CONTINUED EVALUATION OF NOISE BARRIERS IN FLORIDA

FL-ER-85-02

Prepared for:

The Florida Department of Transportation
605 Suwannee Street
Tallahassee, Florida 32299-0450

Prepared by:

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August 22, 2002

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DISCLAIMER

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Florida Department of Transportation or the U.S. Department of Transportation. This report was prepared in cooperation with the State of Florida Department of Transportation and U.S. Department of Transportation.

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16. Abstract
This report details work of a continuing project investigating the effectiveness of in-situ in the state of Florida. Data collection started on November 30, 2000 and the last site was visited in May, 2002. Broadband (A-weighted) and 1/3 octave band sound levels were measured at locations above the barrier, behind the barrier and in some cases at the end of the barrier for purposes of direct insertion loss estimation. Measurement results from these sites were used to evaluate the effectiveness of the barrier, and the TNM, STAMINA 2.0 (using older national reference energy mean emission levels), and STAMINA 2.1 (with Florida specific reference energy mean emission levels) computer prediction models. Additionally, work was begun to determine the meteorological effects on barrier performance and estimation techniques to determine length of the shadow zones created behind highway noise barriers.

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EXECUTIVE SUMMARY

The sound levels in the vicinity of twelve barriers in the state of Florida were measured during a previous study (Part 1). This first effort resulted in several findings that included:

1. Florida barriers appear to provide 5-10 dB benefit to 1st row receivers.
2. The Federal Highway Administration (FHWA) Traffic Noise Model (TNM) often, but not always, predicts greater insertion losses than STAMINA 2.0 or 2.1.
This is thought to be directly related to TNM continuing to predict ground effects in presence of a taller noise barrier, while STAMINA does not.
3. Predicted reference energy mean emission levels were better using STAMINA but propagation losses from source to barrier to receiver were better predicted by TNM.
4. Shadow zones benefits, as determined by a 5 dB: L_{Aeq} sound level reduction, generally were limited to under 400 feet behind even the taller noise barriers.

This report details continuing work of a project investigating the effectiveness of in-situ noise barriers in the state of Florida. Seven new sites were measured and one previous site was re-visited. Data collection procedures were consistent for all sites in both projects. A mobile noise laboratory was used to collect sound level data, both broadband (A-weighted) and 1/3 octave band. The mobile laboratory allows use of a microphone array above and behind the barrier to measure existing sound levels. While measurement locations were consistent with those used in Part 1 for continuity and easy comparison of data, additional microphone locations were also used farther from the barrier to gather greater information on local area sound level patterns, especially shadow zones.

Measurement results from these sites were used to evaluate the effectiveness of the barrier, and the performance of the TNM, STAMINA 2.0 (using older national reference energy mean emission levels), and STAMINA 2.1 (with Florida specific reference energy mean emission levels) computer prediction models. Additionally, work was begun to determine the meteorological effects on barrier performance and estimation techniques to determine length of the shadow zones created behind highway noise barriers.

It was observed that the first and second row of homes were generally near the measurement locations of 49.2 feet (15 meters) and 98.4 feet (30 meters) from the barrier. Most barriers are effective, providing 5 dB:L_{Aeq} or more insertion loss at these homes, with the exception of one site. It can be concluded that the barriers are effective and beneficial.

Three Florida Department of Transportation (FDOT) reports were available that predicted insertion losses near the Part 2 measurement sites, complementing the findings in Part 1 of the study that also had three comparative sites from FDOT reports. Each of the Part 2 sites received more insertion loss than predicted. At two of the sites, the constructed barrier heights specified were quite different than the original design. From this small database it would seem that past predictions have led to barrier designs that benefit the nearby residences.

In direct statistical comparison to the STAMINA 2.0 and STAMINA 2.1 model, TNM proved to be the better model. When the absolute error was calculated, STAMINA 2.0 had a slightly better minimum error and a better maximum error for prediction of the propagation loss

from reference to receiver.

TNM, using the “Average” pavement input continually over-predicted the absolute sound levels. When TNM was run using the open graded asphalt concrete (“OGAC”) input, the predicted levels were much better (under 2 dB:L_{Aeq} of error) than when using the “Average” pavement type input. This is thought to occur since Florida uses an open graded, asphalt friction mix. Further review showed that propagation is predicted well but the REMELs start the error, since they are the “heart” of the model. This would tend to point out that although pavement type is not allowable as an abatement measure, it should be used when predicting existing cases to allow more accurate representation of the sites.

Rover microphone positions were used at greater distances from the barrier than in Part 1 to help determine the edge of shadow zone. Based on this information, an empirical model was developed for the shadow zone length, based on predicted insertion loss, that could help the analyst determine the extent of benefitted receivers. The prediction models currently do not predict length of shadow zone since background levels are not considered. Work is continuing to improve this derived methodology.

Meteorological data was also collected and statistical correlation determined. Correlations were low, which is thought to be due to: 1) the short distance reviewed (reference site to other microphone positions); and, 2) all data being taken in very light wind conditions. Although at this time no definite conclusions can be drawn, correlation did occur for the lapse rate under low wind conditions. Further measurements will be used to pursue this topic and this work will be reported on at a later date.

Overall, it can be stated that the barriers are providing substantial reduction for the neighbors along the highway. This is true for most first row homes and the majority of second row homes. In some cases, third row homes are also being benefitted. The predictive process used in the past seems to be providing adequate protection to the highway neighbors.

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I. INTRODUCTION

This report details work of a continuing project investigating the effectiveness of in-situ noise barriers in the state of Florida. In Part 1 [1] of this project, sound levels were measured above and behind twelve barrier sites across Florida. Data collection for Part 2 started on November 30, 2000 and the last site was visited on May 23, 2002. Throughout this report, the first reporting will be referred to as Part 1, while this latest report will be referred to as Part 2.

In Part 2 of the study, seven new sites were measured and one site, originally measured in Part 1, was re-visited. Data collection procedures were consistent for all sites in both projects. A mobile noise laboratory was used to collect sound level data. The mobile laboratory allows use of a multiple microphone array above and behind the barrier to measure existing sound levels. While measurement locations were consistent with those used in Part 1 for continuity and easy comparison of data, additional microphone locations were also used where possible to gather greater information on local area sound level patterns.

Broadband (A-weighted) and 1/3 octave band sound levels were measured at locations above the barrier, behind the barrier and in some cases at the end of the barrier for purposes of direct insertion loss estimation. Measurement results from these sites were used to evaluate the effectiveness of each barrier as well as evaluate the Federal Highway Administration Traffic Noise Model (TNM)[2], STAMINA 2.0 [3] and STAMINA 2.1 [4]. Additionally, an empirically derived methodology was used to investigate a simple model to estimate the shadow zones created behind highway noise barriers.

Meteorological data was also collected and this data was used to investigate wind and temperature refraction effects with in-situ barriers. This data at multiple barrier locations permitted a review of refraction effects on traffic noise barrier effectiveness.

This report summarizes the findings from the first effort, presents the data collected from the present work and presents conclusions based on the combined data of Part 1 and 2.

II. SUMMARY OF FINDINGS FROM PART 1

The sound levels in the vicinity of twelve barriers in the state of Florida were measured [1] during Part 1 of this study. This first effort resulted in several findings that included:

1. Florida barriers appear to provide 5-10 dB benefit to 1st row receivers.

2. TNM often, but not always, predicts greater insertion losses than STAMINA 2.0 or 2.1. This is thought to be directly related to TNM continuing to predict ground effects in presence of a taller noise barrier, while STAMINA does not.

3. Absolute sound levels were better using STAMINA but propagation losses were better predicted by TNM. The reference energy mean emission levels (REMELs) proved to be a significant part of the difference.

4. Shadow zones benefits, as determined by a 5 dB: L_{Aeq} sound level reduction, generally were limited to under 400 feet (122 meters) behind even the taller noise barriers.

Table 1 contains a brief summary of the noise barriers tested in Part 1. Measurements were conducted with careful regard to published procedures [5][6][7]. The final insertion loss reported were determined using the indirect method prescribed by American National Standards Institute (ANSI) [6]. The estimated lengths of the shadow zone shown in Table were reported in Part 1, using a method derived by the research team. Refinements and further work on this approximation method for shadow zone length continues.

The applicable data from Part 1 of this study was combined to form a more complete data base to permit further analysis. These final results are discussed later in this paper.

Table 1. Summary of Part 1 Results
[All Reported Values Were Measured at 5 Feet (1.5 meters) from Ground Plane].

Site	Major Source	Effective Barrier Height	15 meters Behind Barrier	30 meters Behind Barrier	Length of Shadow Zone
A. Jacksonville	I-95	18.5 ft. (5.6m)	NA	7 dB:L_{Aeq}	210 ft. (64 m)
B. Jacksonville	I-295	13.5ft. (4.1m)	8 dB:L_{Aeq}	5 dB:L_{Aeq}	141 ft. (43 m)
C. Daytona Beach	S.R.5A	14.5 ft. (4.4m)	10 dB:L_{Aeq}	9 dB:L_{Aeq}	254 ft. (77 m)
E. Brandon	I-75	41 ft. (12.5m)	2 dB:L_{Aeq}	8 dB:L_{Aeq}	362 ft. (110 m)
F. Clearwater	S.R. 636	11 ft. (3.4m)	6 dB:L_{Aeq}	3 dB:L_{Aeq}	130 ft. (40 m)
G. St. Petersburg	S.R. 682 (54th Ave. S.)	7.3 ft. (2.2m)	5 dB:L_{Aeq}	3 dB:L_{Aeq}	73 ft. (22 m)
H. Ft. Lauderdale	I-95	14.5 ft. (4.4m)	9 dB:L_{Aeq}	9 dB:L_{Aeq}	243 ft. (74 m)
I. Deerfield Beach	I-95	13.1 ft. (4.0m)	6 dB:L_{Aeq}	5 dB:L_{Aeq}	150 ft. (46 m)
J. Miami	I-195	18 ft. (5.5m)	6 dB:L_{Aeq}	5 dB:L_{Aeq}	90 ft. (27 m)
K. South Miami	U.S. 41 (Tamiami Trail)	11 ft. (3.4m)	11dB:L_{Aeq}	7 dB:L_{Aeq}	489 ft. (149 m)
L. Hialeah	S.R.924 (Gratigny Parkway)	25.3 ft. (7.7m)	7 dB:L_{Aeq}	7 dB:L_{Aeq}	157 ft. (48 m)

III. OBJECTIVES AND METHODOLOGY

The goals of this second phase of the project were similar to Part 1, to measure sound levels at existing noise highway noise barrier locations and evaluate effectiveness of these barriers. These objectives were expanded in Part 2 and included:

1. Are Florida highway noise barriers effective?
2. Where is the edge of the shadow zone?
3. Have previous analysis predictive results for environmental documents been accurate?
4. How well do the Federal Highway Administration (FHWA) models predict sound levels behind noise barriers?
5. Does meteorology (refraction) have a significant impact on barrier performance?

