# Noise and Vibration Technical Report for H Street/Benning Road Streetcar Project

April, 2013

# 1. EXECUTIVE SUMMARY

This report documents the noise and vibration study performed for the H Street/Benning Road Streetcar Project, referred to as H/Benning Streetcar Project in this report. The study evaluates the potential noise and vibration impacts from construction and operation of the alignment under consideration.

## 1.1 Summary of Noise Impact Analysis

The project uses DC local funds however in order to analyze the noise impacts Federal Highway Administration (FHWA) methods and Federal Transit Administration (FTA) Guidance Manual (Ref. 1) was used. Potential noise and vibration impacts were assessed for streetcar operations, the Car Barn and Training Center (CBTC), and construction. Key assumptions for the impact assessment are:

- Streetcar audible warnings: The noise impact analysis of the streetcar operations includes bell noise at streetcar stops and stop lights but does not include warning horns. The warning horns would be used at operator's discretion to alert pedestrians and motor vehicle drivers of a potential safety risk, which is the same way that horns are used on buses.
- The maximum speed for the streetcars will be 25 mph.
- The streetcar schedule will be 6 trains per hour between 6 AM and 12 midnight.
- The noise and vibration generated by streetcar operations will be similar to what has been observed at modern streetcar systems in Portland, OR and Seattle, WA.
- The noise from storage and maintenance activities at the CBTC has been evaluated for the initial fleet size of 5 vehicles and for the future maximum fleet size of 15 vehicles.

The results of the noise analysis using FTA guidance are shown in Table 1 and results using FHWA methodology are given in Table 2. It should be noted that this street car project does not use any federal funds and hence FTA and FHWA policies, guidance and regulations are not applicable to this project. The project team used the FTA and FHWA noise analysis methodologies because they reflect the best available research on the topic.

| Table 1: Summary of FTA Noise Impacts and Mitigation | | | | | | | |
|---|---|---|---|---|---|---|---|
| **FTA Land Use** | **Receiver/ Cluster Number [a]** | **Type of Land Use [b]** | **Exceed FTA Impact Threshold** | | **Number of Impacted Receivers [c]** | **Amount Exceeds Thresholds, dBA** | **Recommended Mitigation Option [d]** |
| | | | **Moderate** | **Severe** | | | |
| **Streetcar Operations** | | | | | | | |
| 1 | -- | -- | -- | -- | -- | -- | -- |
| 2 | R6 | MFR | Yes | No | 20 | 1[e] | 1 |
| | R7 | MFR | Yes | No | 20 | 2[e] | |
| 3 | -- | -- | -- | -- | -- | -- | -- |
| **Car Barn and Training Center** | | | | | | | |
| 1 | -- | -- | -- | -- | -- | -- | -- |
| 2 | R14 | MFR | Yes | No | 10 | 1[f] | 2 |
| 3 | -- | -- | -- | -- | -- | -- | -- |

Notes:

(a) See Appendix D for the locations of receiver clusters.
(b) SFR = Single-family residences, MFR = Multi-family residences.
(c) Represents the number of impacted residential units for Category 2 land uses.
(d) Mitigation Option 1 is the use of wheel/rail lubrication, friction modifier, and optimization of wheel/rail profiles.
Mitigation Option 2 is a 20 ft high soundwall located along the western edge of the property line blocking direct line of sight between first floor residences in R14 and the shop and maintenance activities at the CBTC.
(e) Based on worst case with substantial wheel squeal plus normal train noise.
(f) Predicted noise levels would exceed the FTA noise impact threshold when the size of the streetcar fleet stored and serviced at the CBTC approaches 15. The noise levels are predicted to be below the FTA impact thresholds when the fleet size is less than 10.

| Table 2: Summary of FHWA Traffic Noise Impacts and Abatement | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **FHWA Land Use** | **Receiver/ Cluster Number [a]** | **Type of Land Use [b]** | **Predicted Traffic Noise (Leq), dBA** | | | **Number of Impacted Receivers [c]** | **Amount Build 2040 Exceeds NAC[d], dBA** | **Abate. Feasible or Reasonable** |
| | | | **No Build 2013** | **No Build 2040** | **Build 2040** | | | |
| B | R1 | MFR | 68 | 69 | 69 | 10 | 1 | No[e] |
| | R6 | MFR | 68 | 69 | 69 | 20 | 2 | |
| | R7 | MFR | 70 | 71 | 71 | 20 | 5 | |
| | R8 | MFR | 69 | 70 | 70 | 4 | 4 | |
| | R9 | MFR | 67 | 68 | 68 | 21 | 2 | |
| | R10 | MFR | 72 | 73 | 73 | 48 | 7 | |
| | R11 | MFR | 71 | 72 | 72 | 10 | 6 | |
| | R12 | MFR | 71 | 71 | 71 | 4 | 5 | |
| | R13 | MFR | 70 | 71 | 71 | 3 | 5 | |
| | R15 | SFR | 69 | 70 | 70 | 4 | 4 | |
| | R16 | SFR | 70 | 71 | 71 | 6 | 5 | |
| C | M1 | Hospital | 70 | 71 | 71 | -- | 5 | No[e] |
| | I26 | Golf Course | 69 | 70 | 70 | -- | 4 | |

Notes:

(a) See Appendix D for the locations of receiver clusters.
(b) SFR = Single-family residences, MFR = Multi-family residences.
(c) Represents the number of impacted residential units for Category B land uses.
(d) The DDOT NAC is 66 dBA for Category B and C receivers.
(e) Noise abatement is not feasible because the sensitive receiver property line abuts the H Street/Benning Road sidewalk.

## 1.2 Summary of Vibration Impact Analysis

Table 3 presents the results of the groundborne vibration impact assessment. The conclusions of the vibration analysis shown in are:

- Groundborne vibration from streetcar operations is predicted to exceed the FTA impact threshold at 2 clusters of residences representing 14 dwelling units. All of the potential vibration impact at residences is due to wheel impacts at special trackwork frogs.
- The potential vibration impact at residences can be eliminated through the use of "well-designed" flange-bearing frogs for the special trackwork on H Street and Benning Road.
- The predicted groundborne noise level inside the auditorium of the Atlas Theater is close to the impact threshold. Post-construction noise measurements inside the auditorium of the Atlas Theater are recommended to verify that the groundborne noise levels are below the impact threshold.

**Table 3: Summary of Vibration Impact Assessment for Category 2 Land Uses**

| FTA Land Use | Receiver/ Cluster Number (a) | Type of Land Use (b) | Exceed FTA Impact Threshold | | | | Number of Impacted Receivers w/o Mitigation (d) | Recommended Mitigation Option (e) |
|---|---|---|---|---|---|---|---|---|
| | | | Without Mitigation | | With Mitigation | | | |
| | | | GBV (c) | GBN (c) | GBV (c) | GBN (c) | | |
| Category 1 | -- | -- | -- | -- | -- | -- | -- | -- |
| Category 2 | R1 | 2 | Yes | -- | No | -- | 10 (f) | 1 |
| | R15 | 2 | Yes | -- | No | -- | 4 (f) | |
| Category 3 | -- | -- | -- | -- | -- | -- | -- | -- |
| Special Buildings | -- | -- | -- | -- | -- | -- | -- | -- |

Notes:
(a) See Appendix E for location of receiver clusters.
(b) SFR = Single-family residences, MFR = Multi-family residences.
(c) GBV = Groundborne vibration, GBN = Groundborne noise
(d) Represents the number of impacted residential units for Category 2 land uses.
(e) Mitigation Option 1 is the use of "well-designed" flange-bearing frog.
(f) Includes a +10 VdB adjustment for noise from special trackwork.

