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CENTER FOR TRANSPORTATION RESEARCH

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Traffic Noise Barrier Study on SH 190 in Rowlett, Texas

Dr. Manuel Trevino

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16. Abstract

The Texas Department of Transportation (TxDOT) commissioned a study in 2013 to analyze the feasibility and effectiveness of lightweight noise barriers on Interstate Highway 30 (I-30), near downtown Dallas. The study led to the installation of two adjacent transparent highway noise barriers in 2013 and 2018, respectively. The success of that project led to the possibility of similar installations at other locations in the Dallas District and elsewhere. Two locations in Rowlett—the President George Bush Turnpike (main lanes) and the State Highway (SH) 190 (frontage roads), near Lake Ray Hubbard—presented a similar noise problem for the residential sites along the highway, with existing noise walls that were apparently insufficient to attenuate the traffic noise. Based on the experience obtained at the I-30 site, TxDOT decided to perform a similar study for the turnpike and SH 190. As a result, new transparent extensions to the existing wall were designed in 2018 and installed in the summer of 2019. This final report presents the outcome of this research. The activities included the site selection for residential noise monitoring; investigation of the pavement characteristics related to noise generation; and the computer modeling of the highway noise and the acoustic design of noise walls considering the geometry of the road, its profile, traffic, and the existing noise walls. Residential sound pressure level tests were performed at various residential locations for several months, before and after the completion of the installation. A portable weather station was used to monitor the conditions at the time of the tests. Measurements were conducted throughout the day—morning, afternoon, and evening—and test days occurred approximately once a month. An analysis of the sound pressure level tests, along with the weather variables and their influence on the noise levels, is presented. The results confirm the effectiveness of the walls, in the form of significant noise level reductions.

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Manuel Trevino

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Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

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The cooperation of the residents along SH 190 is acknowledged, especially those who kindly allowed CTR to perform noise measurements at their properties at all times of the day.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

This is one of the two final reports developed under Research Project 0-6804, *Life Cycle Cost and Performance of Lightweight Noise Barrier Materials along Bridge Structures*, a study funded by the Texas Department of Transportation (TxDOT). This project started in 2013 as an investigation of the feasibility of lightweight noise barriers on a segment of Interstate Highway 30 (I-30), in Dallas. The first two reports for this project presented the preliminary findings on the research conducted on the two noise barrier segments on that highway. In 2017, the project scope was expanded to include a similar study on State Highway (SH) 190, and the President George Bush Turnpike (PGBT), in Rowlett, east of Dallas. The third report, 0-6804-3, submitted to TxDOT in August 2019, included the preliminary noise analysis and recommendations for the SH 190/PGBT project site. The fourth report, 0-6804-4, the other final report for this project, submitted to TxDOT in July 2020, contains the final results and recommendations from the research conducted on the I-30 noise barriers. This final report, 0-6804-5, documents all the findings about the study conducted on SH 190 as part of this project, including field data as well as analyses, conclusions, and recommendations.

1.1. Background

Noise associated with transportation has progressively become a nuisance to communities along roads, especially in densely populated areas. As traffic volumes of people and freight continue to grow, roads expand and noise levels rise. Nowadays, transportation agencies have become more environmentally sensitive and make efforts to address pollution problems, including those related to noise. Multiple factors affect the level of traffic noise, such as traffic volume; vehicular speed; terrain; grade; pavement type, condition, and texture; surface absorption; weather conditions; and shielding provided by walls, fences, buildings, or even dense vegetation. The most frequently used noise abatement measure has been the construction of noise barriers on the side of the road. Such barriers are normally built along highways that carry heavy traffic in urban areas, where noise pollution is likely to be greater and affect more people.

Noise barriers are normally solid wall structures built between the highway and the impacted activity area to reduce noise levels. Barriers do not eliminate the noise; they only reduce the noise levels perceived by certain benefitted receivers, normally those in proximity to the road. Barriers are especially effective for those receivers situated directly behind it; they can experience a decrease in noise level of typically 5 to 10 dBA. Noise barriers are not effective for homes on a hillside overlooking a road, or for buildings that rise above the barrier; the barrier must be high enough and long enough to block the view of the road. Common materials for barrier construction are concrete and masonry; other materials are metal and acrylic.

The height, length, and material are key components to the effectiveness of the barrier. Openings in the barriers, such as those designed to allow access to side roads or driveways, decrease their effectiveness.

Noise barriers can reduce visibility and lighting for both the receivers behind the barrier and the drivers using the facility. Barriers can also present a problem for businesses along the road by restricting views and access by customers. Barriers constructed with transparent materials can address these problems by reducing the visual impact of opaque barriers, providing aesthetic value by preserving scenic vistas.

1.2. Research Project Description

In 2013, the Dallas District of TxDOT asked CTR to develop a research project to investigate the use of lightweight noise barriers to retrofit existing noise walls on the south side of I-30 in an effort to mitigate the noise pollution generated at the highway that affects residences in the Kessler Park neighborhood, west of downtown Dallas. This research endeavor was also intended to be a pilot project for transparent noise barriers. The first transparent noise barrier in Texas was installed as part of this study. The positive results prompted the installation of a second transparent wall adjacent to it. The overall success of the noise barrier installations on I-30 suggested that similar barriers could be implemented at other locations in the Dallas District and elsewhere. Therefore, when a similar need arose at the District for a segment of SH 190, the 0-6804 Research Project was subsequently extended to include an analogous study on that roadway, located in Rowlett, east of Dallas. This study began in June 2017.

When the need to expand or improve a highway with existing noise barriers arises, it is often also necessary to increase the height of the walls to mitigate the additional noise, if the noise is expected to increase. It is normally the case that an increase in highway capacity leads to an increase in highway noise that requires additional noise mitigation. New, lightweight transparent materials, such as those utilized in the I-30 project, offer the potential to add extensions to existing barriers and avoid the cost of reconstruction typically required when increasing the height of the concrete walls. The fact that the material is lightweight makes it unnecessary to have to structurally retrofit the concrete walls in order to make them able to support the additional weight. Another advantage of the transparent lightweight material is the aesthetic appeal that they provide. A full discussion of the advantages and disadvantages of this type of noise barrier material, as well as the selection process for the I-30 project, is presented in Report 0-6804-4 (*Trevino 2020).*

As a result of this study, 4-ft. transparent acrylic extensions were installed on top of the existing concrete walls during the summer of 2018 to increase their height and provide additional benefits in the form of noise level reductions. The study involved selecting sites for noise tests, conducting noise tests for several months, modeling noise impacts and designing new wall extensions, monitoring the wall installation, performing some more noise tests after the new wall extensions were installed to measure their performance, and finally, analyzing the data to assess the effectiveness of the walls.

1.2.1. Objective and Tasks

The main objective of this study is to assess the feasibility and effectiveness of lightweight noise barriers on SH 190 in Rowlett. The tasks are as follows:

- Select residential sites for noise monitoring.
- Conduct a feasibility study for lightweight traffic noise walls.
- Perform noise modeling.
- Recommend noise mitigation measures.
- Perform the acoustical design of the barriers.
- Conduct periodic inspections of the barriers' condition.
- Perform sound measurements before and after the barriers' installation.
- Analyze measurements and evaluate performance.

1.2.2. Report Organization

This report consists of eight chapters:

- Chapter 1 describes the project, the objectives, this report's contents, and the highway in question.
- Chapter 2 presents the process for the selection of the residential sites subject of noise monitoring.
- Chapter 3 presents a condition survey conducted on the pavements of SH 190/PGBT, and the results of tire-pavement noise tests performed on such pavements.
- Chapter 4 presents the Traffic Noise Modeling, which characterizes all aspects of the highway (geometry, traffic, receivers, profiles, elevations, existing walls, etc.) and predicts noise levels. The modeling also includes the design of additional noise mitigation measures.
- The residential noise testing program is presented in Chapter 5, describing the equipment and test procedures.
- The results of such tests for both the pre-barrier condition stage (prior to the noise wall extension) and post-barrier condition (after the wall extension) are presented in Chapter 6, along with the analysis of those results, as well as the weather variables and their influence on noise measurements.
- Chapter 7 presents the monitoring activities for the noise walls, including their installation and regular visual inspections.
- Finally, Chapter 8 includes a summary, conclusions, and recommendations.

1.3. Highway Description

The segment in question, referred in this report as SH 190, is located in Rowlett, east of Dallas, close to Lake Ray Hubbard. The section of interest includes the main lanes, which are part of the PGBT, as well as the frontage roads, between the area south of Main Street and the north shore of the lake. The existing noise walls and their additions related to this project are placed only in the frontage roads (SH 190); however, the noise that is the subject of study is created by both the main lanes (PGBT) and SH 190.

The PGBT is a 52-mile toll road running through the northern, northeastern, and western suburbs, forming a partial loop around Dallas (Figure 1.1). It is named for the late George H. W. Bush, the 41st President of the United States. At its west end near Belt Line Road in Irving, SH 161 continues southwest to Interstate 20 (I-20) in Grand Prairie. The discontinuous toll-free frontage roads along the turnpike from I-35E in Carrollton east to its end at I-30 in Garland have the SH 190 designation. SH 190 signage appears only along the Garland, Richardson, Plano, and Carrollton sections of the frontage road with the undersign “frontage road only.” At intersections with city streets, only the Bush Turnpike signs are displayed, not the SH 190 signage. Prior to the construction of the main lanes as a tollway, SH 190 was used as the name of the planned main lanes too. Similarly, the section west of I-35E was planned as part of SH 161. Bush Turnpike is signed as a north–south road from I-20 to I-35E (the “Western Extension”), an east–west road from I-35E to the Merritt Main Lane Gantry (the original sections) and as a north–south road from the Merritt Main Lane Gantry to I-30 (the “Eastern Extension”), as the PGBT makes a nearly 90-degree curve in both places (*NTTA n.d.*).

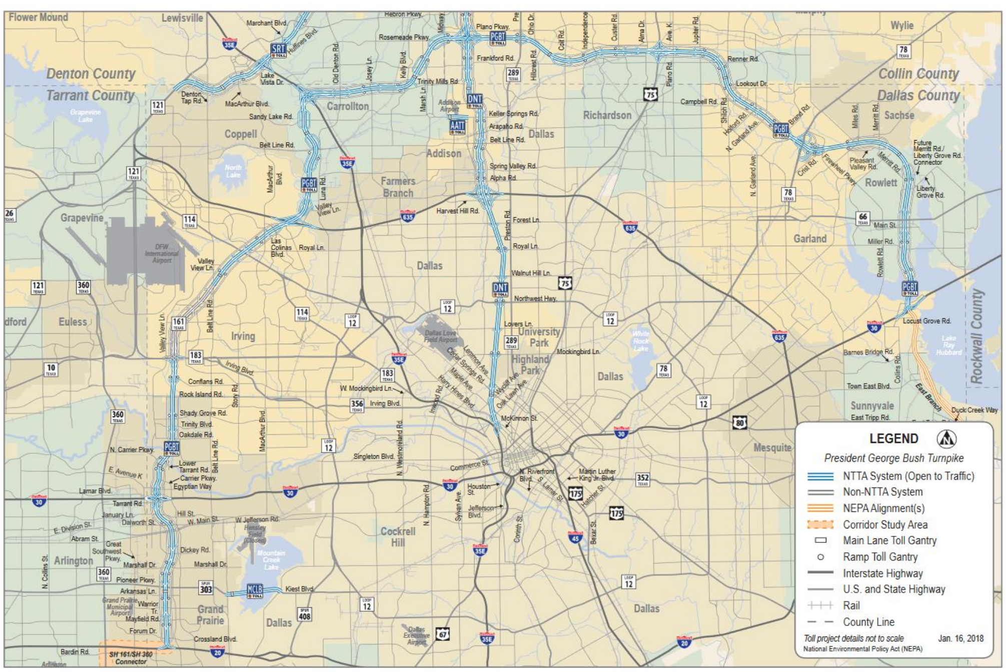


Figure 1.1 Map of the PGBT (Source: NTTA)

The turnpike segment from State Highway 78 to the interchange at I-30 is known as the PGBT Eastern Extension (PGBT-EE); it consists of five sections (Sections 28 to 32, Figure 1.2), which opened to traffic in December 2011. The project was broken into five sections for purposes of managing and expediting the design and construction. There is a newer segment of the PGBT; this one is on the west side of Dallas, from south of SH 183 to I-20. It opened to traffic in October 2012.

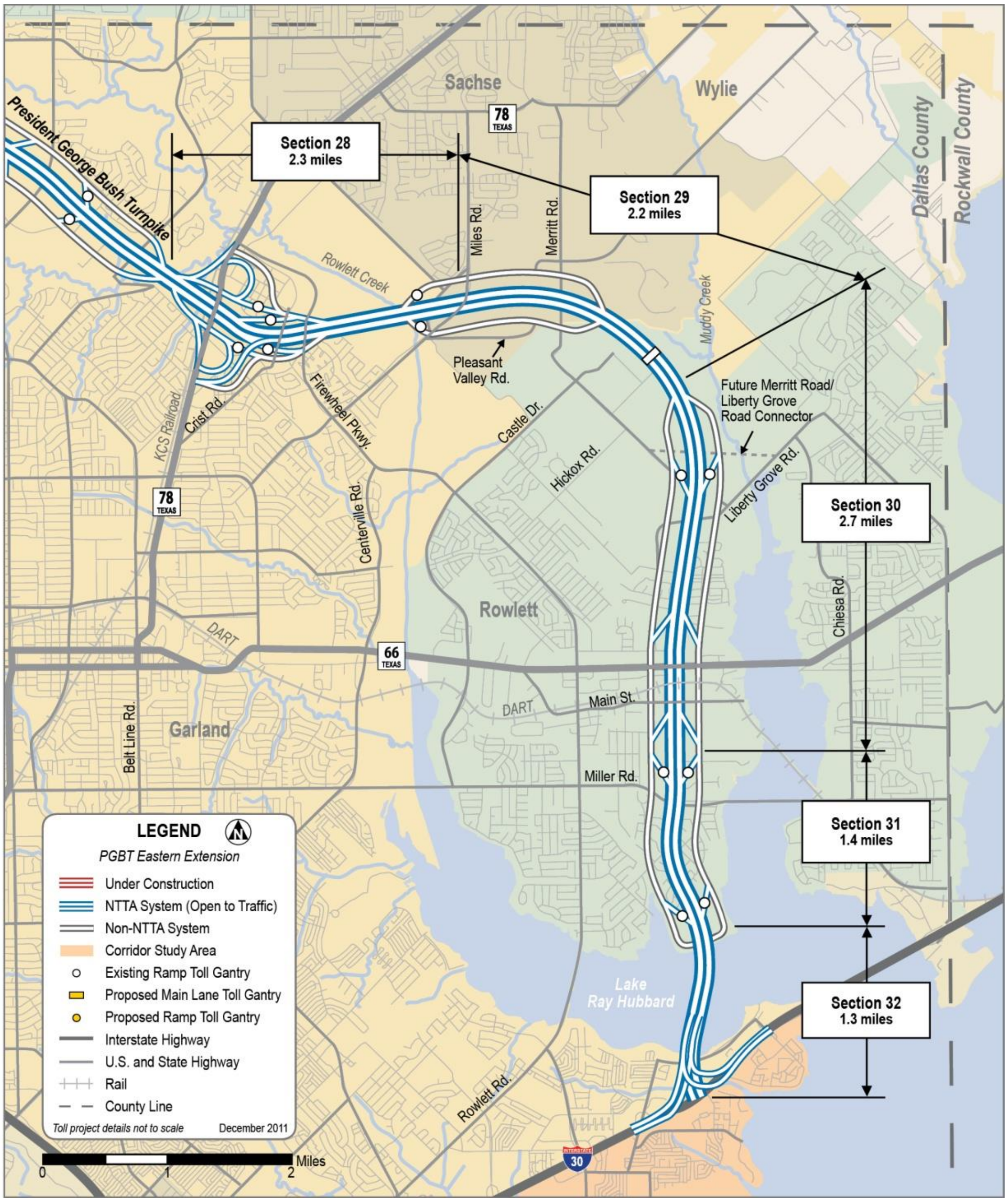


Figure 1.2 PGBT Eastern Extension (Source: NTTA 2013)

In particular, Section 31 is the section of interest in this study (Figure 1.3). The 1.4-mile section extends from south of Main Street to the north shore of Lake Ray Hubbard.

The PGBT is operated by the North Texas Tollway Authority (NTTA). The NTTA maintains the main lanes, while TxDOT maintains the frontage roads.

The NTTA was responsible for constructing main lane and ramp pavements, bridge and drainage structures, retaining walls, noise barriers, illumination, signing, pavement markings, traffic signals, landscaping, ITS infrastructure, and four ramp toll gantries for electronic toll collection.

Figure 1.3 Project location (Source: NTTA 2013)

1.3.1. Geometry

The highway section of interest is oriented north-south. It consists of three main lanes with inside and outside shoulders in each direction, separated with a 48-ft. wide median and a continuous concrete traffic barrier (CTB), as well as two and three lanes of frontage roads for the northbound direction, and two lanes for the southbound frontage road.

The PGBT main lanes are 12-ft. wide; the right (outside) shoulder is 10-ft. wide and the left (inside) shoulder is 12-ft. wide to allow a disabled vehicle to stop without interfering with the through traffic lanes. Both shoulders are paved with concrete and match the adjoining pavement section. The frontage road lanes are 12-ft. wide as well.

The vertical alignment of this section of highway corresponds to slightly rolling terrain. An important consideration is that the rolling terrain also varies in the east-west orientation, so with the highway segment oriented north-south, these variations are reflected in such way that the vertical profiles between main lanes, frontage roads and neighborhood are not even throughout the length of the road studied; this results in different elevations between them, making the noise walls not entirely effective for shielding the neighborhoods (please see Section 1.3.5 for more information on this subject).

1.3.2. Pavements

The original pavement type for both the main lanes and the frontage roads is continuously reinforced concrete pavement (CRCP). The finishing for the CRCP is transverse tining. The pavement for main lanes and ramps consists of 13 in. of CRCP, supported by 1.5 in. of asphalt bond breaker, 6 in. of cement-stabilized base (CSB), and 12 in. of either lime stabilized subgrade (LSS) or cement-stabilized subgrade (CSS). Below these layers there is a 2 to 8 ft. layer of moisture treated subgrade (MTS) to reduce swelling of the expansive soils. The shoulders have the same thickness and materials as the main lanes. The frontage road pavement section consists of 11 in. of CRCP over 4 in. of asphaltic concrete pavement (ACP) and 12 in. of CSS. Those original pavements constructed in 2011 are still in place, and are in good condition at present. A thorough evaluation of the pavement conditions is presented in Chapter 3.

Images of the northbound main lanes are presented in Figures 1.4 and 1.5. Figures 1.6 and 1.7 show views of the southbound main lanes.

Pictures of the northbound frontage road are shown in Figures 1.8 to 1.10. Figure 1.9 shows the transition from three to two lanes. Figure 1.11 shows an image of the southbound frontage road.

Figure 1.4 View of the northbound main lanes

Figure 1.5 View of the northbound main lanes

Figure 1.6 View of the southbound main lanes

Figure 1.7 View of the southbound main lanes

Figure 1.8 View of the northbound frontage road

Figure 1.9 View of the northbound frontage road (transition from three to two lanes)

Figure 1.10 View of the northbound frontage road

Figure 1.11 View of the southbound frontage road

1.3.3. Residential Communities

There are four main neighborhoods along the SH 190/PGBT-EE Section 31 (from south of Miller Street to the north shore of Lake Ray Hubbard) that are affected by the highway traffic noise, i.e., the noise generated by the traffic traversing the toll road and the frontage roads. These communities are called Ridgecove and Magnolia Springs on the west side of the highway, and Harborside and Lake Forest Estates on the east side of the road.

These neighborhoods were approved by the City of Rowlett prior to the construction of the PGBT-EE, with full knowledge of the upcoming highway and its location.

A timeline of the history pertaining to the highway and the surrounding neighborhoods is presented below (*NTTA 2013*):

- 1968: A loop around Dallas County (Loop 9) is identified
- February 1995: Rowlett adopted Resolution 2-21-95C, which created zoning to coincide with the approved SH 190 concept plan
- December 1995: Harborside 1 was re-platted to conform to the approved zoning plan
- February 1996: Harborside 2 was platted
- October 1997: Harborside 3 was platted, showing future SH 190
- July 1998: Ridgecove was platted, showing future SH 190
- December 2000: Magnolia Springs 3B was platted, showing future SH 190
- October 2004: Final Environmental Impact Statement (FEIS) approved by FHWA
- May 2005: Magnolia Springs 5 was platted, showing future SH 190
- July 2008: Re-evaluation approved by FHWA
- August 2008: Highway construction began
- December 2011: PGBT-EE opened to traffic

1.3.4. Existing Noise Walls

When the PGBT-EE project was initially designed, the traffic noise analysis determined that the proposed project would result in a traffic noise impact (Section 6.1.2 has a discussion of noise impact). Therefore, NTTA constructed noise barriers to mitigate traffic noise impacts along the project. Through the environmental re-evaluation of 2008, it was determined that noise barriers were both feasible and reasonable to mitigate traffic noise. There are two existing noise walls, which are made of concrete and are 8-ft. tall. One is on the east side (northbound direction) and the other one is on the west side (southbound direction). These walls are placed between the frontage roads and the residences and were constructed at the same time the highway was constructed. The east-side wall is 2,858 ft. long, and the west-side wall is 2,949 ft. long. The east-side wall shields the Harborside Community and the west-side wall protects the Ridgecove Community.

Figure 1.12 shows the residential communities along the highway, as well as the location of the existing noise walls relative to the highway and the neighborhoods.

Figure 1.12 Residential communities and existing noise walls in the area of interest

As Figure 1.12 shows, the walls do not protect all the homes in the residential communities in question. On the east side, Lake Forest Estates is completely unprotected from the noise, and Magnolia Springs, on the west side, is in the same situation. Lake Forest Estates has some privacy walls separating residences from the highway. Ridgecove and the majority of Harborside are protected by the existing walls. There are some homes on Kirby Road, on the west side, that are not part of any residential community that are also unprotected by the walls and exposed to the noise in close proximity to the frontage road.

Figures 1.13 to 1.15 show some views of the existing concrete walls from the neighborhood side and from the highway side.

Figure 1.13 View of the east noise wall from the neighborhood side

Figure 1.14 View of the west noise wall from the neighborhood side

Figure 1.15 View of the west noise wall from the westbound main lanes

As Figure 1.15 indicates, most of the homes are two-story residences; thus, the 8-ft. walls only partially block the line of sight between the highway and the receivers. Therefore, some of the noise travels unobstructed from the source to the receivers. The problem is more complex when the differences in elevation between the main lanes and the frontage roads are considered, as the vertical profiles of frontage road, main lanes, and the neighborhood first-row residences do not match throughout the length of the section of interest. For instance, Figure 1.16 shows a view from the main lanes of PGBT towards the homes of the Ridgecove Community on the west side of the highway, indicating a clear line of sight to the backyards, which signifies that the noise has a direct unobstructed path towards the receivers. In this photograph, the noise wall is not visible from the main lanes. The concrete wall in this image is the CTB. This is an example where the noise wall has no benefit in terms of mitigating the noise generated from the main lanes for this particular residence.

Figure 1.16 View from the main lanes towards the back of the residences on the west side of PGBT

1.4. Summary

This chapter describes the 0-6804 project, outlining the origin of the SH 190 study and how it fits into the research. The objective and tasks for this part of the project were described, along with the organization of this report.

A description of the characteristics of the SH 190/PGBT section of highway of interest is presented, including geometry, pavements, the adjacent residential communities affected by the highway traffic noise, and the existing noise walls.

Chapter 2. Residential Locations

This chapter presents the work related to the selection of sites for noise monitoring along SH 190/PGBT. These residential locations were selected for measuring noise levels throughout the development of this project. The first-row residential sites selected are intended to be representative of the locations and conditions prevailing at the various neighborhood communities affected by the highway noise from SH 190/PGBT. The process for selecting the residential sites is presented in the next paragraphs, followed by a detailed description of each of the sites.

2.1. Initial Residential Site Selection

The initial site selection process started with a field trip around the neighborhoods along SH 190/PGBT, conducted in June 2017. Mr. George Reeves and Mr. Wade Odell, with TxDOT, showed the CTR researcher various accessible sites along the highway for possible noise test locations. The possible sites were documented with photographs, videos, and notes. The following month the researcher came back to the sites; this time, noise measurements were taken as well as GPS coordinates. This information was used to determine the best-suited test sites. Among the key factors for site selection were accessibility, and proximity to the highway (first-row receivers). For accessibility, permission was obtained from a couple of owners to access their driveway and property so that the tests could be conducted regularly in the following months. Besides these homes, few receivers' sites were easily accessible for routinely performing noise field tests. Another consideration for the site selection was having sites that were protected by existing noise walls, as well as sites not protected by walls, in order to have representative locations for both cases.

Initially, four sites were chosen for the northbound direction, i.e., on the east side of the highway, and four were selected for the southbound direction, i.e., to the west of the highway. The eight sites are summarized in Table 2.1.

Table 2.1 SH 190 residential sites for noise monitoring

Site Number	Side	Community	Address	GPS Coordinates	
				Latitude	Longitude
1	East	Harborside	5010 Southport Dr.	N 32° 52.971'	W 96° 33.308'
2	East	Harborside	2205 Mermaid Cir.	N 32° 53.041'	W 96° 33.335'
3	East	Harborside	4901 Harborview Blvd.	N 32° 53.399'	W 96° 33.343'
4a	East	Lake Forest Estates	3401 Francesca Ct.	N 32° 53.624'	W 96° 33.332'
6	West	Magnolia Springs	4317 Rose Leaf Ct.	N 32° 53.424'	W 96° 33.435'
7	West	Magnolia Springs	2629 Kirby Rd.	N 32° 53.235	W 96° 33.438'
8	West	Ridgecove	4509 Meadowcove Dr.	N 32° 52.945'	W 96° 33.378'
12	West	Ridgecove	2414 Brittany Dr.	N 32° 53.025'	W 96° 33.409'

The location of these residences is illustrated in Figure 2.1.

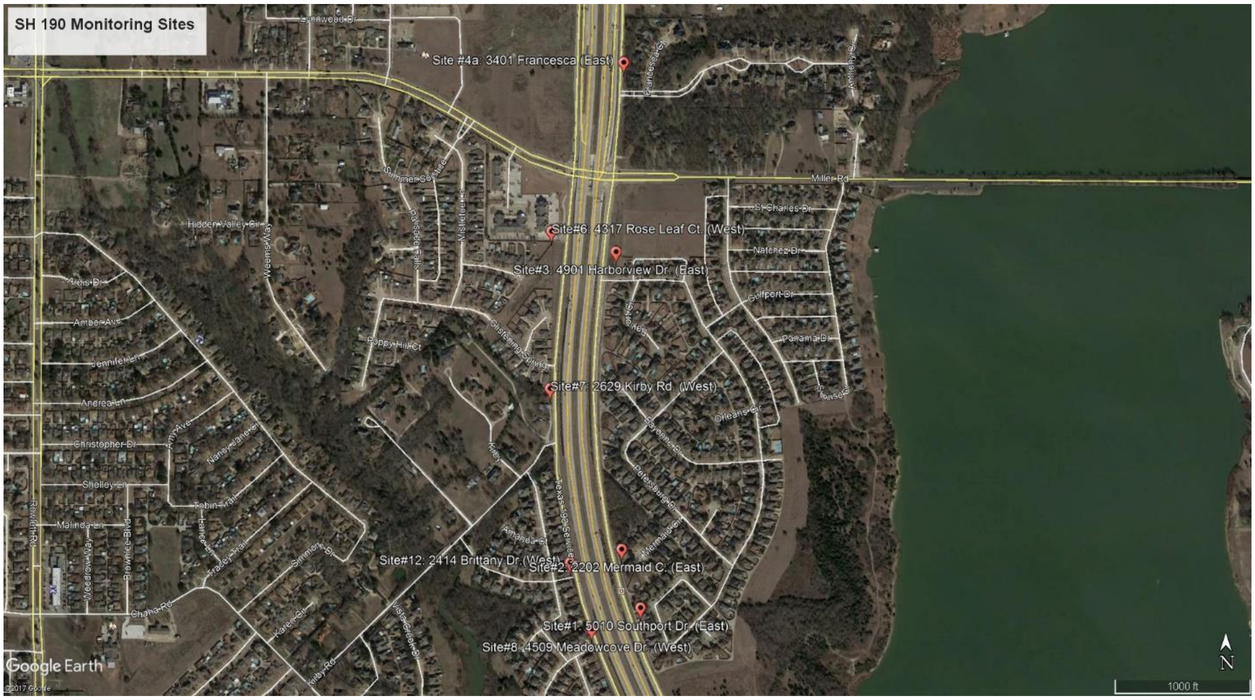


Figure 2.1 Initial residential sites along SH 190

These eight sites were monitored throughout the first stage of the project, from July 2017 to January 2018. This period corresponds to the noise wall prior to the acrylic additions, also referred as the pre-barrier condition.

2.2. Description of Residential Sites

2.2.1. Site #1: 5010 Southport Drive

This residence is located on the east side of SH 190, within the Harborside Community. Figure 2.2 shows a map of this site. This is one of the residences that are behind an existing 8-ft. tall noise wall. Figure 2.3 shows the front of the house, as seen from Southport Drive. In the background of this picture, the existing noise wall can be seen. The back of this residence (Figure 2.4) faces the highway; therefore, the noise measurements are taken at the backyard. The location for measurements can be accessed from the service alley that runs approximately parallel to the existing noise wall protecting the majority of the Harborside Community (Figure 2.5).

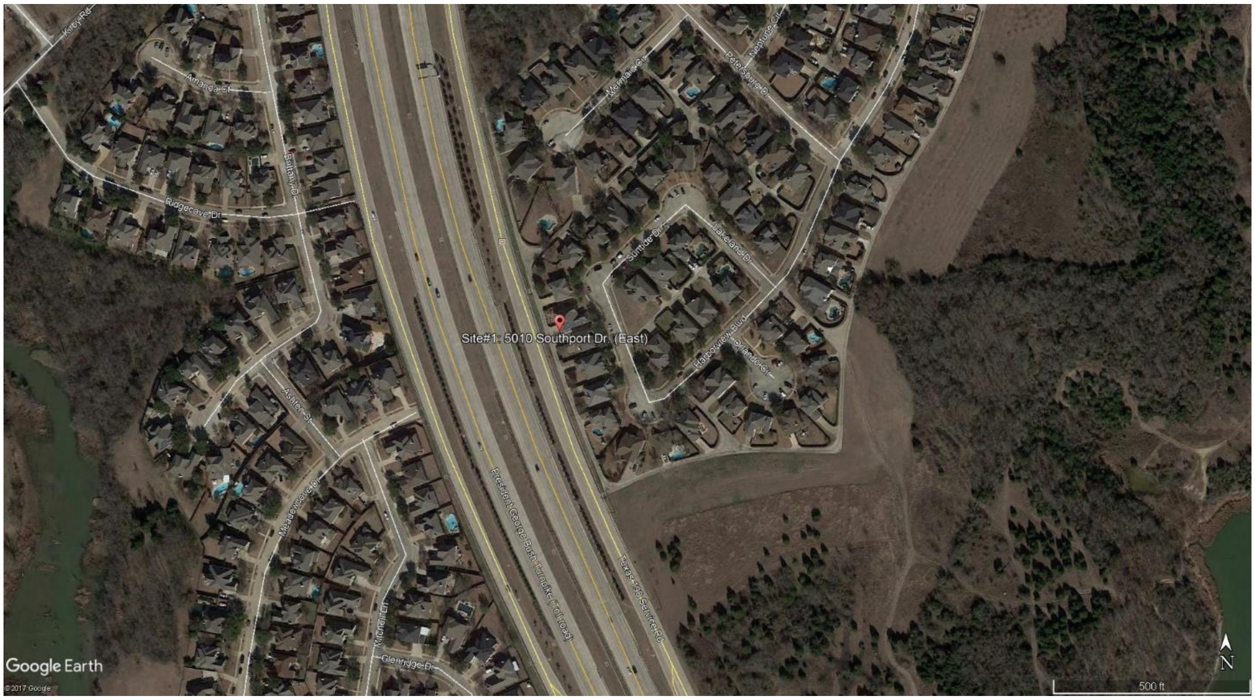


Figure 2.2 Map of Site #1: 5010 Southport Drive

Figure 2.3 Front view of Site #1: 5010 Southport Drive

Figure 2.4 View of Site #1: 5010 Southport Drive from the back.