Figure 1 indicates the standard microphone positions used at each measurement site while Table 2 provides a description of each site for Part 2 of the project. It should be noted that the microphone positions shown in Figure 1 are identical to those used in Part 1 of this study. These microphone positions are defined by the ANSI standard [6] and allow continuity between Part 1 and 2 of the study. However, in Part 1, it was determined that more sites, farther from the noise barrier, were needed to better define the shadow zone behind the barrier. To accomplish this, "rover" sites were used when open space was available at greater distances.

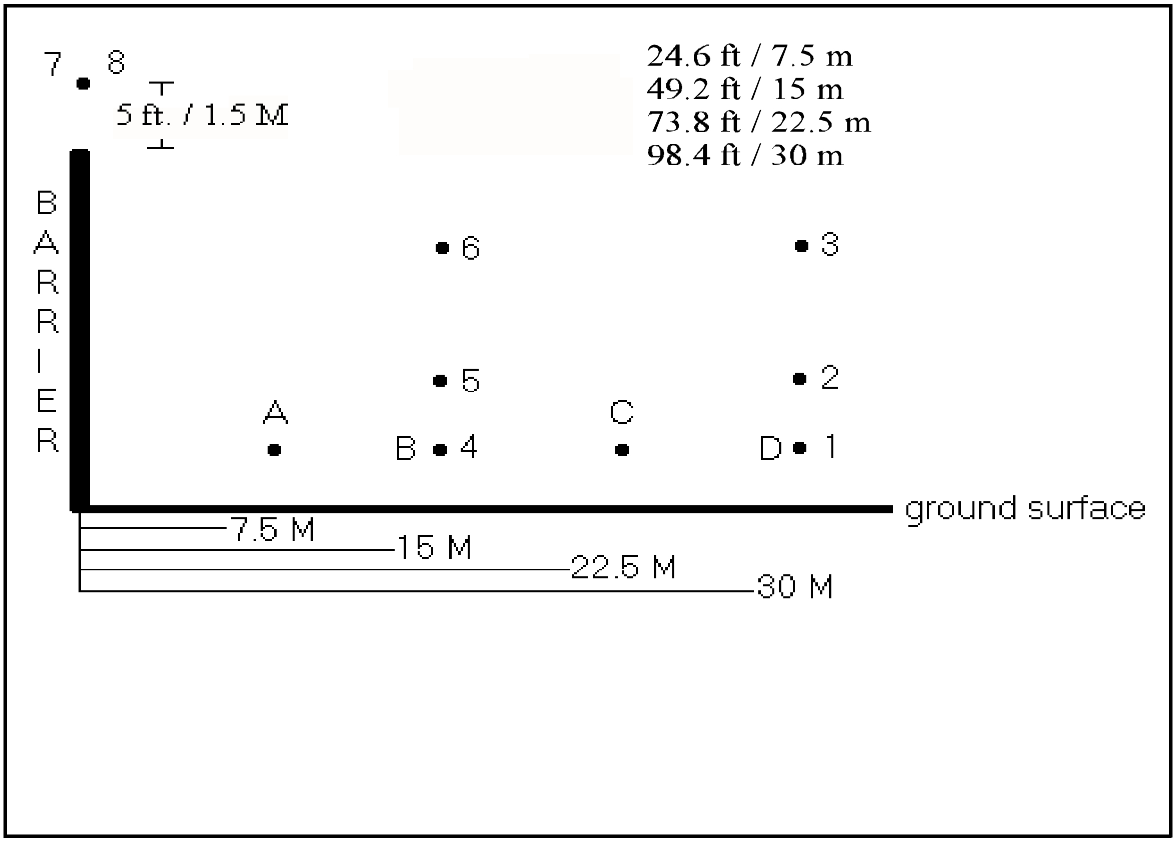

Figure 1. Microphone Locations Above and Behind the Barrier.

The effectiveness of the barrier was evaluated by placing the primary emphasis on the receiver locations at a height of 5 feet (1.5 meters) above the ground plane. These were microphone locations 1, 4, A, B, C and D. All rover sites were also at 5 feet above the local ground plane and used in the barrier shadow zone determination. Significant attenuation was assumed to occur if at least 5 dB:L_{Aeq} of insertion loss (noise reduction after the barrier is constructed compared to the no-barrier case) occurred. A 5 dB:L_{Aeq} reduction in noise levels represents a perceptible change in the soundscape for most individuals. This also agrees with FDOT policy as stated in

Table 2. Summary of Part 2 Sites

Site	Major Source	Barrier Height* feet / meters	Effective Height* feet / meters
M. Wildwood	S.R. 44	9.4 / 2.9	9.4 / 2.9
N. Maitland	S.R. 414	12.1 / 3.7	11.6 / 3.5
O. Ft. Lauderdale (H. Repeat)	I-95	14.5 / 4.4	14.5 / 4.4
P. Boynton Beach	I-95	20.9 / 6.4	18.4 / 5.6
Q. Palm Beach Gardens	I-95	19.8 / 6.0	19.3 / 5.9
R. Palm Harbor, Tampa	S.R. 586	5.7 / 1.7	7.7 / 2.3
S. New Port Richey	S.R. 54	11.0 / 3.4	11.0 / 3.4
T. Longwood (wood fence only)	I-4	NA	NA

* *Barrier height is the height above ground at the base of the barrier while effective height is the height above the receiver ground plane*.

Chapter 17 of the Project Development and Environmental Manual [8] where a benefitted receiver is defined as:

> "A benefitted receiver is a noise sensitive receiver that will obtain a minimum of 5 dBA of noise reduction as a result of the use of a specific noise abatement activity regardless of whether or not they are identified as impacted. Only benefitted receivers will be included in the calculation needed to determine that any particular noise abatement scheme has a reasonable cost."

and substantial noise reduction is defined as:

> "This is an effort to reduce traffic noise impacts at benefitted receptors by 10 decibels or more if possible, with a minimal acceptable level of reduction at no less than 5 decibels."

Part 1 and Part 2 of this project used the ANSI standard [6] indirect method for determining sound levels behind a highway noise barrier. The reader is directed to Part 1 of this project [1] for all measurement details, description of equipment, quality control measures and analysis methodologies. However, some methodology differences did occur from Part 1. The most significant change was due to a finding from Part 1. The measurements behind the barrier did not give a clear definition of the edge of the "shadow zone," the region of reduced sound levels near the barrier, because the microphone positions were too close to the barrier. For this reason, Part 2 included additional measurements at further distances from the noise barrier than Part 1 using these rover microphone positions. Accordingly, based on the availability of acceptable unshielded measurement sites, "rover" microphone positions were used. These "rover" positions varied in distance from the barrier from site to site. Each rover microphone position is described later in this report. This information was used to obtain a better estimate of the region where the shadow zone no longer existed. It was assumed that the shadow zone no longer existed if the sound levels were equal to the background levels or if a 5 dB:L_{Aeq} reduction had not occurred for receiver points 5 feet (1.5 meters) above the ground.

The Part 2 specific site parameters (geometry of site, traffic volume, traffic classification traffic speed, wind speed, wind vector direction, temperature) were carefully recorded during measurements and were used to build computer model input files using the FHWA model STAMINA 2.0, the state specific model STAMINA 2.1, and the 1.0b version of TNM. The predicted levels from computer models were compared and evaluated against the measured data. The data collected for this project is ideal for validation of highway noise diffraction models such as TNM and STAMINA. Trends found in Part 1 were reviewed using the data from the Part 2 sites. Data for both parts of the study were later combined, permitting significant acoustic phenomenon to be explored in more depth.

Measurement of sound levels for all sites in Part 2 was conducted during the middle of the week from about 1100 to 1400 hours. Testing began in November of 2000 and was completed in May of 2002. Test procedures were conducted according to applicable guidelines [5][7] and the ANSI [6] barrier testing procedures. Sound Levels were measured for multiple 20 minute time periods, where four per site were desirable and collected at most sites. Traffic and weather information were taken concurrently to allow data to be grouped into sets. This allowed detailed computer modeling to be done for comparative purposes. The major details for each site is described in the following sections of text. Photographs and further site details are also included in Appendix A for all sites visited in Part 2 of this study.

Site M. Measurements were taken along S.R. 44 in Sumter County, Florida on November 30, 2000. The highway noise barrier was built to protect a mobile home park and has a height of 9 feet 5 inches (2.8 meters) at the measurement location. The site was influenced by heavy trucks and the exhaust stacks were visible from the homes and microphone locations, indicating that the barrier did not break the line of sight for heavy truck stacks. Possible problem areas in modeling include the close spacing of the mobile homes resulting in complex fields of diffraction and reflections.

Site N. After equipment factory re-calibrations, this site was measured on July 10, 2001. The site is located in Maitland, Florida and included a 12 foot (3.7 meter) barrier protecting a subdivision from traffic traveling on S.R. 414. The site is a residential area and had intermittent traffic including some heavy truck exhaust noise. Low volumes of traffic were experienced leading to large fluctuations in the sound field.

Site O. This site was originally designated Site H from Part 1 of the project.

Measurements were made again on September 11, 2001. The open space and availability to measure at much greater distances from the barrier was the primary reason the site was revisited. The additional measurements included the same locations as the first visit (see Figure 1) but also included microphone locations at greater distances from the barrier. A grid of microphones was placed at distances from 98.4 feet (30 meters) to 196.9 feet (60 meters) behind the barrier with the intent to better describe the shadow zone edge. The site is located in the Fort Lauderdale area along I-95 near Sunrise Boulevard. The barrier height at the measurement location was 16 feet 4 inches (5.0 meters). The reference sound levels at the barrier were similar to the Site H (Part 1) measurements as were the levels behind the barrier.

Site P. The site is located in the Boynton Beach area and protected a residential area from I-95 near Gateway Boulevard. Measurements were made on February 25, 2002. This is a taller barrier, measuring 20 feet 11 inches (6.4 meters) at the location of the microphones.

Site Q. This site is located in the Palm Beach Gardens area, along I-95, and measurements were made on February 26, 2002. The barrier measured 19 feet 10 inches (6.0 meters) and protects a residential mobile home park.

Site R. The site is located in the Palm Harbor/Tampa area along S.R. 586 (Curlew Road). Measurements were made on March 25, 2002. This is a short barrier located on slightly elevated terrain and provided some protection to the first row residents but truck exhaust stacks were visible. The barrier is 5 feet 8 inches (1.7 meters) on the residential side. Terrain features on the residential side of the barrier presented some modeling challenges.