## 2. PROJECT DESCRIPTION

The District Department of Transportation (DDOT) has developed a vision for a 37-mile streetcar system in the District of Columbia to develop and maintain an efficient, reliable, and convenient transit service that enhances connectivity within and between neighborhoods and supports community revitalization and economic development. As part of these future plans, DDOT has initiated construction the H Street/ Benning Road Streetcar line. The streetcar will provide an enhanced connection to Union Station for residents in the H Street/Benning Road area. Phase I of the project was the acquisition of three streetcar vehicles.

Phase 2 of the project includes the installation of an Overhead Catenary System (OCS) along the entire 2.2 mile H Street/Benning Road NE corridor from Union Station to Oklahoma Avenue NE. The project also includes the construction of a Car Barn and Training Center (CBTC) on the eastern end, power substations located at the ends of the line and at the midline, and an interim western destination serving Union Station. The H Street/Benning Road streetcar is projected to be in service in late 2013.

## 3. NOISE AND VIBRATION ASSESSMENT METHODOLOGY

### 3.1 Noise Assessment Approach

The basic approach used to identify potential noise impacts is:

1. **Identify sensitive receivers**. Noise-sensitive land uses along the corridor were identified first using aerial photography followed by field visits to confirm land uses and the presence of any features, such as intervening structures, that may provide acoustic shielding. Sensitive receivers were grouped in clusters based on their location relative to the tracks and land use.

2. **Determine existing conditions**. As discussed in Section 5 and Appendix B, existing noise levels were measured along the project corridor at 10 sites. The measurements are important because the Federal Transit Administration (FTA) noise impact thresholds are a sliding scale that is a function of the existing noise levels (Ref. 1). The existing noise measurements are also necessary to calibrate the Traffic Noise Model (TNM) that is used to evaluate noise impacts based on the Federal Highway Administration's (FHWA) noise impact criteria. Section 6 includes a summary of the FTA and FHWA noise impact criteria. It also includes a discussion on the FTA's vibration impact criteria for streetcar operations.
3. **Develop prediction models**. The noise prediction models use standard formulas used to characterize noise from rail transit vehicles and measurements of noise at existing streetcar and light rail systems. The prediction models incorporate the forecasted future number of streetcar operations per day, the distribution of these operations throughout the day (early morning, daytime, and nighttime), the distance from the tracks, the streetcar speed, and the presence of walls, berms, or structures that provide acoustic shielding for the receivers. The predictions of noise from streetcar operations include the additional noise from the use of the streetcar bells to alert passengers and patrons in stations that a streetcar is approaching. To make this technical study compliant to FHWA noise requirements, traffic noise models of the project corridor were developed using the FHWA computer program TNM 2.5. The models incorporate traffic counts and speeds from the noise measurements, topography, and traffic flow for the current year and the future project year.
4. **Estimate future noise levels at the representative receivers**. The prediction models were used to estimate future streetcar noise for each cluster of sensitive receivers. Predictions for each cluster are based on the distance from the proposed project to the closest sensitive receiver and the expected streetcar and traffic parameters. The predicted levels of noise from streetcar operations and vehicular traffic were compared to the applicable FTA and FHWA impact thresholds to identify potential noise impacts (see Section 8).
5. **Evaluate mitigation options**. Mitigation options were evaluated for all locations where the predicted noise levels exceed the FTA impact thresholds (see Section 7.3). Where the project noise approached the DDOT's Noise Abatement Criteria (NAC), appropriate mitigation options were evaluated for reasonableness and feasibility (See Section 8.5).

## 3.2 Sources of Streetcar Noise

Following is an overview of the primary noise sources associated with construction and operation of streetcar systems:

**Streetcar Operations:** This is the normal noise from streetcars operations. At higher speeds the operational noise is dominated by the noise from steel wheels rolling on the steel rails (wheel/rail noise). At lower speeds, both the wheel/rail noise and the noise from the vehicle traction motors and the auxiliary equipment on the vehicle (e.g. air conditioning, compressors, and motor controllers) are important factors in the overall operational noise levels. The levels of wheel/rail noise are strongly dependent on the condition of the operating surfaces of the wheels and the rails. An important assumption in the noise assessment is that the wheels and rails would be maintained in good condition through periodic truing of the wheels and grinding of the rails.

**Traffic Noise:** Sometimes the introduction of a new rail transit system will result in substantial changes in traffic patterns and volumes. For example, traffic may be shifted from the streetcar route to parallel roads, which would reduce levels of traffic noise along the streetcar route and increase noise levels along the parallel routes. The proposed project would result in small changes in traffic patterns and volumes in the project area. The forecasted changes were incorporated in TNM models and the predicted traffic noise was evaluated.

**Audible Warnings:** The streetcars will be equipped with horns and bells as audible warning devices. The primary purpose of the bells is to alert pedestrians and patrons at streetcar stops that a streetcar is approaching. The bells are expected to be used on a regular basis as streetcars approach, stop to load or unload patrons, and when starting from stoplights to signal that the streetcar is moving. In other locations audible warnings (either bells or horns at driver's discretion) would be used only to alert pedestrians and motor vehicle drivers of a potential safety risk, which is the same way that horns are used on buses.

**Special Trackwork:** The H Benning Road section of the proposed DC Streetcar System will be constructed of continuously welded track, which eliminates the clickety-clack noise associated with older rail systems. The one exception is the special trackwork for turnouts and crossovers, where two rails must cross. A fixture called a “frog” is used where rails must cross. The wheel impacts at the gaps in the rails of a standard frog cause noise levels near special trackwork to increase by approximately 6 dB. It is common for streetcar systems to use “flange-bearing” frogs. That is, there are ramps before and after the gap where the load is transferred from the wheel tread to the wheel flange. The ramps on typical streetcar flange-bearing frogs are short enough that the load transfer is quite abrupt and generates substantial noise.

The additional noise generated by the frogs can be reduced by increasing the length of the ramp so that the load transfer is more gradual. A “well-designed” flange-bearing frog with a ramp angle of between 1:20 and 1:100 will minimize and may eliminate the increase in noise caused by the rapid load transfer.

**Wheel Squeal:** Wheel squeal is generated when steel-wheel transit vehicles traverse tight radius curves. It is very difficult to predict when and where wheel squeal will occur. A general guideline is that there is the potential for wheel squeal at any curve with a radius that is less than approximately 400 feet. There is the potential for the DC streetcars to generate wheel squeal on the sharper curves at the “Star” junction. Sensitive receivers that are located within 100 feet of the tight curves could be affected by wheel squeal noise. Common approaches to controlling wheel squeal include (1) applying a friction modifier to the railhead and/or the wheel tread, (2) applying lubricant to the gauge face of the rail or the wheel flange, and (3) optimizing the wheel and rail profiles. Using resilient wheels and maintaining the tracks will help control wheel squeal; also, periodically truing wheels will maintain an optimum profile and can help minimize wheel squeal. It is expected that either on-vehicle or wayside applicators of lubricant or friction modifier will be required to fully control wheel squeal.

**Ancillary Equipment:** Ancillary equipment is defined as the wayside equipment needed to support a transit system. The only ancillary equipment likely to generate noticeable noise is the traction power substation (TPSS) units, although modern TPSS units are relatively quiet. Three TPSS units are planned for this project. The key guidelines to avoid impacts from TPSS units are to locate them at least 50 feet away from the sensitive receivers, direct the fans in the TPSS away from the receivers or insulate the TPSS with sound insulating features such as a sound wall or a partial enclosure.