Figure 2.5 Noise measurements at Site #1: 5010 Southport Drive

2.2.2. Site #2: 2205 Mermaid Circle

This residence is located on the east side of SH 190, within the Harborside Community. Figure 2.6 shows a map of this site. This home is also behind the existing 8-ft. tall noise wall. Figure 2.7 shows the front of the house, as seen from Mermaid Circle. In the background of this picture, the existing noise wall can be seen. The back of this residence (Figure 2.8) faces the highway;

therefore, the noise measurements are taken at the backyard. The location for measurements can be accessed from the same service alley that runs behind most of the houses of the Harborside Community (Figure 2.9).

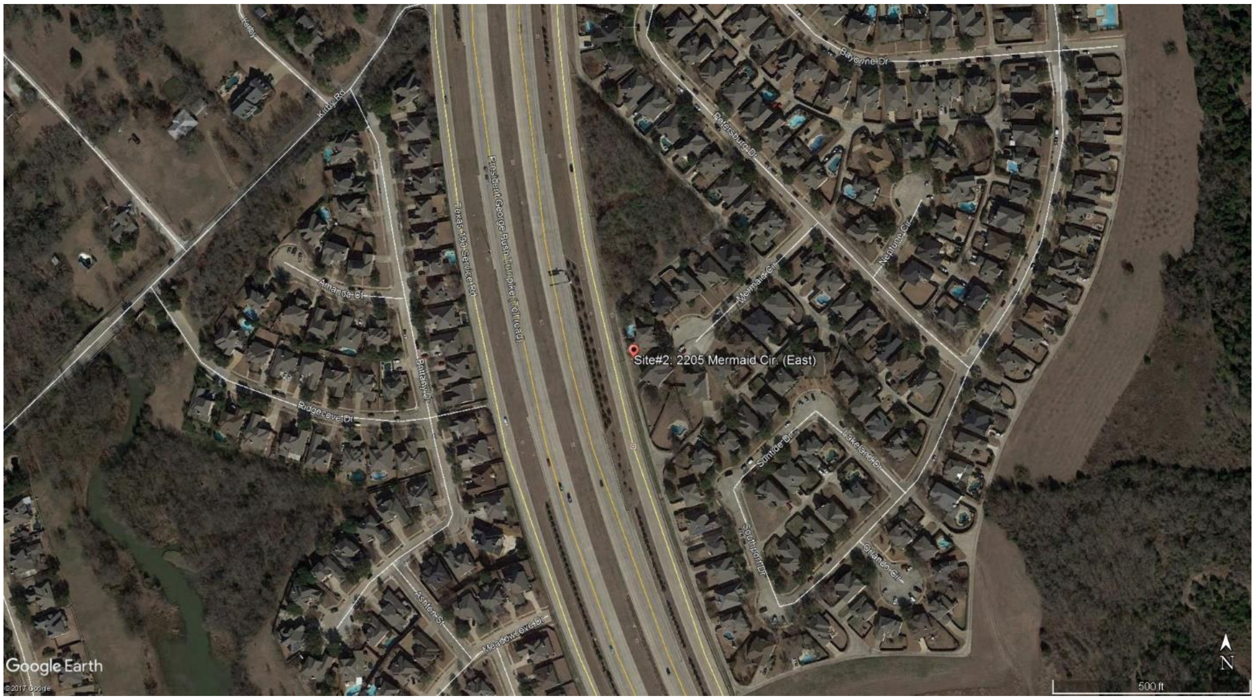


Figure 2.6 Map of Site #2: 2205 Mermaid Circle

Figure 2.7 View of Site #2: 2205 Mermaid Circle from the front of the house

Figure 2.8 Noise measurement at Site #2: 2205 Mermaid Circle showing the back of the residence and existing noise wall

Figure 2.9 Noise measurement at Site #2: 2205 Mermaid Circle

2.2.3. Site #3: 4901 Harborview Boulevard

This residence is located on the east side of SH 190/PGBT, within the Harborside Community. Figure 2.10 shows a map of this site. It is one of the northernmost houses in the Harborside Community. Unlike the previous two sites, this home is not protected by noise walls. It sits next to an elevated section of PGBT, as shown in Figure 2.11. Furthermore, the yard is next to the frontage road, with no protection from the noise; however, a short stone fence exists in the lot, separating the home from the yard. Figure 2.12 shows the front of the house, as seen from Harborview Boulevard, which at this point is perpendicular to SH 190; therefore, the façade shown in Figure 2.12 is perpendicular to the toll road, as shown in Figure 2.13. In the background of this picture, the small stone wall within the property can be seen. The noise measurements are taken on the side of the house that faces the highway (Figure 2.14).

Figure 2.10 Map of Site #3: 4901 Harborview Boulevard

Figure 2.11 Highway view from Site #3: 4901 Harborview Boulevard

Figure 2.12 Front view of Site #3: 4901 Harborview Boulevard

Figure 2.13 Front view of Site #3: 4901 Harborview Boulevard and SH 190

Figure 2.14 Noise measurement at Site #3: 4901 Harborview Boulevard

2.2.4. Site #4a: 3401 Francesca Court

This residence is located on the east side of SH 190/PGBT, within the Lake Forest Estates Community. Figure 2.15 shows a map of this site. The front of the house faces Francesca Court (Figure 2.16). The existing noise walls do not protect this home; however, it sits next to an elevated section of PGBT, just like Site #3, as shown in Figures 2.17 and 2.18. Furthermore, the yard is next to the frontage road, with no protection from the noise; however, a short privacy brick wall separates the home from the frontage road, as illustrated in Figure 2.17. The noise measurements are taken next to the brick wall in the back of the house, which faces the highway (Figure 2.18).

Figure 2.15 Map of Site #4a: 3401 Francesca Court

Figure 2.16 Front view of Site #4a: 3401 Francesca Court

Figure 2.17 Noise measurement at Site #4a: 3401 Francesca Court

Figure 2.18 Noise measurement at Site #4a: 3401 Francesca Court

2.2.5. Site #6: 4317 Rose Leaf Court

This residence is located on the west side of SH 190/PGBT, within the Magnolia Springs Community. This community is gated and access requires a code. However, the backside of this residence can be accessed from the frontage road of SH 190. Figure 2.19 shows a map of this site. The front of the house faces Rose Leaf Court. Noise walls do not protect this home; however, it sits next to an elevated section of PGBT, just like Site #3 and 4a, as shown in Figures 2.21 through 2.24. The backyard is next to the frontage road, but separated by a grassy area, a short metal gate, and a short wooden fence (Figure 2.20). The location for the noise measurements is shown in Figures 2.20 through 2.24.

Figure 2.19 Map of Site #6: 4317 Rose Leaf Court

Figure 2.20 Noise measurement at Site #6: 4317 Rose Leaf Court

Figure 2.21 Noise measurement at Site #6: 4317 Rose Leaf Court

Figure 2.22 Noise measurement at Site #6: 4317 Rose Leaf Court

Figure 2.23 Noise measurement at Site #6: 4317 Rose Leaf Court

Figure 2.24 Noise measurement at Site #6: 4317 Rose Leaf Court

2.2.6. Site #7: 2629 Kirby Road

This residence is located on the west side of SH 190/PGBT, within the area of the Magnolia Springs Community. However, the house appears not to pertain to the gated community. Figure 2.25 shows a map of this site. Access to the residence is through a private drive next to the frontage road of SH 190. Permission was obtained from the residents to access their property for the purposes of this research. There is no protection from the noise, and the house sits in close proximity to both the frontage road and main lanes with clear line of sight to both. This is the site that is more exposed to noise from all the sites considered in this study. The front of residence faces the frontage road of SH 190, as shown in Figures 2.26 and 2.27. The location for the noise measurements is the front yard, as shown in Figures 2.28 and 2.29. The proximity of the frontage road and main lanes can be seen in Figure 2.29. This photograph also shows that the main lanes and frontage road are only separated by a very short berm with scattered trees.

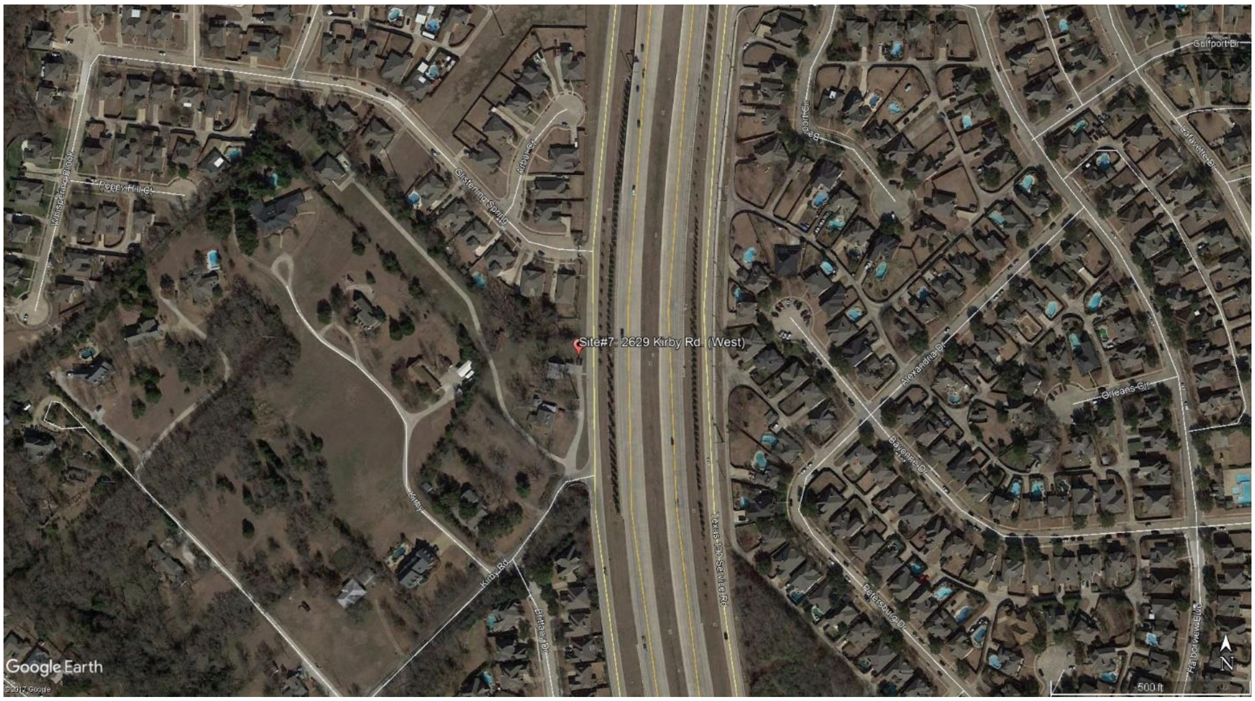


Figure 2.25 Map of Site #7: 2629 Kirby Road

Figure 2.26 Front view of Site #7: 2629 Kirby Road, as seen from the frontage road of SH 190

Figure 2.27 Front view of Site #7: 2629 Kirby Road, as seen from the main lanes of SH 190

Figure 2.28 Noise measurement at Site #7: 2629 Kirby Road

Figure 2.29 Noise measurement at Site #7: 2629 Kirby Road

2.2.7. Site #8: 4509 Meadowcove Drive

This residence is located on the west side of SH 190/PGBT and pertains to the Ridgecove Community. Figure 2.30 shows a map of this site. Access to the residence is through a dead-end street perpendicular to the frontage road of SH 190. The front of the residence can be seen from the street, and the left side of the home faces the highway, as seen in Figure 2.31. There is an 8-ft.

tall noise wall that protects the house from the noise, and the wall is between the frontage road and the side yard of the house. The location for the noise measurements is the front yard, as shown in Figures 2.31 and 2.33.

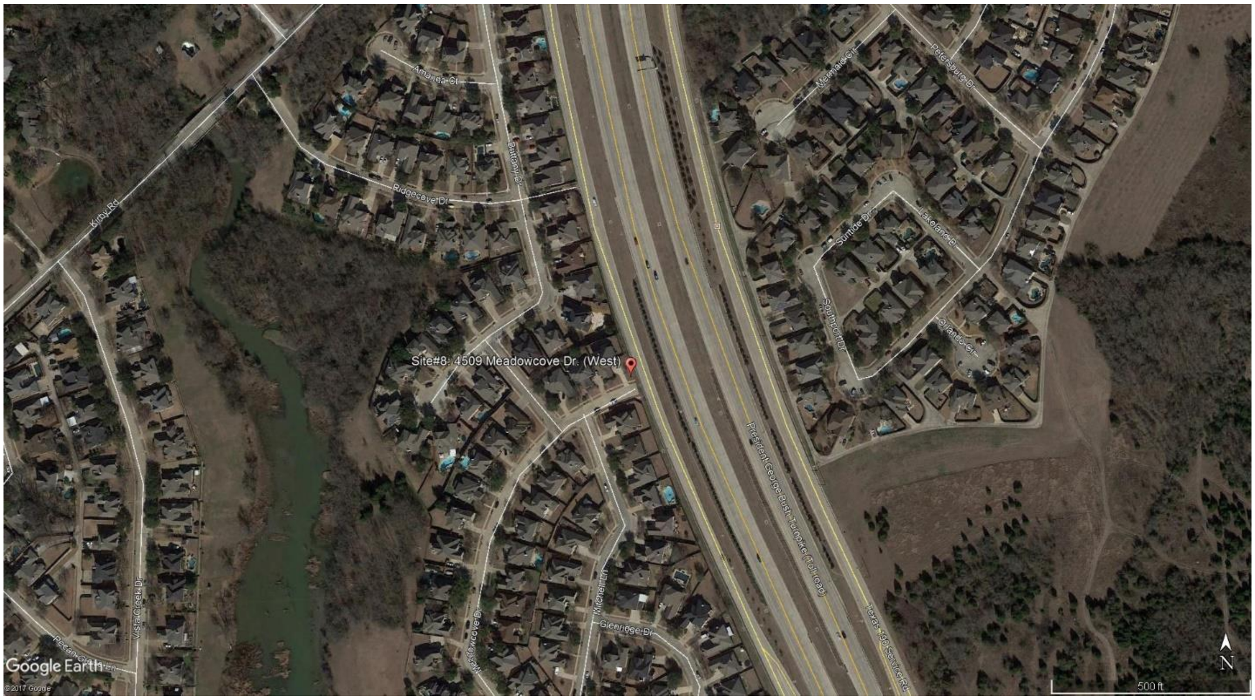


Figure 2.30 Map of Site #8: 4509 Meadowcove Drive

Figure 2.31 Front view of Site #8: 4509 Meadowcove Drive

Figure 2.32 View of SH 190 and noise wall from Site #8: 4509 Meadowcove Drive

Figure 2.33 Night-time measurement at Site #8: 4509 Meadowcove Drive

2.2.8. Site #12: 2414 Brittany Drive

This residence is located on the west side of SH 190/PGBT, within the Ridgecove Community. Figure 2.34 shows a map of this site. The front of the residence can be seen from the street, and the back side of the home faces the highway, as seen in Figure 2.35. There is a small paved driveway on the south side of the residence that allows access to the back of the homes next to a retaining wall. This driveway functions as an easement and is used by the CTR researcher to conduct noise tests. At this site, the highway is at a higher elevation relative to the residences, and the aforementioned retaining wall is adjacent to the back of the first-row houses. The existing noise wall stands on top of the retaining wall. The retaining wall height varies, but at this location it is approximately 12-ft. tall. The driveway, the retaining wall, and the placement of the noise meter for the noise measurement can be seen in Figures 2.35 to 2.37.

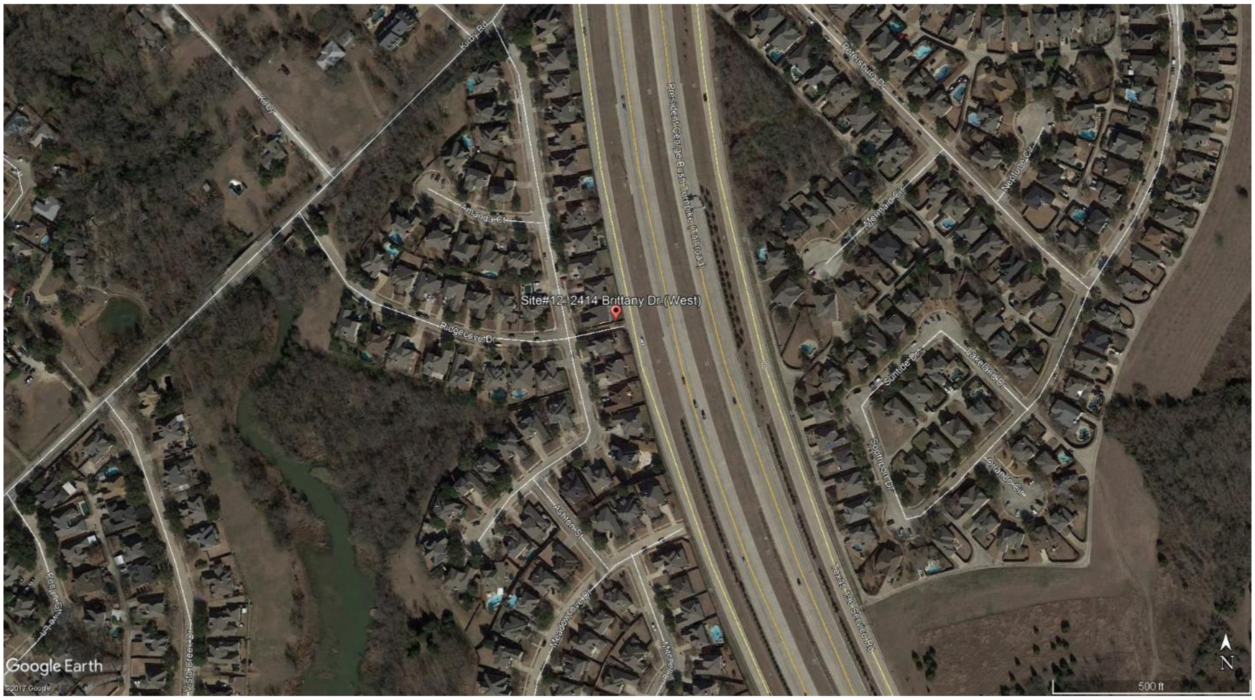


Figure 2.34 Map of Site #12: 2414 Brittany Drive

Figure 2.35 Front view of Site #12: 2414 Brittany Drive

Figure 2.36 Noise measurement at Site #12: 2414 Brittany Drive

Figure 2.37 Noise measurement at Site #12: 2414 Brittany Drive

2.3. Additional Residential Sites

After the pre-barrier test period was finalized, the noise modeling and analysis was performed. The outcome of the modeling was the design of noise walls (please see Chapter 4). The model recommended the construction of two new noise walls and the increase in height for the two existing walls. However, TxDOT decided that no new walls were going to be constructed, and that the project was going to focus only on adding height to the existing noise walls; also, it was determined that the project northernmost boundary was going to be Miller Road. Therefore, the Lake Forest Estates and Magnolia Springs residential sites were excluded, along with one of the Harborside sites that is not shielded by a noise wall. From then on, the project scope included only furnishing additional height for the existing walls shown in Figure 1.12.

This meant that residential sites #3, #4a, #6, and #7 were eliminated from further consideration for noise mitigation. With this change in scope, three new sites were added to be monitored during the next stage of the study, after the new additions to the walls were in place. These new sites were added in August 2019. The residential sites considered from that time until the end of the project are summarized in Table 2.2. This table also shows the sites that were eliminated.

Table 2.2 SH 190 residential sites for noise monitoring for post-barrier addition stage

Site Number	Side	Community	Address	GPS Coordinates	
				Latitude	Longitude
1	East	Harborside	5010 Southport Dr.	N 32° 52.971'	W 96° 33.308'
2	East	Harborside	2205 Mermaid Cir.	N 32° 53.041'	W 96° 33.335'
~~3~~	~~East~~	~~Harborside~~	~~4901 Harborview Blvd.~~	~~N 32° 53.399'~~	~~W 96° 33.343'~~
~~4a~~	~~East~~	~~Lake Forest Estates~~	~~3401 Francesca Ct.~~	~~N 32° 53.624'~~	~~W 96° 33.332'~~
4	East	Harborside	4902 Bayport Cir.	N 32° 53.322'	W 96° 33.352'
5	East	Harborside	4714 Petersburg Dr.	N 32° 53.167'	W 96° 33.370'
~~6~~	~~West~~	~~Magnolia Springs~~	~~4317 Rose Leaf Ct.~~	~~N 32° 53.424'~~	~~W 96° 33.435'~~
~~7~~	~~West~~	~~Magnolia Springs~~	~~2629 Kirby Rd.~~	~~N 32° 53.235~~	~~W 96° 33.438'~~
8	West	Ridgecove	4509 Meadowcove Dr.	N 32° 52.945'	W 96° 33.378'
12	West	Ridgecove	2414 Brittany Dr.	N 32° 53.025'	W 96° 33.409'
13	West	Ridgecove	1906 Benedict Ct.	N 32° 52.772'	W 96° 33.288'

Table color key:

Existing site	Eliminated site	Added site

Figure 2.38 shows the residential locations after August 2019, with the existing noise walls.

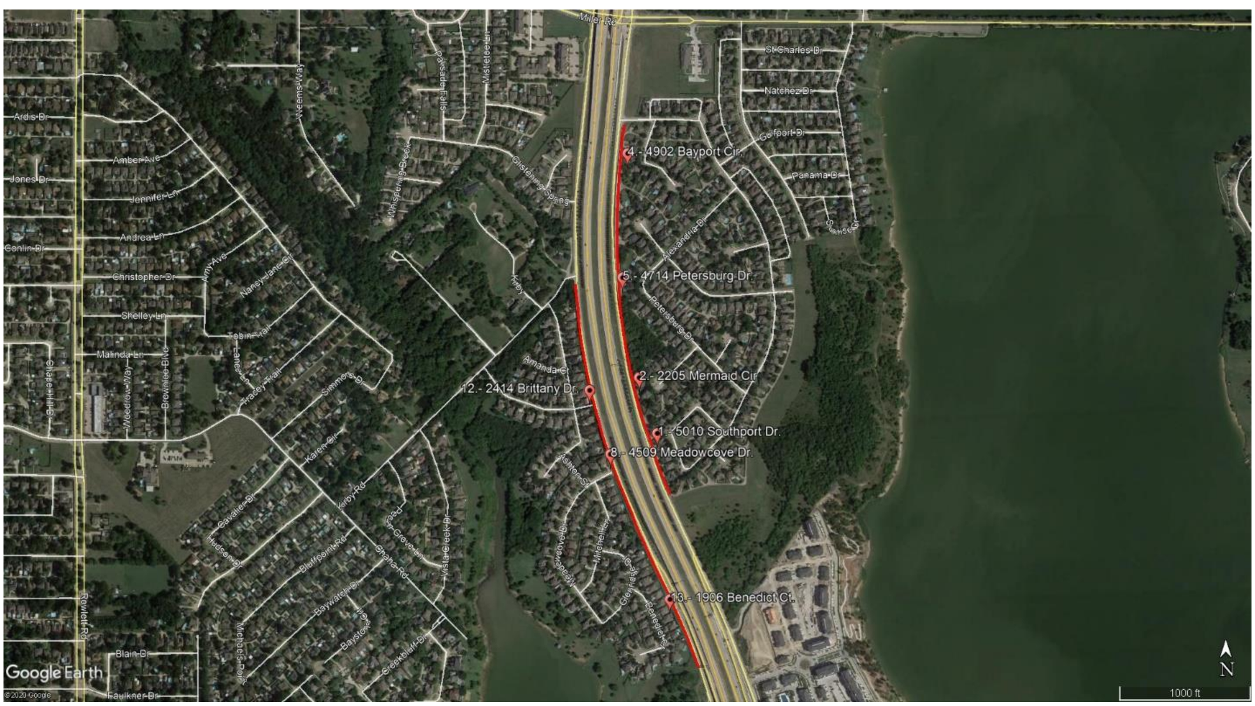


Figure 2.38 Final SH 190 residential sites

Figure 2.39 shows the residential sites as part of their residential communities that remained within the scope of the project, after Lake Forest Estates and Magnolia Springs were eliminated for noise mitigation.

Figure 2.39 Final SH 190 residential sites and their communities

The new sites are described in the following paragraphs.

2.3.1. Site #4: 4902 Bayport Circle

This residence is located on the east side of SH 190/PGBT, within the Harborside Community. Figure 2.40 shows a map of this site. This is one of the northernmost houses that is behind the existing 8-ft. tall noise wall. Figure 2.41 shows the front of the house, as seen from Bayport Circle, with the noise wall visible in the background, on the right side of the image. The back of this residence (Figure 2.42) faces the highway, therefore, the noise measurements are taken at the backyard. As the other monitored sites in the Harborside Community, this location can be accessed from the service alley that runs approximately parallel to the existing noise wall (Figure 2.43).

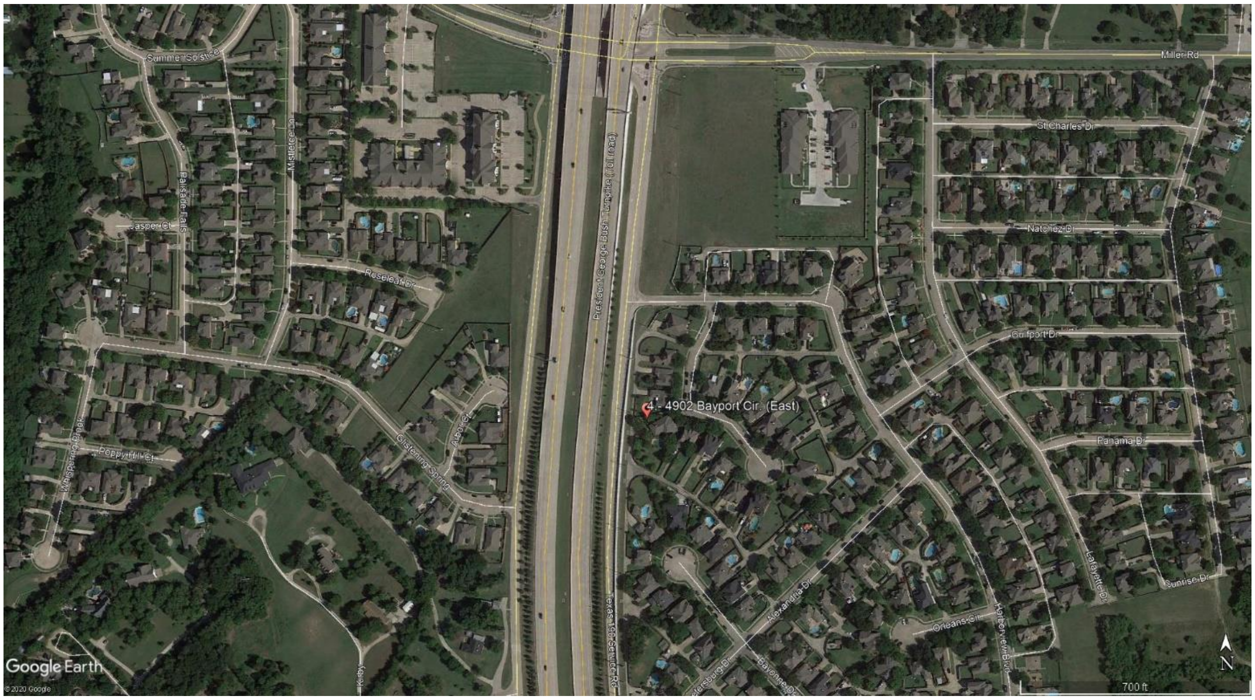


Figure 2.40 Map of Site #4: 4902 Bayport Circle

Figure 2.41 Front view of Site #4: 4902 Bayport Circle

Figure 2.42 Back view of Site #4: 4902 Bayport Circle

Figure 2.43 Noise measurement at Site #4: 4902 Bayport Circle behind noise wall and new noise wall addition

2.3.2. Site #5: 4714 Petersburg Drive

This residence is also located on the east side of SH 190/PGBT, within the Harborside Community. Figure 2.44 shows a map of this site. The front view from Petersburg Drive is shown in Figure 2.45, and the back view from the alley is shown in Figure 2.46. A photograph from a noise measurement showing the sound meter placement in relation to the wall is presented in Figure 2.47.

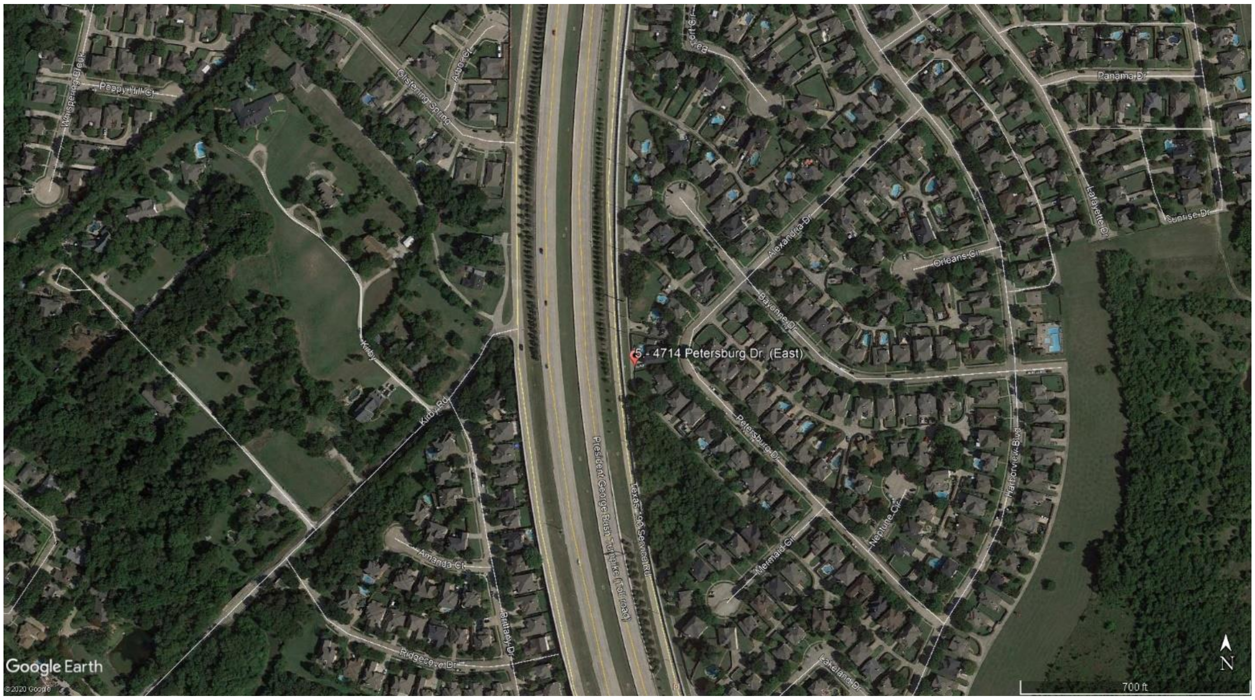


Figure 2.44 Map of Site #5: 4714 Petersburg Drive

Figure 2.45 Front view of Site #5: 4714 Petersburg Drive

Figure 2.46 Back view of Site #5: 4714 Petersburg Drive

Figure 2.47 Noise measurement at Site #5: 4714 Petersburg Drive behind noise wall and noise wall addition

2.3.3. Site #13: 1906 Benedict Court

This residence is located on the west side of SH 190/PGBT, within the Ridgecove Community. Figure 2.48 shows a map of this site. The front of the house, as seen from Benedict Court, is shown in Figure 2.49. Figures 2.50 and 2.51 show noise tests being performed at this location. The existing concrete noise wall is behind the wooden privacy fence and cannot be seen from the backyard. This residence is the home of Mr. Scott Parish, who is one of the neighbors who came out to a public information meeting about the project held at Rowlett Community Centre on August 9, 2018. Mr. Parish complained about the high noise levels perceived at his residence, and invited the researcher to take noise readings at his backyard. On August 24, 2018, the CTR researcher, accompanied by TxDOT's Mr. Daniel Salazar, scouted this location and conducted a noise test there; a value of 67.0 dBA was obtained for the equivalent noise level averaged over the course of the test (L_{eq}). This residential location was later incorporated as one of the regular noise monitoring sites for the post-barrier stage.