Site S. The site is located in New Port Richey area. The site visit and measurements were on March 26, 2002. This site included an 11 foot (3.4 meter) barrier that protected an apartment complex from S.R.54 traffic.

Site T. This site was measured to get a more direct insertion loss in the future. The barrier does not yet exist and will be built in the near future. A five foot (1.5 meter) wood fence is present, but has multiple openings greatly reducing any effectiveness. Measurements were conducted on May 23, 2002. The same microphone positions will be measured upon completion of the barrier.

Meteorological data was collected in Part 1 of this project but analysis was not performed because of limited data. The meteorological data collection continued for Part 2 and the data was combined to investigate wind and temperature refraction effects on barrier performance. Wind speeds were collected for the three perpendicular axes, at 5 feet (1.5 meters) and 19.7 feet (6 meters) from the ground surface for both Part 1 and 2 project sites. Temperatures were also collected at these heights using aspirated thermometers. These measurements were made concurrently with the sound level measurements and recorded using a commercial data logger unit to store the data on site and perform initial data reduction. More detail on this equipment and method are included in the Part 1 report [1].

An evaluation of the pavement/tire interaction was also performed. Calculated results from the TNM were compared using both the “Average” pavement type, which is required by FHWA policy, and open graded asphalt concrete, “OGAC”. The differences in predicted results are reported as well as their effect on the reference energy mean emission levels (REMELs).

IV. RESULTS AND ANALYSIS

A. Measurement of Absolute Sound Levels

Absolute sound levels, or more appropriately sound pressure levels, are defined in this report as the actual sound level measured at a microphone location. Table 3 contains the average values for all 20 minute L_{Aeq} sound levels measured at each of the standard microphone positions for the eight sites of Part 2, designated M through T. All data, from each measurement period, are shown in Appendix B. Reference levels (Microphone Locations 7 and 8 above the barrier) ranged from 70-80 dB:L_{Aeq} and levels behind the barrier ranged from 51 dB:L_{Aeq} at site M to 72 dB:L_{Aeq} at site T. Items marked by dashes indicate either equipment problems for the microphone or that data was rejected during quality control measures.

Table 3 shows that sound levels change with distance behind the barrier and with height above the ground plane. A quick comparison of Microphone Locations 7 and 8 to the other locations behind the barrier, quickly shows that substantial noise level reduction is occurring. This is further substantiated by comparing the Site T microphone location sound levels to the positions at other sites. Site T only had a short wood fence that was not effective in reducing noise levels.

As previously described, Part 2 included microphone positions at "rover" locations further from the barrier than the standard locations as shown in Figure 1. Table 4 includes the results of sound level measurements at additional positions (rovers) behind the noise barrier at five sites. Additionally, the L_{90} and L_{99} measured values for microphone location 1 (98.4 ft. or 30 meters from the barrier) are also shown in Table 4. It is assumed that these statistical levels represent

Table 3. Summary of Measured Sound Levels at Sites M-T, dB:L_{Aeq}

Microphone	M	N	O	P	Q	R	S	T
1	51.0	54.6	63.3	58.7	55.3	55.1	56.7	63.4
2	52.8	54.7	65.2	59.7	57.8	56.1	56.9	65.3
3	58.9	56.7	--	--	62.3	--	58.1	72.1
4	53.5	55.1	64.8	59.1	57.9	57.6	57.2	66.7
5	55.7	55.4	66.3	59.8	59.1	61.4	56.9	69.2
6	61.7	--	--	64.6	64.7	--	59.8	71.9
7 & 8	70.4	70.8	80.1	77.7	77.1	69.2	70.5	75.7
A	57.6	55.9	--	60.5	57.3	--	57.7	68.4
C	55.6	55.4	--	59.0	58.2	--	--	64.6

lulls in the traffic noise and since they are 30 meters behind the barrier tend to represent the background noise levels without the highway.

Figures 2a to 2c depict examples of how the measured sound levels for each site were plotted for further analysis. These example plots used the combined A-weighted levels derived from the 1/3 octave band measurement locations and permitted the researchers to visualize the sound field behind the barrier.

Table 4. Rover and Extra Microphone Results

Site N	Site O	Site Q	Site R	Site S
120' from wall (36.6 m) 52 dB:L_{Aeq}	187' from wall (57.0 m) 60 dB:L_{Aeq}	200' from wall (61.0 m) 56 dB:L_{Aeq}	167' from wall (50.9 m) 53 dB:L_{Aeq}	mic. 4 no wall 63 dB:L_{Aeq}
140' from wall (42.7 m) 54 dB:L_{Aeq}	217' from wall (66.1 m) 60 dB:L_{Aeq}	Run 2: 380' from wall (115.8 m) 57 dB:L_{Aeq}	218' from wall (66.4 m) 51 dB:L_{Aeq}	mic. 1 no wall 60 dB:L_{Aeq}
160' from wall (48.8 m) 55 dB:L_{Aeq}	--	Run 3: 380' from wall (115.8 m) 55 dB:L_{Aeq}	265' from wall 52 dB:L_{Aeq}	mic. 4 with wall 56 dB:L_{Aeq}
180' from wall (54.9 m) 55 dB:L_{Aeq}	--	--	315' from wall (96.0 m) 53 dB:L_{Aeq}	mic. 1 with wall 55 dB:L_{Aeq}
200' from wall (61.0 m) 53 dB:L_{Aeq}	--	--	--	--
220' from wall (67.1 m) 51 dB:L_{Aeq}	--	--	--	--
L_{90} 48 dB:L_{Aeq}	L_{90} 59 dB:L_{Aeq}	L_{90} 53 dB:L_{Aeq}	L_{90} 47 dB:L_{Aeq}	L_{90} 52 dB:L_{Aeq}
L_{99} 46 dB:L_{Aeq}	L_{99} 57 dB:L_{Aeq}	L_{99} 50 dB:L_{Aeq}	L_{99} 43 dB:L_{Aeq}	L_{99} 49 dB:L_{Aeq}

Figure 2. Examples of Sound Level Plots Behind the Barrier.

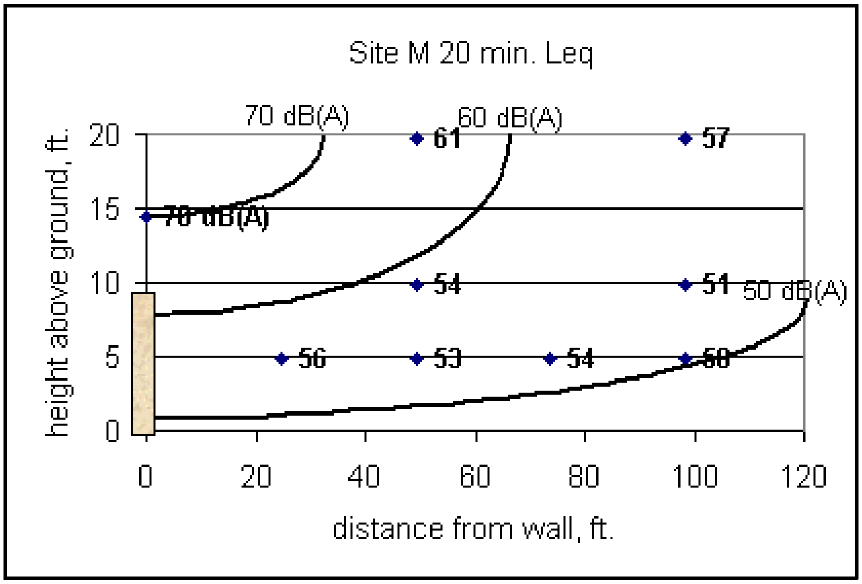

Figure 2a. Measured sound levels at Site M.

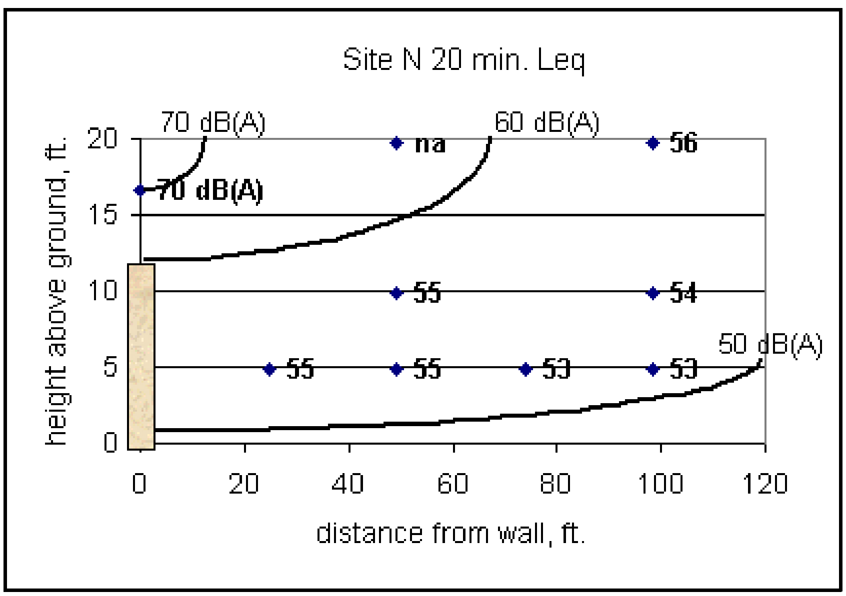

Figure 2b. Measured sound levels at Site N.

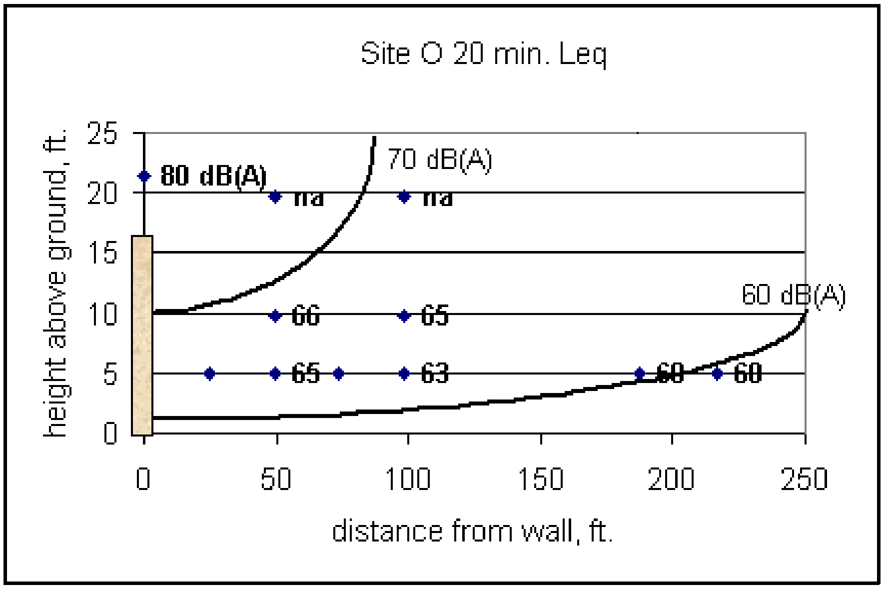

Figure 2c. Measured sound levels at Site O.