**Construction:** All the sources discussed above are associated with the operation of the proposed project. Although construction of a streetcar project entails relatively limited use of heavy equipment compared to other rail projects, construction activities nevertheless would generate relatively high noise levels. Measures recommended for mitigating construction noise impacts include: (1) obtaining a noise variance permit for nighttime construction, (2) using specialty equipment with enclosed engines and high-performance mufflers, (3) installing temporary barriers and (4) locating equipment and staging areas as far from noise-sensitive receivers as possible. In addition, the contractor should be required to develop and implement a Noise Control Plan to mitigate potential construction noise impacts at the sensitive receivers.

## 3.3 Vibration Assessment Approach

The approach for the vibration assessment was basically the same as for the noise assessment. The primary differences are:

- The propagation of vibration through the ground must be based on measurements while the propagation of noise through air can be based on standard attenuation formulas.

- Existing vibration is not a consideration when assessing vibration impacts. This is because everyone is exposed to some audible environmental noise while it is relatively rare for people to be exposed to perceptible groundborne vibration unless they are located near a construction site or near roadways with potholes, wide expansion joints, or other irregularities in the roadway surface.
- Outdoor spaces are not considered sensitive to groundborne vibration. In contrast, outdoor spaces where quiet is important for their intended function are considered noise sensitive (e.g., spaces intended for meditation or study associated with cemeteries, monuments, or historical spaces).
- Vibration assessment is applicable only for FTA based evaluation of streetcar operations. There is no vibration assessment required by the FHWA for vehicular traffic changes due to the project.

The basic steps used to identify potential vibration impacts are:

1. **Identify sensitive receivers**. For this project the vibration sensitive receivers are identical to the noise sensitive receivers. This is not always the case because outdoor open spaces such as parks may be considered to be noise sensitive but are not vibration sensitive. Also, special land uses such as recording studios and concert halls are often considered more sensitive to groundborne vibration than to airborne noise.
2. **Determine existing conditions**. The existing conditions were characterized with measurements of vibration propagation at four locations and measurements of ambient vibration levels at six sites. The measurements of vibration propagation are important because local geologic conditions have a strong effect on the amplitudes of vibration that reach sensitive receivers (see Section 4.2 and Appendix C for more details). Although ambient vibration is not the basis of impact analysis, the measurements of ambient vibration were used to characterize vibration levels from buses and trucks in the project area. The primary source of existing vibration in the corridor is vehicular traffic on H Street and Benning Road.
3. **Develop prediction models**. The vibration prediction models are based on the measurements of the vibration levels generated by the operation of modern streetcar systems in Portland, OR and Seattle, WA.
4. **Estimate future noise and vibration levels at the representative receivers**. The prediction models were used to predict vibration levels from streetcar operations at all sensitive receivers in the H/Benning streetcar corridor. The predictions were compared to the applicable FTA impact thresholds to identify potential noise and vibration impacts (see Section 8).
5. **Evaluate mitigation options**. Mitigation options were evaluated for all locations where the predicted vibration levels exceed the applicable FTA impact thresholds (see Sections 8.5).

## 3.4 Sources of Streetcar Vibration

Both the construction and operation of a modern streetcar system will generate vibration that is transmitted through the ground and into nearby buildings. It is very rare for the vibration to be high enough for there to be any risk of structural damage to buildings. However, it is possible for construction vibration to approach risk thresholds for minor cosmetic damage and both construction and streetcar operations have the potential to generate vibration that may be intrusive to building occupants. Following is a list of vibration sources associated with streetcar systems.

**Streetcar Operations:** Streetcar operations create groundborne vibration that can be intrusive to occupants of buildings that are located close to the tracks. This is particularly important for residential land uses that are located within 40 ft of streetcars operating at 25 mph. The predicted levels of streetcar vibration at all receivers are well below the thresholds used to protect sensitive and fragile historic structures from damage. A key assumption in the vibration predictions is that the optimal wheel and rail profiles would be maintained for the DC Streetcar System through periodic truing of the wheels and rail grinding.

**Special Trackwork:** The groundborne vibration near special trackwork increase by approximately 10 dB due to the wheel impacts at the gaps in the rails. The ramps on typical streetcar flange-bearing frogs are short enough that the transfer of the load is quite abrupt and generates substantial vibration in addition to noise. Use of well-designed flange-bearing frogs with longer ramps can substantially reduce the impacts that cause high vibration from special trackwork. The "well-designed" flange-bearing frog with a minimum ramp length of two feet recommended to reduce noise would also be sufficient to reduce vibration. Similar to noise impacts the vibration impacts caused by this special trackwork can be eliminated by the use of a "well-designed" flange-bearing frog.

**Construction:** Construction of a streetcar project entails relatively less use of heavy equipment compared to other rail projects. Nevertheless, the construction activities of the project would generate relatively high vibration levels. Measures recommended for controlling construction-related vibration are: (1) a pre-construction survey of important and potentially fragile historic resources in the project area, (2) construction vibration limits for all buildings in the corridor, (3) vibration monitoring at buildings that require lower vibration limits such as fragile historic buildings that are located within 200 feet of heavy construction activities and at any locations where there are complaints about construction vibration, and (4) alternate construction procedures to reduce vibration from activities such as vibratory compaction, demolition, and pile driving. In addition, the contractor should be required to develop and implement a Vibration Control Plan to mitigate potential construction vibration impacts at the sensitive receivers.

# 4. INVENTORY OF NOISE AND VIBRATION SENSITIVE LAND USES

Noise and vibration sensitive receivers in the H/Benning Streetcar Project corridor were identified using a combination of aerial photographs, Google Streetview, and a windshield survey during the ambient noise and vibration measurements. Existing sensitive receivers in the H/Benning Streetcar Project corridor consist of single- and multi-family residences, churches, a school, community centers, clinics, a medical facility, a child care center, a library, non-profit and government agencies, the Museum of Oddity, a theater, a playhouse, and a golf course and country club. In addition there are several restaurants and bars, barber shops, beauty salons and other businesses along the project corridor. The land use categories used by FTA and FHWA are discussed in Section 6. Table 4 through Table 7 are inventories of the sensitive receivers in the project corridor. Drawings showing the location of clusters or individual receivers are provided in Appendix D.

Some key points from the inventory of sensitive receivers are:

- Residential land uses: There are 16 residential clusters that include 237 residential dwelling units. Most of the residences have outdoor spaces such as front yards, back yards, balconies or patios that show evidence of frequent human activity.
- Institutional land uses: There are 26 institutional land uses consisting of churches, schools, community centers, and other institutional land uses that have primarily daytime use. The Greater Northeast Medical Center is also considered as an institutional land use because there is no evidence of the center having facilities for overnight patients.
- Theaters and Playhouses: The Atlas Theater and the H Street Playhouse are located in the project area. The Atlas Theater is a concert hall and it is classified as an FTA Category 1 noise-sensitive land use. The H Street Playhouse is classified as an FTA Category 3 noise-sensitive land use. For vibration sensitivity, both receivers are classified under the FTA "Special Buildings" category: The H Street Playhouse as a theater and the Atlas Theater as a concert hall.
- Restaurants, Barber Shops and Other Businesses: Commercial land uses are generally not considered noise or vibration sensitive by FTA. However, the FHWA Noise Abatement Criteria includes these receivers as Category E land uses if there are exterior areas where frequent human

use occurs. There are 40 clusters in the project corridor that include 213 businesses consisting of restaurants, bars, nightclubs, barber shops, arts stores, and other businesses. There was no evidence of frequent human use of exterior areas that would be exposed to the project noise at any of the businesses.

There also are several known historic and archeological resources in the project area. The Atlas Theater, the H Street Playhouse, and the Lanston Terrace Dwellings (Cluster R14) are NHRP listed buildings. There are an additional five buildings in the project area that have been recommended for NHRP listing and another five buildings that are potentially eligible for listing. Groundborne vibration from streetcars is substantially lower than the most stringent criteria for structural damage. Therefore, the project is unlikely to cause any cosmetic or structural damage to these buildings and the historic and archeological resources are evaluated based on the current use of the buildings and the potential for occupant annoyance.