Figure 2.48 Map of Site #13: 1906 Benedict Court

Figure 2.49 Front view of Site #13: 1906 Benedict Court

Figure 2.50 Inside the backyard of Site #13: 1906 Benedict Court with an SH 190 overhead sign in the background

Figure 2.51 Inside the backyard of Site #13: 1906 Benedict Court

2.4. Summary

This chapter presents the sites in the various residential communities along SH 190/PGBT that were selected for noise monitoring. The selection process included accessibility and consideration of the residence locations relative to the highway and the existing noise walls. Eight sites were selected for the pre-barrier phase of the project: four on the east side (northbound direction), and four on the west side (southbound direction) of the highway. After the acoustical design of the walls was performed, the scope of the project changed slightly. The focus of the project was only on the existing walls and their retrofitting with new additions. Four of the original residential sites were dropped and three were added for the post-barrier phase of the project. During this phase, seven sites were monitored—four on the east side and three on the west side.

Chapter 3. Pavement Condition Survey and Tire-Pavement Noise Tests

This chapter presents the analysis and results of the pavement noise tests and the pavement condition survey for the highway traffic noise evaluation on SH 190/PGBT in Rowlett, between Lake Ray Hubbard and Miller Heights Drive. It is a well-known fact that the pavement condition and the friction generated at the tire-pavement interface are the key components of highway noise. Therefore, inspecting the pavement condition, both the main lanes and frontage roads, and measuring the tire-pavement noise were part of this work. This information was important to better understand the noise levels in the area and determine the study's course of action to generate the most effective recommendations for noise mitigation.

3.1. Introduction

The approximately 1.4-mile highway segment that was surveyed and tested for noise extends from south of Miller Heights Drive to the north shore of Lake Ray Hubbard (Figure 3.1).

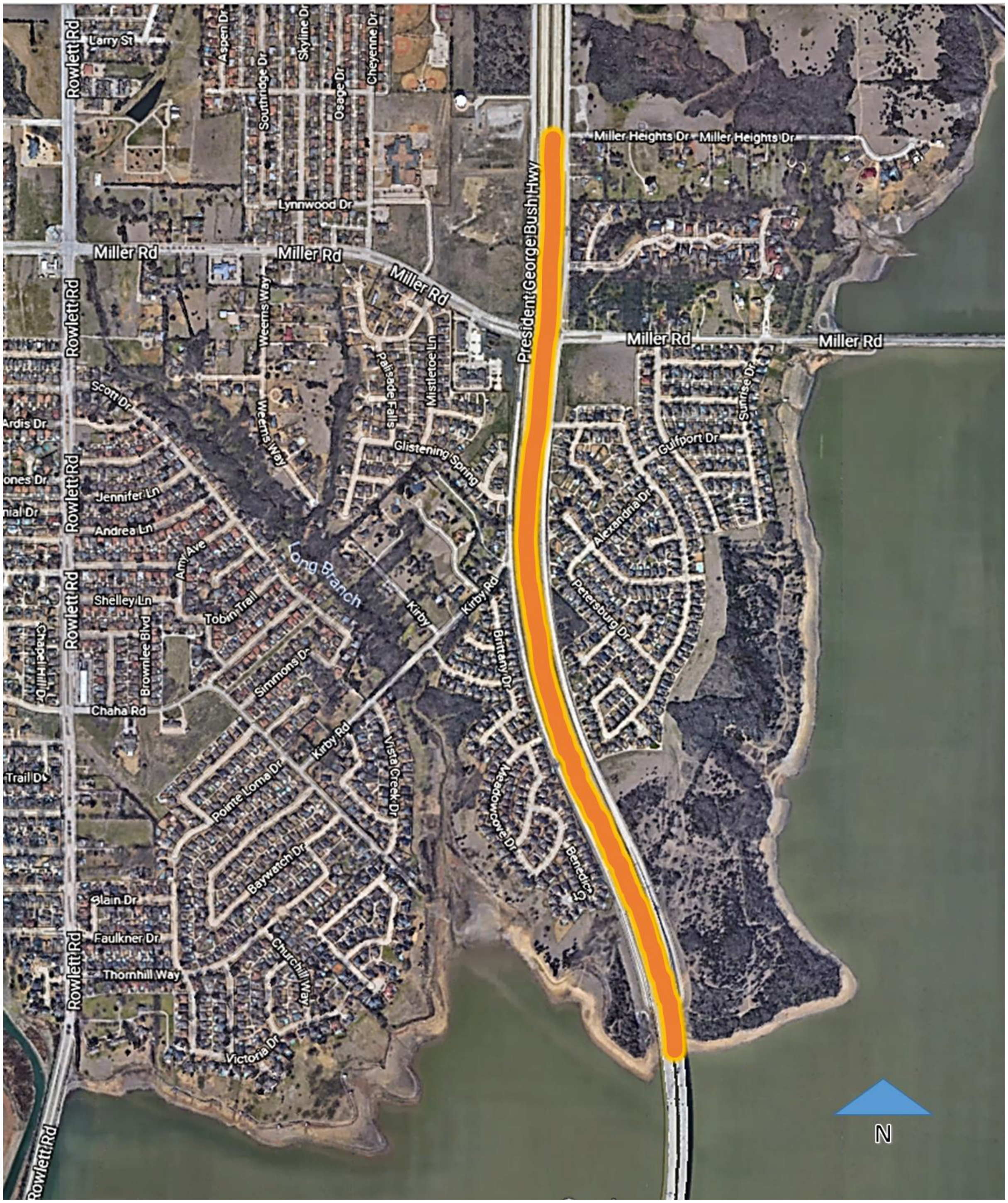


Figure 3.1 SH 190 location map with section of pavement studied

Environmental noise measurements are a key component of this study. These measurements were conducted at various residences near the turnpike before the new sound wall installation to characterize the pre-barrier condition, and were conducted after the placement of new walls to characterize the post-barrier condition. Tire-pavement noise is a major component of the noise recorded in those tests, especially at highway speeds. On-board sound intensity (OBSI) tests are the best method to evaluate solely the noise generated at the tire-pavement interface. Thus, to thoroughly investigate the noise generated from the highway, CTR ran OBSI tests on the SH 190/PGBT pavements, including the main lanes and the frontage roads. The tests were conducted in November 2017. The condition of the pavement is an integral component of noise generation. In general, pavements in poor condition are also louder, as the distresses contribute to the roughness and unevenness of the surface. Therefore, a pavement condition survey was also conducted in October 2017 for both the main lanes and the frontage roads.

3.2. Pavement and Condition Survey

The PGBT main lanes and SH 190 frontage roads pavements throughout the 1.4 miles of interest in this study consist of transversely tined continuously reinforced concrete pavement (CRCP). The spacing between the transverse tines is 1-inch. The purpose of tining is to improve drainage and reduce hydroplaning of the vehicle tires on the pavement surface in the presence of water. However, tining is also related to higher tire-pavement noise levels and the occurrence of high noise at annoying frequencies to the human ear, especially in the 1-kHz frequency band.

Prior to the OBSI tests, a visual condition survey was conducted on the pavement; the survey was done partially by visual observations at various locations, mainly at sites accessible from the frontage roads, and some of it was conducted by means of videos taken from the vehicle, attaching a GoPro camera to a mount and driving at highway speeds (Figure 3.2). Subsequently, the videos were analyzed by playing them at very slow speeds in order to closely observe the surface condition. The relevance of the pavement condition in relationship to noise generation is that the presence of distresses makes a pavement louder, as the riding surface becomes uneven and rough on a distressed pavement. Both the severity and the amount of distresses correlate with higher noise levels produced at the tire-pavement interface.

Figure 3.2 GoPro camera mounted on research vehicle on SH 190 prior to recording survey videos

The CRCP in this section of SH 190 was constructed in August and September of 2011. This information was found on the pavement itself: during the condition survey, two inscriptions were found on the main lanes pavement surface indicating the date the concrete was cast, one on the northbound direction, from August 31, 2011 (Figure 3.3), and one in the southbound direction, from September 10, 2011 (Figure 3.4). A CRCP that is 9 years old is considered fairly new.


Figure 3.3 SH 190 Northbound main lane. Pavement cast on 8/31/2011 as indicated by inscription on the shoulder recorded by video

Figure 3.4 SH 190 Southbound main lane. Pavement cast on 9/10/2011 as indicated by inscription on the shoulder recorded by video

The pavement condition for the SH 190/PGBT is excellent, with minimal distresses; no punchouts or delaminations were observed. Punchouts and delaminations are normally considered as the major distresses occurring on CRCP. Figures 3.5 through 3.21 show various views of the SH 190/PGBT pavement, including main lanes and frontage roads.

Transverse cracks are a normal occurrence on CRCP. Transverse cracking is defined as cracks that are mainly perpendicular to the pavement centerline. Crack spacing and crack widths are two parameters of importance on CRCPs. From the visual survey conducted on the pavements, the crack spacing is adequate and the crack openings do not seem wide, so the cracks appear in good condition. There is very little spalling in a few of the cracks. Few longitudinal cracks were observed, but they appear to be very minor.

Figure 3.5 Southbound main lanes

Figure 3.6 Northbound frontage road

Figure 3.7 Southbound main lanes

Figure 3.8 Southbound main lanes

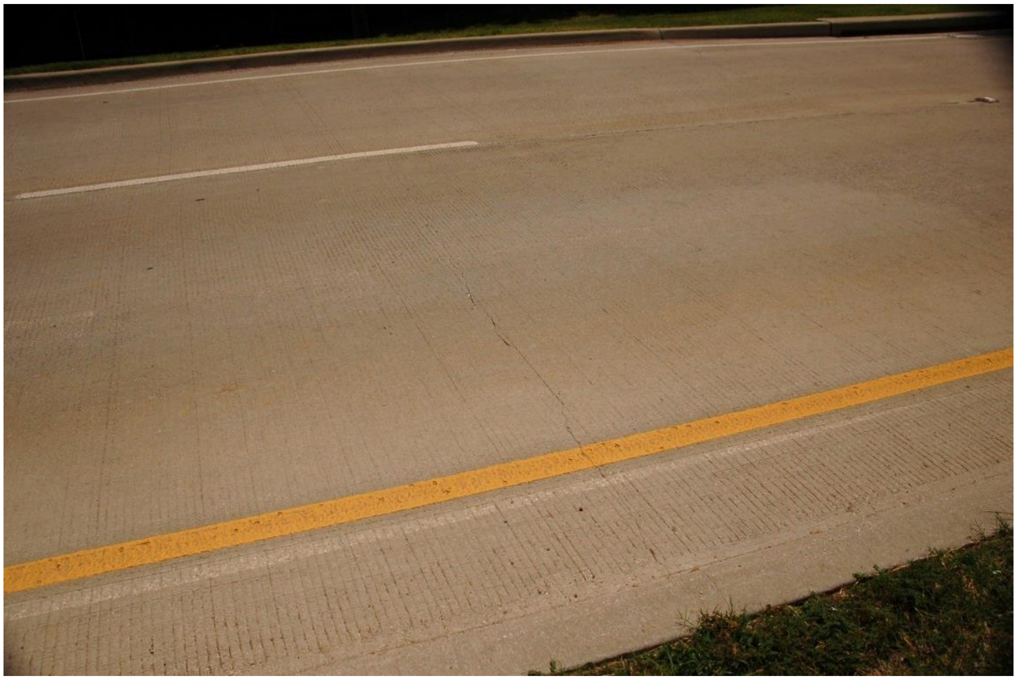


Figure 3.9 Northbound frontage road

Figure 3.10 Northbound exit ramp

Figure 3.11 Northbound frontage road. Transverse cracks

Figure 3.12 Northbound frontage road. Longitudinal crack as recorded by video

Figure 3.13 Northbound frontage road. Minor spalling of the longitudinal joint as recorded by video

Figure 3.14 Northbound frontage road. Minor spalling of the transverse crack as recorded by video

Figure 3.15 Northbound frontage road. Transverse cracks as recorded by video

Figure 3.16 Southbound frontage road. Pavement in excellent condition as recorded by video

Figure 3.17 Northbound main lane. Pavement in excellent condition as recorded by video

Figure 3.18 Northbound frontage road. Pavement in excellent condition as recorded by video

Figure 3.19 Northbound main lane. Expansion joints in the elevated section as recorded by video

Figure 3.20 Southbound main lane. Pavement in excellent condition as recorded by video

Figure 3.21 Southbound main lane. Pavement in excellent condition as recorded by video

It is estimated that the condition of the SH 190 pavements is excellent and does not contribute to the generation of additional tire-pavement noise.

3.3. Speed Limits and Traffic Flow

Speed limits and traffic flow are important factors that have a decisive influence on noise levels generated by traffic on any given facility. Vehicles traveling at higher speeds generate more noise; free traffic flow allows for higher speeds as well, therefore, it is also associated with higher noise.

The posted speed limit on the main lanes for the segment in question is 70 mph (Figure 3.22), and the posted speed limit on the frontage roads is 50 mph (Figure 3.23). During all of CTR's visits to the site—which included trips once or twice per month since July 2017, with observations at several times of the day and night, as well as condition surveys and OBSI tests—the flow of traffic was always continuous and the turnpike did not reach the level of congestion, not even during rush hours. No lane closures or accidents were observed. Therefore, the observed traffic was always free-flowing.

Figure 3.22 Main lanes 70 mph speed limit sign

Figure 3.23 Frontage road 50 mph speed limit sign

The combination of free-flowing traffic condition with high speed limits and the limited number of exit and entrance ramps in this stretch of the turnpike results in high traffic flow at higher speeds, which translates into higher noise levels.

3.4. On-Board Sound Intensity Test Description

Over the last few years, the OBSI method has become the most common technique for the evaluation of tire-pavement noise. The OBSI test method provides an objective measure of the acoustic power per unit area produced as a result of the operation of a vehicle; the close proximity of the OBSI device to the tire-pavement interface allows for the objective, repeatable, and reliable acoustical evaluation of pavements. Dr. Paul Donavan and General Motors (*Donavan*) first developed this near-field measurement method for traffic noise. As the name indicates, the method measures sound intensity, which is defined as the average rate of sound energy transmitted in a specified direction at a point through a unit area normal to this direction at the point. The units are watt per square meter (W/m^2) (*Sandberg*). As such, it is a vector quantity with magnitude and direction, as opposed to sound pressure, which is a scalar quantity. The direction of sound intensity can be associated with the direction of sound propagation or the direction of the orientation of the probe used for measuring sound intensity.

A group of experts from all parts of the United States that had used the method over the last several years developed an AASHTO Standard (TP 76-13) in an effort to make the procedure a uniform test method that allows various pavements and textures to be directly compared (*AASHTO*). TxDOT, as well as CTR, as expert users of this test method, were involved in this effort. Once it was standardized, the test method has become widely accepted throughout the country and elsewhere, and this has enabled the use of a unified procedure for measuring tire-pavement noise.

The procedure utilizes a fixture positioned close to the tire to hold the sound intensity probe. The sound intensity probe consists of two pairs of half-inch microphones spaced 16 mm apart and preamplifiers in a side-by-side configuration. A foam windscreen is placed over the microphones to reduce the wind noise. The probe is positioned 4 in. away from the plane of the tire sidewall and 3 in. above the pavement surface, mounted to the rear tire on the passenger side of the test vehicle. Signals from the microphones are input into a real-time analyzer. Measurements are taken at 97 km/h (60 mph) at two intensity probe locations. One location corresponds to the leading edge and the other to the trailing edge of the tire-pavement contact patch. Figure 3.24 shows the intensity probe positions and distances in relation to the tire and pavement.

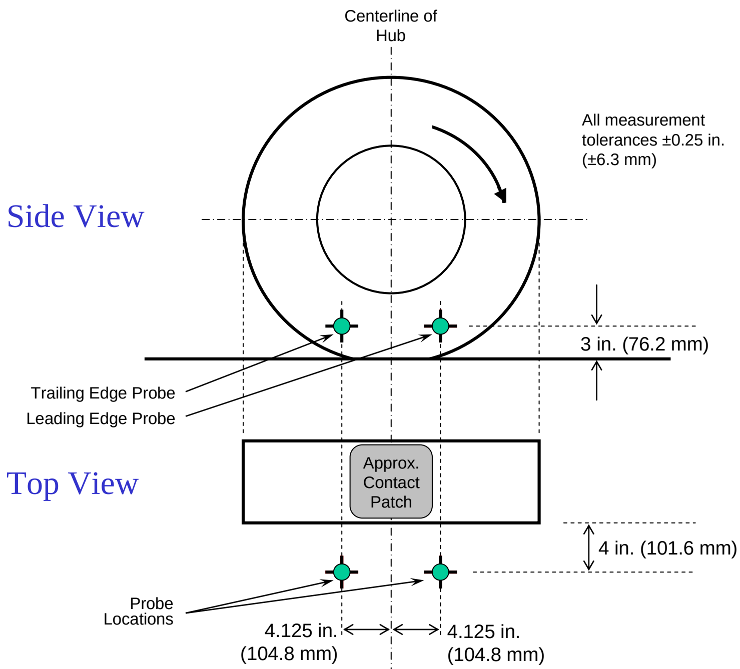


Figure 3.24 Sound intensity probe showing leading and trailing edges

At a minimum, two valid test runs shall be performed for a test section, according to the standard. In most cases, three replicate measurements are collected, and then averaged to obtain the overall noise levels. Each measurement is averaged over a 5-second period, yielding test sections that, given the traveling speed of 60 mph, are 440 ft.-long. Therefore, a test section is defined as a 440 ± 10 ft. (134 ± 3 m) length of pavement over which a sound intensity measurement is made.

The results are reported as overall A-weighted sound intensity levels, and as A-weighted one-third octave band levels. The overall sound intensity level is the sound intensity level corresponding to the energy sum of the A-weighted sound intensity within the one-third octave bands ranging from 400 to 5000 Hz.

$$\textbf{Overall Sound Intensity Level} = \mathbf{10 \times Log_{10}\left(\sum_{i=400}^{i=5000} 10^{(L_i/10)}\right)}$$

Where L_i is the A-weighted intensity level in the one-third octave band with center frequency *i*. The leading and trailing edge are energy-averaged to calculate a single result that is the average of test runs, commonly referred to as the tire average.

The system used to measure the sound intensity using the on-board method comprises the following equipment: two matched microphone pairs, four preamplifiers, four cables, computer and data acquisition software, probe holders (fixture), and associated items mounted on the test vehicle, the vehicle itself, and the test tires. Some parts of such equipment are shown in Figure 3.25.

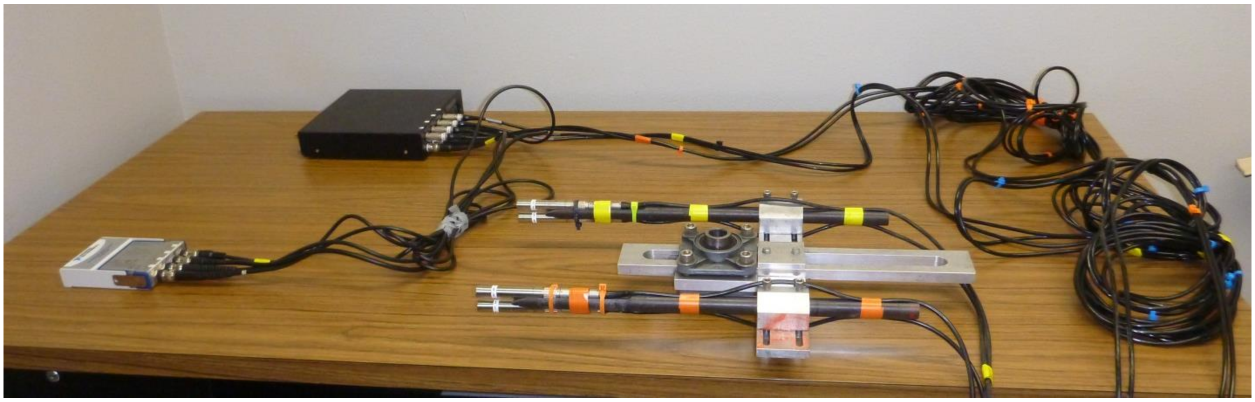


Figure 3.25 OBSI fixture and data acquisition equipment

The OBSI fixture is a custom-machined jig that bolts to the wheel rim and supports a sound intensity probe at very close proximity to the front and rear tire-pavement contact point. Because the device is bolted to the wheel, the vertical distance from the pavement does not vary as the suspension oscillates, and because there is a robust bearing connecting the bolted on assembly to the microphone holders, the device does not rotate with the wheels. A slender vertical bar affixes to the car body to steady the assembly and provide resistance to the small amount of rotational force generated by friction in the bearing. The fixture holds the microphone pairs in a vertical position (Figure 3.26).

The system utilizes two pairs of half-inch, phase-matched condenser free-field microphones (Figure 3.27). Preamplifiers are affixed to each individual microphone for signal amplification, and these, in turn, are attached to a plastic probe holder that keeps a space of 16-mm between microphones, in a side-by-side configuration. Each pair of microphones is fitted with a spherical windscreen.

The microphones and preamplifiers utilized for this project are manufactured by G.R.A.S., and comply with the requirements of the international standard IEC 1094 for Measurement Microphones, and as required by the AASHTO OBSI Standard, and also comply with the Class 1 requirements of ANSI S1.9. These devices can measure the real part of a complex sound intensity in sound fields with a high level of background noise, such as occurs on the highway.

Figure 3.26 OBSI Fixture

Figure 3.27 Half-inch Sound Intensity Microphone Pair

The test tires and the test vehicle are other fundamental components of the system. The AASHTO standard only specifies that the test vehicle should be a passenger car, in which the test tire is not covered on the outboard side. The load on the test tire due to the weight of the vehicle including passengers, test hardware, fuel, and other contents shall be 800 ± 100 lb. (360 ± 45 kg) during the test, according to the standard. The test tires are also standardized. The "Standard Reference Test Tire" (SRTT) for OBSI must comply with Standard ASTM 2493 *(ASTM)*. Figure 3.28 shows the test vehicle and the OBSI fixture.

Figure 3.28 Test vehicle and OBSI fixture

3.5. SH 190/PGBT OBSI Tests

The OBSI tests on SH 190/PGBT were performed on November 28, 2017. Tests were conducted both on the main lanes and the frontage roads. For the main lanes, three subsections were identified in the northbound direction (labeled as NB1, NB2, and NB3, respectively) and three in the southbound direction (labeled as SB1, SB2, and SB3, respectively).

For the frontage roads, there were two northbound subsections (labeled as NB FR1 and NB FR2, respectively), and three southbound subsections (labeled as SB FR1, SB FR2, and SB FR3, respectively). As mentioned in the previous paragraphs, each subsection is 440 ft. long, tests are conducted at 60 mph and averaged over 5 s periods, per standard specifications.

Figure 3.29 shows the test vehicle with the OBSI equipment on the frontage road of SH 190.

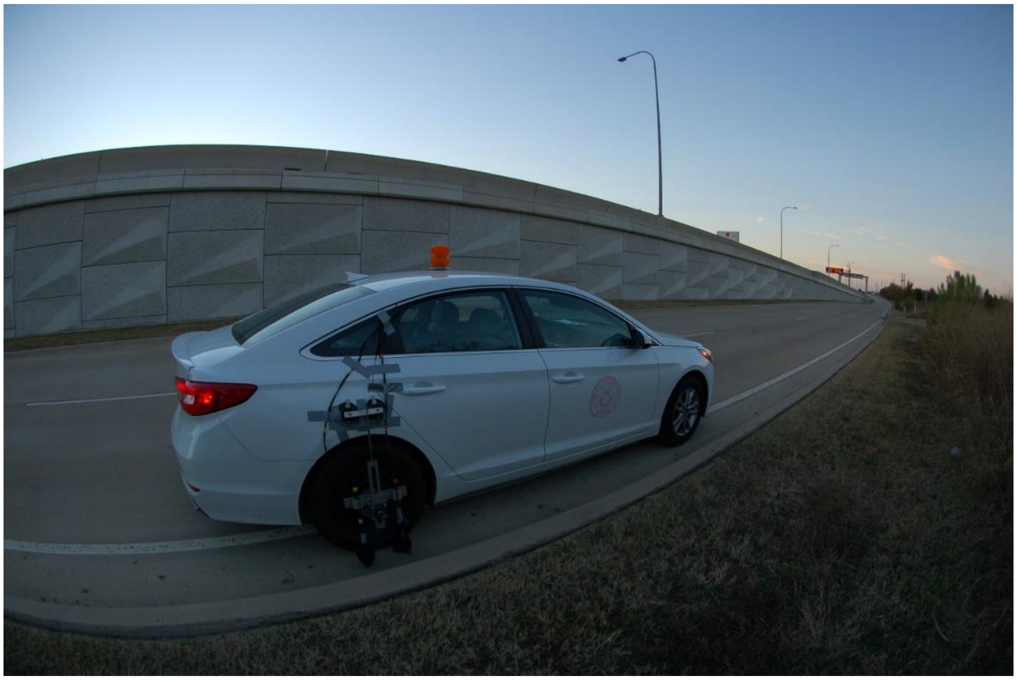


Figure 3.29 OBSI Test vehicle on SH 190 frontage road

The overall results of the SH 190/PGBT tests are summarized in Figure 3.30. Each vertical bar in the graph corresponds to a subsection. There are also bars that correspond to the average of the main lanes and the average of the frontage roads, respectively. The vertical axis indicates the overall sound intensity level for each subsection, which is the average of at least three test runs in each case.

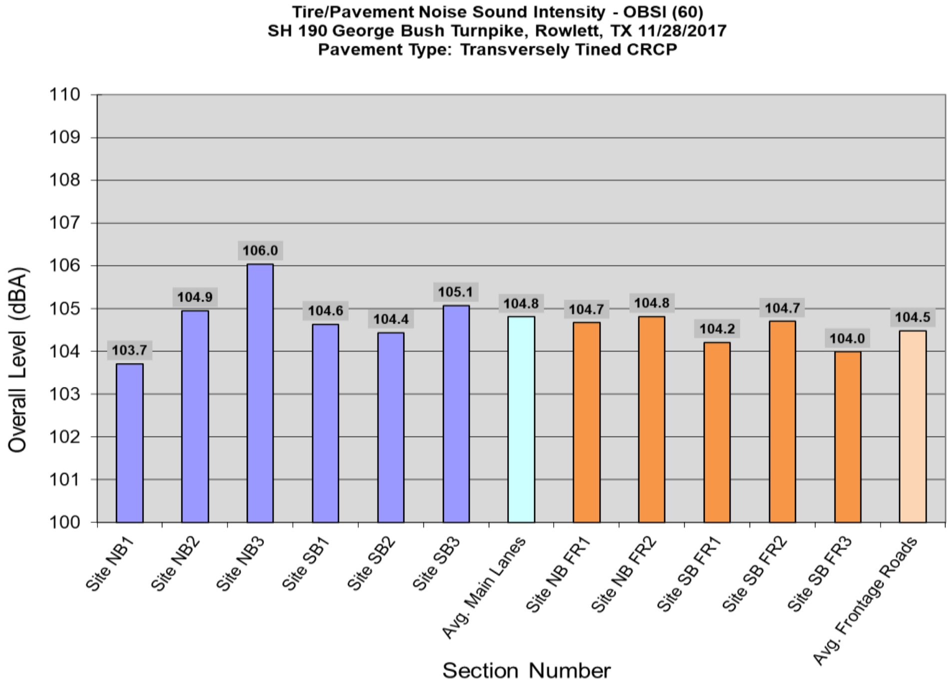


Figure 3.30 OBSI Test results for SH 190 main lanes and frontage roads

Overall noise levels are very similar for main lanes and frontage roads; this was expected, given the similar condition of the pavements. Noise levels range from 103.7 to 106.0 dBA for the main lanes, with an average of 104.8 dBA. For the frontage roads, the range is from 104.0 to 104.8 dBA and the average is 104.5 dBA. The northbound main lanes present the highest variability. The results appear to be very reasonable and consistent, and within the expectations for a transversely tined CRCP. As indicated in the previous section, transverse tining in CRCP is normally correlated with higher tire-pavement noise levels and the occurrence of high noise at annoying frequencies to the human ear, especially in the 1-kHz frequency band. Figure 3.31 shows the frequency spectra for each subsection, a graph of which confirms this statement; all of the curves show the characteristic peak in the 1-kHz frequency band, typical of this pavement type.

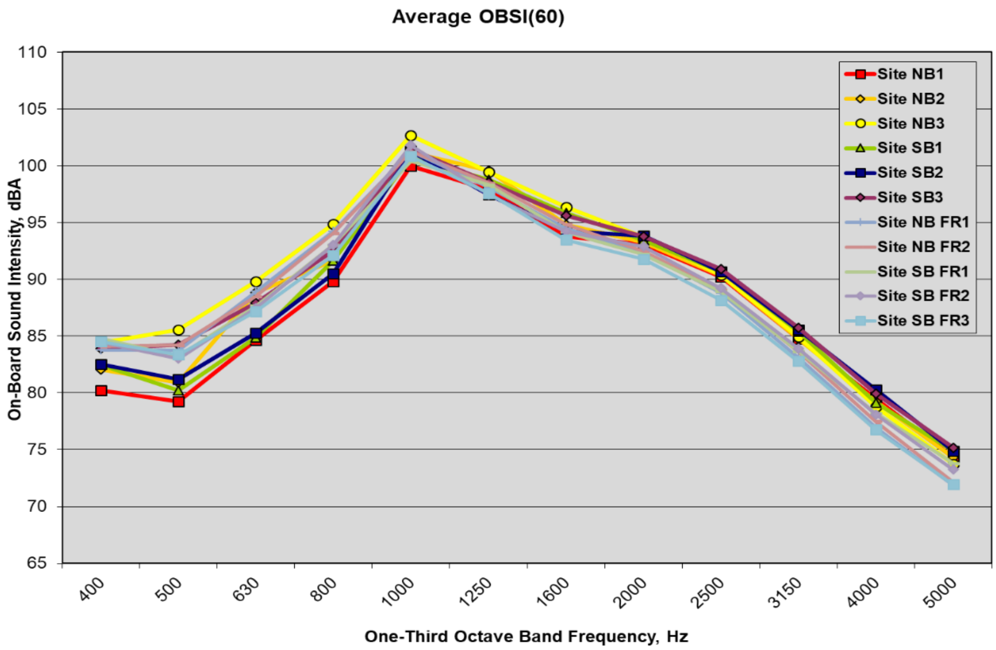


Figure 3.31 OBSI spectral analyses for SH 190 main lanes and frontage roads

The results of the spectral analyses indicate that all the subsections of main lanes and frontage roads are virtually identical in regard to their tire-pavement noise generation levels and frequencies.

3.5.1. Comparison with Other Pavement Sections

To provide an idea of how the pavements on SH 190/PGBT compare relative to other pavement surfaces, the chart in Figure 3.32 was prepared, showing a variety of pavements, pavement types, and their overall average noise levels, as obtained from various OBSI tests. These are all recent OBSI tests performed by CTR in the Austin area. The pavements include thin overlay mixes (TOMs, represented by red bars), permeable friction courses (PFCs, in blue), dense graded asphalt concrete (DGAC, in orange), chip seals (green), and transversely tined CRCP (yellow). The chart is sorted from quieter to louder pavements.

At 104.8 dBA and 104.5 dBA for the main lanes and frontage roads, respectively, the SH 190/PGBT pavements are stacked toward the louder side of the graph, and are close to being the loudest CRCP among those represented in the graph.

In conclusion, the SH 190/PGBT test results are very typical for transversely tined CRCP—the values can be considered very normal and expected. Nevertheless, they are slightly on the louder range for this type of pavement. There are other pavement surfaces and treatments that can provide lower noise levels as shown in the graph. As a recommendation for the future, the pavement surfaces of SH 190/PGBT, which are structurally sound, in excellent condition, and with many years of service life ahead, could be overlaid with a quieter overlay such as a PFC or a TOM, for noise mitigation purposes. These quieter pavements have been proven to deliver good acoustical performance to alleviate the noise generated by vehicular traffic on highways. This would result in lower noise levels in the adjacent residential communities, as well as lower noise levels perceived by the driving public as users of the facility.