B. Computer Modeling of Absolute Sound Levels

The sound level measurements were used to test the accuracy of the computer models TNM, and versions 2.0 and 2.1 of STAMINA. Tables 5-7 include the average error summaries of this testing for TNM, STAMINA 2.0 (using the older National REMELs [3]), and STAMINA 2.1 (with Florida specific REMELs[4]). The reader is referred to the first report [1] for a complete description of the statistical tests used. The residual term is the absolute value of the error, it is always a number greater than or equal to zero, whereas the error term can be positive or negative.

Table 5. Summary of TNM Absolute Errors (Predicted-Measured Sound Level)

Mic.	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**
1	3.7	-2.1	2.8	0.6	5.1	2.5	-1.8	6.6
2	4.2	-0.9	2.0	1.1	4.5	5.5	-0.5	7.6
3	3.4	0.4	--	--	4.0	--	1.4	2.4
4	2.8	-0.7	1.6	2.0	4.5	4.4	-0.7	6.4
5	3.9	1.0	1.8	2.1	4.4	7.3	1.5	5.6
6	5.2	--	--	3.0	4.1	--	5.4	4.5
7&8	2.6	1.9	3.6	2.6	4.3	4.3	3.7	3.0
A	0.3	0.0	--	-1.1	4.4	--	-0.1	6.3
C	-0.9	-2.1	--	0.8	3.3	--	--	7.0

Table 6. Summary of STAMINA 2.0 Absolute Errors (Predicted-Measured Sound Level)

Mic.	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**
1	9.3	0.7	4.9	4.1	9.9	3.2	0.0	7.4
2	9.4	2.0	4.7	4.7	9.1	4.8	1.1	5.8
3	5.0	2.2	--	--	8.0	--	2.2	-0.6
4	8.1	1.7	6.0	3.3	7.0	4.3	0.7	6.2
5	8.6	3.7	1.7	5.0	8.0	3.1	3.3	4.3
6	5.5	--	--	6.1	7.7	--	3.9	1.6
7&8	2.2	0.5	0.3	-2.0	0.7	-0.7	1.2	0.5
A	4.6	1.2	--	-0.6	6.2	--	0.5	5.7
C	4.8	0.6	--	3.7	7.0	--	--	7.4

Table 7. Summary of STAMINA 2.1 Absolute Errors (Predicted-Measured Sound Level)

Mic.	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**
1	7.4	0.6	3.4	3.0	8.1	4.1	0.5	6.3
2	7.5	1.8	3.1	3.6	7.3	5.8	1.7	4.7
3	3.3	2.3	--	--	6.2	--	2.9	-1.4
4	6.2	1.6	1.8	2.4	5.4	5.4	1.4	5.1
5	6.8	3.4	3.0	4.0	6.3	4.1	4.0	3.5
6	3.7	--	--	5.0	5.9	--	4.8	0.8
7&8	0.8	1.1	-0.5	-2.7	-0.7	0.7	2.5	-0.3
A	2.8	1.2	--	-1.3	4.6	--	1.4	4.4
C	2.9	0.5	--	2.7	5.3	--	--	6.3

Table 8 shows that TNM performed the best in five out of the six statistics evaluated. STAMINA 2.0 slightly out-performed TNM with an average minimum error of -2.0 dB:L_{Aeq} but in all other cases, TNM had the best performance. It can also be seen that, on average, TNM had an error of 2.8 dB:L_{Aeq} while STAMINA 2.0 and 2.1 were 4.0 and 3.3, respectively. Finally, the variance shows significant scatter in the data.

It is clear from the comparison of predicted absolute error (Tables 5-7) that all models primarily over-predicted sound levels for these sites. This is especially true for sites Q, R and T using TNM and site M, Q and T with the 2.0 and 2.1 versions of STAMINA. REMELs also appear to be better for the STAMINA models than the TNM. Finally, significant errors existed for all models.

Table 8. Summary of Absolute Error Statistics

Statistic	**TNM dB:L_{Aeq}**	**STAMINA 2.0 dB:L_{Aeq}**	**STAMINA 2.1, dB:L_{Aeq}**
min	-2.1	**-2.0**	-2.7
max	**7.6**	9.9	8.1
average	**2.8**	4.0	3.3
variance	**5.9**	8.9	6.0
root MSSE	**3.7**	5.1	4.1
avg. residual	**3.1**	4.1	3.4

C. Computer Modeling Performance of Propagation Losses

The previous section discussed the results of the "absolute" sound levels measured at the eight sites. The accuracy of the models at determining propagation losses for the sound levels at and behind the barrier provide a measure of how effective the models can predict future case scenarios. Propagation loss refers to the difference between the reference sound level at the barrier compared to a sound level at a position behind the barrier. The propagation loss includes effects such as geometric spreading, ground interaction/absorption, diffraction and atmospheric refraction. The propagation loss is not the same as insertion loss. Insertion loss is the sound level difference before the barrier was built at the exact microphone location compared to after the barrier is in place. In this project, propagation losses can be measured directly from the data while insertion losses require using the ANSI indirect method [6] since all barriers were already in place. Table 9 contains the average measured propagation losses for each site at each microphone location, while Tables 10-12 contain summaries of the errors of the TNM and STAMINA computer model results when measured and predicted levels are compared. In these tables, each site is named in the first column and each microphone position results are displayed in the other columns.

Table 9. Measured Propagation Losses (Propagation Loss is the difference between the reference level, microphone location 7 & 8, and the microphone level behind the barrier, dB:L_{Aeq})

Site	**1**	**2**	**3**	**4**	**5**	**6**	**A**	**C**
M	19.4	17.7	11.6	17.0	14.9	8.8	12.9	14.9
N	16.4	16.1	14.1	15.7	15.5	--	14.9	15.6
O	16.7	14.8	--	15.3	13.7	--	--	--
P	19.1	18.0	--	18.6	17.9	13.1	32.3	18.7
Q	21.7	19.3	14.8	19.1	17.9	12.3	19.7	18.9
R	14.2	13.1	--	11.6	7.9	--	--	--
S	14.3	14.2	13.1	13.7	14.3	11.1	13.0	--
T	12.8	10.7	4.0	9.8	8.0	4.2	7.6	11.4

Table 10. TNM Propagation Loss Errors (Predicted Propagation Loss-Measured Propagation Loss)

Site	1	2	3	4	5	6	A	C
M	-1.1	-1.5	-0.7	-0.2	-1.2	-2.6	2.3	3.5
N	3.9	2.8	1.4	2.6	0.9	--	1.8	4.0
O	0.8	1.5	--	2.0	1.8	--	--	--
P	2.0	1.5	--	0.6	0.5	-0.4	3.7	1.8
Q	-0.8	-0.2	0.4	-0.2	-0.1	0.2	-0.1	1.0
R	1.7	-1.2	--	-0.1	-3.0	--	--	--
S	1.2	0.0	-1.0	0.5	-2.1	-2.7	0.6	--
T	-3.6	-4.6	0.6	-3.3	-2.6	-1.5	-3.3	-3.9

Table 11. STAMINA 2.0 Propagation Loss Errors

Site	1	2	3	4	5	6	A	C
M	-7.0	-7.1	-2.8	-5.8	-6.3	-3.2	-2.4	-2.5
N	-0.3	-1.6	-1.8	-1.2	-3.2	--	-0.7	-0.2
O	-4.5	-4.4	--	-5.7	-1.3	--	--	--
P	-6.1	-6.8	--	-5.4	-7.1	-8.1	-1.4	-5.7
Q	-9.2	-8.4	-7.3	-6.3	-7.3	-7.0	-5.5	-6.3
R	-3.9	-5.5	--	-5.0	-3.8	--	--	--
S	2.0	0.8	-0.4	1.1	-1.5	-2.3	0.6	--
T	-7.0	-5.3	1.1	-5.8	-3.8	-1.2	-5.2	-6.9

Table 12. STAMINA 2.1 Propagation Loss Errors

Site	**1**	**2**	**3**	**4**	**5**	**6**	**A**	**C**
M	-6.7	-6.8	-2.5	-5.5	-6.0	-3.0	-2.0	-2.2
N	0.5	-0.7	-1.2	-0.5	-2.3	--	-0.1	0.6
O	-3.9	-3.7	--	-2.3	-3.5	--	--	--
P	-5.7	-6.3	--	-5.1	-6.7	-7.7	-1.4	-5.4
Q	-8.8	-8.0	-6.9	-6.0	-6.9	-6.6	-5.3	-6.0
R	-3.4	-5.2	--	-4.7	-3.5	--	--	--
S	2.0	0.8	-0.4	1.1	-1.5	-2.3	1.1	--
T	-6.7	-5.0	1.1	-5.4	-3.9	-1.2	-4.8	-6.7

*Due to conditions at Site R, microphone positions 1, 2 and 3 were placed 15m behind the barrier and microphone 4, 5, and 6 were 7.5m behind the barrier.

Table 13 is a summary of the statistical testing of the propagation errors. TNM out-performed the STAMINA models in all error statistics except the maximum error. Both STAMINA models were better than TNM for this statistic with the best value of 1.2 dB:L_{Aeq} by the STAMINA 2.0 model. The large minimum errors and negative averages indicate that the STAMINA models tend to underpredict the propagation losses. The average error by TNM is quite good at 0.1 dB:L_{Aeq} but the minimum and maximum error, along with variance, show that propagation loss errors of over 4 dB occur.

Table 13. Statistics of the Modeled Propagation Loss Errors

Statistic	**TNM dB:L_{Aeq}**	**STAMINA 2.0 dB:L_{Aeq}**	**STAMINA 2.1, dB:L_{Aeq}**
min	**-4.6**	-9.2	-8.8
max	4.0	**1.2**	2.0
average	**0.1**	-4.1	-3.6
variance	**4.4**	7.7	8.0
root MSSE	**2.1**	4.9	4.6
avg. residual	**1.7**	4.2	3.9

D. Measured and Predicted Insertion Losses

Insertion loss is the result of placement of a barrier and a reduction in sound levels behind the barrier. Insertion loss depends not only on the barrier attenuation but also shielding, ground effects, transmission loss through the barrier, reflections, and flanking noise. Refraction effects may also change the insertion loss as changes in weather occur. Insertion loss (IL) is determined by Equation 1:

$$IL = SPL_{before} - SPL_{after} \qquad [1]$$

In words, the sound level at a specific location with a barrier is subtracted from the sound level at the same location without a barrier. To directly measure insertion loss, measurements must be taken before a barrier is built and then after the barrier is in place. A common reference location is also needed to allow for changes in traffic volume. Since measurements at specific locations before barrier construction were not available, the indirect ANSI method was used to determine insertion loss. Computer models are needed to help determine the insertion loss using the ANSI indirect method. The measured levels with a barrier in place and the predicted sound levels predictions of sound levels in the absence of a barrier estimated by computer models are adjusted using the measured data. Using this approach, and TNM as the model, modeling errors of the absolute sound levels and propagation loss errors were used to make corrections. Table 14 contains the predicted TNM insertion loss, the TNM prediction error for each microphone location and the “adjusted” insertion loss for each microphone location.