Construction activities that generate higher levels of vibration have some potential to cause structural damage to these buildings. However, through a careful choice of equipment and planning, the potential for cosmetic structural damage from construction activities can be minimized.

**Table 4: Inventory of Residential Land Uses**

| No. | Cluster ID | Description[(a)] | Adjacent Street | Number of Dwelling Units [(b)] | FTA Noise Category [(c)] | FTA Vibration Category [(d)] | FHWA Noise Category [(e)] |
|---|---|---|---|---|---|---|---|
| 1 | R1 | MFR | 3rd St. | 10 | 2 | 2 | C |
| 2 | R2 | MFR | 3rd St. | 4 | 2 | 2 | C |
| 3 | R3 | MFR | 4th St. | 8 | 2 | 2 | C |
| 4 | R4 | MFR | 4th St. | 2 | 2 | 2 | C |
| 5 | R5 | MFR | 12th St. | 32 | 2 | 2 | C |
| 6 | R6 | MFR | Florida Ave. | 20 | 2 | 2 | C |
| 7 | R7 | MFR | 15th St. | 20 | 2 | 2 | C |
| 8 | R8 | MFR | 16th St. | 4 | 2 | 2 | C |
| 9 | R9 | MFR | 17th St. | 21 | 2 | 2 | C |
| 10 | R10 | SFR | 18th St. | 48 | 2 | 2 | C |
| 11 | R11 | MFR | 19th St. | 10 | 2 | 2 | C |
| 12 | R12 | MFR | 19th St. | 4 | 2 | 2 | C |
| 13 | R13 | MFR | 20th St. | 3 | 2 | 2 | C |
| 14 | R14 | MFR | 21st St. | 40 | 2 | 2 | C |
| 15 | R15 | SFR | 24th St. | 4 | 2 | 2 | C |
| 16 | R16 | SFR | 25th St. | 6 | 2 | 2 | C |

Notes:

(a) Description = Type of land use, SFR = single-family residence, MFR = multi-family residence.

(b) Number of individual dwelling units in the cluster that are exposed to the project noise and/or vibration.

(c) FTA land use category for noise. Details of the FTA land use categories are discussed in Section 6.

(d) FTA land use category for vibration. Details of the FTA land use categories are discussed in Section 6.

(e) FHWA land use category for noise. Details of the FHWA land use categories are discussed in Section 6.

| Table 5: Inventory of Institutional Land Uses | | | | | | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Receiver ID** | **Receiver Name** | **Description[(a)]** | **Adjacent Street** | **FTA Noise Category [(b)]** | **FTA Vibration Category [(c)]** | **FHWA Noise Category [(d)]** |
| 1 | I1 | Necomb Child Development & Care | Child Care | 5th St. | 3 | 3 | C |
| 2 | I2 | Institute of Behavioral Change & Research Inc. | Institute | 5th St. | 3 | 3 | C |
| 3 | I3 | Community Development Center | Institute | 5th St. | 3 | 3 | C |
| 4 | I4 | EBT Training Center | Institute | 6th St. | 3 | 3 | C |
| 5 | I5 | 24-Hour Protection Govt. Services | Institute | 6th St. | 3 | 3 | C |
| 6 | I6 | DC Community Services | Institute | 6th St. | 3 | 3 | C |
| 7 | I7 | Adnoi Church | Church | 5th St. | 3 | 3 | C |
| 8 | I8 | DC Govt.: Animal Disease Control Division | Institute | 6th St. | 3 | 3 | C |
| 9 | I9 | Douglas Church | Church | 11th St. | 3 | 3 | C |
| 10 | I10 | Temple of Praise | Church | 10th St. | 3 | 3 | C |
| 11 | I11 | The Red Palace (Museum of Oddities) | Museum | 12th St. | 3 | 3 | C |
| 12 | I12 | Penthacostal Church | Church | 12th St. | 3 | 3 | C |
| 13 | I13 | Comprehensive Community Health | Clinic | 12th St. | 3 | 3 | C |
| 14 | I14 | RL Christian Library | Library | 13th St. | 3 | 3 | C |
| 15 | I15 | United House of Prayer for All People | Church | 13th St. | 3 | 3 | C |
| 16 | I16 | St. John's Church of God | Church | 13th St. | 3 | 3 | C |
| 17 | I17 | Joy of Motion Dance Center | Institute | 13th St. | 3 | 3 | C |
| 18 | I18 | Trinidad Baptist Church | Church | 16th St. | 3 | 3 | C |
| 19 | I19 | Benning Street Medical Clinic | Clinic | 18th St. | 3 | 3 | C |
| 20 | I20 | Church of God in Christ | Church | 20th St. | 3 | 3 | C |
| 21 | I21 | St. Elmo Crawford Dental Clinic | Clinic | 20th St. | 3 | 3 | C |
| 22 | I22 | Northeast Academy of Dance | Institute | 20th St. | 3 | 3 | C |
| 23 | I23 | Prevention Works (Non-Profit) | Non-Profit | 25th Pl. | 3 | 3 | C |
| 24 | I24 | Springarn Senior High School | School | 26th St. | 3 | 3 | C |
| 25 | I25 | G C Langston Country Club | Institute | 26th St. | 3 | 3 | C |
| 26 | I26 | Langston Golf Course | Golf Course | 26th St. | 3 | 3 | C |
| 27 | M1 | Greater Northeast Medical Center | Medical Facility [(e)] | 17th St. | 3 | 3 | C |

Notes:

(a) Description = Type of land use.
(b) FTA land use category for noise. Details of the FTA land use categories are discussed in Section 6.
(c) FTA land use category for vibration. Details of the FTA land use categories are discussed in Section 6.
(d) FHWA land use category for noise. Details of the FHWA land use categories are discussed in Section 6.
(e) This clinic does not appear to have facilities for overnight patients. Otherwise, the clinic would be in the same category as the residential land uses.

| Table 6: Inventory of Theaters and Playhouses | | | | | | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Receiver ID** | **Receiver Name** | **Description[(a)]** | **Adjacent Street** | **FTA Noise Category [(b)]** | **FTA Vibration Category [(c)]** | **FHWA Noise Category [(d)]** |
| 1 | T1 | Atlas Theater | Theater & Concert Hall [e] | 13th St. | 1 | Special Building | C |
| 2 | T2 | H Street Playhouse | Playhouse | 14th St. | 3 | Special Building | C |

Notes:

(a) Description = Type of land use.
(b) FTA land use category for noise. Details of the FTA land use categories are discussed in Section 6.
(c) FTA land use category for vibration. Details of the FTA land use categories are discussed in Section 6.
(d) FHWA land use category for noise. Details of the FHWA land use categories are discussed in Section 6.