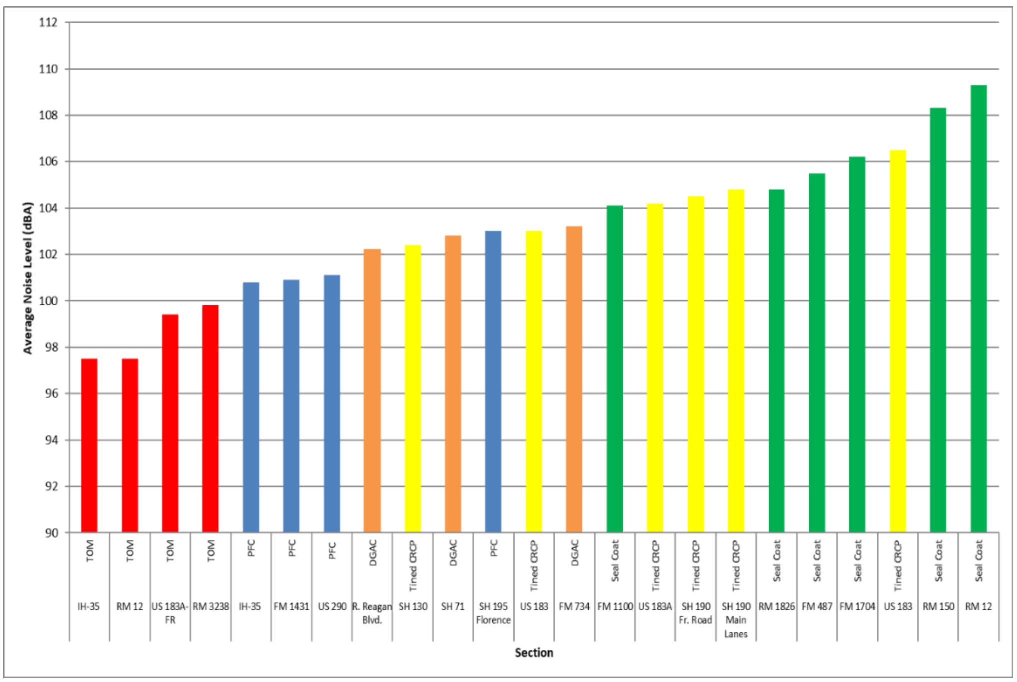


Figure 3.32 OBSI test results comparison of SH 190/PGBT with other pavements, sorted by noise level

3.6. Summary

This chapter presented the results of a condition survey and of tire-pavement noise tests conducted on both the main lanes and the frontage roads of the pavements of SH 190/PGBT. The pavement condition, especially for the case of a distressed pavement, can have a definitive influence on the generation of tire-pavement noise at highway speeds.

The condition survey revealed that the pavements are in excellent condition; therefore, it is considered that the pavement condition is not contributing to an increase in tire-pavement noise.

The noise generated at the tire-pavement interface was evaluated by means of the OBSI test, which is widely considered the best way of measuring the main component of traffic noise at the source: where the tire and the pavement are in contact.

The results of the tests, both for the main lanes and the frontage roads, are very typical of the pavement type present in this facility, CRCP. However, a comparison with other pavements indicates that the SH 190/PGBT pavements are among the loudest compared to other CRCPs. CRCP is generally regarded as one of the loudest pavement types, mainly due to the typical transversely tined finishing applied to these surfaces for safety purposes.

It is recommended that, in order to reduce the noise at the source, a quieter pavement overlay could be considered, such as a TOM or a PFC, both of which are capable of providing substantial noise reductions over a typical transversely tined CRCP.

Chapter 4. Traffic Noise Modeling

This chapter presents the noise analysis performed with a computer program, for the segment of SH 190/PGBT from just north of Miller Road to the north shore of Lake Ray Hubbard. The following sections explain the information contained in the model, including geometry, receivers, traffic, noise walls, and pavements. The purpose of the analysis is to predict noise levels based upon all the information entered into the model, and to come up with the acoustical design of noise walls, i.e., the height of the wall that is necessary to achieve a certain noise level reduction. The following sections present the model, the inputs, and the results.

4.1. Introduction

The design of the noise wall was performed by means of the FHWA Traffic Noise Model (TNM) program, Version 2.5 (Figure 4.1).

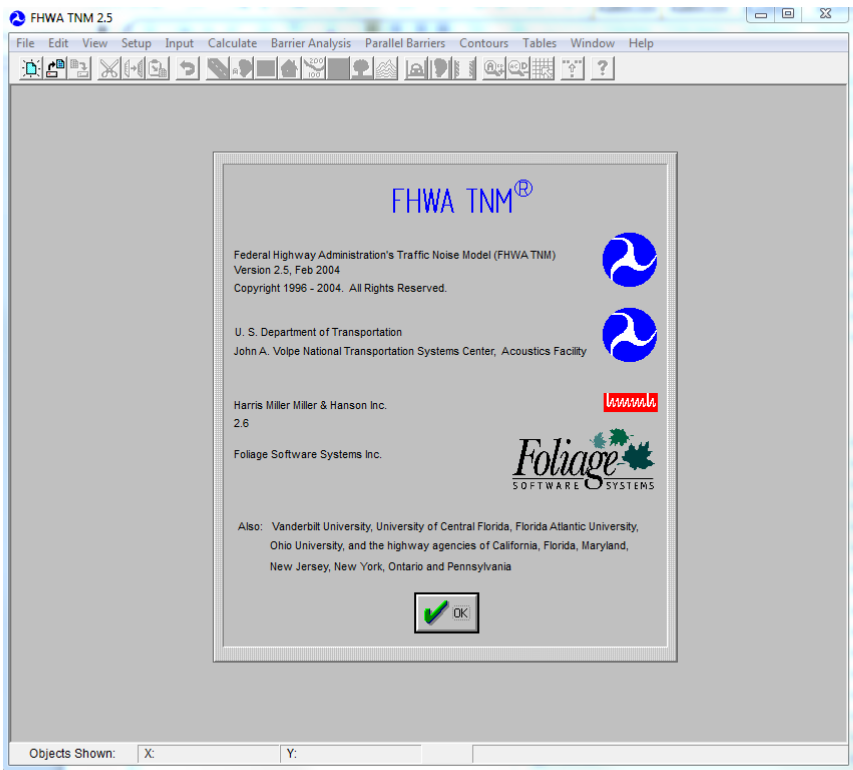


Figure 4.1 FHWA Traffic Noise Model (TNM) program, version 2.5

This program makes use of the geometry and topography of the highway and adjacent terrain, including number of lanes in each direction, presence of barriers or walls (e.g., noise walls, CTB, or jersey barriers), curves, elevations, etc.; the location of the receivers, terrain lines, and the traffic, its composition (i.e., passenger cars, trucks, etc.), and its future forecast.

4.2. TNM - Receivers

Eight receivers were included in the model. These receivers correspond to the initial residential monitoring locations that were used during the pre-barrier field-measuring stage of this study. The receivers are as follows:

- Site #1, R1. 5010 Southport Drive
- Site #2, R2. 2205 Mermaid Circle
- Site #3, R3. 4901 Harborview Boulevard
- Site #4a, R4a. 3401 Francesca Court
- Site #6, R6. 4317 Rose Leaf Court
- Site #7, R7. 2629 Kirby Road
- Site #8, R8. 4509 Meadowcove Drive
- Site #12, R12. 2414 Brittany Drive

4.3. TNM - Traffic

The traffic figures included in the model correspond to future traffic projections. The predicted values for traffic volumes correspond to the year 2030. Traffic values were obtained from TxDOT.

4.4. TNM - Noise Walls

Two noise walls were considered in the model: the existing 8-ft. tall walls along the east (northbound) and west (southbound) sides. Therefore, they were modeled as 8-ft. tall walls. For the analysis, each wall had four up-increments and four down-increments in height; all the increments were 2-ft. Therefore, for the barrier analysis, each wall was analyzed for a maximum height of 16 ft. and a minimum height of zero, with the following increment heights (Table 4.1):

Table 4.1 Noise wall heights and increments

Increment	Barrier Height (ft.)
4 down	0
3 down	2
2 down	4
1 down	6
Reference	8
1 up	10
2 up	12
3 up	14
4 up	16

The noise wall descriptions are as follows (Table 4.2):

Table 4.2 Noise wall descriptions

Noise Wall	Status	Side	Community	Limits		Length (ft.)
				Northernmost	Southernmost	
1	Existing	West	Ridgecove	Kirby Rd.	Southern end of Ridgecove Community	2,949
2	Existing	East	Harborside	Harborview Dr.	Southern end of Harborside Community	2,858

The noise walls are illustrated in Figure 4.2, along with the receivers' locations.

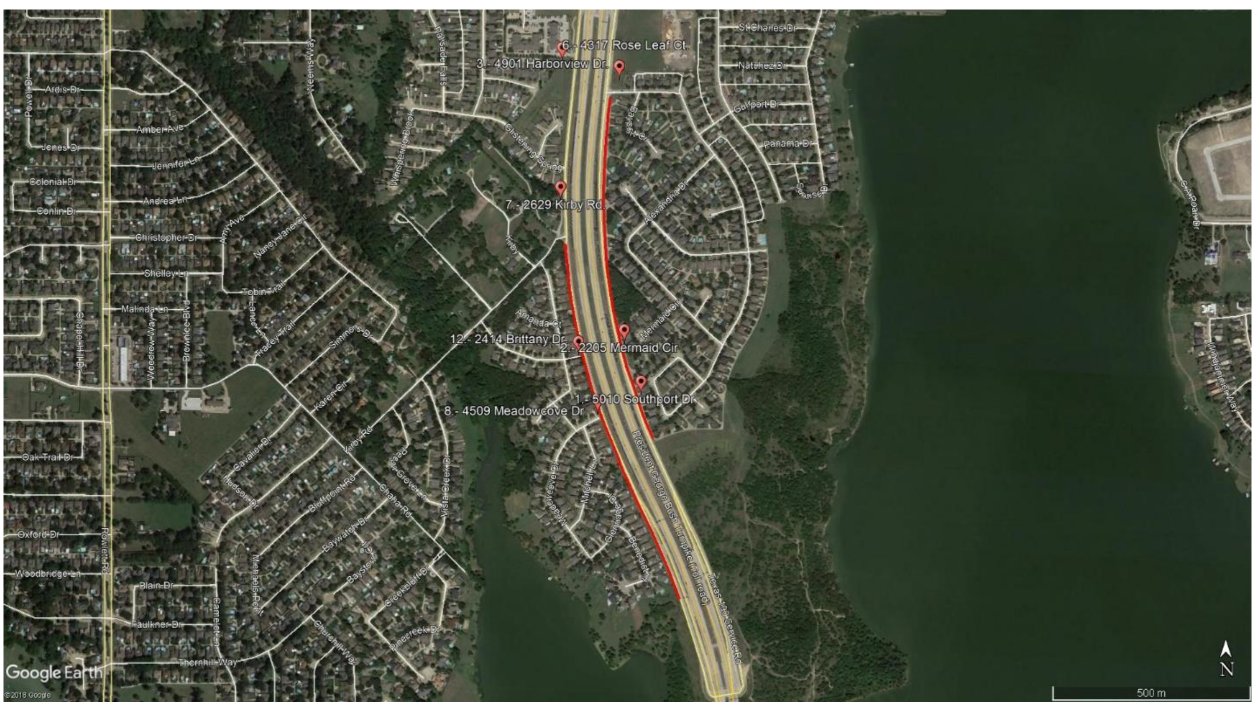


Figure 4.2 Existing noise walls on SH 190

4.5. TNM - Pavements

The model was run first using “Average” pavement, as recommended by the FHWA. However, in order to try to represent the existing road conditions, and to investigate variability due to pavement surface, it was run also using the “PCC” (Portland cement concrete) option of TNM. The pavement on SH 190 is transversely tined CRCP for both main lanes and frontage roads. However, for noise level prediction and the barrier analyses, average pavement was used as recommended by the FHWA.

4.6. TNM - Illustrations

A plan view of the TNM model is shown in Figure 4.3, which is a representation as seen on the computer screen, showing the geometry of the highway lanes, walls, and receivers.

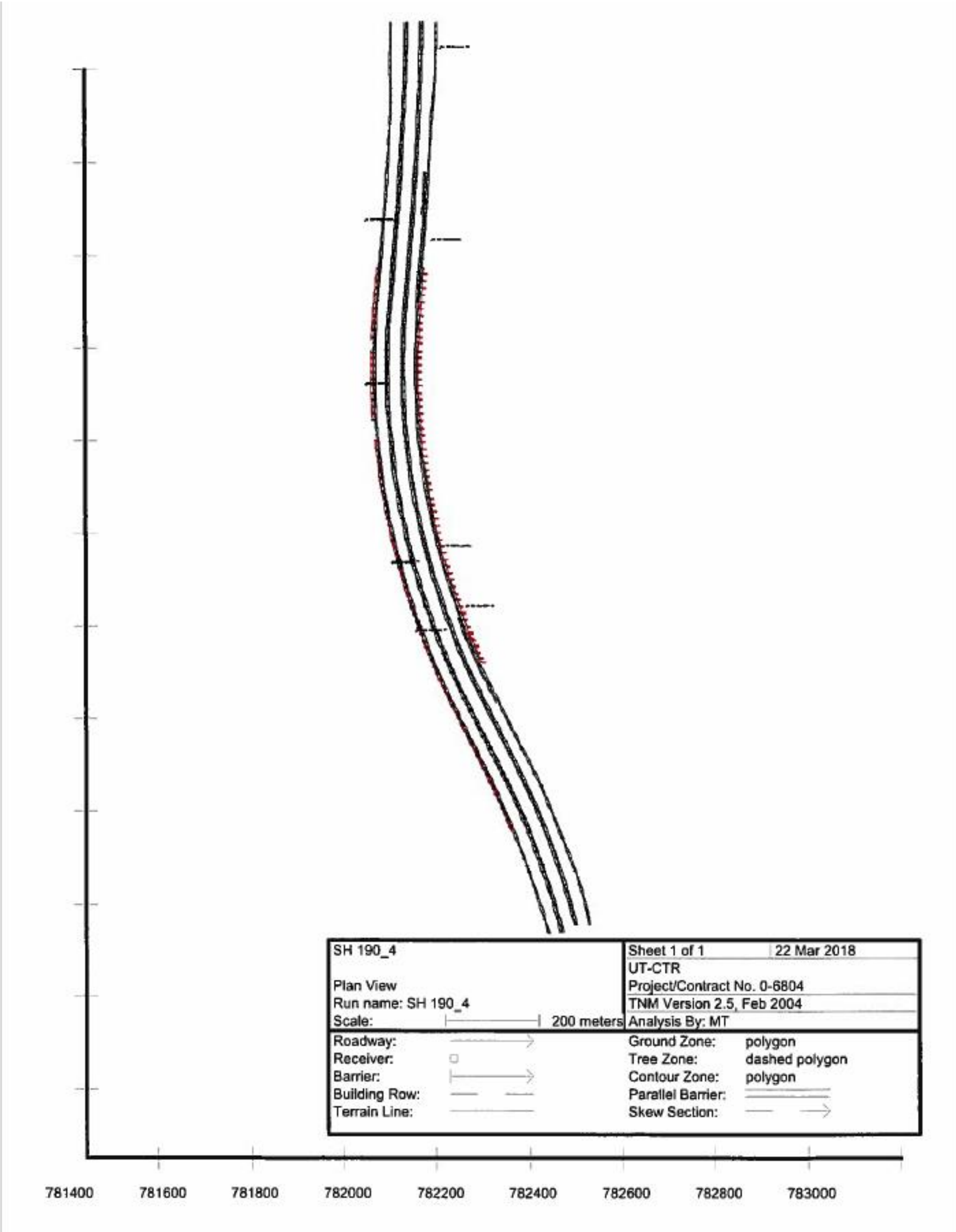


Figure 4.3 Plan view of the TNM model

An example of a skew view generated from TNM showing receiver R1, with Existing Noise Wall 1, on the left, and Existing Noise Wall 2, on the right, is shown in Figure 4.4.

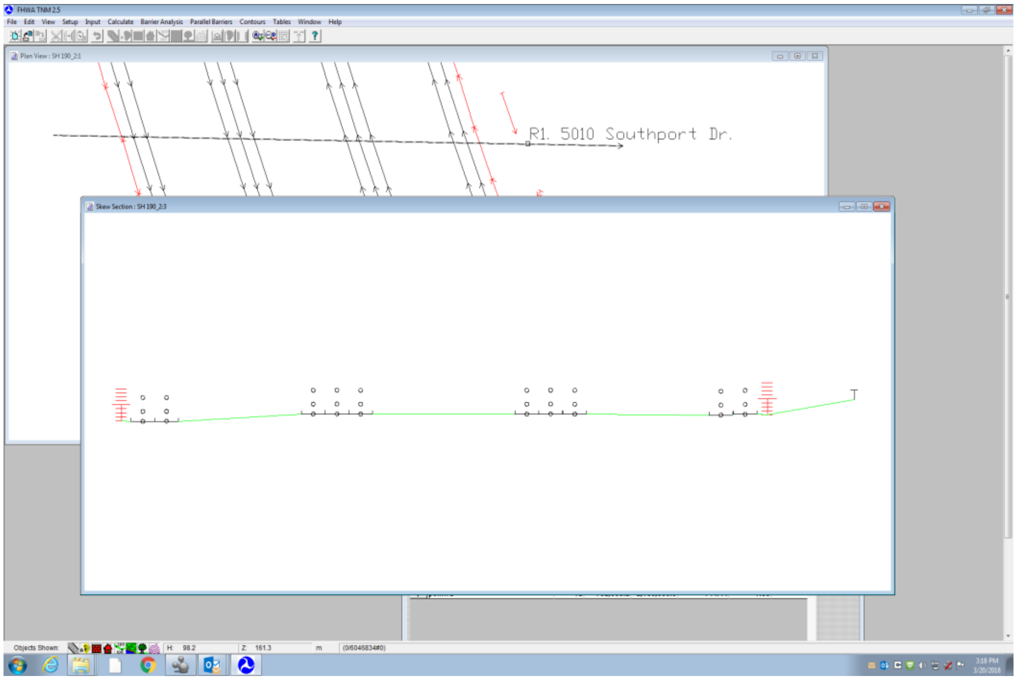


Figure 4.4 Skew view from TNM

Another example of a skew section from TNM is shown in Figure 4.5, which depicts the west side wall, named Existing Noise Wall 1 in the model, on the left, and the east wall, named Existing Noise Wall 2 in the model, on the right, as well as receivers R8 and R1.

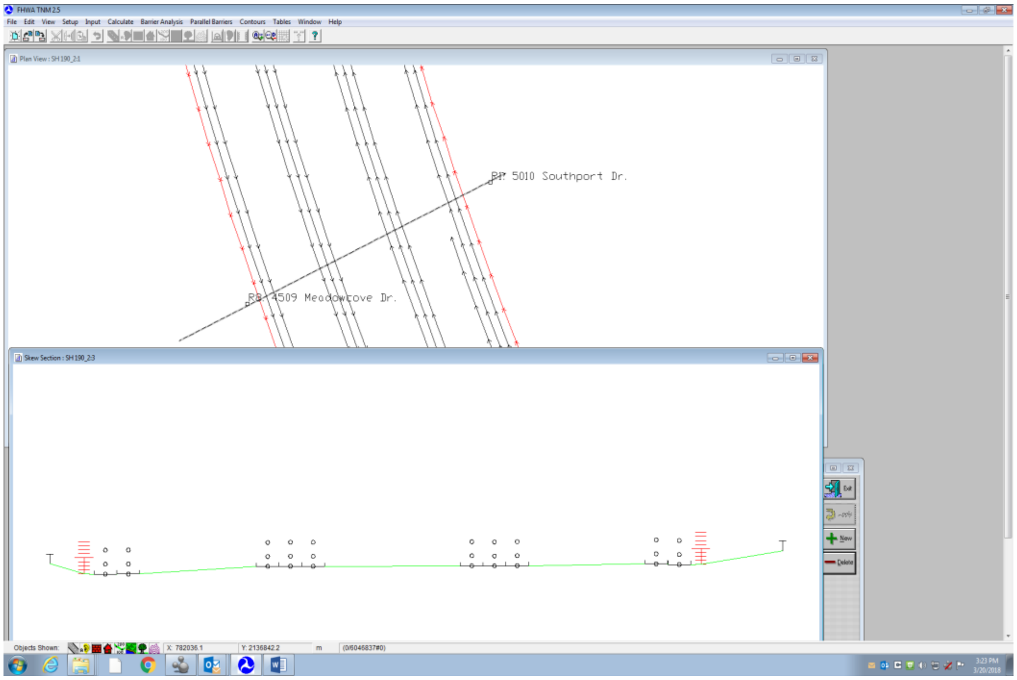


Figure 4.5 Skew view from TNM

4.7. TNM Results

The first set of results are shown in Table 4.3. This table shows TNM results for both "Average" and "PCC" pavements, compared to actual field noise measurements. The field tests include all the data collected in this project (up to the pre-barrier condition stage) in the "Average Level" column, as well as the highest measurement at each particular location, in the "Highest Level" column. The table also indicates whether there is an impact, according to the Section 6.1.2.

Table 4.3 Field results vs. TNM results with "Average" pavement and "PCC" pavement

Receivers	Field Tests				TNM (Average Pavement)				TNM (PCC Pavement)			
	Average Level (dBA)	Impact	Highest Level (dBA)	Impact	No Barriers (dBA)	Existing Barriers (dBA)	Impact (W/Barriers)	Noise Reduction (dBA)	No Barriers (dBA)	Existing Barriers (dBA)	Impact (W/Barriers)	Noise Reduction (dBA)
R1. 5010 Southport Dr.	67.5	Yes	72.8	Yes	69.6	68.9	Yes	0.7	71.9	71.2	Yes	0.7
R2. 2205 Mermaid Cir.	68.4	Yes	73.4	Yes	69.0	68.5	Yes	0.5	71.3	70.7	Yes	0.6
R3. 4901 Harborview Dr.	67.1	Yes	71.5	Yes	67.6	67.5	Yes	0.1	69.7	69.7	Yes	0.0
R4a. 3401 Francesca Ct.	67.5	Yes	76.3	Yes	67.5	67.5	Yes	0.0	69.5	69.5	Yes	0.0
R6. 4317 Rose Leaf Ct.	68.3	Yes	73.8	Yes	65.1	65.1	No	0.0	67.1	67.1	Yes	0.0
R7. 2629 Kirby Rd.	73.2	Yes	76.5	Yes	70.6	70.6	Yes	0.0	73.0	73.0	Yes	0.0
R8. 4509 Meadowcove Dr.	67.7	Yes	72.1	Yes	72.0	71.7	Yes	0.3	74.3	74.0	Yes	0.3
R12. 2414 Brittany Dr.	58.9	No	62.7	No	69.5	61.8	No	7.7	71.8	63.4	No	8.4

Actual field measurements indicate that all receivers but one (R12) had an impact, as described in Section 6.1.2. The same outcome was produced by TNM with PCC pavement, and a very similar result was obtained by using TNM with average pavement. Only R6 changed to no impact when using TNM with the average pavement option. In general, the TNM results are a fairly consistent representation of the actual field measurements. Even though it is an obvious and expected result, the receivers that are currently not shielded by any barriers (R4a, R6, and R7) show the same result for both the "No Barriers" and "Existing Barriers" runs, which indicates that the models are producing reasonable and consistent results. For all these numbers, the "Reference Height" of 8-ft. was used for all the existing walls.

The TNM PCC pavement option is assumed to be a more accurate representation of the actual noise levels for receivers R6 and R7 only, whereas the average pavement option seems like a fairly close representation of actual noise levels for all the other receivers. This can only be verified if the model is validated using actual traffic counts at the time the field measurements are taking place.

Actual noise levels were determined from field measurements conducted over several months (July 2017 through January 2018) at various times of the day and night. The procedure for recording noise levels is presented in Chapter 5, and the noise test results are presented in Chapter 6.

4.7.1. TNM Barrier Analyses

A detailed barrier analysis for all the considered heights (the heights shown in Table 4.1) was performed for the existing walls in the model. The results are shown in Tables 4.4 and 4.5. Additionally, two new noise walls were proposed, designed, and analyzed for the purpose of shielding the residential areas that are not currently protected by existing walls, particularly Magnolia Springs and the adjacent homes along Kirby Road, on the west side of the highway. However, TxDOT decided at this time, since this is considered a pilot project, not to construct any new walls.

Table 4.4 shows the barrier analysis for Existing Noise Wall 1, on the west side of SH 190.

Table 4.4 Barrier analysis: Existing Noise Wall 1

Barrier Analysis: Existing Noise Wall 1						
Sample Receiver:	R8. 4509 Meadowcove Dr.			R12. 2414 Brittany Dr.		
Barrier Height (ft)	No Barrier LAeq1h Calculated dBA	With Barrier Calculated LAeq1h dBA	Noise Reduction Calculated dB	No Barrier LAeq1h Calculated dBA	With Barrier Calculated LAeq1h dBA	Noise Reduction Calculated dB
0	72	72	0	69.5	69.5	0
2	72	72	0	69.5	69.2	0.3
4	72	71.9	0.1	69.5	66.6	2.9
6	72	71.7	0.3	69.5	63.7	5.8
(Existing Height) 8	72	71.7	0.3	69.5	61.8	7.7
10	72	66.6	5.4	69.5	60.1	9.4
12	72	63	9	69.5	58.7	10.8
14	72	60.6	11.4	69.5	57.7	11.8
16	72	58.6	13.4	69.5	56.7	12.8

For the case of Existing Noise Wall 1, there are two representative receivers, R8 and R12. Receiver R12 represents a unique case, because besides being behind the existing noise wall, it is also below a deep embankment and its corresponding tall retaining wall. This receiver consistently registered the lowest noise levels among the monitored residential locations, as its natural profile shields it well from the highway noise, as explained in Section 6.1.2. For receiver R8, the analysis shows that an additional height of 4 ft. on top of the existing wall would reduce noise by a substantial level (greater than 7 dBA). Therefore, for Existing Noise Wall 1, it is recommended to add 4 ft. to the existing height, for a total of 12 ft. of wall. Figure 4.6 shows the TNM screen of the barrier analysis for Existing Noise Wall 1.

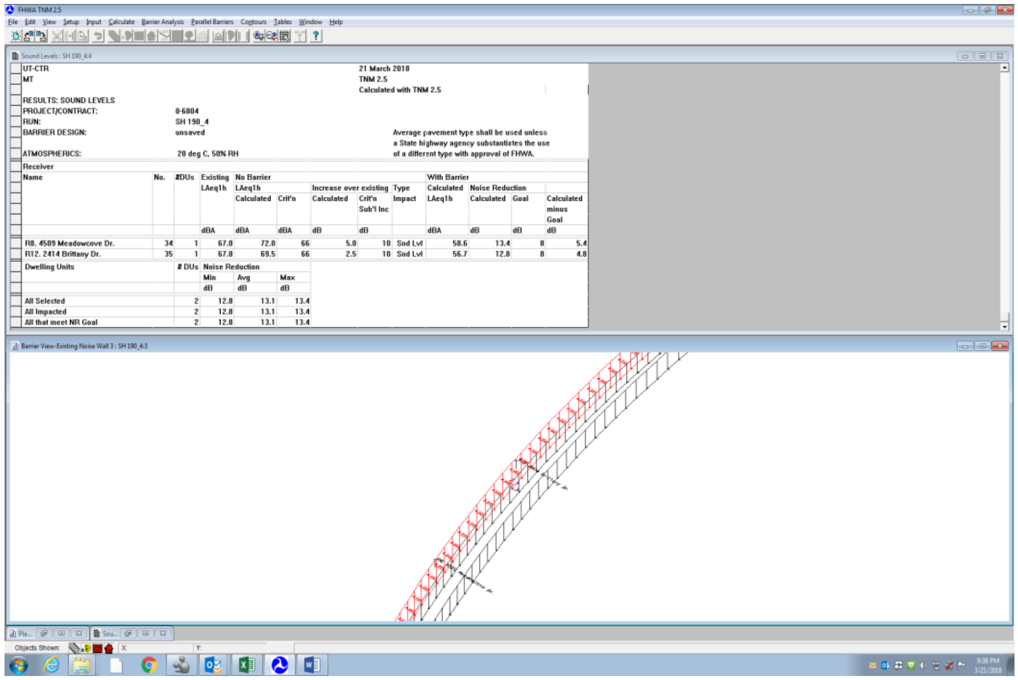


Figure 4.6 TNM Barrier Analysis for Existing Noise Wall 1

Table 4.5 shows the barrier analysis for Existing Noise Wall 2, which is on the east side of SH 190, protecting the Harborside Community.

Table 4.5 Barrier analysis: Existing Noise Wall 2

Barrier Analysis: Existing Noise Wall 2						
Sample Receiver:	R1. 5010 Southport Dr.			R2. 2205 Mermaid Cir.		
Barrier Height (ft)	No Barrier LAeq1h Calculated dBA	With Barrier Calculated LAeq1h dBA	Noise Reduction Calculated dB	No Barrier LAeq1h Calculated dBA	With Barrier Calculated LAeq1h dBA	Noise Reduction Calculated dB
0	69.6	69.6	0	69	69	0
2	69.6	69.6	0	69	69	0
4	69.6	69.6	0	69	68.8	0.2
6	69.6	69.4	0.2	69	68.6	0.4
(Existing Height) 8	69.6	68.9	0.7	69	68.5	0.5
10	69.6	67.1	2.5	69	68.4	0.6
12	69.6	64.6	5	69	66.9	2.1
14	69.6	62.7	6.9	69	63.4	5.6
16	69.6	61.3	8.3	69	61.2	7.8

For Existing Noise Wall 2, there are two representative receivers in the TNM model: R1 and R2. The analysis indicates that an additional height of 8 ft. on top of the existing 8-ft.-tall concrete wall would be necessary to drop the noise levels significantly (greater than 7 dBA). Therefore, a 16-ft. tall wall would be recommended. Figure 4.7 shows the TNM screen during the barrier analysis of Existing Noise Wall 2.

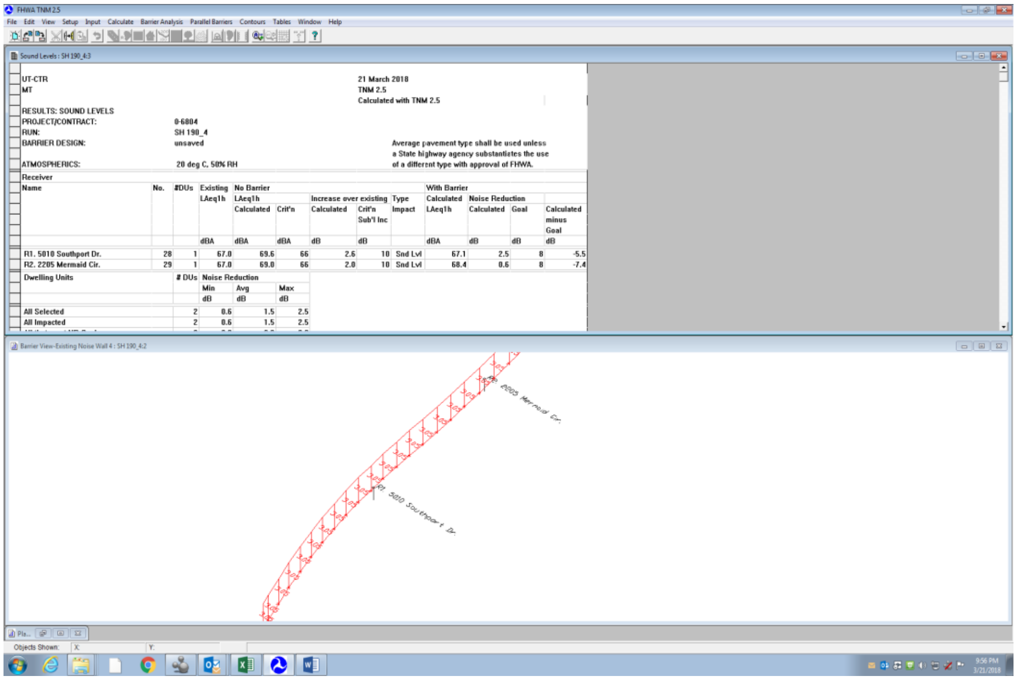


Figure 4.7 TNM Barrier Analysis for Existing Noise Wall 2

4.8. Summary and Discussion of Results

It was recommended to increase the height of Existing Noise Wall 1, on the west side of SH 190, next to the Ridgecove Community, by 4 ft. for a total of 12 ft. in order to provide a substantial noise level reduction. And for Existing Noise Wall 2, on the east side of SH 190, next to the Harborside Community, it was recommended to increase its height by 8 ft. for a total height of 16 ft.

Besides the existing noise walls, two new noise walls were proposed, designed, and analyzed for the purpose of shielding the residential areas that are not currently protected by existing walls, particularly Magnolia Springs and the adjacent homes along Kirby Road, on the west side of the highway (e.g., R7). However, TxDOT decided at that time, since this was considered a pilot project, not to construct any new walls.