In some cases, data were available to make a more direct comparison. The last column of Table 14, “Measured IL”, is a measured estimate of the insertion loss using microphone locations either beyond the end of the barrier or on the opposite side of the roadway. For example, Site S allowed access to a field on the opposite side of S.R. 54 and this enabled measurement of mirrored microphone locations 1 and 4 on the other side of the roadway in the absence of a barrier. With this information, another method for insertion loss could be employed, assuming sound levels on both sides of the facility were similar. At Site S, the influence of ground effects on levels without a barrier are clearly present.

Site T was not used in the insertion loss estimates since it had a wooden fence with slat and other openings. It should be noted that upon completion of the noise barrier at Site T, additional measurements will be performed.

Table 14. Insertion Loss Estimate for Each Site and Microphone Position, dB

Site	Mic. Location	TNM IL	correction	Adjusted IL	Measured IL
M	1	7.4	-1.1	8.5	--
	2	6.6	-1.5	8.1	--
	3	3.5	-0.7	4.2	--
	4	8.7	-0.2	8.9	--
	5	7.1	-1.2	8.3	--
	6	2.3	-2.6	4.9	--
	A	9.3	2.3	7.0	--
	C	8.8	3.5	5.3	--
N	1	8.5	3.9	4.6	--
	2	8.8	2.8	6.0	--
	3	7.6	1.4	6.2	--
	4	10	2.6	7.4	--
	5	10.4	0.9	9.5	--
	6	--	--	--	--
	A	11.9	1.8	10.1	--
	C	9.5	4.0	5.5	--

Table 14 Continued.

Site	Mic. Location	TNM IL	correction	Adjusted IL	Measured IL
O	1	9.9	0.8	9.1	--
	2	9	1.5	7.5	--
	3	--	--	--	--
	4	11.7	2.0	9.7	--
	5	10.9	1.8	9.1	--
P	1	12.3	2.0	10.3	--
	2	12.1	1.5	10.6	--
	3	--	--	--	--
	4	12.6	0.6	12.0	--
	5	12.9	0.5	12.4	--
	6	9.6	-0.4	10.0	--
	A	13.8	3.7	10.1	--
	C	12.7	1.8	10.9	--
Q	1	8.2	-0.8	9.0	--
	2	10.3	-0.2	10.5	--
	3	9.1	0.4	8.7	--
	4	14	-0.2	14.2	--
	5	13.2	-0.1	13.3	--
	6	9.6	0.2	9.4	--
	A	15.5	-0.1	15.6	--
	C	14	1.0	13.0	--

Table 14 Continued.

Site	Mic. Location	TNM IL	TNM pred.-meas.	Adjusted IL	Measured IL
R	1	9.2	1.7	7.5	--
	2	7.2	-1.2	8.4	--
	3	--	--	--	--
	4	7	-0.1	7.1	--
	5	2.2	-3.0	5.2	--
	6	--	--	--	--
	A	--	--	--	--
	C	--	--	--	--
S	1	8.2	1.2	7.0	*4.5*
	2	7.6	0.0	7.6	--
	3	7.1	-1.0	8.1	--
	4	9.2	0.5	8.7	*7.1*
	5	9.5	-2.1	11.6	--
	6	4.6	-2.7	7.3	--
	A	10.3	0.6	9.7	--

E. TNM Pavement Type Evaluation

The pavement type input features of the TNM were tested during the computer model analysis portion of Part 2. It was found that using the open-graded asphalt concrete (OGAC) pavement type produced more accurate results than using the default "Average" pavement type in Florida. The effect was to reduce the source reference levels which helped reduce the overall error since TNM was over-predicting the source levels by about 3 dB:L_{Aeq}. This was as expected since a friction-based open graded asphalt is used in Florida. Table 15 shows the results of this analysis.

Table 15. Comparison of Predicted and Measured Reference Levels, dB(A)

Site	$TNM_{AVERAGE}$ - Meas.	TNM_{OGAC} - Meas.	STAM2.0 - Meas.	STAM2.1 - Meas.
M	2.5	1.5	2.6	1.5
N	2.3	1.4	0.9	1.5
O	3.4	2.2	0.4	-0.5
P	3.2	2.0	-1.1	-2.2
Q	3.4	2.1	-0.4	-1.7
R	4.3	2.3	-0.9	0.6
S	3.2	1.8	0.0	2.1
T	3.7	1.8	0.8	-0.3
average	3.3	2.0	0.4	**0.2**
root MSSE	3.3	2.0	**1.2**	1.5

Table 15 shows that the STAMINA 2.1 model with Florida specific REMELs [4] was the best model, on average. The STAMINA 2.0 model using the older National REMELs [9] had more error than STAMINA 2.1, but was most often better than TNM. TNM consistently over-predicted the reference levels when using the default “Average” pavement type. Marked improvement in predictions resulted when the “OGAC” pavement type was used as input but overprediction still occurred.

Figures 3-6 depict the REMEL prediction errors based on measured values for each site. It can be seen that when “Average” pavement is used in TNM, significant over-prediction occurs at all sites. Figure 4 shows that when the older National REMELs [9] are used in STAMINA 2.0 there are both over-predictions and under-predictions with no clear trend. Figure 5 shows similar results for STAMINA 2.1 with Florida specific REMELS. Of importance, is that even though the average error is less for STAMINA 2.1, STAMINA 2.0 was better at five of the eight sites.

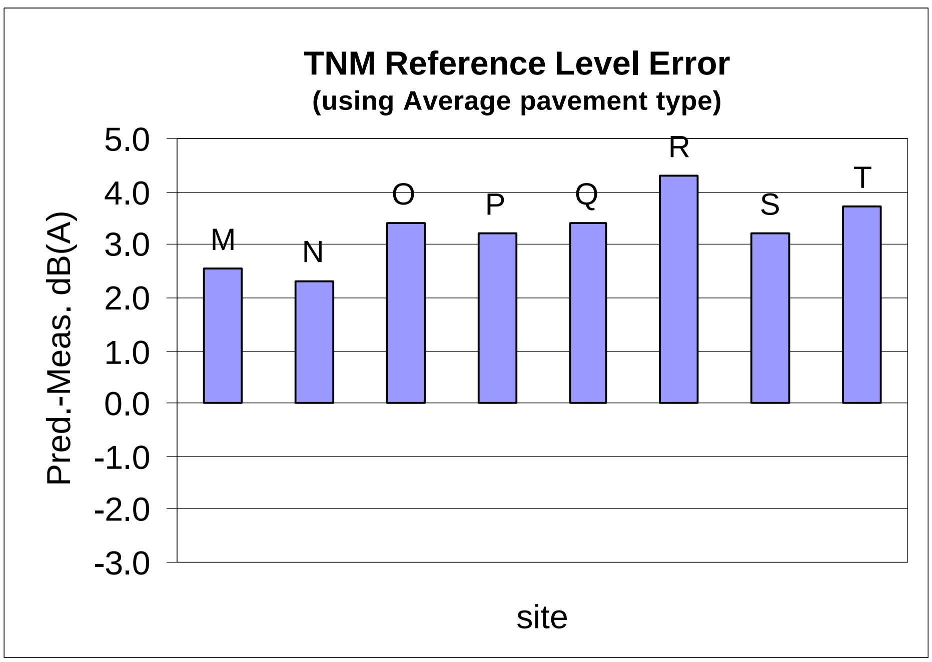

Figure 3. TNM Reference Level Errors (using “Average” pavement type) for Part 2.

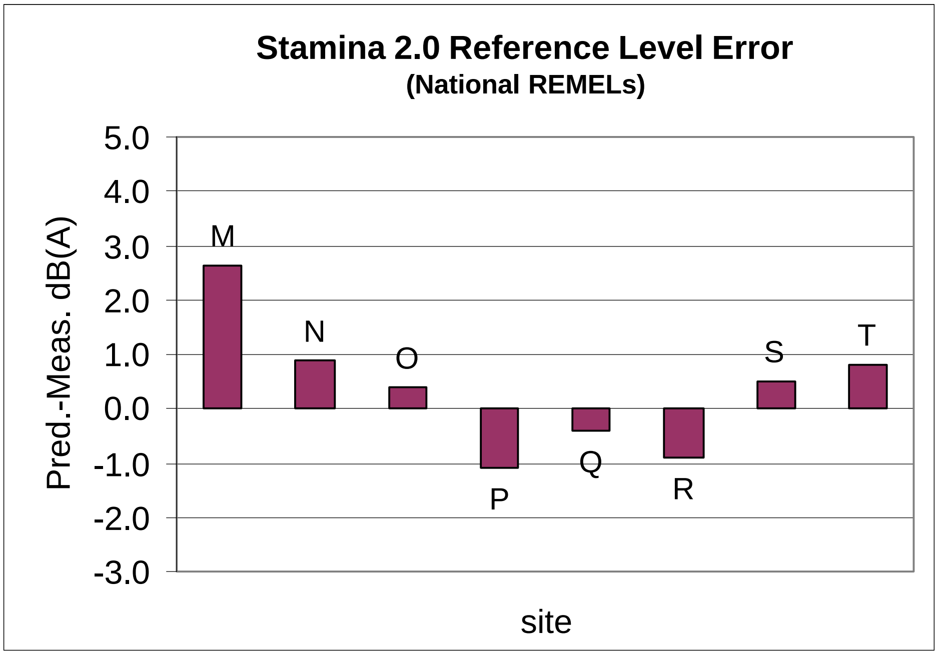

Figure 4. STAMINA 2.0 Reference Level Errors for Part 2.