| Table 7: Inventory of Commercial Land Uses | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **No.** | **Cluster ID** | **Adjacent Street** | **Number of Restaurants/ Bars** | **Number of Barber Shops/ Salons** | **Number of Other Business Spaces** | **FTA Noise Category [(a)]** | **FTA Vibration Category [(a)]** | **FHWA Noise Category [(b)]** |
| 1 | E1 | 4th St. | 3 | 0 | 5 | N/A | N/A | E |
| 2 | E2 | 5th St. | 0 | 1 | 4 | N/A | N/A | E |
| 3 | E3 | 6th St. | 0 | 0 | 1 | N/A | N/A | E |
| 4 | E4 | 4th St. | 2 | 0 | 7 | N/A | N/A | E |
| 5 | E5 | 5th St. | 1 | 0 | 6 | N/A | N/A | E |
| 6 | E6 | 6th St. | 1 | 0 | 1 | N/A | N/A | E |
| 7 | E7 | 7th St. | 1 | 2 | 0 | N/A | N/A | E |
| 8 | E8 | 7th St. | 2 | 1 | 4 | N/A | N/A | E |
| 9 | E9 | 8th St. | 0 | 0 | 8 | N/A | N/A | E |
| 10 | E10 | 7th St. | 0 | 1 | 4 | N/A | N/A | E |
| 11 | E11 | 8th St. | 3 | 0 | 17 | N/A | N/A | E |
| 12 | E12 | 9th St. | 0 | 0 | 8 | N/A | N/A | E |
| 13 | E13 | 10th St. | 0 | 1 | 5 | N/A | N/A | E |
| 14 | E14 | 11th St. | 2 | 1 | 6 | N/A | N/A | E |
| 15 | E15 | 10th St. | 0 | 0 | 2 | N/A | N/A | E |
| 16 | E16 | 11th St. | 1 | 1 | 4 | N/A | N/A | E |
| 17 | E17 | 12th St. | 1 | 0 | 0 | N/A | N/A | E |
| 18 | E18 | 12th St. | 2 | 0 | 2 | N/A | N/A | E |
| 19 | E19 | 12th St. | 3 | 2 | 0 | N/A | N/A | E |
| 20 | E20 | 12th St. | 0 | 1 | 1 | N/A | N/A | E |
| 21 | E21 | 13th St. | 5 | 3 | 8 | N/A | N/A | E |
| 22 | E22 | 12th St. | 0 | 0 | 1 | N/A | N/A | E |
| 23 | E23 | 12th St. | 1 | 0 | 2 | N/A | N/A | E |
| 24 | E24 | 13th St. | 3 | 0 | 6 | N/A | N/A | E |
| 25 | E25 | 13th St. | 0 | 1 | 3 | N/A | N/A | E |
| 26 | E26 | 14th St. | 3 | 0 | 9 | N/A | N/A | E |
| 27 | E27 | 14th St. | 1 | 0 | 2 | N/A | N/A | E |
| 28 | E28 | 16th St. | 3 | 0 | 8 | N/A | N/A | E |
| 29 | E29 | 16th St. | 1 | 0 | 1 | N/A | N/A | E |
| 30 | E30 | 16th St. | 1 | 0 | 2 | N/A | N/A | E |
| 31 | E31 | 17th St. | 0 | 0 | 1 | N/A | N/A | E |
| 32 | E32 | 19th St. | 2 | 0 | 3 | N/A | N/A | E |
| 33 | E33 | 18th St. | 0 | 2 | 1 | N/A | N/A | E |
| 34 | E34 | 18th St. | 0 | 0 | 3 | N/A | N/A | E |
| 35 | E35 | 19th St. | 2 | 0 | 0 | N/A | N/A | E |
| 36 | E36 | 20th St. | 0 | 2 | 3 | N/A | N/A | E |
| 37 | E37 | 20th St. | 0 | 0 | 4 | N/A | N/A | E |
| 38 | E38 | 21st St. | 0 | 0 | 1 | N/A | N/A | E |
| 39 | E39 | 24th St. | 1 | 1 | 1 | N/A | N/A | E |
| 40 | E40 | 24th St. | 0 | 0 | 4 | N/A | N/A | E |

Notes:

(a) Restaurants and other business spaces are not considered as noise or vibration sensitive land uses by FTA.

(b) FHWA considers exterior uses at restaurants, bars and other business spaces as Category E land uses. See Section 6 for more details.

# 5. AFFECTED ENVIRONMENT

The following sections document the ambient noise and vibration and present the details of the vibration propagation tests. Appendix A provides the fundamentals of noise and vibration. Appendix B provides the photographs and maps of the ambient noise and vibration measurement sites and presents the detailed measurement data. Appendix C provides the 1/3 octave best fit coefficients for the vibration propagation test results. Appendix D provides the cluster diagrams showing the locations of the sensitive receivers.

## 5.1 Existing Conditions - Noise

The existing ambient noise levels along the project corridor were documented through measurements performed at representative sensitive receivers between June 26 and June 29, 2012. The primary existing noise source in the project area is vehicular traffic on H Street and Benning Road. Long term noise measurements were performed at four sites and short term noise measurements were performed at six sites. The key noise metrics used in the study are listed below. See Appendix A for additional details.

- ***Decibel Scale (dB):*** A logarithmic scale, known as the decibel scale (dB), quantifies sound intensity and compresses the scale to a more convenient range.
- ***A-Weighted Sound Level (dBA):*** The A-weighted decibel scale (dBA) filters sound to better approximate the sensitivity of human hearing.
- ***Equivalent Sound Level (Leq)****:* The equivalent sound level (Leq) is the most common means of characterizing community noise. Leq represents a constant sound that, over a specified period of time, has the same sound energy as the time-varying sound. Leq is used by FTA to evaluate noise impacts at institutional land uses, such as schools, churches, and libraries. The maximum 1-hour Leq is used by FHWA to assess traffic noise impacts.
- ***Day-Night Sound Level (Ldn)****:* Ldn is the most common measure of total community noise over a 24-hour period. It is used by FTA to evaluate residential noise impacts from proposed transit projects. Ldn is a 24-hour Leq with an adjustment to reflect the greater sensitivity of most people to nighttime noise. The adjustment is a 10 dB penalty for all sound that occurs between the hours of 10:00 PM to 7:00 AM. The effect of the penalty is that, when calculating Ldn, any event that occurs during the nighttime is equivalent to ten occurrences of the same event during the daytime. Long-term measurements for this project were performed for periods of 24 hours, except at one site where an equipment malfunction caused the monitoring to terminate after 10 hours.
- ***Percent Exceedance Level (Lxx)****:* This is the sound level that is exceeded for xx% of the measurement period. For example, L99 is the sound level exceeded 99 percent of the measurement period. For a one hour period, the sound level is less than L99 for 36 seconds of the hour and the sound level is greater than L1 for 36 seconds of the hour. L1 represents typical maximum sound levels, L33 is approximately equal to Leq when free-flowing traffic is the dominant noise source, L50 is the median sound level, and L99 is close to the minimum sound level.
- ***Maximum Sound Level (Lmax***): Lmax is the maximum sound level that occurs during an event such as a train passing. For this analysis Lmax is defined as the maximum sound level using the “slow” setting on a standard sound level meter.

The ambient noise measurement results are summarized in Table 8. The locations of the noise measurement sites are shown in Figure 1. Photographs from each site are included in Appendix B. The Ldn is 70dBA or higher at 3 of the 4 long term measurement sites. The high noise levels are due to the proximity to traffic on H Street and Benning Road. The noise drops substantially farther away from the road; at LT-4 the noise is 64dBA. This site is over 300 feet from Benning Road. Traffic on H Street and

Benning Road included automobiles, city buses, and medium and heavy trucks. The long and short term measurement sites are described below.

**Long Term Measurement Sites**

**LT-1: 201 I Street:** This measurement was performed outside the Senate Square apartment complex, which is located between at the intersection of H Street and 3rd Street. The measurement at this site was for 24 hours, starting at 1:50 on June 28, 2012. The primary source of noise at this site was from traffic on H Street. The measured Ldn at this site was 74 dBA.

**LT-2: 1521 Benning Road:** This measurement was performed in front of the Pentacles Apartment Complex located southeast of the intersection of H Street and Benning Road. The measurement was performed for 24 hours, starting at 12:20 PM on June 27, 2012. The primary noise source was traffic on Benning Road. The measured Ldn at this site was 74 dBA.