As for the other impacted receivers, R3 (in the Harborside Community), R4a (in the Lake Forest Estates Community), and R6 (in the Magnolia Springs Community), because of the height of the highway relative to the residences, and the distance between the highway and the homes, a possible noise barrier would shield these residences only from the noise coming from the frontage roads, which are at the same level as the residences, but would not protect them from the noise coming from the main highway lanes, which are at a higher elevation. However, potential noise walls at these locations would not benefit a significant number of receivers.

Chapter 5. Residential Noise Testing Program

This chapter presents the field-testing procedure conducted as part of the research work at the residential sites along SH 190/PGBT in Rowlett, east of Dallas. The field test program consists of noise measurements near the highway, between south of Main Street and the north shore of Lake Ray Hubbard, an area that is affected by the highway noise.

5.1. Introduction

The noise data collection took place at the neighborhood sites before the noise wall installation and continued after the completion of the wall until the conclusion of the project. Initially, eight locations were selected. For the subsequent stage of data collection, four of those sites were eliminated, and three new sites were added. These are described in detail in Chapter 2. Measurements were performed at these locations approximately once per month. During each test day, measurements were conducted at all locations at various times of the day, including morning, afternoon, and evening, to cover a wide range of traffic and weather conditions. The purpose of the noise tests was to gather noise data before and after the new sound wall were installed, to assess the noise levels prevailing at the various locations and evaluate the effectiveness of the walls. The pre-barrier condition data-collection period covered a 7-month period, from July 2017 through January 2018. The post-barrier testing period started in August 2019, when the wall additions were finished and continued until the end of the project.

5.2. Test Equipment and Procedure

The noise measurements consist of sound pressure level (SPL) tests. For these, an SPL meter measures the noise level over a specified time period, and the average noise level over that time period is the result of the test. The SPL meter is illustrated in Figure 5.1. The time-averaged value of the SPL during the test interval, i.e., the "equivalent continuous sound level" [L_{eq}(A)] is used. L_{eq}(A) is defined as the equivalent steady-state sound level that, in a given time period, contains the same acoustic energy as a time-varying sound level during the same period (Figure 5.2). L_{eq}(A) is used for all traffic noise analyses for TxDOT highway projects. The meter is placed on a tripod standing 1.50 meters above the ground. The test interval for this project consists of 10-minute periods.

Figure 5.1 SPL meter

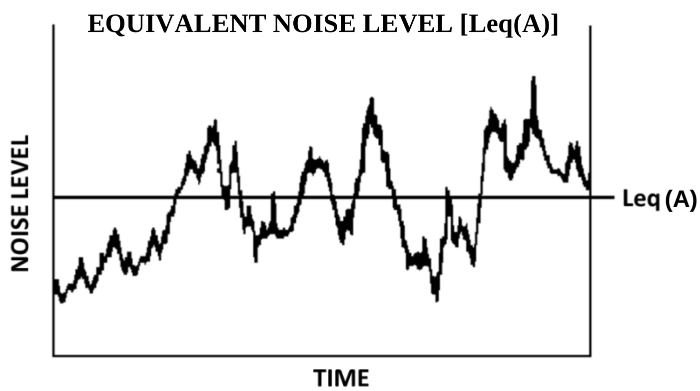


Figure 5.2 Leq(A): average noise level over a period of time

For this project, weather conditions at the time of each test were monitored by means of a portable weather station equipped with a data logger and software. The weather station used in this project is manufactured by Davis Instruments and the model is called Vantage Vue (shown in Figure 5.3). It consists of an Integrated Sensor Suite (ISS) and a wireless console. The ISS contains all the sensors and devices to measure weather variables—a rain collector, temperature and humidity sensors, an anemometer, and a wind vane. It is solar-powered, and a lithium battery provides backup. It communicates wirelessly to the console by means of low-power radio transmission. The console is battery-operated and has an LCD display (Figure 5.4). The ISS measures temperature, relative humidity, dew point, wind speed, wind direction, highest wind speed (gust), gust direction, wind chill, heat index, barometric pressure, total rain, and rain rate, and records the values for each of these variables at 1-minute intervals. Figure 5.5 shows the weather station mounted in the back of the research vehicle. The software, also created by Davis Instruments, is called WeatherLink, version 6.0.0.

Figure 5.3 Davis Instruments portable weather station, showing the ISS

Figure 5.4 Vantage Vue wireless console

Figure 5.5 Weather station mounted in the back of research vehicle

The sequence of operations for noise measurements is as follows:

- Mount weather station on its base.
- Verify communication between ISS and console.
- Calibrate the SPL meter.
- Mount the SPL meter on tripod approximately 1.5 m above the ground.
- Level the weather station.
- Position the weather station in such way that the solar panel faces south.
- Start recording period.

Leveling and correct orientation of the weather station must be done at each location in order to obtain accurate wind speed and wind direction readings. Leveling is done with the aid of a bubble level on top of the ISS. A mirror compass, shown in Figure 5.6, is used for the orientation of the weather station. The sighting mirror in the compass allows for higher precision; its use with the weather station is shown in Figure 5.7.

Figure 5.6 Mirror compass utilized for orientation of the weather station

Figure 5.7 Use of the mirror compass for orientation of the weather station: the solar panel of the weather station, in the background, is positioned so that it faces south

Steps 1 through 3 are only necessary at the beginning of a series of measurements, i.e., the beginning of each recording period (morning, early afternoon, and evening).

At the end of the day, the weather station data is downloaded from the console to a computer by means of a USB connection. The WeatherLink software facilitates analyses and graphic interpretation of weather data. Some images from the screens generated by the software are presented in Figures 5.8 and 5.9.

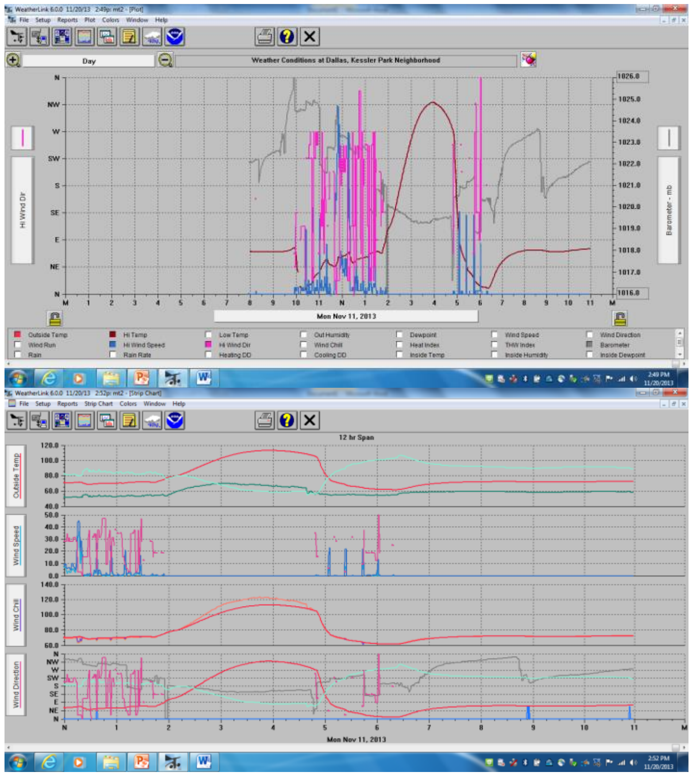
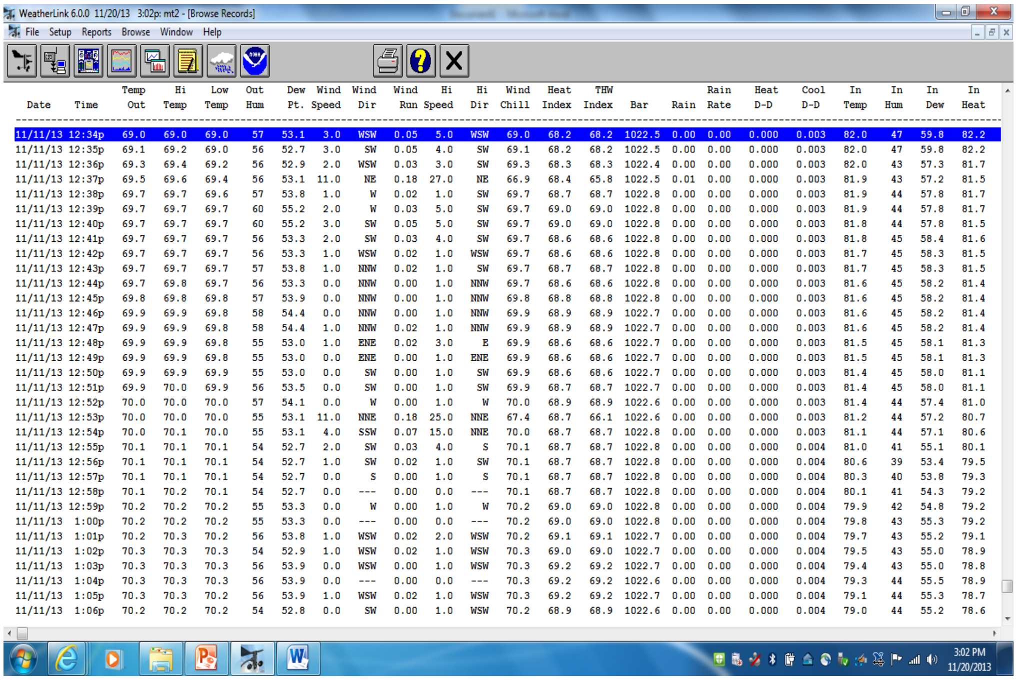


Figure 5.8 Weather plots of daily records generated by WeatherLink



Date	Time	Temp Out	Hi Temp	Low Temp	Out Hum	Dew Pt.	Wind Speed	Wind Dir	Wind Run	Hi Speed	Hi Dir	Wind Chill	Heat Index	THW Index	Bar	Rain	Rain Rate	Heat D-D	Cool D-D	In Temp	In Hum	In Dew	In Heat
11/11/13	12:34p	69.0	69.0	69.0	57	53.1	3.0	WSW	0.05	5.0	WSW	69.0	68.2	68.2	1022.5	0.00	0.00	0.000	0.003	82.0	47	59.8	82.2
11/11/13	12:35p	69.1	69.2	69.0	56	52.7	3.0	SW	0.05	4.0	SW	69.1	68.2	68.2	1022.5	0.00	0.00	0.000	0.003	82.0	47	59.8	82.2
11/11/13	12:36p	69.3	69.4	69.2	56	52.9	2.0	WSW	0.03	3.0	SW	69.3	68.3	68.3	1022.4	0.00	0.00	0.000	0.003	82.0	43	57.3	81.7
11/11/13	12:37p	69.5	69.6	69.4	56	53.1	11.0	NE	0.18	27.0	NE	66.9	68.4	65.8	1022.5	0.01	0.00	0.000	0.003	81.9	43	57.2	81.5
11/11/13	12:38p	69.7	69.7	69.6	57	53.8	1.0	W	0.02	1.0	SW	69.7	68.7	68.7	1022.8	0.00	0.00	0.000	0.003	81.9	44	57.8	81.7
11/11/13	12:39p	69.7	69.7	69.7	60	55.2	2.0	W	0.03	5.0	SW	69.7	69.0	69.0	1022.8	0.00	0.00	0.000	0.003	81.9	44	57.8	81.7
11/11/13	12:40p	69.7	69.7	69.7	60	55.2	3.0	SW	0.05	5.0	SW	69.7	69.0	69.0	1022.8	0.00	0.00	0.000	0.003	81.8	44	57.8	81.5
11/11/13	12:41p	69.7	69.7	69.7	56	53.3	2.0	SW	0.03	4.0	SW	69.7	68.6	68.6	1022.8	0.00	0.00	0.000	0.003	81.8	45	58.4	81.6
11/11/13	12:42p	69.7	69.7	69.7	56	53.3	1.0	WSW	0.02	1.0	WSW	69.7	68.6	68.6	1022.8	0.00	0.00	0.000	0.003	81.7	45	58.3	81.5
11/11/13	12:43p	69.7	69.7	69.7	57	53.8	1.0	NNW	0.02	1.0	SW	69.7	68.7	68.7	1022.8	0.00	0.00	0.000	0.003	81.7	45	58.3	81.5
11/11/13	12:44p	69.7	69.8	69.7	56	53.3	0.0	NNW	0.00	1.0	NNW	69.7	68.6	68.6	1022.8	0.00	0.00	0.000	0.003	81.6	45	58.2	81.4
11/11/13	12:45p	69.8	69.8	69.8	57	53.9	0.0	NNW	0.00	1.0	NNW	69.8	68.8	68.8	1022.8	0.00	0.00	0.000	0.003	81.6	45	58.2	81.4
11/11/13	12:46p	69.9	69.9	69.8	58	54.4	0.0	NNW	0.00	1.0	NNW	69.9	68.9	68.9	1022.7	0.00	0.00	0.000	0.003	81.6	45	58.2	81.4
11/11/13	12:47p	69.9	69.9	69.8	58	54.4	1.0	NNW	0.02	1.0	NNW	69.9	68.9	68.9	1022.7	0.00	0.00	0.000	0.003	81.6	45	58.2	81.4
11/11/13	12:48p	69.9	69.9	69.8	55	53.0	1.0	ENE	0.02	3.0	E	69.9	68.6	68.6	1022.7	0.00	0.00	0.000	0.003	81.5	45	58.1	81.3
11/11/13	12:49p	69.9	69.9	69.8	55	53.0	0.0	ENE	0.00	1.0	ENE	69.9	68.6	68.6	1022.7	0.00	0.00	0.000	0.003	81.5	45	58.1	81.3
11/11/13	12:50p	69.9	69.9	69.9	55	53.0	0.0	SW	0.00	1.0	SW	69.9	68.6	68.6	1022.7	0.00	0.00	0.000	0.003	81.4	45	58.0	81.1
11/11/13	12:51p	69.9	70.0	69.9	56	53.5	0.0	SW	0.00	1.0	SW	69.9	68.7	68.7	1022.7	0.00	0.00	0.000	0.003	81.4	45	58.0	81.1
11/11/13	12:52p	70.0	70.0	70.0	57	54.1	0.0	W	0.00	1.0	W	70.0	68.9	68.9	1022.6	0.00	0.00	0.000	0.003	81.4	44	57.4	81.0
11/11/13	12:53p	70.0	70.0	70.0	55	53.1	11.0	NNE	0.18	25.0	NNE	67.4	68.7	66.1	1022.6	0.00	0.00	0.000	0.003	81.2	44	57.2	80.7
11/11/13	12:54p	70.0	70.1	70.0	55	53.1	4.0	SSW	0.07	15.0	NNE	70.0	68.7	68.7	1022.8	0.00	0.00	0.000	0.003	81.1	44	57.1	80.6
11/11/13	12:55p	70.1	70.1	70.1	54	52.7	2.0	SW	0.03	4.0	S	70.1	68.7	68.7	1022.8	0.00	0.00	0.000	0.004	81.0	41	55.1	80.1
11/11/13	12:56p	70.1	70.1	70.1	54	52.7	1.0	SW	0.02	1.0	SW	70.1	68.7	68.7	1022.8	0.00	0.00	0.000	0.004	80.6	39	53.4	79.5
11/11/13	12:57p	70.1	70.1	70.1	54	52.7	0.0	S	0.00	1.0	S	70.1	68.7	68.7	1022.8	0.00	0.00	0.000	0.004	80.3	40	53.8	79.3
11/11/13	12:58p	70.1	70.2	70.1	54	52.7	0.0	---	0.00	0.0	---	70.1	68.7	68.7	1022.8	0.00	0.00	0.000	0.004	80.1	41	54.3	79.2
11/11/13	12:59p	70.2	70.2	70.2	55	53.3	0.0	W	0.00	1.0	W	70.2	69.0	69.0	1022.8	0.00	0.00	0.000	0.004	79.9	42	54.8	79.2
11/11/13	1:00p	70.2	70.2	70.2	55	53.3	0.0	---	0.00	0.0	---	70.2	69.0	69.0	1022.8	0.00	0.00	0.000	0.004	79.8	43	55.3	79.2
11/11/13	1:01p	70.2	70.3	70.2	56	53.8	1.0	WSW	0.02	2.0	WSW	70.2	69.1	69.1	1022.7	0.00	0.00	0.000	0.004	79.7	43	55.2	79.1
11/11/13	1:02p	70.3	70.3	70.3	54	52.9	1.0	WSW	0.02	1.0	WSW	70.3	69.0	69.0	1022.7	0.00	0.00	0.000	0.004	79.5	43	55.0	78.9
11/11/13	1:03p	70.3	70.3	70.3	56	53.9	0.0	WSW	0.00	1.0	WSW	70.3	69.2	69.2	1022.7	0.00	0.00	0.000	0.004	79.4	43	55.0	78.8
11/11/13	1:04p	70.3	70.3	70.3	56	53.9	0.0	---	0.00	0.0	---	70.3	69.2	69.2	1022.6	0.00	0.00	0.000	0.004	79.3	44	55.5	78.9
11/11/13	1:05p	70.3	70.3	70.2	56	53.9	1.0	WSW	0.02	1.0	WSW	70.3	69.2	69.2	1022.7	0.00	0.00	0.000	0.004	79.1	44	55.3	78.7
11/11/13	1:06p	70.2	70.2	70.2	54	52.8	0.0	SW	0.00	1.0	WSW	70.2	68.9	68.9	1022.6	0.00	0.00	0.000	0.004	79.0	44	55.2	78.6

Figure 5.9 WeatherLink screen showing weather records for every minute

5.3. Summary

This chapter presents the noise testing program for the residential locations in the neighborhoods along SH 190/PGBT, before and after the lightweight transparent noise barriers were installed. Eight residential locations were monitored prior to the wall additions, and seven locations were monitored after the noise walls were retrofitted. The noise measurements, performed with SPL meters, were collected for the purpose of evaluating the effectiveness of the new noise barriers. The tests were conducted at different times of the day to account for the variability in traffic and climatic conditions. At the same time the noise tests were performed, a weather station was used to monitor climatic variables. A detailed description of the equipment utilized for the measurements was presented, as well as the methodology for the field work.

Chapter 6. Noise Test Results and Analysis

This chapter presents the results and analysis of the noise data collected as part of the research work conducted before and after the noise wall installations on the existing noise walls on SH 190. For the context of this report and this project, "pre-barrier" refers to the condition prior to any modification or extension of the existing noise walls, and "post-barrier" refers to the condition after the noise walls were retrofitted to provide additional height. This highway section has two existing noise walls, on either side of the highway: one on the east side (northbound direction) and one on the west side (southbound direction). Each of these consists of 8-ft. tall pre-cast concrete panels, placed at the time the PGBT was constructed in 2011.

This project encompasses the extension of the existing walls to improve their effectiveness by providing additional noise reductions.

The data collected consists of sound pressure levels and corresponding weather data from the time of each noise test. The test procedures, methodology, and equipment are described in Chapter 5.

6.1. Analysis of Noise Results

The environmental noise testing period for the pre-barrier condition started in July 2017 and finalized in January 2018. For the post-barrier condition, the data collection started in August 2019 and finished in November 2020, with an interruption from March 2020 to May 2020 due to the COVID-19 pandemic, during which travel was not allowed by CTR, and therefore, no field trips for data collection could be conducted. A total of 291 noise tests were conducted in the vicinity of SH 190/PGBT, at the eleven residential sites described in Chapter 2, following the procedure described in Chapter 5. Those tests account for approximate 49 hours of noise monitoring throughout the project. About 2,910 weather records (one for every minute) were collected while the noise tests were conducted. From those 291 noise tests, 106 correspond to the pre-barrier condition and 185 to the post-barrier period.

The overall average noise level for the pre-barrier measurements, including all eight sites, was 67.4 dBA, the standard deviation was 4.6 dBA, and the coefficient of variance was 6.9%. The smallest noise level recorded was 53.3 dBA (Receiver R12; October 25, 2017; 14:00 hrs.), and the highest was 76.5 dBA, which occurred twice at the same location (Receiver R7; October 25, 2017; 18:15 hrs., and Receiver R7; November 7, 2017; 17:06 hrs.).

For the post-barrier testing period, the overall average for the seven sites considered was 63.5 dBA, the standard deviation was 3.7 dBA, and the coefficient of variance was 5.8%. The smallest noise level recorded was 53.9 dBA (Receiver R12; September 29, 2020; 11:58 hrs.), and the highest was 71.8 dBA (Receiver R13; October 21, 2020; 16:46 hrs.).

6.1.1. Noise by Residential Receiver Location

From the numbers in the previous two paragraphs, it would seem that the overall noise level reduction with the barrier extension is 3.9 dBA, on average. However, this figure is not entirely representative of the effectiveness of the transparent barrier extensions. The noise level analysis was made slightly more complex because some of the residential receiver locations changed from the pre-barrier to the post-barrier conditions when the scope of the project changed, with some locations being dropped while others were added. Please refer to Chapter 2 for more information on the change of the residential locations. Some of the initial residential locations were unshielded from the highway noise by any of the existing concrete barriers, and these were all dropped for the post-barrier phase. Those represented some of the locations exposed to higher levels of noise.

Tables 6.1 and 6.2 present the average noise level results by residential receiver for the pre-barrier condition, and the post-barrier condition, respectively.

Table 6.1 Pre-barrier condition test results

Receivers	Field Tests		
	Average Level dBA	Std. Dev. dBA	C. of Var. %
R1. 5010 Southport Dr.	67.5	3.4	5.1
R2. 2205 Mermaid Cir.	68.4	3.3	4.8
R3. 4901 Harborview Dr.	67.1	2.7	4.1
R4a. 3401 Francesca Ct.	67.5	3.1	4.6
R6. 4317 Rose Leaf Ct.	68.3	2.8	4.0
R7. 2629 Kirby Rd.	73.2	2.2	3.0
R8. 4509 Meadowcove Dr.	67.7	2.9	4.3
R12. 2414 Brittany Dr.	58.9	2.7	4.6
R13. 1906 Benedict Ct. *	67.0	-	-

*Receiver R13 was not part of the pre-barrier condition set of field tests and only had one field test performed. This test was conducted on August 24, 2018 during a scouting trip to this location.

Table 6.2 Post-barrier condition test results

Receivers	Field Tests		
	Average Level dBA	Std. Dev. dBA	C. of Var. %
R1. 5010 Southport Dr.	65.0	2.7	4.2
R2. 2205 Mermaid Cir.	65.4	2.7	4.1
R4. 4902 Bayport Cir.	62.8	3.5	5.5
R5. 4714 Petersburg Dr.	64.0	1.8	2.8
R8. 4509 Meadowcove Dr.	63.8	3.2	5.0
R12. 2414 Brittany Dr.	57.8	2.1	3.6
R13. 1906 Benedict Ct.	65.6	3	4.6

The average noise level results are provided in Figures 6.1 and 6.2, showing the location of each receiver and the location of the noise walls, for the pre-barrier condition, and the post-barrier condition, respectively.

Figure 6.1 Average noise level results by receiver (pre-barrier)

Figure 6.2 Average noise level results by receiver (post-barrier)

Four receivers had noise tests conducted both during the pre-barrier and the post-barrier periods: R1, R2, R8, and R12. Therefore, these are the only four sites for which comparisons between both time periods can be made to ascertain the effectiveness of the new noise wall additions. These are illustrated in Figure 6.3, showing both the pre- and post-barrier average noise levels, as well as those obtained for the other sites.

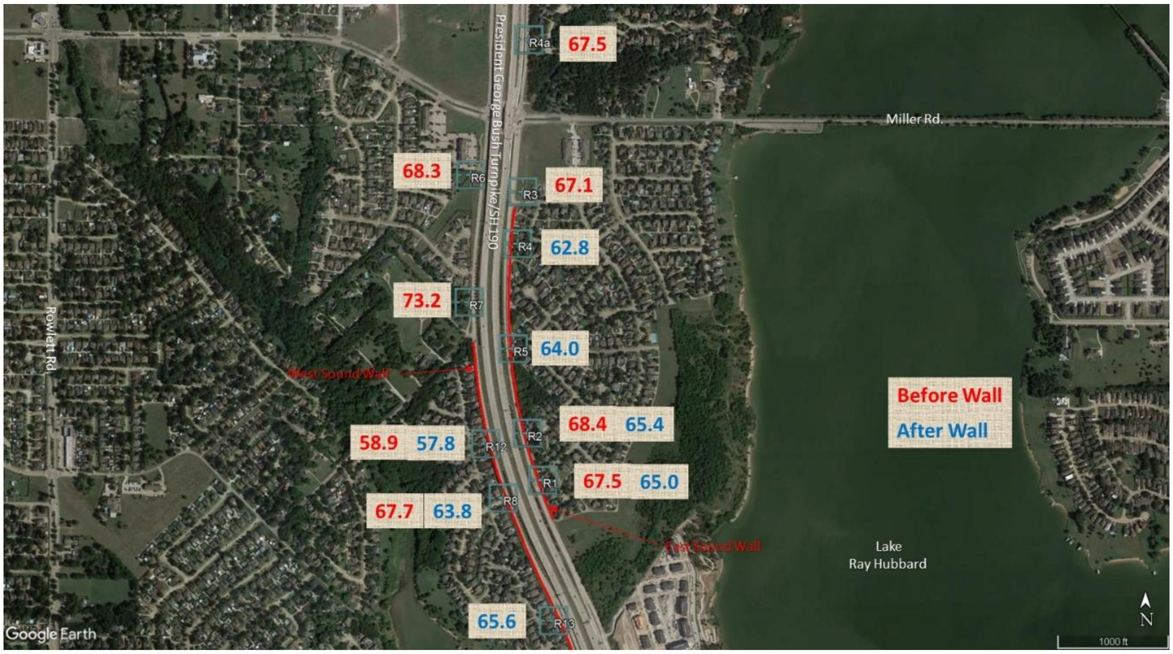


Figure 6.3 Average noise level results by receiver (pre- and post-barrier)

Table 6.3 shows the benefits of the noise wall addition by residential sites in the form of average noise level reductions for those four sites.

Table 6.3 Noise level reductions

Receivers	Noise Level Reduction (dBA)
R1. 5010 Southport Dr.	2.5
R2. 2205 Mermaid Cir.	3.0
R8. 4509 Meadowcove Dr.	3.9
R12. 2414 Brittany Dr.	1.1

The noise level reductions in the table above represent significant benefits provided by the noise wall additions. Two of the four residential sites had reductions of 3 dBA or more. Because of the logarithmic scale of the decibel unit, a 3-dBA differential represents a reduction of half of the acoustic energy reaching those residences, which is the equivalent of cutting the traffic in half. The reason for the smaller benefit provided by the wall addition to R12 is that this residence sits at a much lower elevation relative to the highway; the measurements at this site are conducted below the highway level, with a tall retaining wall and the existing noise wall sitting on top of the retaining wall. The retaining wall at this home is about 12-ft. tall, plus the 8-ft. tall noise wall provides protection to the residence from the traffic noise. Thus, there is a 20-ft. elevation differential for the diffracted noise to reach the receiver, and there is no line of sight to the source. Please see Section 2.2.8 for more details about receiver R12 and photographs. This residence consistently had the lowest noise readings throughout the data collection period, numbers that are significantly lower than at any other residential location measured in this study. Therefore, with the existing retaining wall already providing ample shielding, the noise reduction from the wall additions at this site are comparatively small.

6.1.1.1. Noise Impact

According to FHWA policies (*FHWA-HEP-10-025*), a traffic noise impact occurs when the existing or future noise levels approach or exceed the noise abatement criteria (NAC); TxDOT defines the level of approach as 1 dBA. The NAC are presented in Table 6.4 (*TxDOT 2011*). An impact can also occur when predicted future traffic noise levels substantially exceed the existing noise level, even though the predicted levels may not exceed the NAC.

Table 6.4 Noise abatement criteria

Activity Category	FHWA (dB(A) Leq)	**TxDOT (dB(A) Leq)**	Description of Land Use Activity Areas
A	57 (exterior)	**56 (exterior)**	Lands on which serenity and quiet are of extra-ordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (exterior)	**66 (exterior)**	Residential
C	67 (exterior)	**66 (exterior)**	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools , television studios, trails, and trail crossings
D	52 (interior)	**51 (interior)**	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios
E	72 (exterior)	**71 (exterior)**	Hotels, motels, offices, restaurants/bars, and other developed lands, properties, or activities not included in A-D or F.
F	--	**--**	Agricultural, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing.
G	--	**--**	Undeveloped lands that are not permitted.

Thus, TxDOT policy indicates that an outdoor residential area, such as the subject of these analyses (Activity Category B, in Table 6.4), is considered to have an impact if the noise level is 66 dBA or above (*TxDOT 2011*).

For the pre-barrier condition, 68% of the total individual noise measurements (72 out of 106) correspond to an impact. For the average levels by residential location, all of the residences, except for one (R12), experienced an impact (Table 6.5).

Table 6.5 Average noise levels and impact, by receiver (pre-barrier)

Receivers	Field Tests	
	Actual Level dBA	Impact
R1. 5010 Southport Dr.	67.5	Yes
R2. 2205 Mermaid Cir.	68.4	Yes
R3. 4901 Harborview Dr.	67.1	Yes
R4a. 3401 Francesca Ct.	67.5	Yes
R6. 4317 Rose Leaf Ct.	68.3	Yes
R7. 2629 Kirby Rd.	73.2	Yes
R8. 4509 Meadowcove Dr.	67.7	Yes
R12. 2414 Brittany Dr.	58.9	No
R13. 1906 Benedict Ct. *	67.0	Yes

*Receiver R13: one field test in pre-barrier stage

The explanation for receiver R12 not experiencing an impact is due to the same reason indicated earlier: the site is below the highway level, next to the tall retaining wall.

On the other hand, receiver R7, on Kirby Road, had the highest noise readings among the receivers studied. This house is next to the frontage road, and also is in proximity to the main lanes, and there is no noise wall to shield it from the noise. Moreover, the receiver is at the same level with the highway main lanes and frontage roads, so the noise has a direct path to the receiver. More information on this residence, as well as photographs, can be found in Section 2.2.6.

For the post-barrier condition, 28% of the total measurements (51 out of 185) correspond to an impact. For the average levels by residential location, none of the residences experienced an impact (Table 6.6). This is another indicator of the effectiveness of the noise wall additions.

Table 6.6 Average noise levels and impact, by receiver (post-barrier)

Receivers	Field Tests	
	Actual Level dBA	Impact
R1. 5010 Southport Dr.	65.0	No
R2. 2205 Mermaid Cir.	65.4	No
R4. 4902 Bayport Cir.	62.8	No
R5. 4714 Petersburg Dr.	64.0	No
R8. 4509 Meadowcove Dr.	63.8	No
R12. 2414 Brittany Dr.	57.8	No
R13. 1906 Benedict Ct.	65.6	No

6.1.2. Noise by Test Date

Noise levels were analyzed by measurement date throughout the data-collection period. A chart showing total averages for measurements by date is shown in Figure 6.4. The most noticeable aspect of this chart is that it depicts a substantial reduction in noise levels after the wall additions were in place. The benefits provided by the wall in the form of reduced noise levels are evident in the test measurements from August 2019 through November 2020. The noise levels for the pre-barrier and the post-barrier are fairly consistent within each data-collection period; the pre-barrier levels are consistently higher and the post-barrier levels are consistently lower, when compared to each other. Another important observation is that, within each data-collection period, a seasonal trend can be observed: in general, higher noise levels are associated with the winter months; conversely, the noise levels are lower in the warmer months. This is a common noise seasonal pattern relating colder temperatures with higher noise levels. This seasonal trend where noise levels are lower during the warmer months and increase during the colder season can be observed twice in the chart, once for the pre-barrier period and once for the post-barrier period.