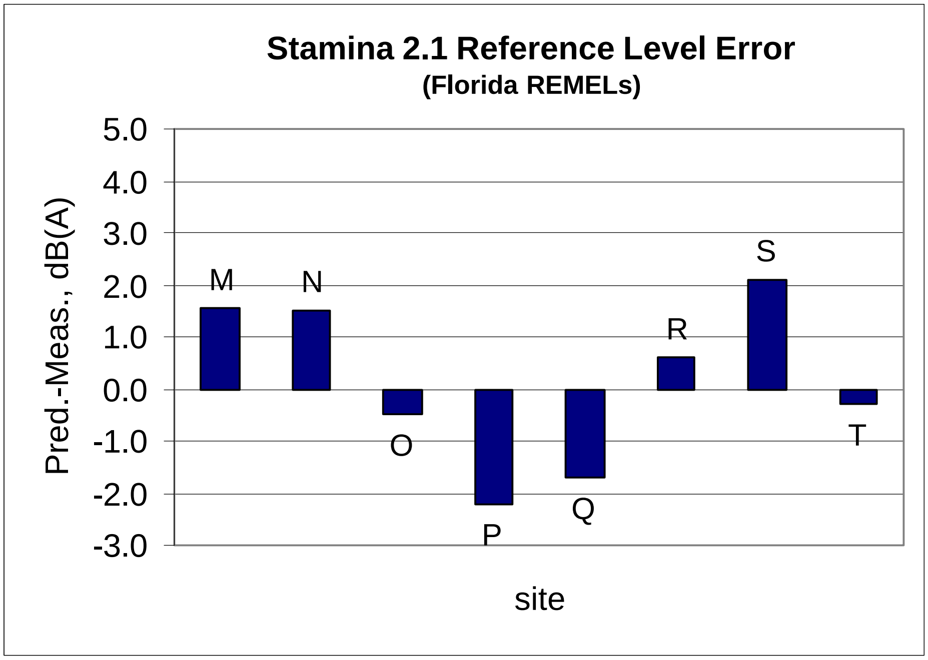

Figure 5. STAMINA 2.1 Reference Level Errors for Part 2.

Finally, when TNM is evaluated using "OGAC" as input for the pavement type, the errors are reduced by about 2 dB(A) as shown in Figure 6. Over-prediction still occurs, but with a much smaller error than when using the "Average" pavement type.

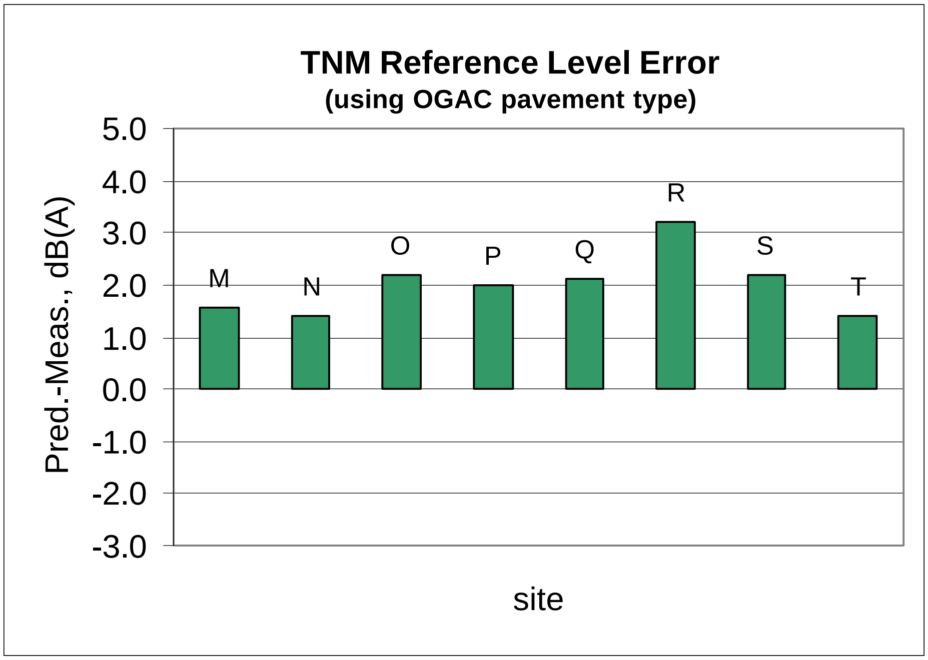

Figure 6. TNM Reference Level Errors (using "OGAC" pavement type) for Part 2.

F. Rover Location Results

Part 2 included microphone positions at "rover" locations further from the barrier than the standard locations shown in Figure 1. Table 4 previously showed the results of the sound level measurements at these additional positions behind the noise barrier barrier at five sites.

The rover locations at Site N indicate that the levels near the barrier were less than further behind the barrier. These levels are often less than background levels in the neighborhood as they are deep in the shadow zone of the barrier and away from neighborhood noise sources. At the 220 foot (67.1 meters) location, the measured rover levels were above the L_{90} level by 3 dB(A) and above the L_{99} level by 5 dB:L_{Aeq}. Based on this information it would appear that the effective shadow zone (5 dB:L_{Aeq} reduction) is somewhere near 220 feet (67.1 meters). The methodology determined by the research team resulted in a predicted shadow zone length of 157 feet (48 meters), so discrepancies do occur. The methodology is still being refined.

Site O rover microphones were located at 187 feet (57 meters) and 217 feet (66.1 meters) from the barrier. These microphones reached a level of 60 dB:L_{Aeq}, 3 dB:L_{Aeq} above the L_{99} level. From this information it appears that the edge of the shadow zone is at a distance greater than 217 feet (66.1 meters) from the barrier. The developed methodology predicted 316 feet (96 meters).

Site Q shows that the sound levels behind the barrier were 55-56 dB:L_{Aeq} at distances up to 380 feet from the barrier. In this case, the L_{99} level was 50 dB:L_{Aeq}, indicating that the shadow zone was beyond 380 feet. The methodology predicted a shadow zone length of 390 feet (119 meters).

Site R shows similar trends to Site N and Q, with Rover levels fluctuating slightly but in general they were 52-53 dB:L_{Aeq} at distances up to 315 feet (96 meters) behind the barrier. These levels are 5 dB:L_{Aeq} greater than the L_{90} level and 9 dB:L_{Aeq} greater than the L_{99} level, however the levels appear to decrease to a minimum of 51 dB:L_{Aeq} (at 218 feet from the wall) and then increase back to 53 dB:L_{Aeq} at 315 ft. from the wall. This seems to suggest that the edge of the shadow zone is near the 300 foot location. The methodology predicted a shadow zone length of 251 feet (76 meters). This site points out the difficulty sometime encountered using the L_{99} level as the background level.

Site S included microphones at positions on the opposite side of the road that were able to replicate microphone positions 1 and 4 without a barrier in place. This provides a good indication of the unabated sound levels at these positions but with additional ground effects. Accordingly, another indicator of the direct insertion loss is possible. In this case, the shadow zone appears to extend well beyond 100 feet (30.5 meters) from the barrier. The estimation technique predicted a shadow zone length of 305 feet (93 meters).

Table 16 contains a summary of the estimated shadow zone lengths for both Part 1 and Part 2 measurement sites. Small changes are reported from the Part 1 due to refinements of the method.

Table 16. Effective Barrier Heights above Ground Plane and Shadow Zone Lengths

Site	Major Source	Effective Barrier Height	15 meter Behind Barrier	30 meters Behind Barrier	Length of Shadow Zone
A. Jacksonville	I-95	18.5 ft. (5.6m)	--	7 dB:L_{Aeq}	210 ft. (64m)
B. Jacksonville	I-295	13.5ft. (4.1m)	8 dB:L_{Aeq}	5 dB:L_{Aeq}	141 ft. (43m)
C. Daytona Beach	S.R.5A	14.5 ft. (4.4m)	10 dB:L_{Aeq}	9 dB:L_{Aeq}	254 ft. (77.4m)
E. Brandon	I-75	41.0 ft. (12.5m)	2 dB:L_{Aeq}	8 dB:L_{Aeq}	362 ft. (110.3m)
F. Clearwater	S.R. 636	11.0 ft. (3.4m)	6 dB:L_{Aeq}	3 dB:L_{Aeq}	130 ft. (39.6m)
G. St. Petersburg	S.R.682 (54^{th} Ave. S.)	7.3 ft. (2.2m)	5 dB:L_{Aeq}	3 dB:L_{Aeq}	73 ft. (22.2m)

Table 16. Continued

Site	Major Source	Effective Barrier Height	15 meters Behind Barrier	30 meters Behind Barrier	Length of Shadow Zone
H. Ft. Lauderdale	I-95	14.5 ft. (4.4m)	9 dB:L_{Aeq}	9 dB:L_{Aeq}	243 ft. (74.1m)
I. Deerfield Beach	I-95	13.1 ft. (4.0m)	6 dB:L_{Aeq}	5 dB:L_{Aeq}	150 ft. (45.7m)
J. Miami	I-295	18.0 ft. (5.5m)	6 dB:L_{Aeq}	5 dB:L_{Aeq}	90 ft. (27.4m)
K. South Miami	U.S. 41 (Tamiami Trail)	11.0 ft. (3.4m)	11 dB:L_{Aeq}	7 dB:L_{Aeq}	--
L. Hialeah	S.R. 924 (Gratigny Parkway)	25.3 ft. (7.7m)	7 dB:L_{Aeq}	7 dB:L_{Aeq}	157 ft. (47.9m)
M. Wildwood	S.R. 44	9.4 ft. (2.9m)	9 dB:L_{Aeq}	9 dB:L_{Aeq}	320 ft. (97m)
N. Maitland	S.R.414	11.6 ft. (3.5m)	7 dB:L_{Aeq}	5 dB:L_{Aeq}	157 ft. (48m)
O. Ft. Lauderdale (H. Repeat)	I-95	16.3 ft. (5.0m)	10 dB:L_{Aeq}	9 dB:L_{Aeq}	316 ft. (96m)
P. Boynton Beach	I-95	18.4 ft. (5.6m)	12 dB:L_{Aeq}	10 dB:L_{Aeq}	445 ft. (136m)
Q. Palm Beach Gardens	I-95	19.3 ft. (5.9m)	14 dB:L_{Aeq}	9 dB:L_{Aeq}	390 ft. (119m)
R. Palm Harbor, Tampa	S.R. 586	7.7 ft. (2.3m)	7 dB:L_{Aeq}	7 dB:L_{Aeq}	251 ft. (76m)
S. New Port Richey	S.R. 54	11.0 ft. (3.4m)	9 dB:L_{Aeq}	7 dB:L_{Aeq}	305 ft. (93m)
T. Longwood	I-4	--	--	--	no barrier

Figure 7 shows a scattergram of the data using the ANSI adjusted insertion loss as compared to the predicted shadow zone length. It can be seen that a correlation exists between the two data sets with an r^2 value of greater than 0.71. The r^2 value is a "goodness of fit" statistical parameter where 1.0 would be a perfect approximation of the regression line as compared to real data. However, it is also important to understand that the shadow zone length and insertion loss are not truly independent variables. Even so, the dependence of the two still allows the insertion loss to be used as a surrogate for the shadow zone length. Using this relationship, the shadow zone length could be predicted using the empirically derived logarithmic equation:

$$SZL = 50.6 \exp(0.2\ IL_{30}) \qquad [2]$$

where: SZL = shadow zone length in feet
IL_{30} = the ANSI corrected insertion loss, 98.4 feet (30 meters) behind the barrier