**LT-3: 1720 Benning Road:** This measurement was performed outside a row of townhomes on Benning Road, between 17th and 18th Streets. The measurement at this site was for a duration of 10 hours, starting at 10:10 AM on June 26, 2012. The primary source of noise at this site was traffic from Benning Road. The average daytime Leq at this site was 67 dBA. The Ldn at this site was estimated to be 70dBA based on the average difference of 3 decibels between Ldn and the daytime Leq at the other three long term noise sites. The monitoring stopped after 10 hours due to an equipment malfunction.

**LT-4: 2101 G Street:** This measurement was performed between the apartment complex at 2101 G Street and Spingarn High School. The measurement was for 24 hours starting at 9:50 AM on June 26, 2012. The microphone was located near a fence separating the school grounds from the Apartment. The microphone was at the setback distance of the apartment building that was 330 ft from Benning Road. The primary noise source at this site was traffic on Benning Road. The measured Ldn at this site was 64 dBA.

**Short Term Measurement Sites**

**ST-1: 501 H Street:** This measurement was performed in front of the H Street Community Development Center, located at 501 H Street. The measurement was for a duration of 1 hour starting at 11:30 AM on June 26, 2012. The primary source of noise was H Street traffic. The measured Leq at this site was 69 dBA.

**ST-2: H Street and 11th Street:** This measurement was performed outside the Douglas Memorial Methodist Church. The measurement was for 1 hour, starting at 1:40 PM on Tuesday June 26, 2012. The primary source of noise was traffic on H Street. The measured Leq at this site was 68 dBA.

**ST-3: H Street and Florida Street:** This measurement was performed in a vacant lot between H Street and Florida Street, east of 14th Street. The measurement was for 1 hour, starting at 3:00 PM. The primary source of noise at this location was traffic on H Street and on Florida Street. The measured Leq at this site was 71 dBA.

**ST-4: Benning Road and 18th Street:** This measurement was performed at the southwest corner of Benning Road and 18th Street. The measurement was for 1 hour, starting at 10:40 AM. The primary source of noise at this location was traffic on Benning Road. The measured Leq was 69 dBA.

**ST-5: Benning Road and 20th Street:** This measurement was performed on the north side of Benning Road, midway between 20th and 21st Streets. The measurement was for 1 hour, starting at 11:50 AM. The primary source of noise at this site was traffic on Benning Road. The measured Leq was 70 dBA.

**ST-6: 2500 Benning Road:** This measurement was performed outside of Spingarn High School. The measurement was for 1 hour, starting at 9:30 AM. The primary noise source was traffic on Benning Road, and intermittent noise from WMATA rapid transit trains. The measured Leq at this site was 56 dBA. The lower noise level at this site was due to the large setback distances from the primary noise sources.

**Table 8: Ambient Noise Measurement Results**

| Site | Location | Type of Land Use[(a)] | Duration | Start Time, hh:mm[(b)] | Distance, ft[(c)] | Leq (daytime), dBA [(d)] | Ldn, dBA [(d)] |
|---|---|---|---|---|---|---|---|
| LT-1 | 201 I Street | 2 | 24hr | 13:50 | 45 | 71 | 74 |
| LT-2 | 1521 Benning Road | 2 | 24hr | 12:20 | 50 | 72 | 74 |
| LT-3 | 1720 Benning Road | 2 | 10hr | 10:10 | 52 | 67 | 70 |
| LT-4 | 2101 G Street | 2 | 24hr | 09:50 | 150 | 61 | 64 |
| ST-1 | 501 H Street | 2 | 1hr | 11:30 | 40 | 69 | -- |
| ST-2 | H and 11th | 2 | 1hr | 13:40 | 25 | 68 | -- |
| ST-3 | H and Florida | 2 | 1hr | 15:00 | 22 | 71 | -- |
| ST-4 | Benning and 18th | 2 | 1hr | 10:40 | 45 | 69 | -- |
| ST-5 | Benning and 20th | 2 | 1hr | 11:50 | 50 | 70 | -- |
| ST-6 | 2500 Benning Road | 3 | 1hr | 09:30 | 330 | 56 | -- |

Notes:
(a) Land use of the nearest sensitive receiver.
(b) Start time of the measurement.
(c) Distance of microphone from the centerline of the nearest traffic lane.
(d) Leq for the duration of the measurement during the daytime hours (7 AM to 10 PM).
(e) Estimated Ldn using the relationship Ldn = Leq + 3 dB. This relationship is based on the average the difference between Ldn and daytime Leq at the three long-term measurement sites.