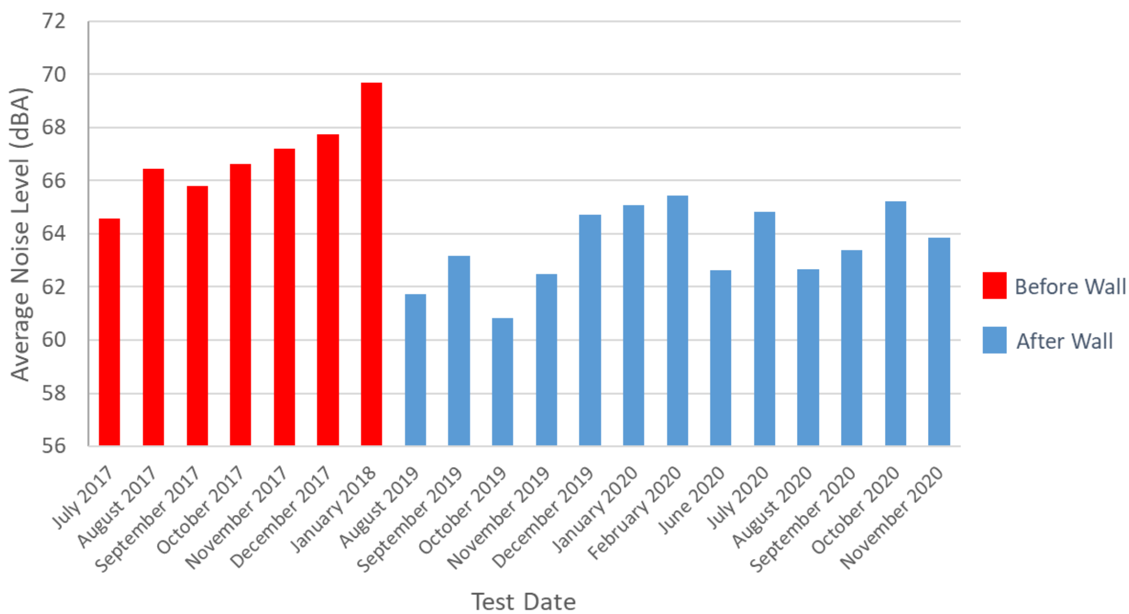


Figure 6.4 Average noise levels by test date

Another way to analyze the data is by receiver location. A plot illustrating this analysis for the pre-barrier stage is presented in Figure 6.5, where each line corresponds to one of the eight receivers for that data-collection period. The seasonal variation trend can be observed. This chart also clearly shows the loudest test site (R7) and the quietest test site (R12) as easily distinguished from the other residences, as explained in the previous section.

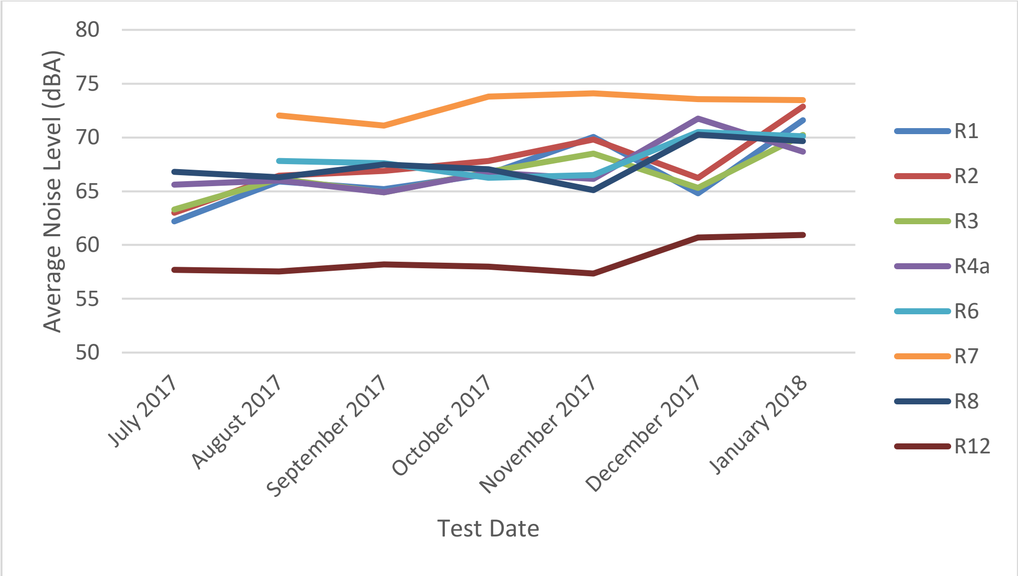


Figure 6.5 Average noise levels by receiver and test date (pre-barrier)

Figure 6.6 shows a similar plot, but with the post-barrier data as well; this graph shows all receivers. This plot also shows that receiver R12 remained the quietest location. Receiver R7 was discontinued for the post-barrier data-collection period, so among the remaining and added sites there is not one that stands out as consistently louder than others. The seasonal trend is also observable, and more importantly, the obvious drop in noise levels with the new noise wall additions since August 2019.

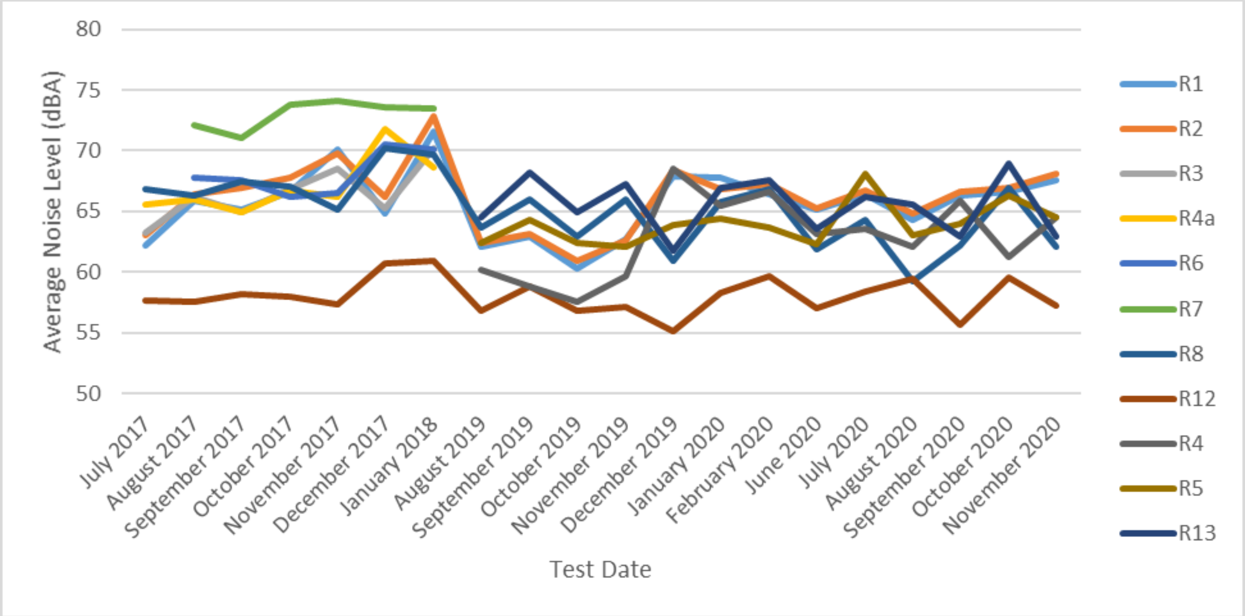


Figure 6.6 Average noise levels by receiver and test date (pre- and post-barrier)

6.1.3. Noise by Time of the Day

Noise measurements were taken at different times of the day and night, to account for different atmospheric conditions as well as for hourly variations in traffic patterns throughout the day. The measurements are grouped into three categories: morning, afternoon, and evening. The influence of the time of the day on the noise results is shown in Figure 6.7. The chart shows that evening is generally the loudest time for traffic noise at SH 190/PGBT. This can be explained by the high traffic volume during the evening rush hour at around 5:00 p.m.

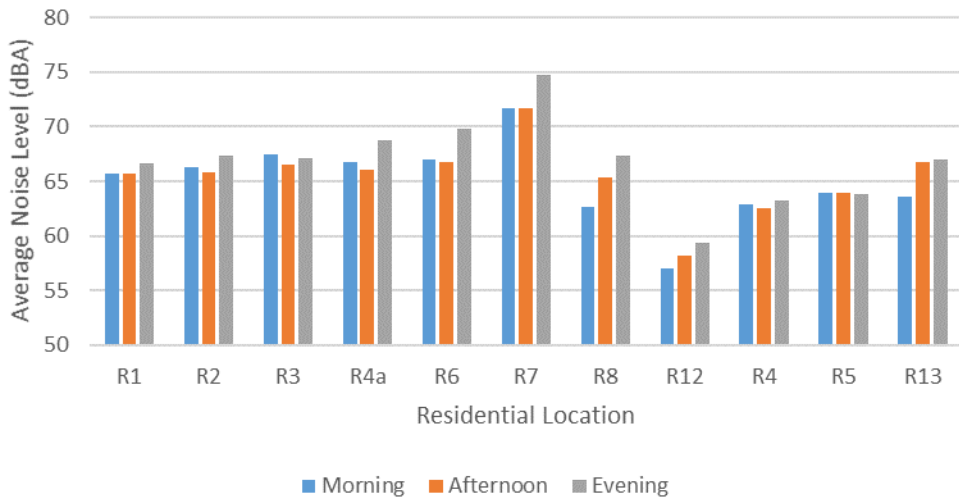


Figure 6.7 Noise measurements by time of the day and receiver

6.1.4. Noise and Weather Variables

6.1.4.1. Temperature

The weather variable that is known to have a greater influence on tire-pavement noise generation is temperature. In general, under colder conditions, the pavement materials as well as the rubber in the tires are stiffer and produce higher noise levels than under warmer conditions. Thus, cold temperatures are correlated to higher tire-pavement noise generation (1 dBA per 10°C) *(Sandberg)*. Therefore, for instance, a change from a temperature of 95°F, typical for the summer in Dallas, to a temperature of 40°F, which is very common in the winter, represents an increase of 3 dBA in tire-pavement noise generation alone, with all the other conditions staying constant. Such a difference in noise levels, attributable to temperature change only, represents a significant increase.

The relationship between noise measurements and air temperature was investigated in Figure 6.8; the chart shows the scattered temperature vs. noise level data points for each of the measurements collected during the project, including before and after wall noise tests. The temperature range for all the measurements taken for the pre-barrier condition was between 45.7 and 97 °F, while the average temperature was 71.6 °F, the standard deviation was 13.3 °F, and the coefficient of variation was 18.6%. For the post-barrier condition, the temperature range was between 35.8 and 98.8 °F, while the average temperature was 74.7 °F, the standard deviation was 17.0 °F, and the coefficient of variation was 22.8%. These and other statistics for temperature and average noise level are shown in Table 6.7. There is a correlation showing that the lower temperatures are linked to higher noise levels, as explained in previous paragraphs, even though the R^2 values are small, but this is typical of other temperature vs. noise level data sets that have been collected during this and other similar projects.

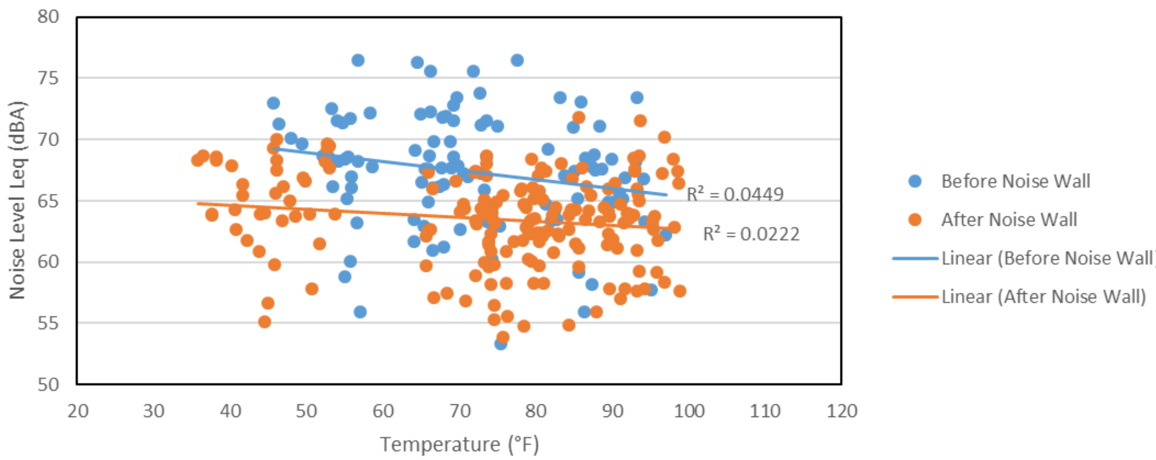


Figure 6.8 Noise level and temperature

Table 6.7 Statistics for temperature and noise level

	Before Wall		After Wall	
	Temperature (°F)	L_{eq} (dBA)	Temperature (°F)	L_{eq} (dBA)
Mean	71.6	67.4	74.7	63.5
Standard Deviation	13.3	4.6	17.0	3.7
Median	69.7	67.7	78.7	63.8
Mode	87.3	68.6	85.7	64.5
C.V. (%)	18.6	6.9	22.8	5.8
Minimum	45.7	53.3	35.8	53.9
Maximum	97.0	76.5	98.8	71.8
Range	51.3	23.2	63.0	17.9
Count	106	106	185	185

6.1.4.2. Wind

The wind and its direction could be important factors influencing the noise levels reached at the neighborhood residential locations. Strong winds blowing towards the residential areas can carry the noise generated by the traffic; for this to happen, it is required that both the wind speed is high enough, and that the wind is blowing in the direction of the receivers. Wind speed and wind direction are analyzed in the next sections.

6.1.4.2.1. Wind Speed

Figure 6.9 shows a plot of noise levels and wind speed, in which each data point corresponds to a noise measurement and the average wind speed that was obtained by the weather station during the noise measurement, for both the pre-barrier and post-barrier periods. It shows that there is some correlation between wind speed and noise levels at the neighborhood (higher noise levels correlated with higher wind speeds). The correlations for the pre- and post-barrier data sets are very much analogous, which is indicated by the almost parallel regression lines. Similarly, Figure 6.10 presents the relationship between noise levels and high wind speeds (maximum gusts), showing comparable correlations, indicating that there is an influence of the gusts on noise levels measured at the neighborhood, without considering the wind direction yet. And again, the regressions represent almost parallel lines for the pre- and post-barrier data sets.

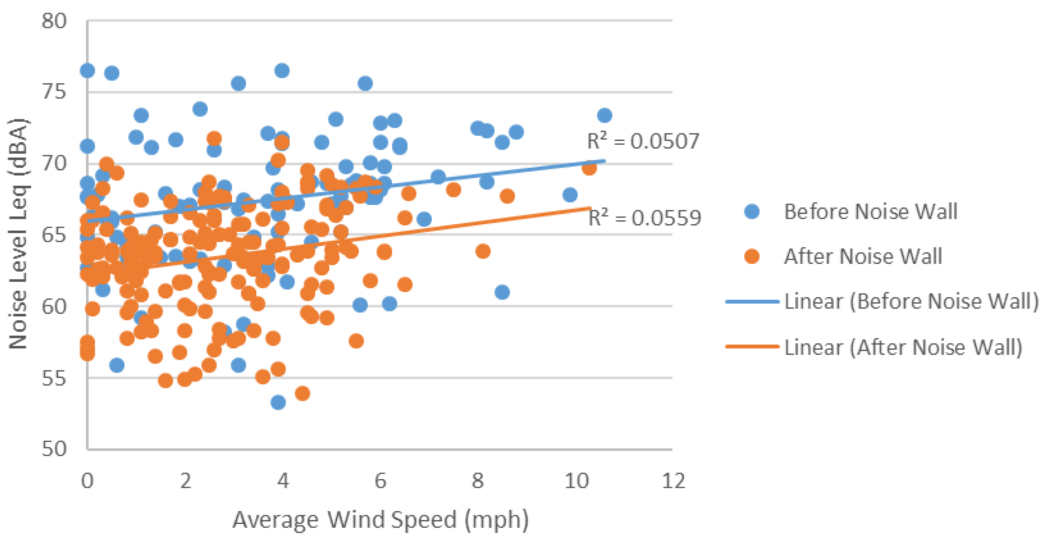


Figure 6.9 Noise level and average wind speed

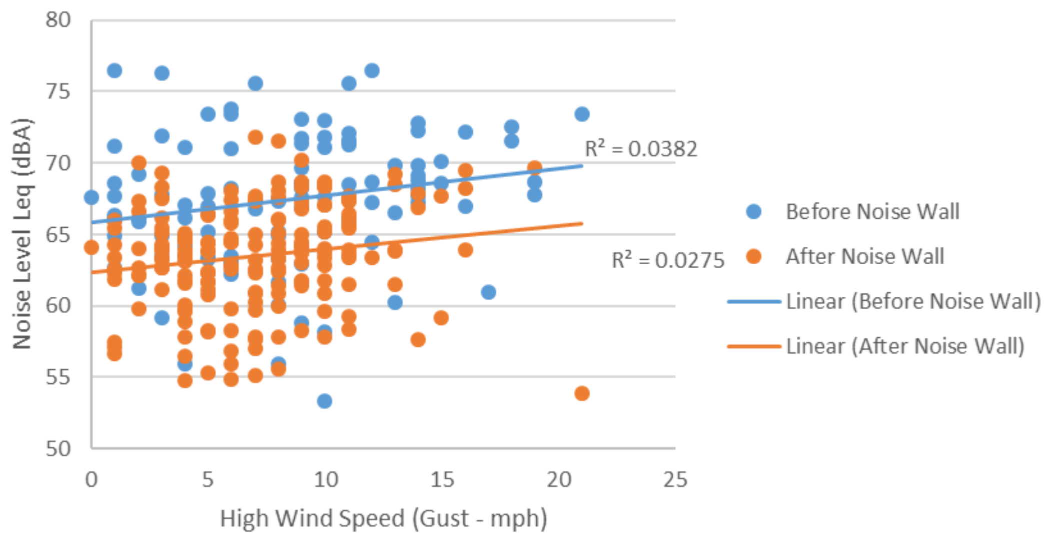


Figure 6.10 Noise level and high wind speed

6.1.4.2.2. Wind Direction

The analysis of the wind direction is presented separately for the pre- and post-barrier data-collection periods. For the wind direction analysis, given that throughout each test period, for an individual test (normally 10 minutes) the wind direction commonly fluctuates, the dominant wind direction for each test is considered to be that of the highest gust within that period. Therefore, for each test, there is an average noise level, an average wind speed, a high wind speed (gust), and a high wind direction. The average wind speed is a scalar, whereas the gust is a vector. Also, for this analysis, a 16-point compass rose is utilized. This means that there are 16 wind directions considered: the four cardinal directions north (N), east (E), west (W), and south (S); the four intercardinal directions, formed by bisecting the angle of the cardinal directions—northeast (NE), southeast (SE), southwest (SW), and northwest (NW); and the eight half-winds, i.e., the direction points obtained by bisecting the angles between the previous directions: north-northeast (NNE), east-northeast (ENE), east-southeast (ESE), south-southeast (SSE), south-southwest (SSW), west-southwest (WSW), west-northwest (WNW), and north-northwest (NNW). Each of these 16 directions forms a 22 ½° angle with the adjacent direction in the wind rose (Figure 6.11). Therefore, all the data for this wind direction analysis are grouped and averaged for each of those 16 directions.

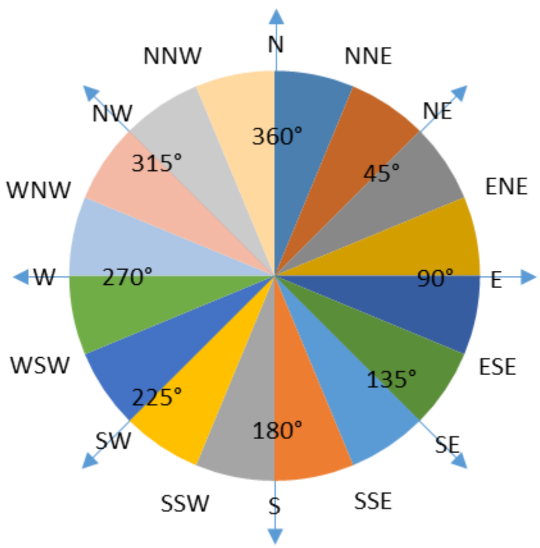


Figure 6.11 16-point compass rose

Given the complexity of the wind direction analysis, the results for each of the data sets are presented in a group of four charts. Each chart has 16 data points, with each data point corresponding to a wind direction of the 16-point compass rose. Therefore, all the data has been grouped and averaged by wind direction. The first chart (labeled as "a") shows the percentage of the tests associated with each wind direction. In the second chart (b), the average noise levels are plotted with the wind direction of the gust as well as the gust speed, combining a bar chart with a scattered plot. Finally, in the third (c) and fourth (d), the gust levels were plotted against the average noise levels, with (c) showing the values for each wind direction, and (d) showing the correlation. Therefore, the data points for (c) and (d) are identical and they are just being visualized in a slightly different way.

The charts for the pre-barrier data set are shown in Figure 6.12.

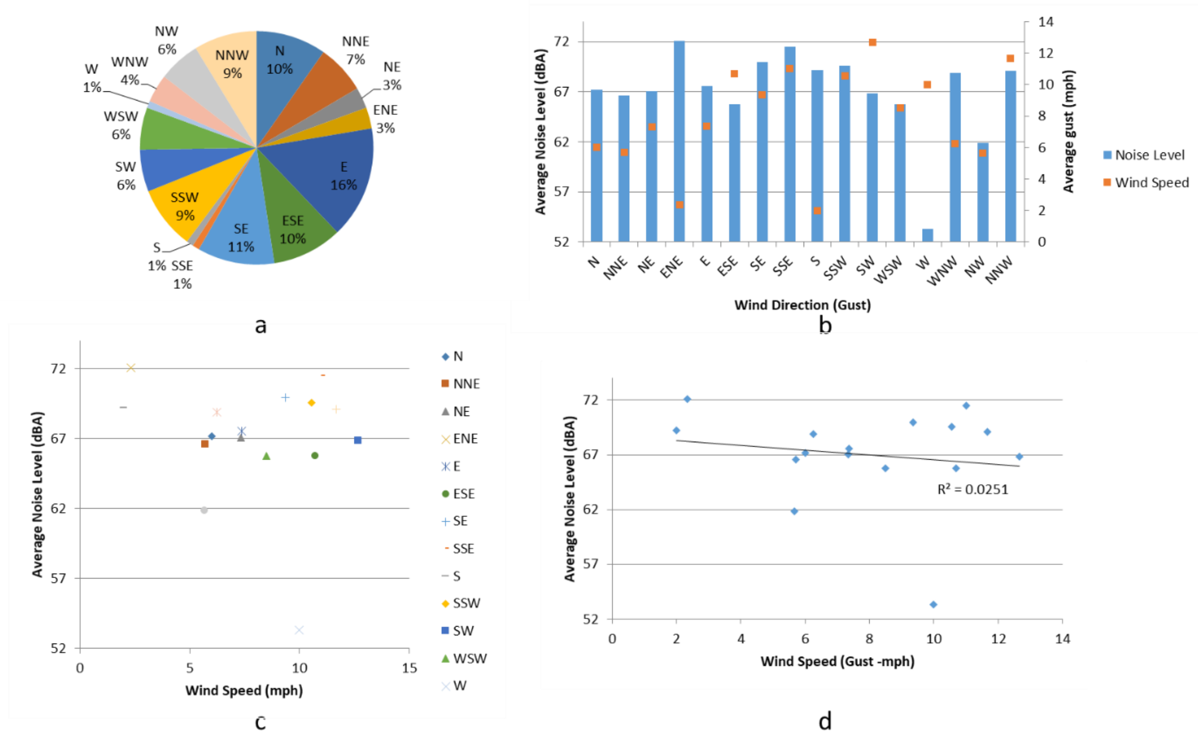


Figure 6.12 Pre-barrier wind, wind direction and noise: a) Dominant wind direction by percentage of time; b) Average noise levels and average gusts by direction; c) Average noise level vs. average gust by direction; and d) Average noise level and average gust correlation

These charts indicate that for the measurements conducted in the pre-barrier condition, the majority of the time (16%) the gusts blew from the E direction, with the SE being the second-most dominant gust direction (11%), and N and ESE being close with 10% each (Figure 6.12 a). However, the highest average noise level (72.1 dBA) occurred when the gusts blew from the ENE direction (Figure 6.12 b and c). The lowest average noise level (53.3 dBA) occurred when the dominant wind came from the W direction, for which the average gust speed was 10 mph, which is relatively high (Figure 6.12 b and c); it should be mentioned that the W-direction dominant wind occurred only once in the 106 measurements in this data set. The correlation between gust speeds and average noise levels is poor and shows that louder noise levels happened with slower gusts, and vice versa (Figure 6.12 d).

For the post-barrier set of data, the wind analysis is presented in Figure 6.13.

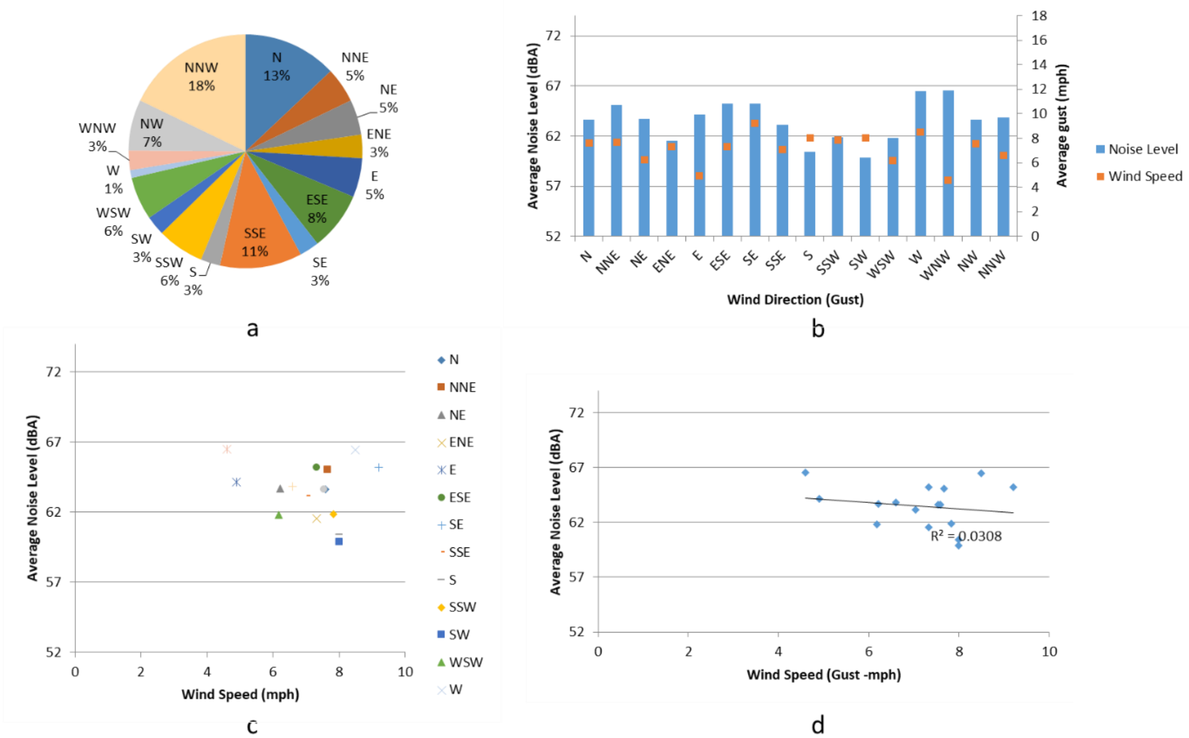


Figure 6.13 Post-barrier wind, wind direction and noise: a) Dominant wind direction by percentage of time; b) Average noise levels and average gusts by direction; c) Average noise level vs. average gust by direction; and d) Average noise level and average gust correlation

These charts indicate that for the measurements conducted in the post-barrier condition, the majority of the time (18%) the gusts blew from the NNW direction, with the N being the second-most dominant gust direction (13%), and SSE is close with 11% (Figure 6.13 a). The highest average noise level (66.5 dBA) occurred when the gusts blew from the WNW direction (Figure 6.13 b and c) and this corresponded to an average of 4.6 mph gust; the WNW dominant wind occurred only five times in 185 measurements. The direction with the lowest average noise level (59.9 dBA) was SW, for which the average gust speed was 8 mph (Figure 6.13 b and c). The correlation between gust speeds and average noise levels is poor and shows that louder noise levels happened with slower gusts, and vice versa (Figure 6.13 d).

6.1.4.3. Relative Humidity

The measurements for relative humidity for the pre-barrier and the post-barrier data collection periods are presented in Figure 6.14. The mean values were 55% and 58%, respectively. For the pre-barrier condition, there is a very small correlation with noise levels indicating that higher relative humidity values corresponded to slightly higher noise levels; for the post-barrier data, there is no correlation. These results are consistent with those of similar studies about relative humidity.

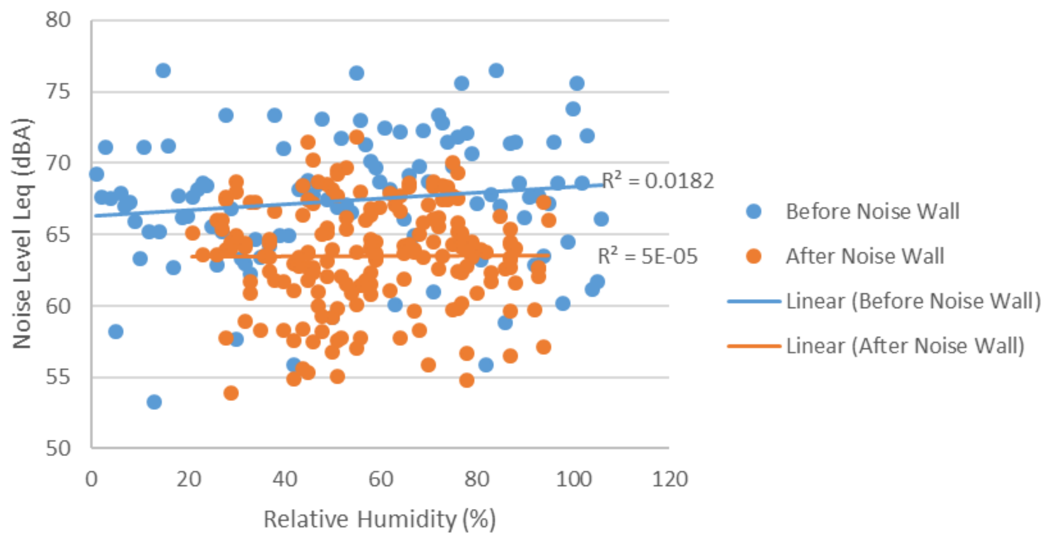


Figure 6.14 Noise level and relative humidity

Table 6.8 summarizes the analysis of weather variables along with noise levels, presenting the descriptive statistics.

Table 6.8 Statistics for weather variables and noise level

	Before Wall					After Wall				
	Temperature (°F)	Relative Humidity (%)	Avg. Wind Speed (mph)	Max. Wind Speed (mph)	L_{eq} (dBA)	Temperature (°F)	Relative Humidity (%)	Avg. Wind Speed (mph)	Max. Wind Speed (mph)	L_{eq} (dBA)
Mean	71.6	55.0	3.6	8.4	67.4	74.7	58.1	2.8	7.0	63.5
Standard Deviation	13.3	14.6	2.6	4.8	4.6	17.0	18.6	1.9	3.8	3.7
Median	69.7	58.0	3.7	9.0	67.7	78.7	57.0	2.5	7.0	63.8
Mode	87.3	69.0	0.0	9.0	68.6	85.7	87.0	0.0	4.0	64.5
C.V. (%)	18.6	26.5	70.9	57.4	6.9	22.8	32.0	69.8	54.3	5.8
Minimum	45.7	21.0	0.0	0.0	53.3	35.8	21.0	0.0	0.0	53.9
Maximum	97.0	84.0	10.6	21.0	76.5	98.8	95.0	10.3	21.0	71.8
Range	51.3	63.0	10.6	21.0	23.2	63.0	74.0	10.3	21.0	17.9
Count	105	105	102	103	106	185	185	185	185	185

6.2. Pre- and Post-Barrier Noise Statistical Analysis

In this section, the effectiveness of the noise barrier additions is analyzed by means of a t-test. The t-test is applied to the pre-barrier and post-barrier noise level residential measurements data sets. The goal of this analysis is to compare noise levels before and after the barriers were in place to ascertain whether the differences between the pre- and post-barrier conditions are significant. A t-test is used to determine if two sets of data are significantly different from each other. The test assumes that the variables being studied—in this case, measured noise levels—follow a normal distribution.

The frequency distribution of measured noise levels for the pre-barrier condition tests is shown in Figure 6.15, along with its histogram. Similarly, Figure 6.16 shows the graph for the post-barrier noise data. The sample sizes are relatively small, but approximately follow a normal distribution.

