50 to 1 factor used for the project. The second section presents the study results and a comparison to the *Phase II* predictions. The third section contains the Appendices.

Appendices A, B and C contain copies of the data collected during the actual modeling procedure. Appendix D describes and lists the scale model equipment, materials and methods used throughout the construction and testing of the modeled highway projects. Appendix E contains the literature of past modeling efforts and Appendix F contains selected photographs of the individual highway project scale models.

SCALE FACTOR AND MODEL REQUIREMENTS

A 50 to 1 scale factor was used in this modeling study. The decision to use a 50 to 1 scale factor was guided by a literature review of prior research, specifically that of Anderson, 1978 and FHWA 1979 (Appendix D).

The choice of scale factor was limited by two primary concerns: (1) The overall physical size of the testing laboratory, and (2) the availability of sensitive microphones corresponding to the desired acoustical frequencies examined during the testing. The University of Louisville provided a building with a measured interior space of 40 feet by 60 feet. The ceiling was constructed of standard acoustical tile which was 10 feet above the floor.

The maximum length of the highway project model was limited by these measurements. It was desired to model approximately 1000 to 2000 feet of roadway for each of the WSDOT highway projects. By applying several proposed scale factors, sample calculations of source to receiver path lengths indicated that a model up to 40 feet long could be constructed in the laboratory. The choice of the 50 to 1 scale factor would accommodate the target of up to 2000 feet of highway project and provide a minimum of 10 feet from the interior reflective wall/ceiling surfaces.

The model consisted of a central wooden platform on the existing floor and within the boundaries of the room. This platform was constructed of a "2 x 4" frame and ½" Type BC sanded plywood The testing platform was primed, painted and the joints between the plywood panels were filled to create a uniform flat surface. Each specific site was constructed and tested on the wooden platform. The platform measured 18 feet by 48 feet and was centered at the middle of the room. This arrangement facilitated adequate work space for construction and testing as well as provided the necessary path length differences required due to the reflective nature of the interior walls.

Selection of the proper microphones needed for the project was also a concern. Small acoustically sensitive microphones have an upper limit for flat frequency response. In acoustical scale modeling it is necessary to match this upper limit of flat response to that employed in the scale model. It was desired to model as large a range of the actual spectrum of automobile frequency noise as possible. FHWA has generalized this spectrum to be in the range of 63 to 8000 hertz. The use of commercially available 1/4" (diameter) sensitive microphones allowed the collection of data up to a flat frequency response of 100,000 hertz. At a scale factor of 50 to 1 this translated into capturing the generalized noise spectrum up to 2000 Hertz. This result agreed with the FHWA (1979) conclusion that capturing up to 100,000 hertz in the scale model is often necessary to provide a good representation of an adequate portion of the highway noise spectrum.

The test data was further classified by LABVIEW for Windows software into four (4) frequency octave ranges at the 50 to 1 scale factor. The octave ranges were 250 hertz, 500 hertz, 1000 hertz and 2000 hertz. All of the data analysis and results for this report were generated using the portion of collected data from the 500 hertz frequency band only, since results were being compared to insertion loss predictions generated by the STAMINA 2.0 software. LABVIEW performed the required calculations to convert the frequency response into decibels over the four octave ranges.

TEST DATA AND RESULTS

This section discusses the test results and data analysis procedure. Results of the scale model verification process are presented first. Next, the measured insertion loss values are presented for each site from the scale model testing procedure. These results are then compared to the predictions developed in the *Phase II* project. The test results are then classified and compared to the rules-of-thumb for special barrier treatments as outlined in the *Phase II* report.

Data Presentation and Analysis

The data files and graphs shown in Appendices A, B, and C illustrate the data gathered from the scale model testing. Each data file contains a listing of individual test points. Each scale model was first tested under a no-barrier scenario. Next, testing was performed with a conventional barrier in place and then with each of the special shape barriers. The barrier heights used in the test were taken directly from *Phase II* report.

Once all the data points were collected, a "best-fit" curve was generated for use in calculating the modeling results for each receiver. Microsoft Excel spreadsheet software was used to calculate this equation from the collected data points. This procedure yielded two sets of data. One set represents the actual data collected while the second represents the smoothing of the data set into a fitted line. The data from the fitted line was then used for direct comparisons of attenuation and insertion loss.