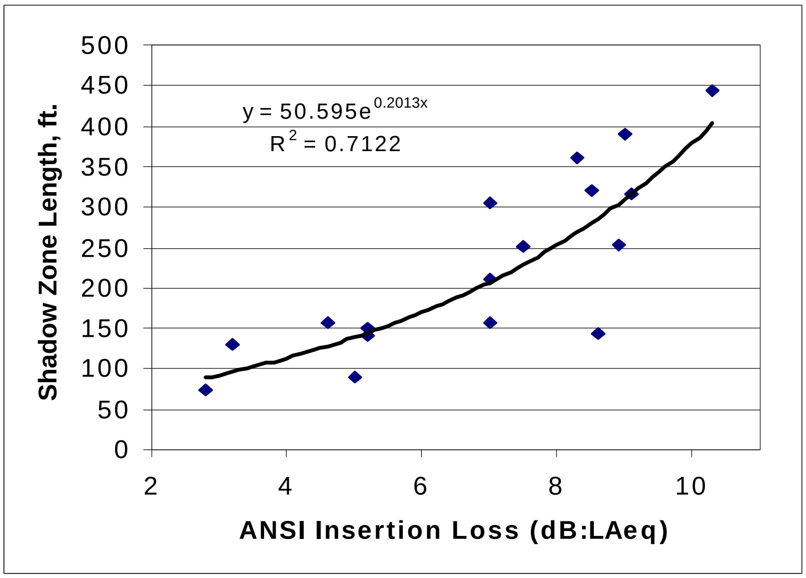

Figure 7. Comparison of ANSI Corrected Insertion Loss and Shadow Zone Length.

It should be noted that this method is only an approximation. Exact values should not be used at this time. Rather, the analyst should use the information to determine how many rows of homes will be benefitted. For example if the shadow zone length is predicted to be 250 feet (76.2 meters) then the rows of homes inside this distance should be considered to be in the "benefitted zone." Then, using prediction modeling, those predicted to receive 5 dB:L_{Aeq} in this "benefitted zone" could be identified. Those beyond this "benefitted zone," even if predicted to receive 5 dB:L_{Aeq} should not be counted because background levels or other effects may not truly allow this insertion loss to occur. It should be remembered that the models only predict the highway noise and do not consider the background levels. As such, the models predict shadow zones extending farther than really occur.

There may be instances when measurements are not available to determine the ANSI corrected insertion loss. In these instances, TNM direct predictions could be used, although with much less confidence and engineering judgement is needed even more. As seen in Figure 8, the r^2 value drops dramatically to a value of 0.40. So the confidence in the prediction is much less than with the ANSI adjusted insertion loss. As such, the analyst should use predicted values in a conservative fashion. Equation 3 can be used to predict shadow zone length from the TNM predicted insertion loss.

$$SZL = 52.2 \exp (0.17\ IL_{TNM}) \qquad [3]$$

where: IL_{TNM} = Insertion loss predicted by TNM at 98.4 feet (30 meters) behind the barrier

Again, conservatism is suggested in using the TNM direct insertion loss approach.

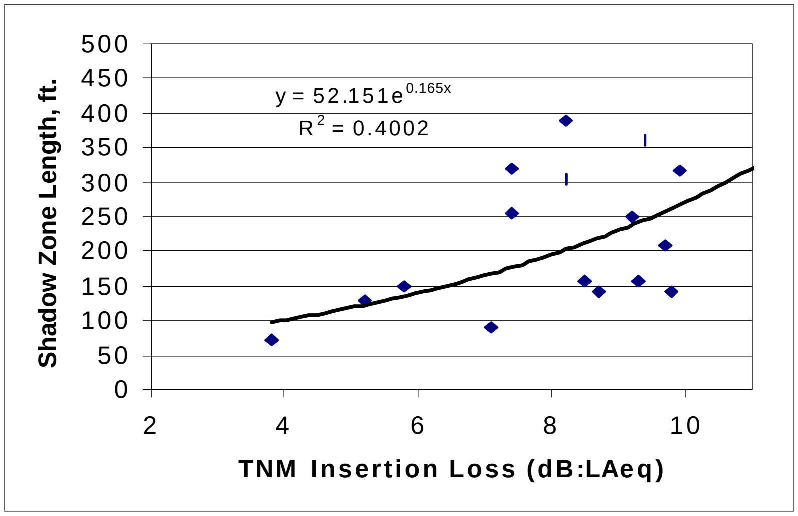

Figure 8. Comparison of TNM Predicted Insertion Loss and Shadow Zone Length.

G. Meteorological Effects

Meteorological data were collected at all of the Part 2 test locations. Table 17 shows the measured and derived meteorological data from the Part 2 sites. The table shows wind conditions at the low (1.5 m, 5 ft.) and the high (6 m, 19.8 ft.) anemometer positions. It also indicates the total number of data points for positive (P) and negative (N) wind directions. These correspond to conditions when the wind is blowing from the roadway to the receivers (P) and from the receivers to the roadway (N). Table 17 also includes the percentage of the perpendicular wind component as compared to the total magnitude of the wind. Additional parameters such as lapse rate and the Richardson's number have been calculated and are shown in Table 18.

Table 17. Meteorological Data for Part 2 Sites

Site	Wind Direction	Data Points	Low Wind (mag.) (m/s)	Low Wind (perp.) (m/s)	% of Mag.	High Wind (mag.) (m/s)	High Wind (perp.) (m/s)	% of Mag.
M	N	3013	0.63	0.33	52.4	1.04	0.48	46.2
	P	3718	0.63	0.40	63.5	1.04	0.77	74.0
N	N	2614	0.87	0.41	47.1	1.21	0.67	55.4
	P	3096	0.87	0.47	54.0	1.21	0.51	42.1
O	N	1776	0.77	0.38	49.4	1.14	0.40	35.1
	P	2485	0.77	0.54	70.1	1.14	0.81	71.1
P	N	588	0.76	0.09	11.8	1.24	0.67	54.0
	P	5593	0.76	0.54	71.1	1.24	1.01	81.5
Q	N	7058	0.69	0.52	75.4	1.07	0.65	60.7
	P	1537	0.69	0.17	24.6	1.07	0.47	43.9
R	N	1110	1.14	0.24	21.1	2.54	1.10	43.3
	P	6624	1.14	0.65	57.0	2.54	1.61	63.4
S	N	4747	0.74	0.43	58.1	1.25	0.77	61.6
	P	2512	0.74	0.36	48.6	1.25	0.49	39.2

Low Wind = 1.5 meters or 4.92 feet High Wind = 6 meters or 19.7 feet

Table 17 shows that the maximum perpendicular wind speed toward the barrier (N) was encountered at Site P and the minimum at site O. The maximum wind speed toward the receiver (P) was at Site R, while the minimum was at Site M.

Table 19 shows the goodness of fit for the correlation coefficients (r^2) when comparing the meteorological effects to the measured noise level difference between the reference microphone location and microphone locations 1-7, A, and C.

Table 18. Additional Meteorological Data

Site	Wind Direction	Richardson Number	Average Lapse Rate (C/m)
M	P	-4	-0.20
	N	-13	-0.18
N	P	-3	-0.11
	N	-10	-0.10
O	P	-2	-0.07
	N	-7	-0.06
P	P	-2	-0.19
	N	-9	-0.20
Q	P	-3	-0.08
	N	-11	-0.09
R	P	-2	-0.23
	N	-5	-0.25
S	P	-3	-0.19
	N	-16	-0.23

* Site T is not included because of equipment problems.

Table 19. Maximum r^2 Values for Noise Difference Versus Temperature and Wind Effects

Site	Maximum r^2	Microphone Location	Frequency	Effect
F	0.61	3	12 kHz	Temperature
G	0.59	5	20 kHz	Temperature
H	0.26	3	20 kHz	Temperature
I	0.57	1	63 Hz	Temperature
J	0.32	3	20 kHz	Temperature
K	0.77	4	10 kHz	Temperature
L	0.44	3	125 Hz & 1 kHz	Temperature
M	0.20	3 & 5	160 Hz, 6300 Hz &	Temperature
N	0.18	2 & 4	125 Hz & 8 kHz	Temperature
O	0.3	1	25 Hz	Temperature
P	0.58	2 & 3	125 Hz & 1250 Hz	Temperature
Q	0.53	4	1250 Hz	Temperature
R	0.47	4	160 Hz	Temperature
S	0.53	6	160 Hz	Wind

It can be seen that strong correlations are not shown for the weather information, either temperature or wind. This is most likely due to the small distances over which effects were measured and that the measurements were taken in light wind cases. Because of these weather conditions, lapse rates (temperature) seemed to play a more important role than did wind shear.

It is also important to note that even though these sites were measured during favorable weather conditions, refraction effects still occurred.

H. Comparison to Design Predictions

This section compares the measured/estimated insertion losses for three of the Part 2 sites where FDOT pre-construction analysis was similar to the measurement locations.

Table 20. Comparison of FDOT PD&E Design to Actual Insertion Loss

Site	**PD&E IL at First Row, dB:L_{Aeq}**	**Part 2 IL, dB:L_{Aeq}**	**Design Wall Ht. (ft)**	**Actual Wall Ht. (ft)**
M	6-9	9	9	9.4
R	5	7	8	5.7
S	4.5	9	8	11

It can be seen from Table 20 that for Site M, the actual barrier height was very close to the designed height and the adjusted insertion loss is close to the PD&E predicted insertion loss. For Site R, the barrier height at the measurement position was over 2 feet shorter than designed but the insertion loss was actually more than predicted by 2 dB. At Site S, the actual barrier height at the measurement location was 3 feet taller than the design height. As such, much more insertion loss is present at Site S than originally predicted. In each of these sites, more insertion loss occurred than was originally predicted.

V. CONCLUSIONS

Most barriers are effective (>5 dB:L_{Aeq} insertion loss at the first row of homes). In this analysis, the first row of homes were generally observed near the microphone positions 49.2 feet (15 meters) from the barrier. The single exception was at Site E. At Site E from Part 1, the noise levels from the highway were effectively reduced, but more by the edge of the fill than the berm and barrier combination. Farther from the barrier, and out of the shadow zone of the edge of fill, the barrier did provide benefits. Accordingly, benefitted receivers do exist at this site, but the barrier on top of the berm does not add much additional attenuation. All other sites had at least 5 dB of insertion loss. It can be concluded that the barriers are effective and beneficial.

At the second row of homes (near the 98.4 feet or 30 meters measurement locations) only two sites were below a 5 dB insertion loss. These were Sites F and G. Site F was a barrier of relatively short length and Site G was the shortest in height of all barriers tested. Again, overall, it can be stated that the barriers are providing substantial reductions and benefits for the receivers.