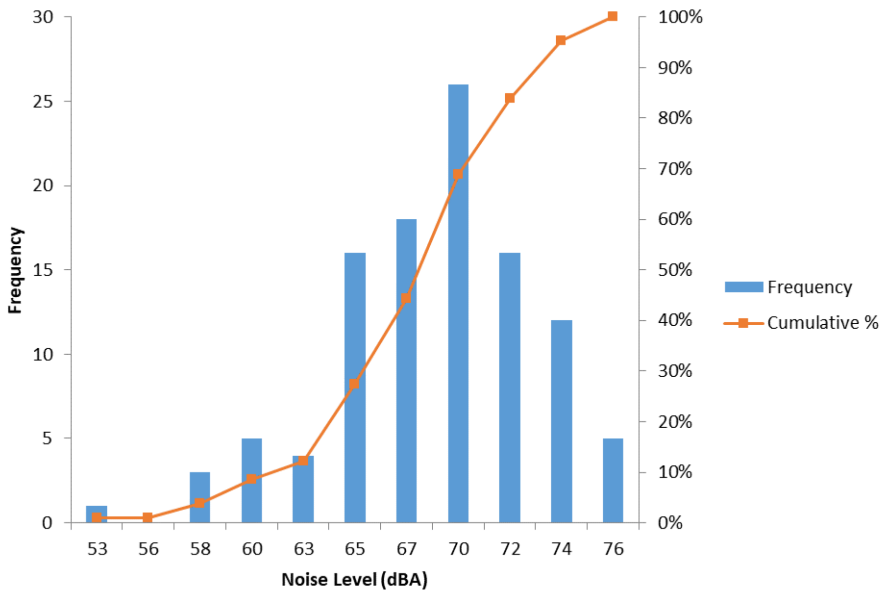


Figure 6.15 Frequency distribution for pre-barrier tests

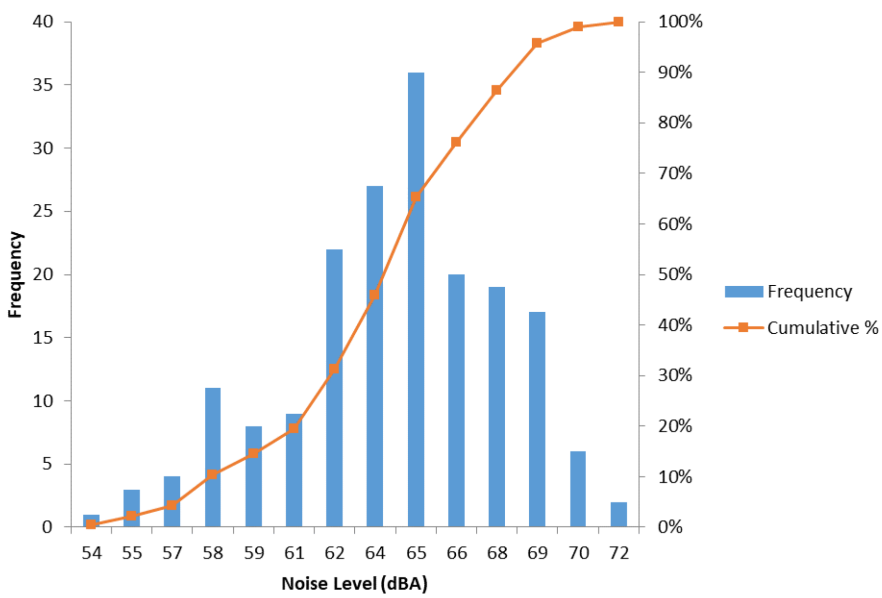


Figure 6.16 Frequency distribution for post-barrier tests

A two-sample t-test was performed with the data sets, with independent (unpaired) samples; the assumptions were equal variances, significance level α=0.05, and a two-tailed distribution. The null hypothesis in this case is that the barrier had no effect on the measured noise levels, and the alternative hypothesis is that the barrier had an effect. If the difference between these distributions is large enough, the null hypothesis would be rejected.

Table 6.9 shows the results for the t-test. The row containing the probability for the t-tests (p-value) is the second to last, and it has been highlighted. If the p-value is less than the significance level α, the difference in noise levels between the groups being compared is considered statistically significant, as was the case in this study (8.19E-14 < 0.05). Therefore, the null hypothesis is rejected, indicating that there is a statistically significant difference between the groups of tests; hence, the t-test supports the measurements indicating that the barrier indeed had an effect on noise levels.

Table 6.9 t-test for pre- and post-barrier noise levels

	Before	*After*
Mean (dBA)	67.4	63.5
Variance	21.430	13.467
Observations	106	185
Pooled Variance	16.360	
t Stat	7.850	
P(T<=t)	8.19E-14	
t Critical	1.968	

6.3. Insertion Loss Tests

Insertion loss (IL) is defined as the reduction of noise level at a given location due to the placement of a noise control device in the sound path between the sound source and that location. Therefore, these tests indicate the benefit that a sound wall provides in the form of a noise level reduction.

In order to conduct IL tests on this project, ideally, two sound pressure level meters and two operators are required to simultaneously perform a test, with one instrument and one operator in front of the noise wall and the other one behind it. The simultaneous operation of the sound meters ensures that the noise levels being measured correspond to the same traffic volume and mix and also to the same meteorological conditions. For this project, there were two opportunities to conduct IL tests, one before the transparent acrylic extensions were in place, and the other one after.

6.3.1. January 31, 2018 Tests

The first set of IL tests was performed on January 31, 2018. On this occasion, still before the new barrier extensions were in place, Mr. Dan Perge, with TxDOT, came to visit the site and kindly helped to operate one of the sound meters, while the CTR researcher operated the other one. Some images from those tests are presented in Figures 6.17 to 6.20.

Figure 6.17 Sound meter in front of noise wall

Figure 6.18 Sound meters in front of wall, and behind the wall, operated by Mr. Dan Perge

Figure 6.19 Mr. Dan Perge operating the sound meter behind the noise wall

Figure 6.20 Sound meter in front of wall, next to SH 190

The tests results are summarized in Table 6.10.

Table 6.10 January 31, 2018 IL Tests

Test Site	Start	End	Next to traffic L_{eq} (dBA)	Behind Noise Wall L_{eq} (dBA)	IL (dBA)
R2	11:42	11:52	80.3	70.6	9.7
R1	12:10	12:20	80.5	70.7	9.8

The outcome of the tests was an IL value of close to 10 dBA for the two different test sites, receivers R2 and R1, on the east side of SH 190. Both tests show great similarity in the noise levels in front and behind the wall and consistency in the results. The intent for that day of field tests was to continue performing more IL tests at various sites. Unfortunately, after the second test, one of the noise meters stopped working, and no more tests could be performed with that instrument. In fact, that sound meter never worked again; it was sent to the manufacturer and could not be repaired. It had to be replaced.

6.3.2. December 17, 2019 Tests

The second opportunity to conduct IL tests happened on December 17, 2019, once the damaged noise meter was replaced by a new instrument; this time, the tests occurred after the new noise wall extensions were installed. On this occasion, Mr. Ray Umscheid, with TxDOT, came to visit the project site, and kindly helped with operation of one of the sound meters. Figures 6.21 to 6.24 show photographs of the tests, presenting the noise meter in front of the wall and behind the wall. Notice the new acrylic panels on top of the concrete walls.

Figure 6.21 Sound meter in front of east noise wall (Photo by Ray Umscheid)

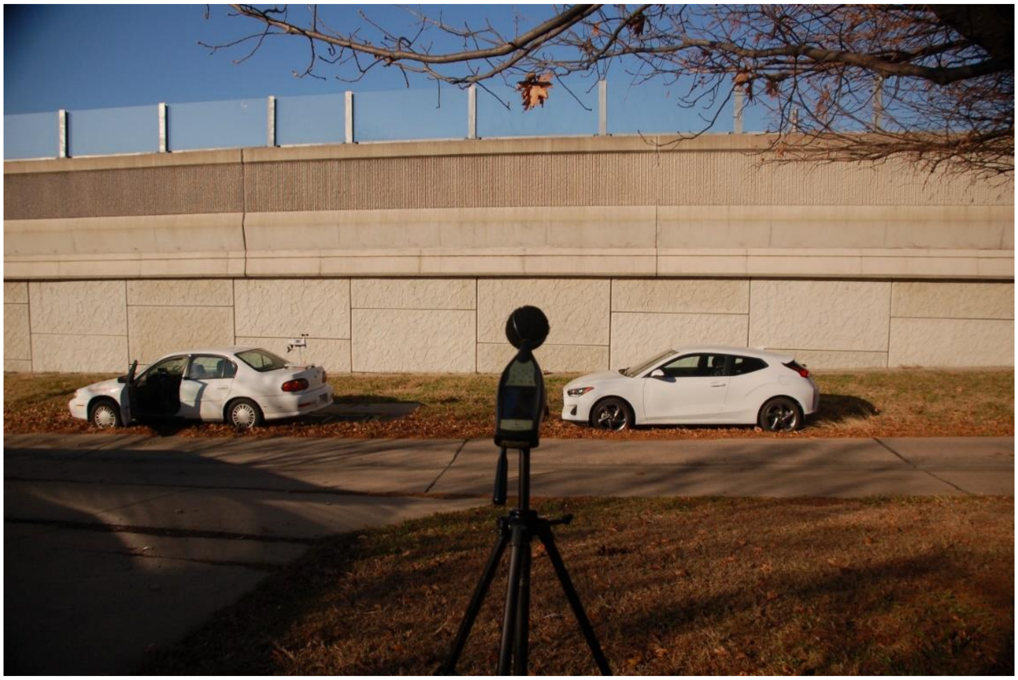


Figure 6.22 Sound meter behind noise wall at Receiver #4 site, during IL test

Figure 6.23 Sound meter at Receiver #4 site, during IL test

Figure 6.24 Mr. Ray Umscheid, operating sound meter at Receiver #1 site

The results of the IL tests are summarized in Table 6.11. These tests indicate even higher IL values than those obtained in January 2018, before the acrylic additions to the wall were in place; these tests represent almost a 3-dBA improvement in the wall's performance over the previous set of tests, which is a significant benefit, corresponding to a reduction of about a half of the acoustic energy. These numbers confirm the effectiveness of the new wall additions.

Table 6.11 December 17, 2019 IL Tests

Test Site	Start	End	Next to traffic L_{eq} (dBA)	Behind Noise Wall L_{eq} (dBA)	IL (dBA)
R4	9:34	9:44	80.5	68.3	12.2
R4	9:47	9:57	81.3	68.7	12.6

6.4. Frequency Spectra

In this section, the frequency spectra of the noise measurements are analyzed. The noise data was analyzed in one-third octave band spectra averaged throughout the pre- and post-barrier testing periods for each location. This analysis illustrates the distribution of noise levels before and after the barrier, among the different frequencies, for each of the residential sites. The graphs for the east side locations are shown in Figure 6.25, and those for the west side locations are presented in Figure 6.26. The locations have been split into east and west of the turnpike for the purpose of organizing them in these plots, as there are eleven total locations. Some of these locations only have pre-barrier or post-barrier spectra recorded. This happens for those receivers that were only part of the study during either the pre- or the post-barrier phase (i.e., R#3, R#4a, R#6, and R#7 were only part of the pre-barrier phase, and R#4 and R#5 were only part of the post-barrier phase).

The plots show that most of the locations present a peak at the 1250 Hz or 1 kHz frequency bands. The shapes of all the spectra are very similar, for both pre- and post-barrier curves. The plot for receiver R#12 stands out because it is flatter and with lower noise levels for all frequency bands than those of the other receivers. This is explained by the additional shielding this location gets from the embankment, as mentioned before. This additional shielding also explains why the pre- and post-barrier spectra show virtually no change for this receiver, indicating that the panels do not represent a substantial noise change. Comparing pre- and post-barrier plots for the other receivers, the spectra look similar, but the barrier additions clearly provide higher reduction in the higher frequencies.

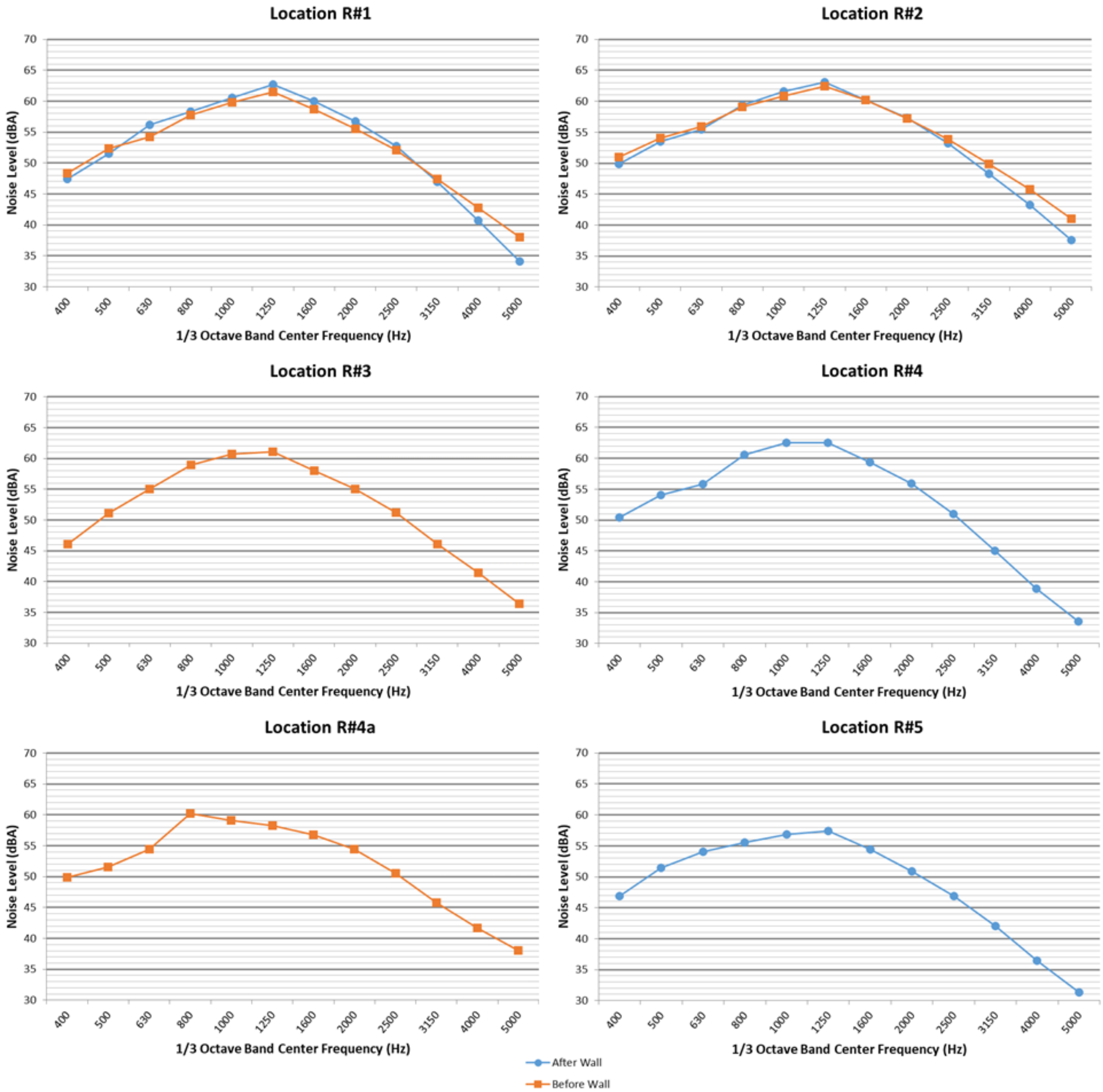


Figure 6.25 Frequency spectra for the east side residential locations

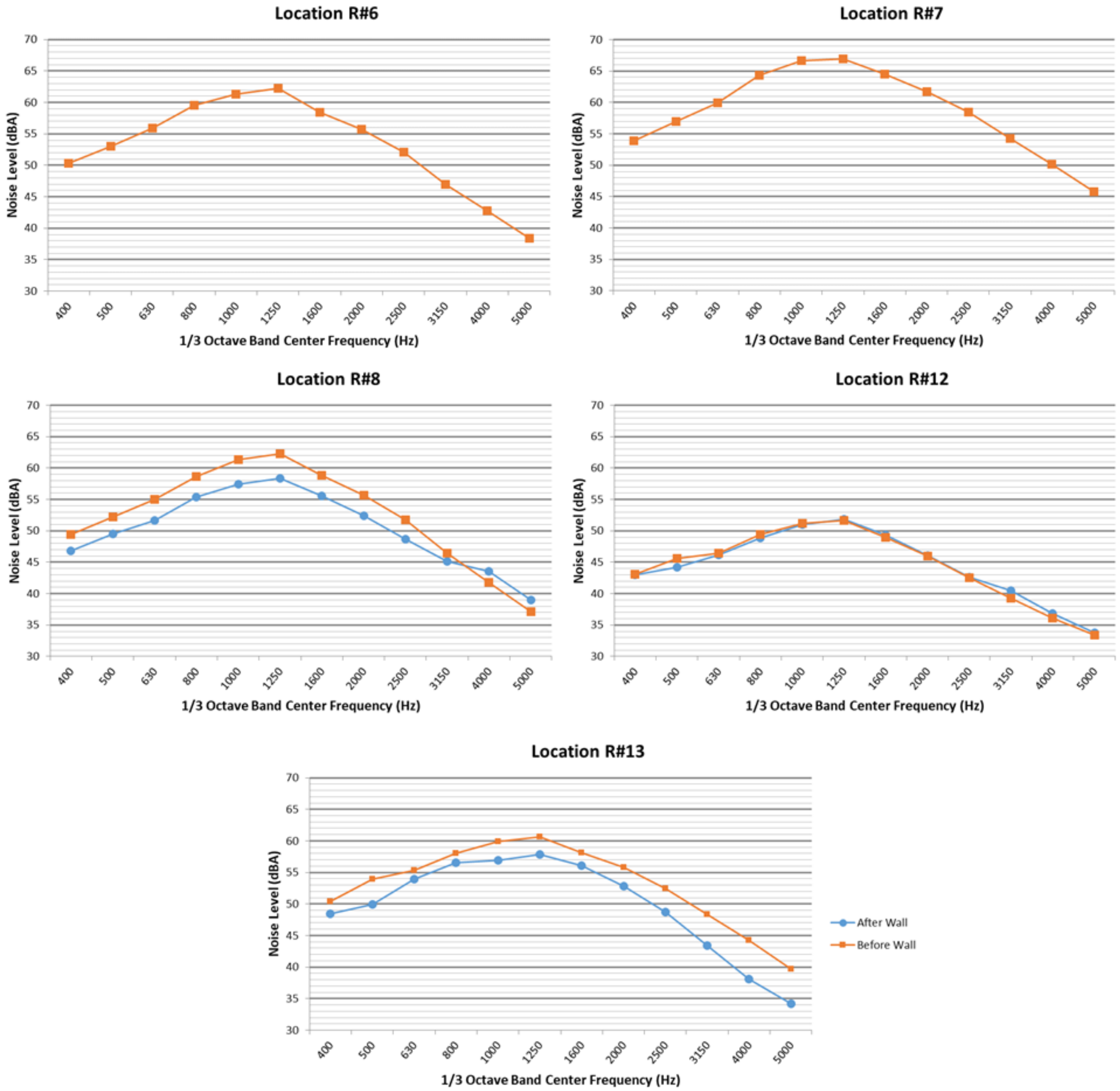


Figure 6.26 Frequency spectra for the west side residential locations

6.5. Summary and Discussion of Results

This chapter presents the results of noise measurements and data analysis for the pre- and post-barrier stages of the SH 190 project. The measurements analyzed comprise two periods: the first one, from July 2017 until January 2018, before the barrier was installed, and the second one, from August 2019 to November 2020, after the new panels had been installed.

Before the new noise barrier additions were installed, the noise results indicated that noise levels were indeed high at most of the receivers' locations studied in this project. All the sites but one represented a noise impact, according to TxDOT policy; therefore, the neighbors' complaints were warranted and, in light of the noise levels measured, it was recommended to implement additional mitigation measures.

After the new transparent panels were added, the noise results experienced a significant drop, which on average was 3.9 dBA. However, this figure is not entirely representative of the effectiveness of the panels, because some of the receivers changed from the pre-barrier to the post-barrier tests. Considering only the receivers that remained from the pre- to the post-barrier stage, the average noise reduction was about 3 dBA, which is still a very significant benefit.

Another way in which the benefits provided by the new barriers are manifested is in the elimination of noise impacts. Prior to the barrier installation, all but one of the receiver locations represented an impact (66 dBA or above). After the barriers were installed, the impacts were eliminated at those locations shielded by the barriers, confirming the effectiveness of the new wall additions.

Weather variables—primarily temperature and wind speed—appeared to have influenced the noise levels. The various times of the day during which the tests are performed—morning, afternoon, and evening—seemed to have a slight impact on noise levels, especially considering that the evening tests consistently represented the times with higher noise levels. These are very likely associated with higher traffic volumes during those times of the day as well.

The seasonal variations also seemed to have an impact on the noise levels detected. Colder seasons were related to higher noise levels. The graphs showing average noise levels by date present two similar patterns of the seasonal variations of noise, one for the pre-barrier condition and the other one for the post-barrier condition, clearly relating higher noise levels with colder months.

In regard to the sample size, the pre-barrier data collection period consisted of seven months, and the post-barrier period spanned thirteen months. It would have been desirable to have longer data-collection periods. For the pre-barrier condition, there is no data for the months of February to June. For the post-barrier condition, there is no data from March to May; it was planned to have a longer testing period, but the delays in the noise wall installation, as well as the coronavirus pandemic, prevented this from happening. Having at least a complete year of data would have been ideal to represent all seasonal changes and their influence on noise.

The IL tests performed both before and after the noise barriers were installed confirm two findings: 1) the effectiveness of the existing concrete walls, which provide almost 10 dBA of IL, a significant benefit in itself, and 2) the substantial increase in benefit provided by the transparent panels, which improve the initial IL by about 3 dBA. This result implies that the presence of the panels accounts for a reduction of about half of the total acoustic energy.

Chapter 7. Noise Wall Monitoring

As a result of the research conducted in this project, the two SH 190 noise walls were retrofitted with additions to provide more height and increase their coverage. This chapter presents the activities related to monitoring the noise walls. The purpose of these monitoring activities was to inspect their installation, detect any problems, and verify their integrity and performance over time.

7.1. Introduction

The project location is illustrated in Figure 7.1; the SH 190 section of interest, between south of Miller Road and the north shore of Lake Ray Hubbard, includes the two existing noise walls on either side of the roadway, protecting the Harborside Community, on the east side of the road, and the Ridgecove Community, on the west side of the road.

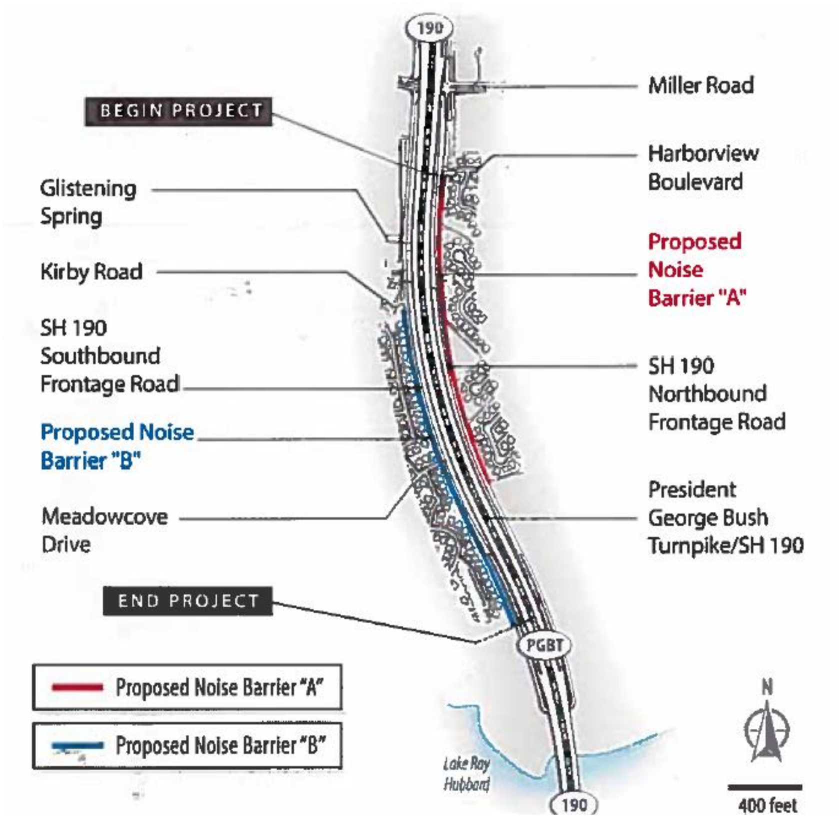


Figure 7.1 Project location (Source: TxDOT)

In 2018, the noise modeling and analysis described in Chapter 4 was performed, and its outcome was the recommendation to increase the height of both of the existing 8-ft. noise walls. Considering this as a pilot project, and based on the other experiences from this project on I-30 (*Trevino 2020*), TxDOT decided to retrofit the walls with transparent noise panels.

Section 1.3.5 presented a description of the existing sound walls. Both existing concrete sound walls on either side of SH 190 have the same design and aspect. Their total height is 8 ft., with the bottom 3-ft. part consisting of a concrete rail, and the top 5 ft. consisting of cast-in-place concrete barrier panels. Drawings of the existing walls showing the side view and the section view are presented in Figure 7.2.

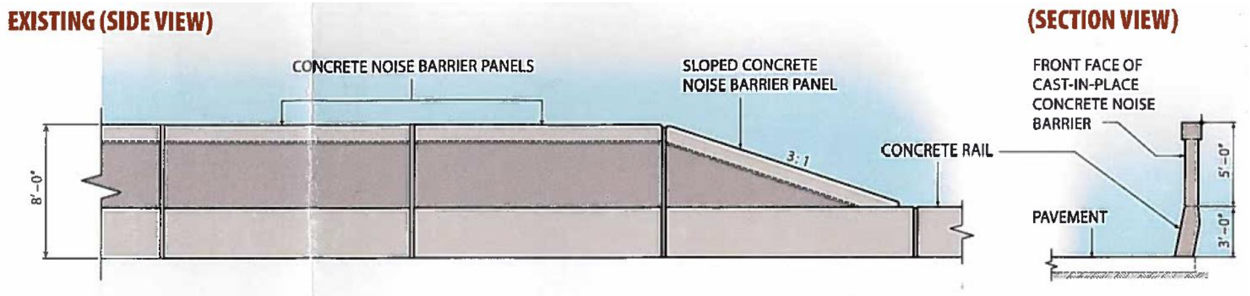


Figure 7.2 Existing SH 190 noise walls drawings (Source: TxDOT)

The acrylic noise wall additions are 4-ft. high and are designed to be attached to the top of the existing concrete and held in place by metal supports. The proposed walls with the new additions are shown in Figure 7.3.

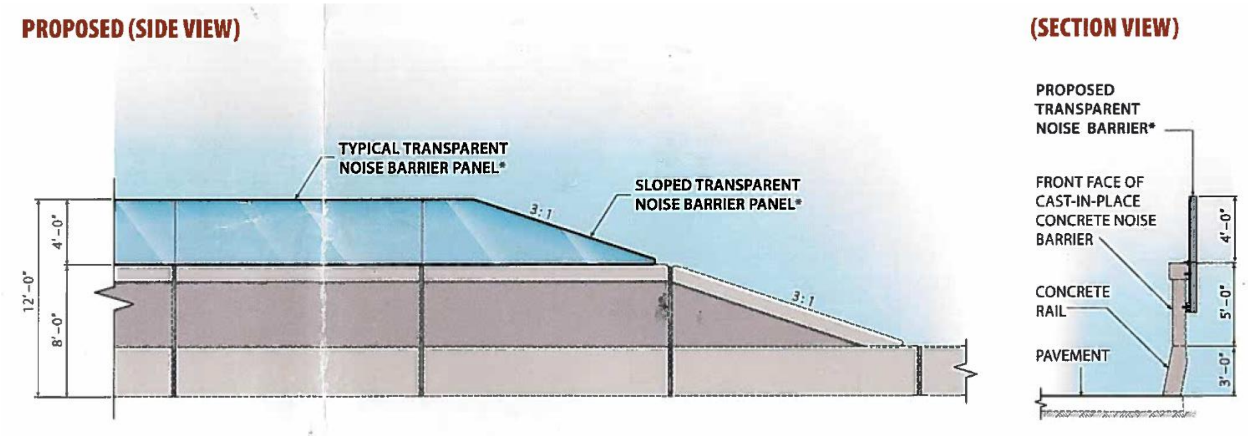


Figure 7.3 Proposed SH 190 noise walls drawings (Source: TxDOT)

There is a detail in the section view of Figure 7.3 that was not exactly constructed as the drawing indicates: the vertical metal supports were not actually anchored behind the concrete wall and bolted to the back of the wall; they were just bolted to the top of the concrete surface without using the back of the wall. This will be seen in subsequent photographs in this chapter.

7.2. Noise Wall Installation

The construction project for the installation of the noise wall additions was let in October 2018; construction was scheduled to start in January 2019 and to be completed in March 2019. However, the installation was delayed: it started in May 2019 and was finished at the beginning of August 2019.

This installation consisted of drilling and bolting vertical metal supports and subsequently sliding acrylic panels in between the metal supports. Four bolts, drilled into the top of the existing concrete wall, secure each vertical post to the top of the concrete; there is no additional reinforcement from either side. In between the metal parts and the acrylic panels, rubber gaskets are placed to achieve seal and prevent the sound from traveling through the openings. The height of the vertical supports, as well as the acrylic panels, is 4 ft. for both the east and west side walls.

The transparent acrylic panels are made of a material called Acrylite, manufactured by Evonic. These panels, on top of the existing 8-ft. tall concrete walls, make for a total wall height of 12 ft. The length of the panels varies to accommodate for the curvature of the geometry of the wall and frontage roads. Most of them are either 6- or 7-ft. long. The panels are 0.5-in.-thick. At either end of the walls the panels are tapered to match the sloped design of the existing concrete walls, as shown in the side view of Figure 7.3.

The total cost for the installation project was $1,735,987. The company that performed the installation is called Post L Group, and they worked as a subcontractor for Select Striping, LLC, the main contractor on this job.

There was a 6- to 10-person crew working every day, including traffic control. The same crew worked on both the east and the west installations. They moved back and forth between the two sides.

The work was performed from the highway side only. Sometimes the crew performed some installation operations from the neighborhood side, but in these cases, the workers were temporarily lifted and suspended in the air by the construction lifting platform to the neighborhood side from the highway side.

Traffic control consisted of a crash truck and traffic cones, providing closure of the outside lane of the frontage road only, leaving the inside lane open to traffic at all times. The main lanes remained undisturbed by this installation.

The heavy lifting equipment for both crew and equipment consisted of two Skyjack scissor lifts and a SkyTrack telehandler.

7.2.1. Installation Chronology

The installation of both the east and west noise wall extensions started on May 6, 2019, and was concluded during the first week of August 2019. There was an initial delay that moved the installation from January 2019 to May 2019, due to fabrication issues. Installation activities took place every weekday, from 8:00 a.m. to 4:00 p.m. However, the foreman at the site mentioned that work operations actually had to conclude at 3:40 p.m. every day, because the traffic control had to leave before 4:00 p.m.

The foreman also mentioned that they experienced a few delays in the installation, due to some unavailable materials: at times, their progress was halted due to not having all the necessary supplies from the manufacturer. In spite of these delays, they were still on schedule (after the initial delay due to the aforementioned fabrication issues). The total time allotted for the completion of the job was 43 days.

Three field trips were conducted by CTR during the installation of the walls; these occurred during the months of May, June, and July of 2019; by the time the August trip was conducted, the wall was completely finalized. During the May 8, 2019, monitoring trip, no progress was observed in the actual construction of the walls; the installation had not yet begun and only some preparation work could be observed, such as the presence of some traffic control devices (cones) and some equipment.

By the June trip, the crews had already made substantial progress with the installation; they had almost finished with the placement of the vertical metal supports for the wall on the southbound side (west); there were only a few of those supports missing. On the northbound side (east), they were about halfway done with the placement of the vertical supports. At the time, no acrylic panels had been installed yet on either side.