Actual insertion loss values were calculated as the mathematical difference between the attenuation observed in the no-barrier scenario and that observed for the other tested barriers. On each of the four modeled sites, the conventional barrier was installed and tested first. Absorptive T-top and Absorptive Single-wall barriers were tested on the Magnolia Road, Kent Commons Play Field and Fourth Avenue models. Absorptive parallel barriers were installed and tested on the Spokane Community College scale model.

In each test, the results for the insertion loss due to the noise barrier appear as the last column of the data file. Each insertion loss value is representative of a point source output. These values were converted to an equivalent line source insertion loss and it is this value that is reported in the following tables.

Scale Model Verification

Verification of the scale model was required to insure that an appropriate representative highway project geometry had been reproduced and that proper materials had been selected for construction of the model. The Magnolia Road project was the first model constructed and was used for the verification testing. A 20 foot tall conventional barrier was installed and one testing run was completed.

Each spark source location was then modeled as a one (1) foot long roadway in a file format that could be read by the STAMINA 2.0 software. The STAMINA model was then executed for each spark source location and the results tabulated. These individual results were then combined and an overall insertion loss for the entire site calculated in the same way as the individual spark source results. The insertion loss results from this test were organized and compared directly to the measured insertion loss calculated for the same receiver.

Summary results from this comparison are illustrated in Table I. The two columns listed as "Scale Model" and "STAMINA" show calculated insertion losses for *Receiver No.1* on the Magnolia Road project. The difference between the scale model and the STAMINA insertion losses are listed as the last column in the table. It is this difference that has been statistically verified using a standard t-test with a confidence interval of 95%. Microsoft Excel spreadsheet software was used for these test calculations.

Examination of the data in Table I demonstrates that the measured insertion loss values from the northbound lanes of the scale model were within an average of 1.2 dB of the STAMINA 2.0 calculation, and the measured insertion loss values from the southbound lanes of the scale model were within an average of 2.0 dB of the STAMINA results. This data is consistent with widely accepted performance limits of the STAMINA 2.0 model and thus verifies the accuracy of the scale modeling facility for subsequent use.

TABLE I
SCALE MODEL VERIFICATION
MAGNOLIA ROAD RECEIVER NO. 1

Spark Number	Station Number	Scale Model Insertion Loss	STAMINA Insertion Loss	Difference
1	87+25 North	5.4 dB	3.3 dB	2.1 dB
6	91+00 North	11.2 dB	8.6 dB	2.6 dB
10	94+00 North	13.2 dB	12.5 dB	0.7 dB
11	94 +75 North	13.3 dB	13.0 dB	0.3 dB
15	97 +75 North	12.4 dB	10.2 dB	2.2 dB
20	101+50 North	8.0 dB	8.7 dB	-0.7 dB
	Average:	**10.6 dB**	**9.4 dB**	**1.2 dB**
	Standard Deviation:			**1.304**
	t-statistic:			**2.217**
	t-critical:			**2.776**

Spark Number	Station Number	Scale Model Insertion Loss	STAMINA Insertion Loss	Difference
33	89+50 South	11.1 dB	9.3 dB	1.8 dB
36	91+75 South	12.9 dB	11.4 dB	1.5 dB
39	94+00 South	14.0 dB	13.8 dB	0.2 dB
40	94+75 South	14.2 dB	14.0 dB	0.2 dB
43	97+00 South	14.3 dB	10.9 dB	3.4 dB
46	99+25 South	13.6 dB	8.7 dB	4.9 dB
	Average:	**13.4 dB**	**11.4 dB**	**2.0 dB**
	Standard Deviation:			**1.841**
	t-statistic:			**2.636**
	t-critical:			**2.776**

Note: The results are considered acceptable if the value of the t-statistic is less than the value of t-critical as established for (N-1) degrees of freedom and using a two-tailed t-test [α=0.05].

Scale Model Test Results
Conventional Barrier

Table II compares results from the conventional barrier scale model testing to the results predicted for the conventional barrier in reported in *Phase II*. The results are listed by highway project name and corresponding modeled receiver location. The barrier height is that determined from the actual STAMINA/OPTIMA design of conventional barriers for these projects.