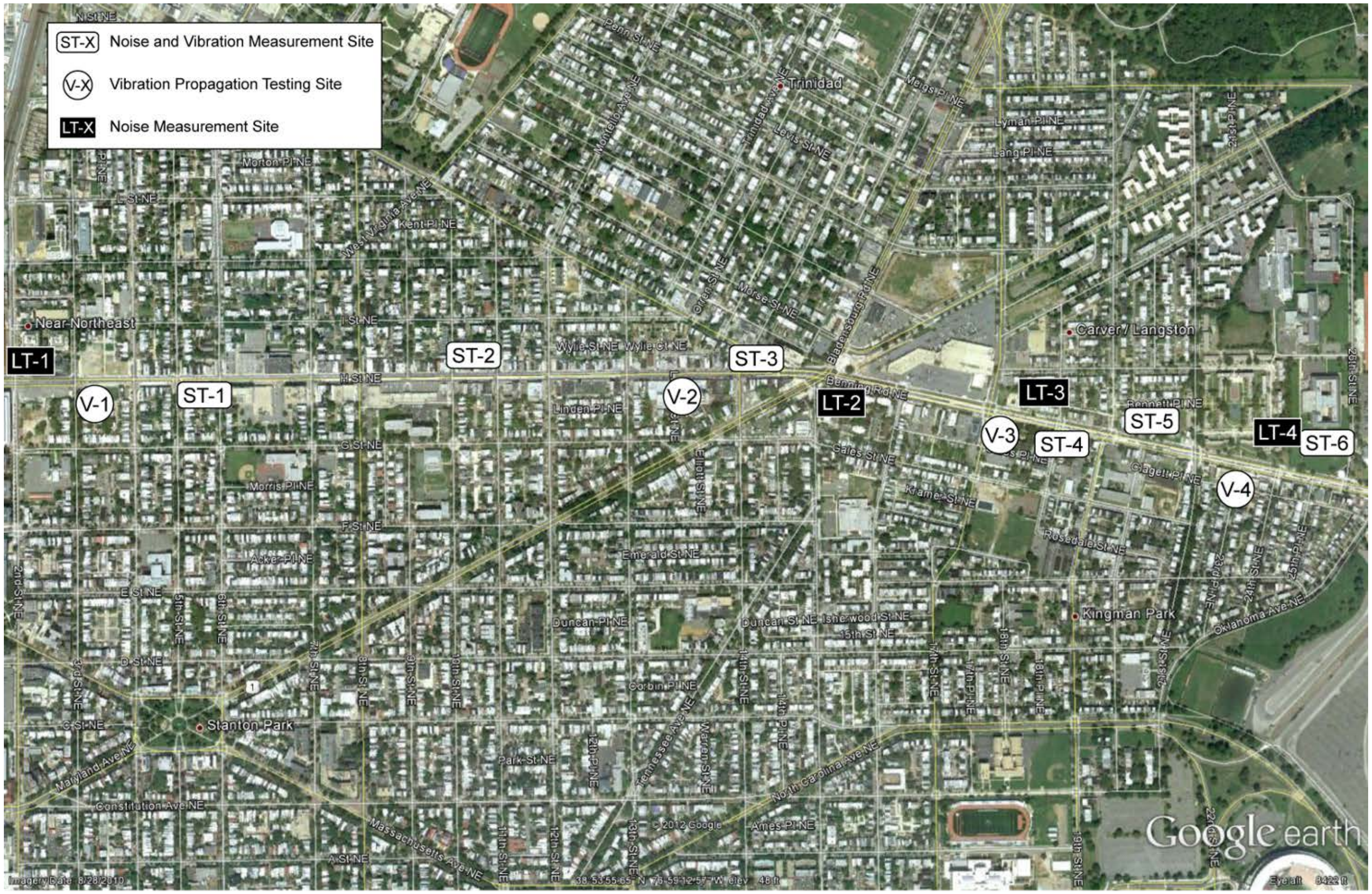



**Figure 1: Overview of Noise and Vibration Measurement Locations**

## 5.2 Existing Conditions - Vibration

Existing vibration sources in the project corridor primarily consist of vehicular traffic and intermittent construction activities. Vehicular traffic is the only permanent vibration source that was observed in the project corridor. When vehicular traffic causes perceptible vibration, the source usually is traced to potholes, wide expansion joints, or other “bumps” in the roadway surface. Therefore, the FTA assessment procedures for vibration from rail transit projects do not require measurements of existing vibration levels.

Localized geologic conditions such as such soil stiffness, soil layering, and depth to bedrock, have a strong effect on ground-borne vibration. Unfortunately, it is difficult to obtain information on subsurface conditions in sufficient detail so that computer models can be used to accurately predict ground vibration. As a result, most detailed predictions of ground vibration are based largely on empirical methods that involve measuring vibration propagation in the soil. The FTA Guidance Manual defines three levels of vibration assessment:

- Screening: Generalized distances of potential impacts are used to quickly determine whether there is any potential for impacts.
- General Assessment: FTA provides a general curve of train vibration vs. distance that is used to estimate the vibration levels. The curve was developed by plotting measured vibration levels from a number of different rail transit systems against distance from the tracks and drawing a line through the top range of the data. The curve provides a conservative (high) estimate of potential vibration impacts. Adjustments are made to the general curve to account for factors such as speed and special trackwork.
- Detailed Assessment: A Detailed Vibration assessment consists of using state-of-the-art tools to characterize how localized soil conditions affect the levels of groundborne vibration. The FTA Guidance Manual recommends using vibration propagation tests to measure how vibration will be transmitted from the streetcar tracks through the ground and into the foundations of nearby buildings (see Figure 2).

Because many of the buildings with vibration sensitive land uses are within a few feet of the sidewalks, the distances between the streetcar tracks and these sensitive receivers would be relatively low. Therefore a Detailed Vibration Assessment including vibration propagation tests was performed for this analysis.

### *5.2.1 Vibration Propagation Test Procedure*

The test procedure consists of using a drop hammer as a vibration source and determining the transfer function relationship between the force generated by the drop hammer and the resulting vibration pulse. The impacts are performed in a line located as close to the planned track centerline as possible and accelerometers are located at several distances from the impact line. Accelerometers may also be located inside nearby buildings to provide information on the propagation path from the track centerline to the building’s occupied spaces. Vibration propagation tests were performed at four locations using a line of 11 impact positions at intervals of 15 feet (marked as *the line of impacts* in Figure 2). The relationship between the exciting force and the resulting vibration level is referred to as the “transfer mobility,” which indicates how easily vibration travels through the earth.

The measured transfer mobility functions for each accelerometer are combined using numerical integration to derive equivalent line-source transfer mobility (LSTM). The relationship between the LSTM and the groundborne vibration created by a streetcar is:

$$Lv = FDL + LSTM$$

where:

| | | |
|---|---|---|
| Lv | = | Train vibration velocity measured at the ground surface |
| FDL | = | Force density function that characterizes the vibration forces generated by the train and track |
| LSTM | = | Measured line source transfer mobility *(all quantities are in decibels assuming a consistent set of decibel reference values)* |

The FDL for modern streetcars was determined through measurements at the Portland, OR and Seattle, WA streetcar systems. It is expected that the vehicle and track system used for the DC Streetcar will be similar to those of the Portland and Seattle systems. The derived FDL is presented with the vibration prediction models in Section 7.2.

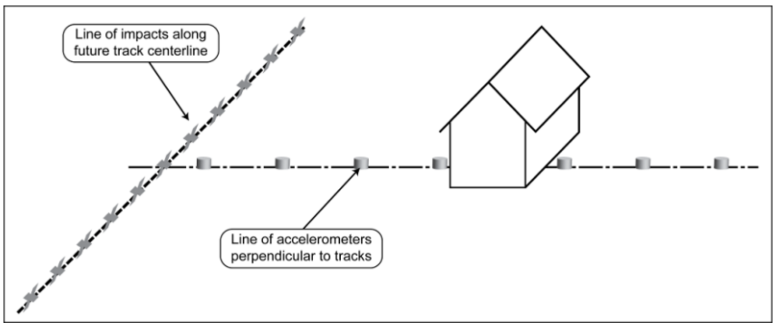



**Figure 2: Schematic of Vibration Propagation Test**

### *5.2.2 Vibration Propagation Test Sites*

The four sites for the vibration propagation tests represent the soil conditions of the vibration sensitive receivers along the H/Benning streetcar corridor. The four test sites were:

**Site V-1:** This measurement was performed just east of the intersection of H Street and 3rd Street in a parking lot. The impact line was located on the south side of H Street and the transducers were located at distances of 25, 37, 50, 75, 100, and 125 feet from the impact line.

**Site V-2:** This measurement was performed at the Atlas Theater. The Atlas Theater includes a front lobby, a box office, an auditorium, and a dance theater. The auditorium is setback approximately 100 ft from the sidewalk and is used for plays and concerts. The indoor spaces in front of the theater are used for dance performances and classes. The vibration impact line was located on the south side of H Street and the transducers went down an alley immediately adjacent to the theater at distances of 25, 50, 100, and 150 feet. Additionally, two transducers were placed inside the lobby, at distances of 75 and 125 feet from the impact line. Because the dance theater has classes throughout the week, the indoor vibration tests were limited to the lobby area. However, the lobby measurements should provide sufficient information on the indoor vibration levels at the theater.

**Site V-3:** This measurement was performed at the apartment complex located at the intersection of Benning Road and 17th Street. The impact line was located on the south side of Benning Road and the transducers were placed on the west side of the apartment building.

**Site V-4:** This measurement was performed between 23rd and 24th Streets, in a vacant lot. The impact line was on the south side of Benning Road. The transducers were located in the driveway of a vacated fast-food building, at distances of 25, 37, 50, 75, 100, and 130 feet.