Three FDOT reports were also available that predicted insertion losses near the measurement sites. Each of the three sites received more insertion loss than predicted by the PD&E report. Also of note was that at two of the sites, the constructed barrier heights were very different than built. From this small database it would seem that past predictions have led to barrier designs that benefit the nearby residences.

In direct statistical comparison to the STAMINA 2.0 and STAMINA 2.1 model, TNM proved to be the better model. The STAMINA models had a slightly better minimum error for absolute sound level prediction and a better maximum error for prediction of the propagation loss from the reference location to the receiver but TNM proved better in all other statistical testing.

TNM, using the “Average” pavement input continually over-predicted the absolute sound levels. When TNM was run using the “OGAC” (open graded asphalt concrete) input, the predicted levels were more accurate (under 2 dB:L_{Aeq} of error) than when using the “Average” pavement type input although over prediction still occurred. This is thought to occur since Florida uses an open graded, asphalt friction mix. Further review showed that propagation is predicted well but the REMELs start the problem with the predicted numbers since they are the “heart” of the model. This would tend to point out that although pavement type is not allowable as an abatement measure, it should be used when predicting existing cases to allow more accurate representation of the sites.

Rover microphone positions were used at greater distances from the barrier to help determine the edge of shadow zone. Based on this information, an empirical model was developed for the shadow zone length, based on predicted insertion loss, that could help the analyst determine the extent of benefitted receivers. The FHWA models are unable to do this at this time since background levels are not considered. Work is continuing to improve this derived methodology.

Meteorological data was also collected and statistical correlation determined. Correlations were low, which is thought to be due 1) the short distance reviewed (reference site to other microphone positions); and, 2) that all data was taken in light wind conditions. Accordingly, at this time, no definite conclusions can be drawn. However, there was correlation particularly for the lapse rate. This points out that even under favorable test conditions, refraction is still present. Work on this phenomenon continues and will be reported at a later date.

Overall, it can be stated that the barriers are providing substantial reduction for the neighbors along the highway. This is true for most first row homes and the majority of second row homes. In some cases, third row homes are also being benefitted. The predictive process used in the past seems to be providing adequate protection to the highway neighbors.

VI. REFERENCES

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APPENDIX A

Site Details

Site M. Wildwood

Date 11/30/2000
Actual Wall height: 9.4 ft

Site N. Maitland

Date 7/10/2001
Actual Wall height: 12.1 ft

Site O. Fort Lauderdale

Date 9/11/2001
Actual Wall height: 16.3 ft

Site P. Boynton Beach

Date 2/25/2002
Actual Wall height: 20.9 ft

Site Q. Palm Beach Garden

Date 2/26/2002
Actual Wall height: 19.8 ft

Site R. Palm Harbor

Date 3/25/2002
Actual Wall height: 5.7 ft

Site S. New Port Richey

Date 3/26/2002
Actual Wall height: 11.0 ft

Site T. Longwood

Date 5/23/2002
Actual Wall height: 6.0 ft

APPENDIX B

Measured Noise Data

Site	Run	mic.1	mic.2	mic.3	mic.4	mic.5	mic.6	mic.7	mic.8
M. Wildwood	1	49.5	51.1	57.2	53.1	53.8	61.3	69.5	69.8
(before interference removal)	2	50.9	54.4	59.8	55.3	55.8	61.7	70.6	70.5
	3	51.7	52.5	59.7	54.9	55.4	62.0	71.1	70.3
	4	51.7	53.2	58.8	53.1	57.1	62.0	70.5	70.8
	Avg	51.0	52.8	58.8	54.1	55.5	61.8	70.4	70.3
M. Wildwood	1	49.5	51.1	57.2	53.1	53.8	61.3	69.5	69.8
(after interference removal)	2	50.9	53.8	59.5	54.0	55.8	61.2	70.6	70.5
	3	51.7	52.5	59.7	54.4	55.4	62.0	71.1	70.3
	4	51.7	53.2	58.8	52.3	57.1	62.0	70.5	70.8
	Avg	51.0	52.7	58.8	53.4	55.5	61.6	70.4	70.3
N. Maitland	1	NA	53.9	55.8	54.7	54.5	NA	69.7	NA
(before interference removal)	2	NA	53.9	56.5	54.7	54.6	NA	71.0	NA
	3	NA	56.2	57.7	55.9	56.6	NA	71.7	NA
	4	NA	54.8	56.6	55.2	55.9	NA	70.6	NA
	Avg	NA	54.7	56.6	55.1	55.4	NA	70.8	NA
N. Maitland	1	NA	53.9	55.8	54.7	54.6	NA	69.7	NA
(after interference removal)	2	NA	53.9	56.5	54.7	54.5	NA	71.0	NA
	3	NA	56.0	57.6	55.7	56.4	NA	71.7	NA
	4	NA	54.7	56.6	55.2	55.8	NA	70.6	NA
	Avg	NA	54.6	56.6	55.1	55.3	NA	70.8	NA
O. Fort Lauderdale	1	63.0	65.0	NA	64.7	66.2	NA	NA	80.0
(before interference removal)	2	63.3	65.3	NA	64.5	66.2	NA	NA	80.0
	3	65.2	65.6	NA	66.2	66.9	NA	NA	80.2
	4	NA	NA	NA	NA	NA	NA	NA	NA
	Avg	63.8	65.3	NA	65.1	66.4	NA	NA	80.1
O. Fort Lauderdale	1	63.0	65.0	NA	64.7	66.1	NA	NA	80.0
(after interference removal)	2	63.2	65.1	NA	64.5	66.2	NA	NA	80.0
	3	63.7	65.6	NA	66.2	66.7	NA	NA	80.2
	4	NA	NA	NA	NA	NA	NA	NA	NA
	Avg	63.3	65.2	NA	65.1	66.4	NA	NA	80.1
P. Fort Lauderdale	1	57.9	59.1	NA	58.7	59.3	64.1	77.3	77.6
(before interference removal)	2	60.3	60.7	NA	59.3	59.9	64.5	77.3	77.4
	3	60.0	60.4	NA	59.3	60.0	64.7	77.9	78.0
	4	60.0	60.2	NA	59.5	60.2	65.2	78.2	78.2
	Avg	59.6	60.1	NA	59.2	59.8	64.6	77.7	77.8
P. Fort Lauderdale	1	57.2	58.7	NA	58.7	59.3	64.1	77.3	77.6
(after interference removal)	2	58.7	59.8	NA	59.0	59.6	64.4	77.3	77.4

Site	Run	mic.1	mic.2	mic.3	mic.4	mic.5	mic.6	mic.7	mic.8
	3	59.1	60.0	NA	59.2	59.9	64.6	77.9	78.0
	4	59.3	60.0	NA	59.4	60.2	65.2	78.2	78.2
	Avg	58.6	59.6	NA	59.1	59.8	64.6	77.7	77.8
Q. West Palm Beach	1	54.4	56.6	61.1	57.5	58.6	64.2	76.1	78.1
(before interference removal)	2	55.0	57.4	61.7	57.2	58.7	64.1	75.9	76.0
	3	56.0	58.3	62.8	58.5	59.4	65.2	76.0	76.0
	4	56.4	58.9	63.4	58.5	59.9	65.4	76.4	77.8
	Avg	55.4	57.8	62.2	57.9	59.2	64.7	76.1	77.0
Q. West Palm Beach	1	54.3	56.6	61.1	57.4	58.5	64.1	76.1	78.1
(after interference removal)	2	54.7	57.0	61.6	57.2	58.6	64.1	75.9	76.0
	3	55.8	58.2	62.8	58.5	59.4	65.2	76.0	76.0
	4	56.2	58.9	63.4	58.4	59.9	65.4	76.4	77.8
	Avg	55.3	57.7	62.2	57.9	59.1	64.7	76.1	77.0
R. Palm Harbor	1	NA	55.8	NA	57.9	61.3	NA	69.6	70.1
(before interference removal)	2	NA	55.8	NA	57.7	61.7	NA	69.6	70.6
	3	NA	56.8	NA	58.8	62.1	NA	68.7	70.5
	4	NA	59.3	NA	56.7	60.4	NA	69.0	68.9
	Avg	NA	56.9	NA	57.8	61.4	NA	69.2	70.0
R. Palm Harbor	1	NA	55.8	NA	57.6	61.1	NA	69.6	70.1
(after interference removal)	2	NA	55.7	NA	57.3	61.6	NA	69.6	70.6
	3	NA	56.5	NA	58.4	62.1	NA	68.7	70.5
	4	NA	56.5	NA	56.7	60.2	NA	69.0	68.9
	Avg	NA	56.1	NA	57.5	61.3	NA	69.2	70.0
S. New Port Richey	1	55.8	55.8	56.9	56.5	55.8	60.4	70.5	70.2
(before interference removal)	2	56.0	56.4	57.1	57.0	56.4	59.3	69.7	70.7
	3	58.5	58.4	59.8	58.4	58.5	60.4	70.8	72.0
	4	56.6	56.8	58.3	57.0	56.7	58.8	70.9	71.1
	Avg	56.7	56.9	58.0	57.2	56.9	59.7	70.5	71.0
S. New Port Richey	1	55.3	55.3	56.5	56.3	55.5	60.4	70.5	70.2
(after interference removal)	2	56.0	56.4	57.1	57.0	56.4	59.3	69.7	70.7
	3	58.5	58.4	59.8	58.4	58.5	60.4	70.8	72.0
	4	56.4	56.8	58.1	57.0	56.7	58.8	70.9	71.1
	Avg	56.5	56.7	57.9	57.2	56.8	59.7	70.5	71.0
T. Longwood	1	63.0	64.9	72.0	66.0	67.6	71.6	75.7	75.2
(before interference removal)	2	63.2	65.5	72.0	66.7	67.8	71.8	76.2	75.4
	3	63.6	65.2	71.8	66.5	68.1	71.9	76.0	75.5
	4	63.8	65.7	73.0	66.7	68.4	72.2	76.1	75.5
	Avg	63.4	65.3	72.2	66.5	68.0	71.9	76.0	75.4

Site	Run	mic.1	mic.2	mic.3	mic.4	mic.5	mic.6	mic.7	mic.8
T. Longwood	1	62.9	64.9	71.9	67.5	67.6	71.5	75.7	75.2
(after interference removal)	2	63.2	65.4	71.9	66.3	67.8	71.8	76.2	75.4
	3	63.5	65.2	71.6	66.5	68.1	71.9	76.0	75.5
	4	63.8	65.7	72.9	66.5	68.3	72.2	76.1	75.5
	Avg	63.3	65.3	72.0	66.7	68.0	71.8	76.0	75.4

APPENDIX C

Measured Weather Data

(Included on CD)