TABLE II
COMPARISON OF MEASURED vs. STAMINA 2.0
INSERTION LOSS FOR CONVENTIONAL BARRIERS

Project Name/ Receiver No.	Barrier Height	Scale Model Insertion Loss	Phase II Insertion Loss	Difference
Magnolia Road Receiver No. 1	20 feet	12.4 dB	10.5 dB	+1.9 dB
Kent Commons Receiver No. 2	19 feet	6.9 dB	8.5 dB	-1.4 dB
Kent Commons Receiver No. 3	19 feet	10.6 dB	9.4 dB	+1.2 dB
Fourth Avenue Receiver No. 43	20 feet	7.6 dB	9.2 dB	-1.6 dB
Fourth Avenue Receiver No. 44	20 feet	11.1 dB	12.1 dB	-1.0 dB
Spokane C.C. Receiver No. 15	24 feet	8.2 dB	10.7 dB	-2.5 dB
Spokane C.C. Receiver No. 34	24 feet	8.3 dB	11.2 dB	-2.9 dB

Note: A positive (+) difference indicates the scale model provided greater insertion loss, compared to the Phase II prediction. Negative (-) differences indicate the scale model provided less insertion loss.

The results contained in Table II show a range of -2.9 dB to +1.9 dB difference between the measured scale model insertion loss values for a conventional knife-edge barrier and the results calculated by STAMINA at the same location. An average difference of -0.9 dB (STAMINA over predicted) over all seven (7) receivers further verifies the accuracy of the STAMINA model in calculating single diffraction insertion loss values for conventional barriers. This result also lends confidence in using the STAMINA model to verify the results of this scale modeling project.

Absorptive T-top Barrier

Table III compares results from the absorptive T-top scale model barrier testing to the results predicted for a shortened conventional barrier as determined in Phase II. The results are listed by highway project name and corresponding receiver location. The barrier height is the reduced height resulting from application of the absorptive T-top. The column labeled "Phase II Insertion Loss" contains the predicted insertion loss for the original taller barriers.

The results of the *Phase II* research suggested that by applying an absorptive T-top to the designed conventional barriers at the Magnolia Road, Kent Commons, and Fourth Avenue sites, the original barrier heights could all be reduced by 5 to 8 feet and still maintain the original insertion loss values. The Spokane Community College site was not included because this site included parallel barriers and would not be suitable for testing a T-top.

The results in Table III indicate that the measured insertion loss of the shortened barriers with an absorptive T-top was less than predicted. If receiver number 43 at the Fourth Avenue site is excluded (less than the requisite two feet line-of-sight break), the scale model results were less than the expected performance by an average of 2.3 dB; However, this still demonstrates that the absorptive T-top does provide increased barrier performance. Reasons for the less than expected performance are discussed in the Conclusion of this report.

TABLE III
ABSORPTIVE T-TOP vs. PHASE II
CONVENTIONAL BARRIER INSERTION LOSS

Project Name/ Receiver No.	Barrier Height	Scale Model Insertion Loss	Phase II Insertion Loss	Difference
Magnolia Road Receiver No. 1	13 feet	9.2 dB	10.5 dB	-1.3 dB
Kent Commons Receiver No. 2	11 feet	5.8 dB	8.5 dB	-2.7 dB
Kent Commons Receiver No. 3	11 feet	7.1 dB	9.4 dB	-1.7 dB
Fourth Avenue Receiver No. 43	15 feet	4.5 dB	9.2 dB	-4.7 dB
Fourth Avenue Receiver No. 44	15 feet	8.5 dB	12.1 dB	-3.6 dB
Spokane C.C. Receiver No. 15	**	**	**	**
Spokane C.C. Receiver No. 34	**	**	**	**

** Spokane Community college not tested with T-top barriers.

Note: A positive (+) difference indicates the scale model provided greater insertion loss, compared to the Phase II prediction. Negative (-) differences indicate the scale model provided less insertion loss.

Absorptive Single-wall Barriers and Absorptive Parallel Barriers (Spokane Community College)

Table IV compares results from the absorptive single-wall scale model barrier testing to the results predicted for the conventional barrier in *Phase II*. The results are listed by highway project name and corresponding receiver location.