Figures 7.4 to 7.15 present photographs of the installation progress from June 13, 2019.

Figure 7.4 Noise wall installation on the east side (June 13, 2019)

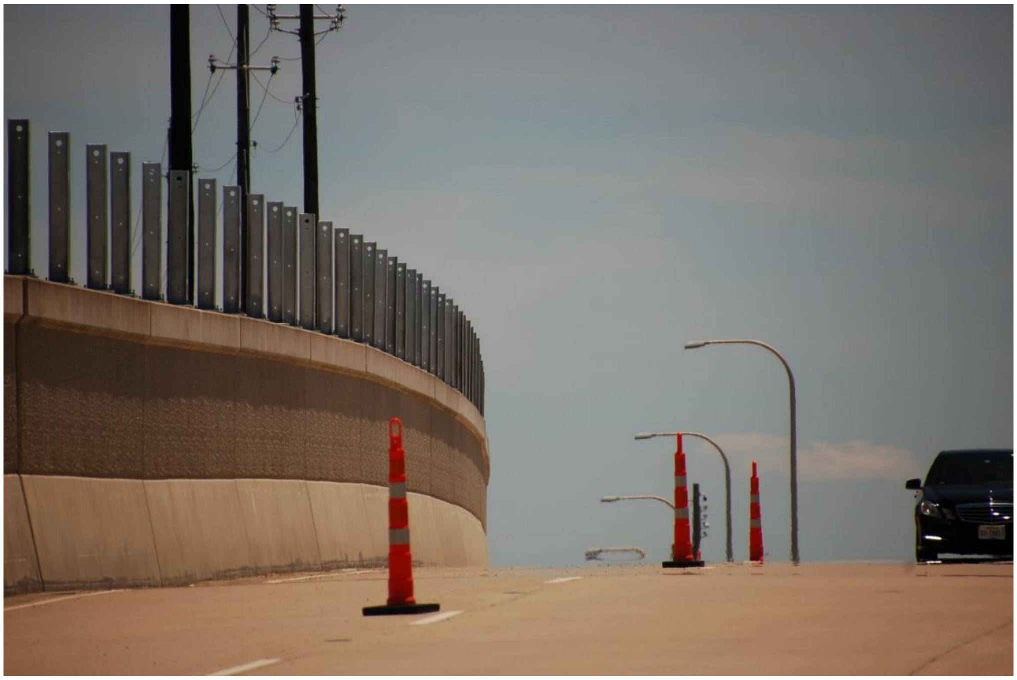


Figure 7.5 Noise wall installation on the east side (June 13, 2019)

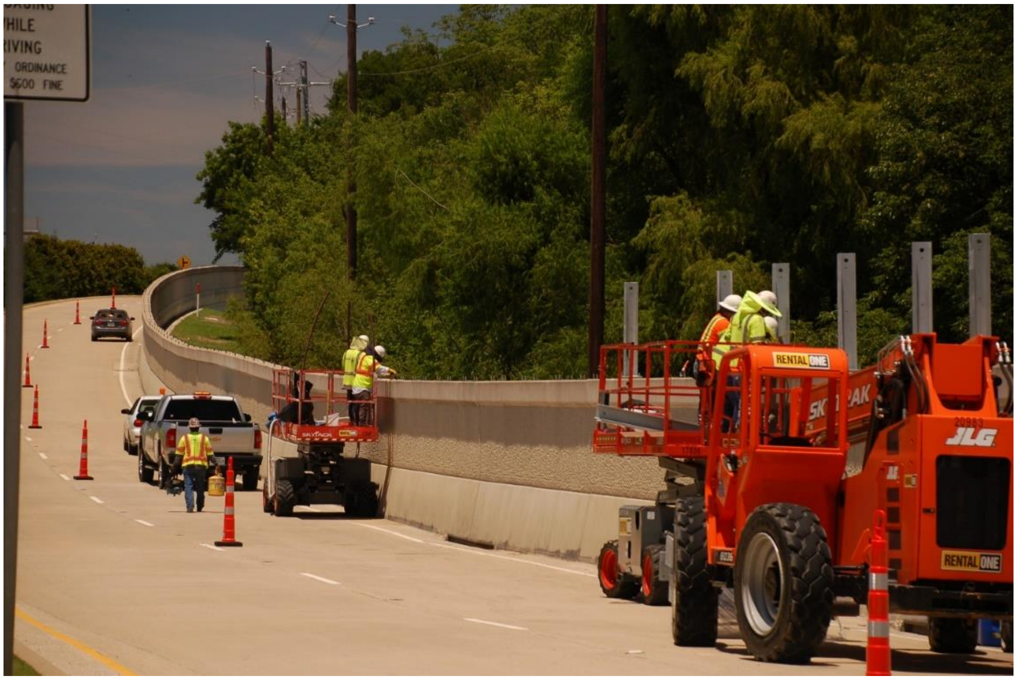


Figure 7.6 Noise wall installation on the east side (June 13, 2019)

Figure 7.7 Noise wall installation detail on the east side (June 13, 2019)

Figure 7.8 Noise wall installation on the east side (June 13, 2019)

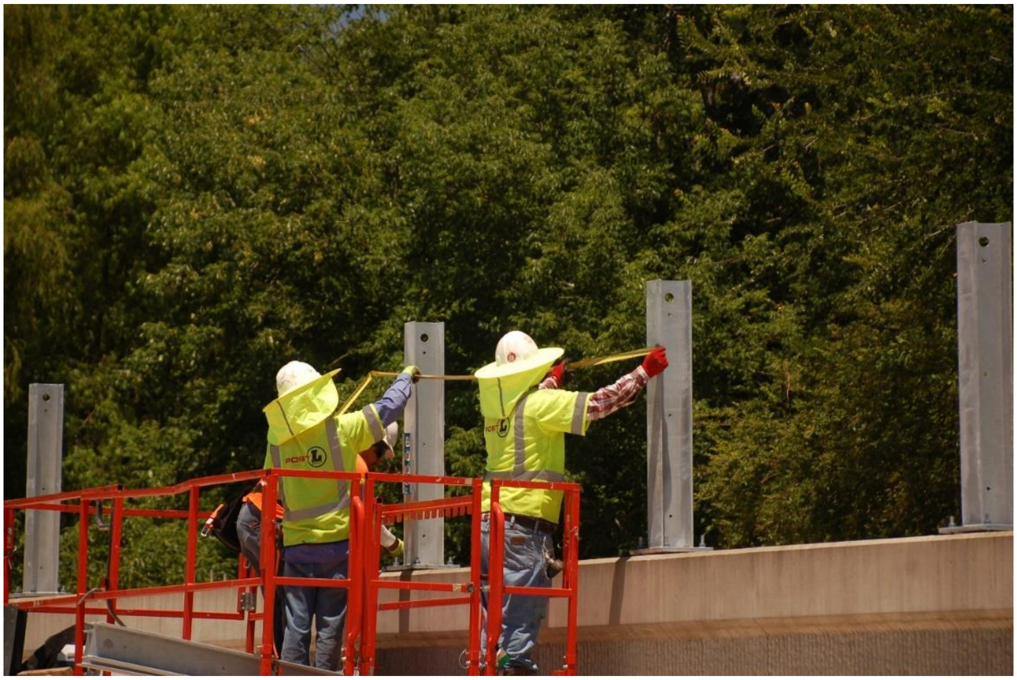


Figure 7.9 Noise wall installation on the east side (June 13, 2019)

Figure 7.10 Noise wall installation on the east side (June 13, 2019)

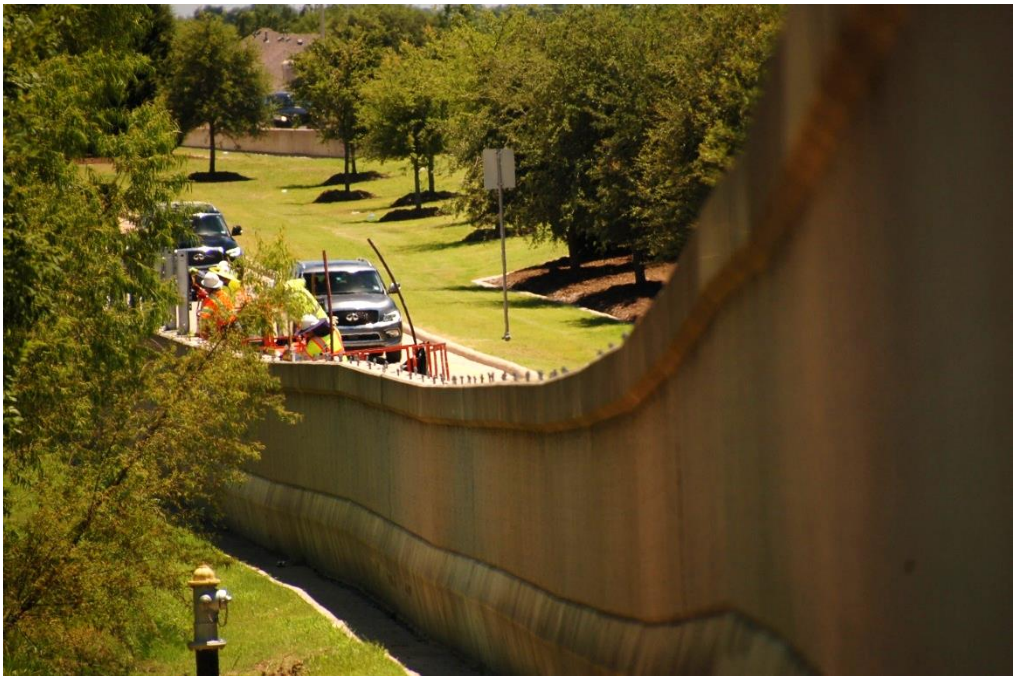


Figure 7.11 Noise wall installation on the east side (June 13, 2019)

Figure 7.12 Noise wall installation on the east side (June 13, 2019)

Figure 7.13 Noise wall installation progress on the west side (June 13, 2019)

Figure 7.14 Noise wall installation progress on the west side (June 13, 2019)

Figure 7.15 Noise wall installation progress on the west side. Sloped southernmost end of the wall (June 13, 2019)

During the July 24, 2019 trip, the new noise walls were very close to being finished. The west side wall was missing only three transparent panels. All the metal supports were in place. On the east side, the installation was about 80% complete. The installation process on this side proceeded from south to north. Thus, on the northernmost end (close to Harborview Boulevard), there were still missing panels and metal supports. The crews were working on this side at the time of the visit.

The foreman in charge indicated that they expected to have the job finalized the following week, depending on the availability of panels and metal parts. They indeed finished on time. Figures 7.16 to 7.27 show various aspects of the wall installations.

Figure 7.16 Northernmost end of the west side wall near Kirby Road, with the wall near completion (July 24, 2019)

Figure 7.17 Contractor's (Select Striping) vehicle inspects the west side wall approaching one of the missing panels (July 24, 2019)

Figure 7.18 West side noise wall very near completion (July 24, 2019)

Figure 7.19 West side noise wall very near completion (July 24, 2019)

Figure 7.20 East side noise wall installation. Acrylic panel placement (July 24, 2019)

Figure 7.21 East side noise wall installation. A crew member tightens nuts to the bolts that hold the vertical support (July 24, 2019)

Figure 7.22 East side noise wall installation. Workers lifted to the neighborhood side (July 24, 2019)

Figure 7.23 East side noise wall installation. Acrylic panel placement (July 24, 2019)

Figure 7.24 East side noise wall installation. Acrylic panel placement (July 24, 2019)

Figure 7.25 East side noise wall installation. Rubber gasket placement (July 24, 2019)

Figure 7.26 East side noise wall installation. A crew member cleans the concrete after the drilling process (July 24, 2019)

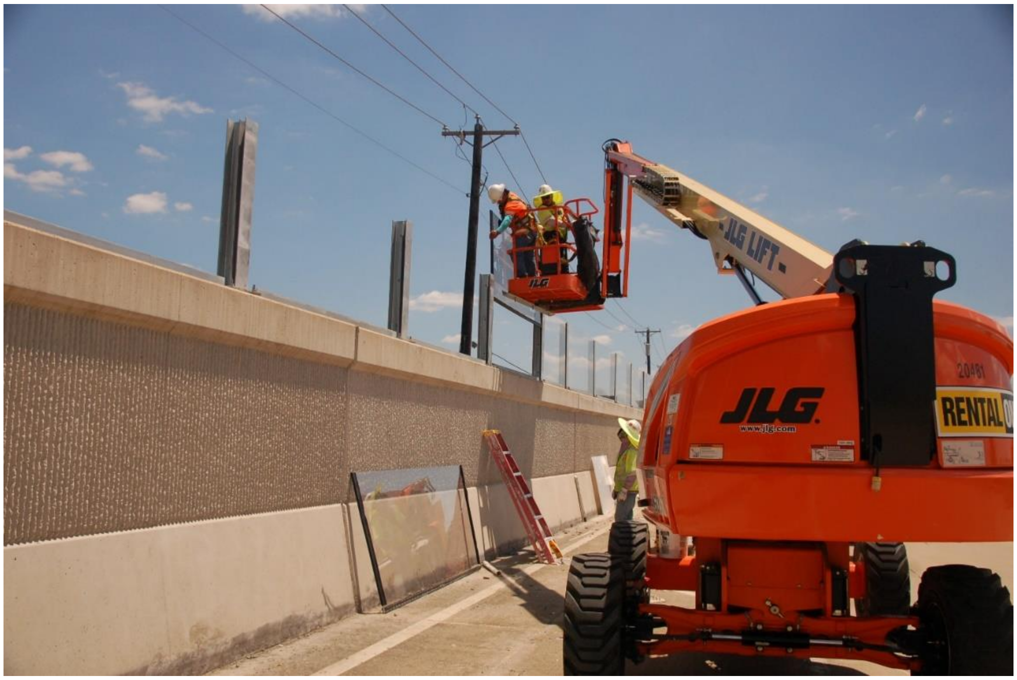


Figure 7.27 East side noise wall installation. Acrylic panel placement (July 24, 2019)

By the time the August visit took place, the walls on both sides were completely finalized, all lanes were open, and the construction equipment and materials had been removed from the site. Figures 7.28 to 7.31 correspond to images of the finished walls captured during the August visit.


Figure 7.28 East side noise wall finalized, as seen from the neighborhood side (August 14, 2019)

7.3. Other Inspection Findings

A problem detected after the noise wall installation is related to the design of the supports and their interface with the existing concrete and panels. Thus, it is a design issue rather than a construction issue. The problem is the presence of a gap (in some instances) between the bottom metal support and the top of the existing concrete wall, and an opening (in all instances) between the acrylic panel and the bottom metal support. The opening forms a square shape. The problem arises from the fact that the panels are placed on top of the existing concrete wall. For the case of the I-30 noise walls, these gaps and openings do not exist because the acrylic panels and metal supports are placed behind the existing concrete wall. Figures 7.29 to 7.31 show examples of these openings in the west side wall, as photographed from the neighborhood side. The small openings occur because the horizontal metal support does not cover the entire span of the acrylic panel due to the presence of the horizontal plates on either end that function as a base for the vertical supports. These are small openings, but the sound from the highway side travels through them and reaches the neighborhood receivers.

Figure 7.29 Gap and opening; west side noise wall finalized, as seen from the neighborhood side (August 14, 2019)

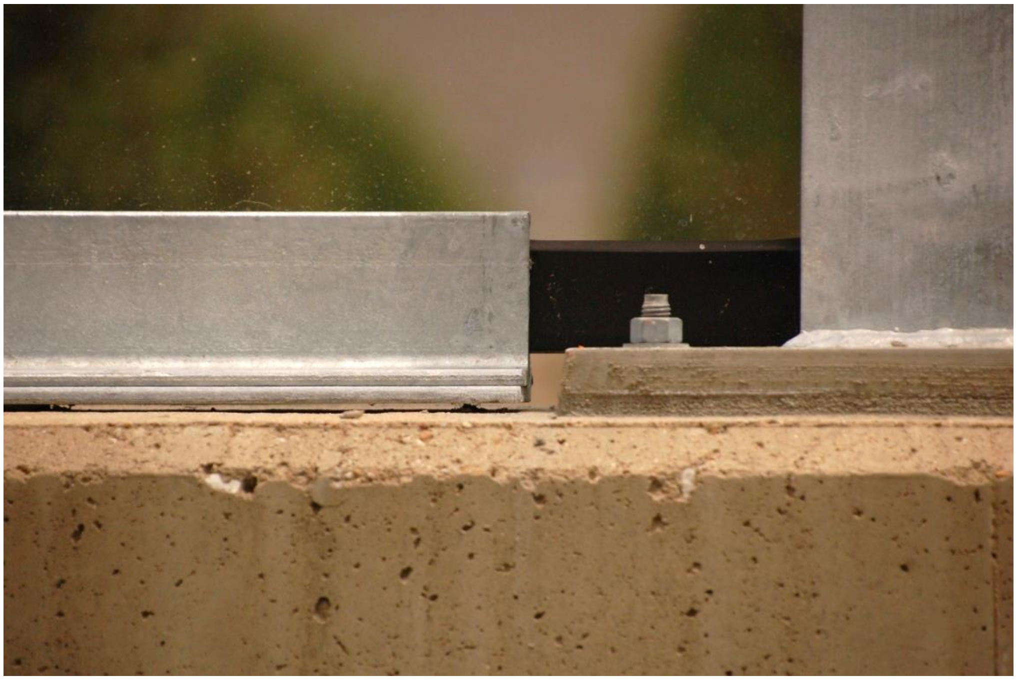


Figure 7.30 Gap and opening; west side noise wall finalized, as seen from the neighborhood side (August 14, 2019)

Figure 7.31 West side noise wall finalized, as seen from the neighborhood side (August 14, 2019)

Another issue that is present in the east side wall, near its northernmost end, approaching Harborview Boulevard, is a warped acrylic panel. The reason for this problem appears to be that the panel may have been fabricated slightly wider than needed. As it was installed in between the metal supports, it had to warp in order to fit. Figures 7.32 and 7.33 show this panel.

Figure 7.32 Warped acrylic panel, east side wall

Figure 7.33 Warped acrylic panel, east side wall

The noise walls continued to be monitored during subsequent field trips as part of this research task after the installation was completed. No other problems were identified with the installation. The walls looked in good shape and the installation appears to be sturdy and reliable.

However, a separate problem was observed with the existing concrete walls that has an impact on noise perceived at the neighborhood: some of the vertical expansion joints in the concrete are open and not sealed; this was more prevalent on the east side wall. The problem arises as a result of the degradation of the flexible joint sealant material that allows for the thermal expansion and contraction of adjacent concrete panels. When this material is in good working condition, the material prevents the highway sound from traveling through the openings and reaching the neighborhood's residences. An example of one such joint in good condition, with the sealant in proper shape, is shown in Figure 7.34. In contrast, Figures 7.35 and 7.36 provide examples of open joints with no sealant material.

Figure 7.34 Expansion joint with sealant material in good condition

Figure 7.35 Open expansion joint without sealant material

Figure 7.36 Noise test conducted in front of noise wall with an open expansion joint without sealant material in the background

An additional problem that does not impact the noise received at the residential locations, but that could potentially affect the structural integrity of the noise walls, is the presence of some separations between the noise wall and the concrete base. This problem exists in some segments of the east side wall, next to the Harborside community, as well as in a segment next to receiver R#12, on the west side, in the Ridgecove community. These openings in the concrete at the base of the walls appear to have developed over time as a result of settlements of the soil and the foundation of the concrete walls relative to the walls. Figures 7.37 to 7.39 illustrate these gaps for the east side wall, and Figures 7.40 and 7.41 show a similar opening for the west side wall.

Figure 7.37 Separation between noise wall and concrete base, east side wall, close to receiver R#1

Figure 7.38 Separation between noise wall and concrete base, east side wall, close to receiver R#1

Figure 7.39 Separation between noise wall and concrete base, east side wall, close to receiver R#1

Figure 7.40 Separation between noise wall and concrete base, west side wall, close to receiver R#12

Figure 7.41 Separation between noise wall and concrete base, west side wall, close to receiver R#12

7.4. Views of the Noise Walls

This section presents various aspects of the noise wall transparent acrylic extensions, including the tapered ends at the northernmost and southernmost locations, as well as views from the main lanes and neighborhood sides of the walls.

Figures 7.42 to 7.57 showcase pictures of the walls taken throughout the project, during different seasons, and at different times of the day and night.

Figure 7.42 East side wall seen from northbound frontage road

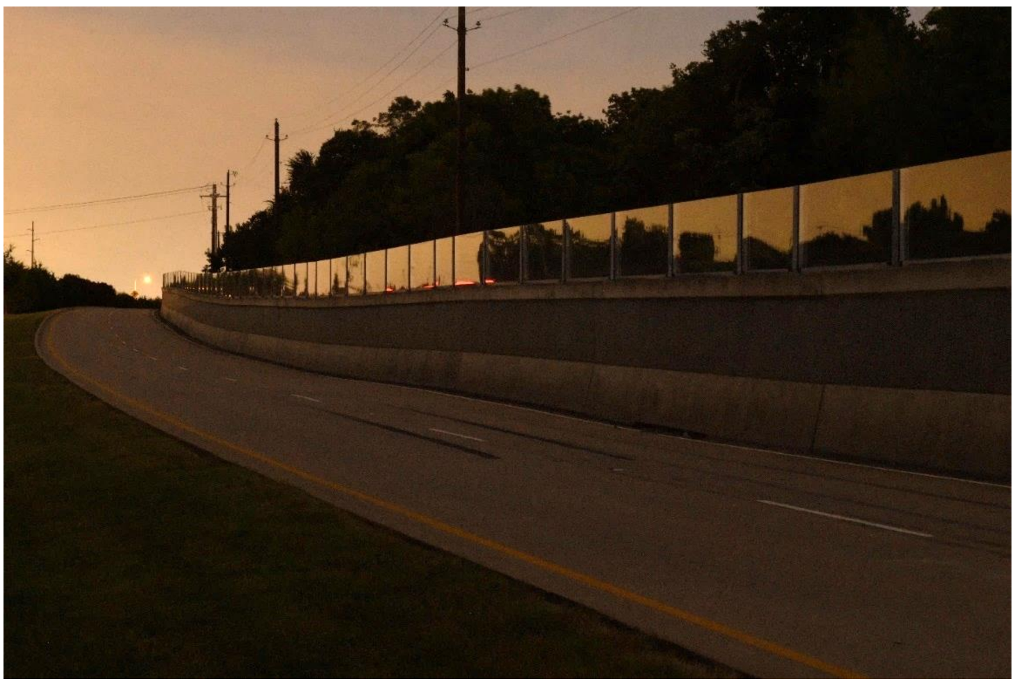


Figure 7.43 East side wall seen from northbound frontage road

Figure 7.44 East side wall seen from neighborhood side

Figure 7.45 West side wall seen from neighborhood side

Figure 7.46 East side wall seen from northbound frontage road

Figure 7.47 West side wall seen from southbound frontage road

Figure 7.48 West side wall seen from main lanes

Figure 7.49 West side wall northernmost end

Figure 7.50 West side wall southernmost end

Figure 7.51 East side wall northernmost end

Figure 7.52 East side wall seen from neighborhood side

Figure 7.53 East side wall northernmost end

Figure 7.54 East side wall seen from neighborhood side

Figure 7.55 East side wall southernmost end

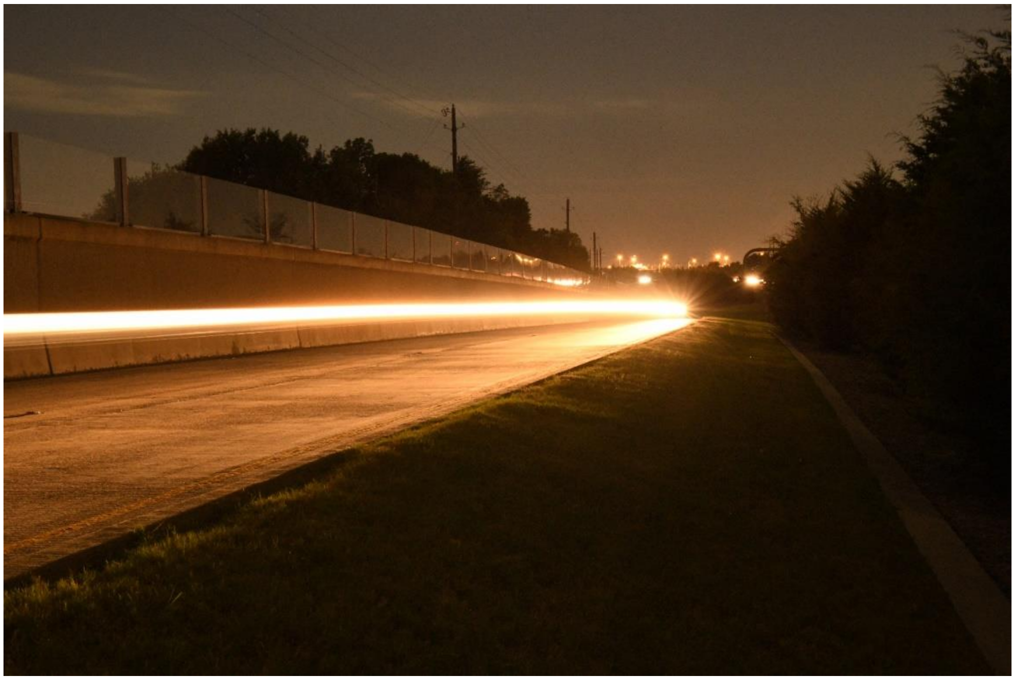


Figure 7.56 West side wall seen from southbound frontage road

Figure 7.57 West side wall seen from main lanes

Chapter 8. Summary, Conclusions, and Recommendations

This report described the SH 190 component of the 0-6804 research project, which was developed as a result of the project's success early on in implementing the first transparent noise barrier in Texas. Installed on I-30, near downtown Dallas, the I-30 sound walls were the first outcome of this research project. The positive results from I-30, both in terms of the field measurements and the perception and opinion of the affected residents, prompted TxDOT to extend the project to implement a similar study in a highway section that had an analogous noise problem. This final report of the 0-6804 project summarizes the following aspects of the SH 190 study:

- A description of the characteristics of the SH 190/PGBT section under study, including geometry, pavements, the adjacent residential communities affected by the highway traffic noise, and the existing noise walls.
- The sites in the various residential communities along SH 190/PGBT that were selected for noise monitoring. The selection process included accessibility and the residence locations relative to the highway and the existing noise walls. The residential sites were chosen for noise monitoring during the noise-testing phase of this project. Eight sites were selected—four on the east side (northbound direction) and four on the west side (southbound direction) of SH 190.
- The change in some of the residential sites for noise monitoring for the post-barrier phase of the project, when the scope of the noise study was reduced to work only on receivers behind the existing walls (ruling out the possibility of constructing new walls). Four residential sites were eliminated, none of which were shielded by existing barriers, and three were added, all of which were behind existing noise walls.
- A pavement condition survey and tire-pavement noise tests conducted on both the main lanes and the frontage roads of the pavements of SH 190. The pavement condition, especially for the case of a distressed pavement, can have a definitive influence on the generation of tire-pavement noise at highway speeds.
- Evaluation of the noise generated at the tire-pavement interface using the OBSI test, which is widely considered the best way of measuring the main component of traffic noise at the source: where the tire and the pavement are in contact.
- The noise testing program for the residential locations in the neighborhoods along SH 190. Eight initial residential locations (and the seven subsequent locations) were monitored following these procedures. The noise measurements, performed with sound pressure level meters, were collected for the purpose of evaluating the effectiveness of the new noise barriers. The tests were conducted at different times of the day to account for the variability in traffic and climatic conditions. At the same time the noise tests were performed, a

weather station was used to monitor climatic variables. A detailed description of the equipment utilized for the measurements was presented, as well as the methodology for the field work.

- The results of noise measurements and data analysis for the pre-barrier and post-barrier stages of SH 190. The measurements analyzed comprise tests conducted from July 2017 until January 2018 for the pre-barrier condition, and from August 2019 until November 2020 for the post-barrier condition; this last data-collection period included a hiatus from March until May 2020 due to the coronavirus pandemic.

The following conclusions are drawn from the data collected and analyzed:

- The results of the OBSI pavement tests, both for the main lanes and the frontage roads, are very typical of the pavement type present in this facility, CRCP. A comparison with other pavements indicates that the SH 190/PGBT pavements are among the loudest compared to other CRCPs. This pavement type is generally regarded as one of the loudest pavement types, mainly due to the typical transversely tined finishing applied to these surfaces for safety purposes.

- The condition survey revealed that the pavements are in excellent condition; therefore, the pavement condition is not contributing to an increase in tire-pavement noise.

- The pre-barrier environmental noise test results indicated that noise levels were indeed very high at most of the receivers' locations studied in this project. All the sites but one represented a noise impact, according to TxDOT policy; therefore, the neighbors' complaints were warranted and, in light of the noise levels measured, it was recommended to implement additional mitigation measures.

- After the new transparent panels were added to the existing walls, the noise results experienced a significant drop of 3.9 dBA, on average. However, this figure is not entirely representative of the effectiveness of the panels, because the pool of receivers changed from the pre-barrier to the post-barrier tests. Considering only the receivers that remained from the pre- to the post-barrier stage, the average noise reduction was about 3 dBA, which is still a very significant benefit, corresponding to a reduction of half of the acoustic energy reaching the receivers.

- Another benefit provided by the new barriers is the elimination of noise impacts. After the barriers were installed, all of the impacts measured before the barriers were in place were eliminated at those locations shielded by the barriers, confirming the effectiveness of the new wall additions.

- Weather variables—primarily temperature and wind speed—appeared to have influenced the noise levels. The various times of the day during which the tests were performed—morning, afternoon, and evening—seemed to have a slight impact on noise levels, especially considering that the evening tests consistently represented the times with higher noise levels. This is very likely associated with higher traffic volumes during those times of the day as well.

- The seasonal variations also had a definite impact on the noise levels detected. Colder seasons were related to higher noise levels. There are two similar patterns of the seasonal variations of noise, one for the pre-barrier condition and the other one for the post-barrier condition.

- In regard to the sample size, it would have been desirable to have a longer data-collection periods. For the pre-barrier condition, there was no data for the months of February to June. For the post-barrier condition, there was no data from March to May; it was planned to have a longer testing period, but the delays in the noise wall installation and the coronavirus pandemic prevented this from happening. Having at least a complete year of data for both periods would have been ideal to represent all seasonal changes and their influence on noise.

- The statistical analysis of the samples of data collected before and after the noise panel additions confirms that statistically, the difference between these samples is large enough to be considered significant, indicating that there is a statistically significant difference between the groups of tests; therefore, the t-test supports the measurements indicating that the barrier indeed had an effect on noise levels.

- The insertion loss tests performed both before and after the noise barriers were installed confirm, first, the effectiveness of the existing concrete walls, which provide an insertion loss of almost 10 dBA—a significant benefit in itself; and second, the substantial increase in benefit provided by the transparent panels, which improve the initial insertion loss by about 3 dBA. This finding implies that the presence of the panels accounts for a reduction of about half of the total acoustic energy.

The following are recommendations for long-term remediation of the traffic noise problem at SH 190:

- It is recommended that, to further reduce the noise at the source, a quieter pavement overlay could be considered for the future, such as a TOM or a PFC, both of which are capable of providing substantial noise reductions over a typical transversely tined CRCP. OBSI tests revealed that the existing pavement is loud. An overlay could be a substantial improvement for the future, especially when the existing pavement begins to deteriorate and generate even higher noise levels.

- During this study, two new noise walls were proposed, designed, and analyzed with the TNM program for the purpose of shielding the residential areas not currently protected by existing walls, particularly Magnolia Springs and the adjacent homes along Kirby Road, on the west side of the highway (e.g., R7). However, TxDOT decided at this time, since this is a pilot project, not to construct any new walls. These receivers are subjected to even higher noise levels than those that are protected by the new acrylic panel walls, so it is recommended to eventually construct these proposed walls.

- Some of the other impacted receivers—R3 (in the Harborside Community), R4a (in the Lake Forest Estates Community), and R6 (in the Magnolia Springs Community)—have special considerations. Because of the height of the highway relative to the residences, and the distance between the highway and the homes, a possible noise barrier would shield these residences mainly from the noise coming from the frontage roads, which are at the same level as the residences, but would not be effective for protecting them from the noise coming from the main highway lanes, which are at a higher elevation. Furthermore, potential noise walls at these locations would not benefit a significant number of receivers.

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