The *Phase II* research suggested that by applying a single-wall absorptive treatment to the designed conventional barriers at the Magnolia Road, Kent Commons, and Fourth Avenue sites, the original barrier heights could all be reduced by 3 to 5 feet and still maintain the original insertion loss values. The Spokane Community College site was also modeled, but this site includes absorptive parallel barriers instead of the single-wall barrier installed at the other three sites. The receivers at this site (numbers 15 and 34) are located on opposite sides of the road.

Table IV demonstrates that the single-wall absorptive barrier did not produce the predicted insertion loss. Examination of the Magnolia Road, Kent Commons, and Fourth Avenue (excluding receiver 43) sites show that, on average, the single-wall absorptive barriers produced 1.2 dB less insertion loss than expected. This result demonstrates, that even thought the measured insertion loss was not as great as expected, the single-wall absorptive treatment does improve barrier performance. The suggested reasons for this difference are discussed in the Conclusion to this report.

The Spokane Community College site included parallel absorptive barriers, and for a six (6) foot shorter barrier produced an average 2.2 dB less insertion loss than expected. If these barriers were included with those at the first three sites (excluding receiver number 43), the average under prediction is only 1.5 dB.

TABLE IV
INSERTION LOSS
COMPARISON OF ABSORPTIVE SINGLE-WALL BARRIER
TO PHASE II CONVENTIONAL BARRIER

Project Name/ Receiver No.	Barrier Height	Scale Model Insertion Loss	Phase II Insertion Loss	Difference
Magnolia Road Receiver No. 1	16 feet	11.0 dB	10.5 dB	+0.6 dB
Kent Commons Receiver No. 2	14 feet	6.2 dB	8.5 dB	-2.3 dB
Kent Commons Receiver No. 3	14 feet	8.8 dB	9.4 dB	-0.6 dB
Fourth Avenue Receiver No. 43	17 feet	5.5 dB	9.2 dB	-3.7 dB
Fourth Avenue Receiver No. 44	17 feet	9.8 dB	12.1 dB	-2.3 dB
Spokane C.C. Receiver No. 15	18 feet	9.5 dB	10.7 dB	-1.2 dB
Spokane C.C. Receiver No. 34	18 feet	8.0 dB	11.2 dB	-3.2 dB

Note: A positive (+) difference indicates the scale model provided greater insertion loss, compared to the Phase II prediction. Negative (-) differences indicate the scale model provided less insertion loss.

CONCLUSIONS

Scale Model Results

The results contained in the *Phase II* report indicated that the special shape barriers could be used if at least a two (2) foot line-of-sight break could be maintained with the theoretical heavy truck exhaust stack. This was accomplished at six (6) of the modelled receivers. However, receiver number 43 at the Fourth Avenue site only obtained 0.8 feet line-of-sight break with parts of the modelled roadways. Examination of Tables III and IV illlustrate the results for the special barrier shapes at this receiver were not as good as at the other receivers, thus confirming the requirement for a two (2) foot line-of-sight break. The results of the measurements for this receiver are therefore not included in the analysis of the performance of the special barrier shapes.

While overall the scale model measurements were not of the same magnitude as predicted, the trend was certainly in the right direction and clearly demonstrate the enhanced performance of the special barrier shapes. There are several factors that are apparently contributing to the smaller measured insertion loss. First, the STAMINA 2.0 model assumes a different acoustic centroid from which the sound source originates for each vehicle classification. These different source heights could not be duplicated in this research. Instead, a fixed scaled height was used throughout for the source height. This difference in source heights could contribute to the measured insertion loss values being less than predicted.

Secondly, the material used for the absorptive treatment was selected from the literature review. However, no Noise Reduction Coefficient data was available from the manufacturer that could verify the actual absorptive characteristics of the material. Therefore, while it can be stated that the material was obviously absorptive (based on the literature review), its absorptive characteristics cannot be quantified. Therefore, some difference in performance from that predicted would be expected.

Thirdly, the results of the *Phase II* project indicated that performance of the single-wall absorptive barriers was dependent on the receiver being located deep in the "shadow zone" of the noise barrier. None of the receivers on any of these four sites were located close to the proposed noise barrier. Therefore, the measured insertion loss of the absorptive single-wall barrier would be less than predicted.

Rules of Thumb Analysis

The rules-of-thumb for absorptive T-top and absorptive single-wall special barriers as developed in *Phase II* are reproduced below. This section of the report will analyze the scale model test results in relation to the reduced conventional barrier heights as determined by these guidelines.

For absorptive T-top special barriers the acoustic rule-of-thumb was obtained by adding 1.5 dB attenuation for a reflective T-top (3' cap width) geometry plus 2.8 dB attenuation for providing an absorptive T-top treatment. The expected additional attenuation provided by the special T-top treatment is therefore:

$$1.5 \text{ dB} + 2.8 \text{ dB} = 4.3 \text{ dB}$$

From this equation, *Phase II* concluded that an absorptive T-top barrier could achieve the same insertion loss as a conventional barrier up to eight (8) feet higher as long as the line-of-sight break was maintained.

Analysis of the results presented in Table III indicate that the T-top barrier did not perform as predicted by this rule of thumb. Because of the reasons stated above, and analysis of these results, it appears that a more appropriate increase in the attenuation would be on the order of 2 to 3 dBA.

Thus an absorptive T-top barrier could be expected to provide the same insertion loss as a conventional knife edge barrier from four (4) to six (6) feet higher, as long as the line-of-sight was broken by at least two (2) feet.

For absorptive single-wall special barriers the acoustic rule of thumb was established as +2.0 dB attenuation for providing an absorptive treatment to the top of a conventional noise barrier. This additional performance suggested that an absorptive single-wall could provide the same insertion loss as a conventional barrier up to four (4) feet higher as long as the line-of-sight break was maintained at least two (2) feet below the top of the absoptive barrier. The absorptive treatment was required to be placed at least one wavelength from the top of the barrier to provide this additional attenuation. Each of the scale models tested satisfied this requirement.

Examination of the results presented in Table IV indicate that these barriers did not perform as predicted by this rule of thumb. Because of the reasons stated above, and analysis of these results, a more appropriate statement of the expected performance of an absorptive single-wall would be approximately 1 dB for those receivers not located deep in the shadow zone. It is reasonable to conclude that the original 2 dB increase in performance could be expected for those receivers located deep in the shadow zone. Therefore, a wall of this type could thus be expected to provide the same insertion loss as a conventional knife edge barrier from two (2) to four (4) feet higher, as long as the line-of-sight was broken by at least two (2) feet.

RECOMMENDATIONS

A review of the data presented and the corresponding conclusions indicate the results of this research effort warrant further investigation into the benefits of special noise barrier shapes. Such efforts should be directed at selecting at least two sites similar to those studied in this research and implementing special barrier shapes in the field. Selection of two sites will allow the testing of both an absorptive T-top and an absorptive single-wall barrier.

After selection of the appropriate sites, a detailed analysis should be accomplished using the results of this study and the information gathered in the *Phase II* project. This analysis will determine which of the special barrier shapes would be appropriate for the selected sites, and would then design all elements of the barriers, including the exact barrier location and dimensions that would duplicate or exceed the results of the scale modeling effort.

During the design phase of the follow-up work, sound level measurements should be made throughout both of the selected sites. In addition to the sound level data, traffic should be counted and classified, and speeds of the different vehicle classes measured. This information will provide a database to which a similar set of measurements after barrier construction can be compared. This procedure will allow the measurement of actual insertion loss values as well as a comparison of measured field data to predicted values at the same location.

Efforts should be made during the bidding and construction process to determine actual in-place costs of these special barrier shapes. It will be important, to the extent possible, to insure that construction costs of these barriers are not artificially low or high. In this manner, both the performance and cost effectiveness of the special barrier shapes can be quantified and used to establish a database which can be applied to future sites at which special barrier shapes may be more cost effective that conventional barriers.

In summary, the results of both the *Phase II* and *Phase III* projects are encouraging and suggest that implementation of special noise barrier shapes would provide more cost effective noise barrier options for the Washington State Department of Transportation. The construction of these barriers is an important next step in finalizing and quantifying the real benefits of these special shapes to the Department. Actual field implementation should validate the conclusions of this report and establish a solid basis for implementing these barriers in future noise mitigation efforts.