**Figure 3: Vibration Propagation Site V-1**

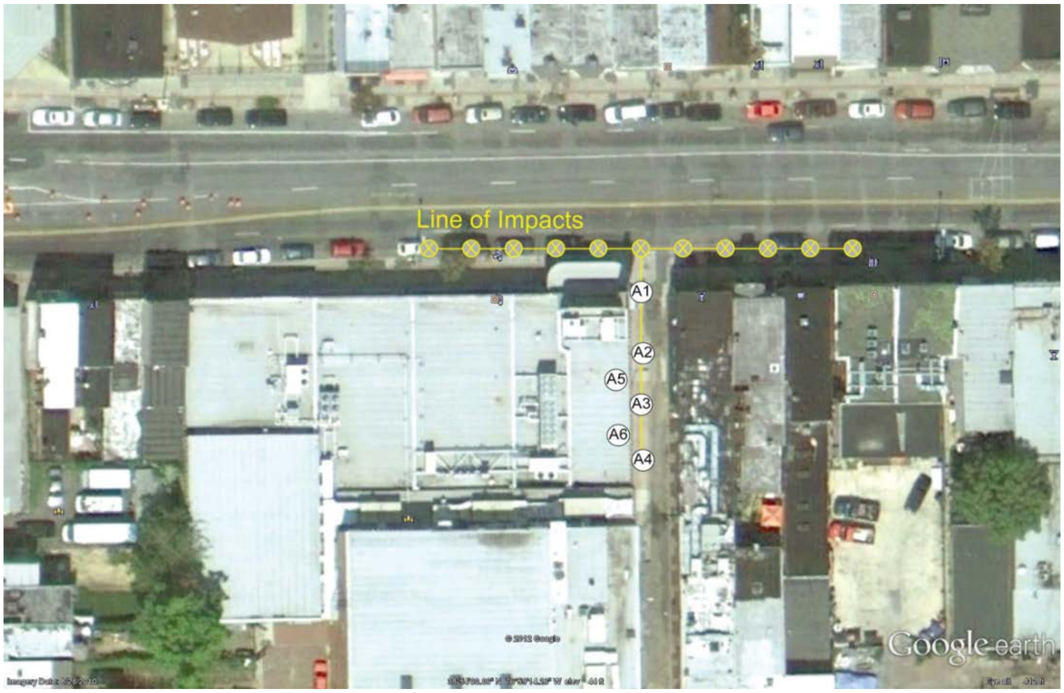



**Figure 4: Vibration Propagation Site V-2**
Note: Sites A5 and A6 were inside the theater


**Figure 5: Vibration Propagation Site V-3**


**Figure 6: Vibration Propagation Site V-4**

### *5.2.3 Results of Vibration Propagation Tests*

The measured LSTM and coherence for sites V-1 through V-4 are shown in Figure 7 through Figure 10. Coherence varies between 0 and 1 and is a measure of the "quality" of the LSTM results. A coherence close to 1 indicates that the vibration response and the exciting force from the drop hammer are closely related. A coherence less than about 0.2 indicates a relatively weak relationship between the exciting force and the vibration response. Low coherence indicates that the vibration signal generated by the drop hammer was lower than the ambient vibration. This will happen when ambient vibration is relatively high, when the distance between the drop hammer and the accelerometer is relatively high, or when the soil is a poor transmitter of vibration at a specific frequency.

Following are a few observations from the propagation test results:

- The LSTM for site V-1 peaked between 20 and 31.5 Hz (Figure 7). The vibration attenuated at a faster rate between 37.5 and 50 ft, but slowed beyond 50 ft. Coherence at this site was good above 20 Hz. Compared to the other test sites, the highest LSTM at 20 Hz was recorded at this site.
- The LSTM for site V-2 peaked between 16 and 40 Hz at all distances except the 25 ft measurement position (Figure 8). The measurement at 25 ft showed an additional vibration peak at 80 Hz.
- At site V-2, the measured LSTM at 100 ft was higher between 20 and 63 Hz compared to the LSTM at 50 ft. This indicates that vibration was transmitted to the 100 ft position through a more efficient path. The 125 ft indoor measurement at the Atlas Theater lobby had a substantially lower LSTM in the 40 to 100 Hz range than the 75 ft indoor measurement (Figure 8).
- In general, at Site V-2, the indoor positions fit well with the other data. Vibration decays with distance, and the 75 and 125 ft positions inside the building fall between the 50 and 150 ft positions outside the building. This indicates that there is little difference in vibration propagation from indoor to outdoor.
- The LSTM at site V-4 peaked between 31.5 and 63 Hz and showed good coherence above 16 Hz (Figure 10).
- At distances below 75 ft, site V-4 showed approximately 5 decibels higher vibration than the other sites. The rate of attenuation with distance was the highest for V-4. At distances greater than 75 ft, the LSTM was similar to the LSTM at the other three sites.

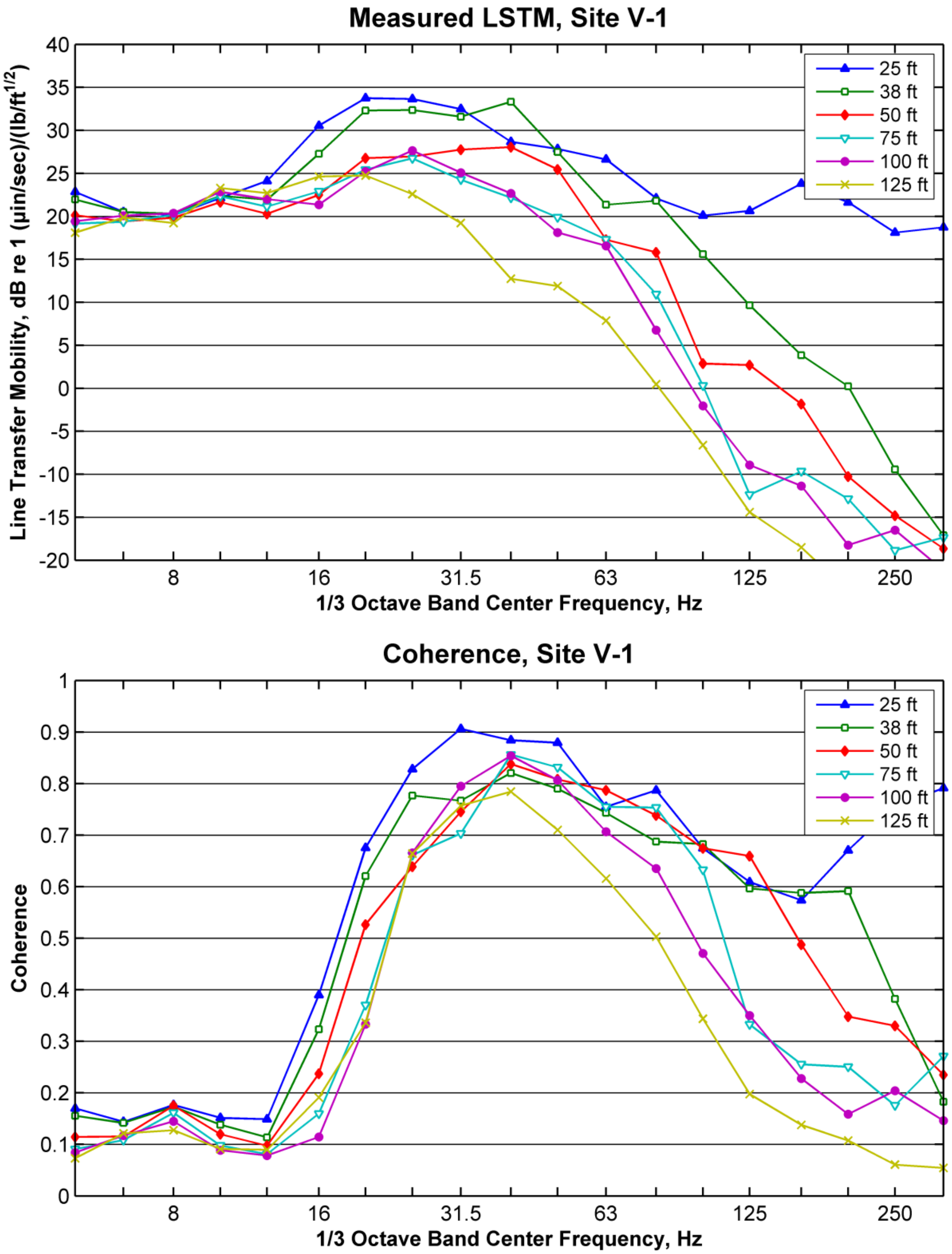



**Figure 7: Measured LSTM and Coherence, Site V-1**

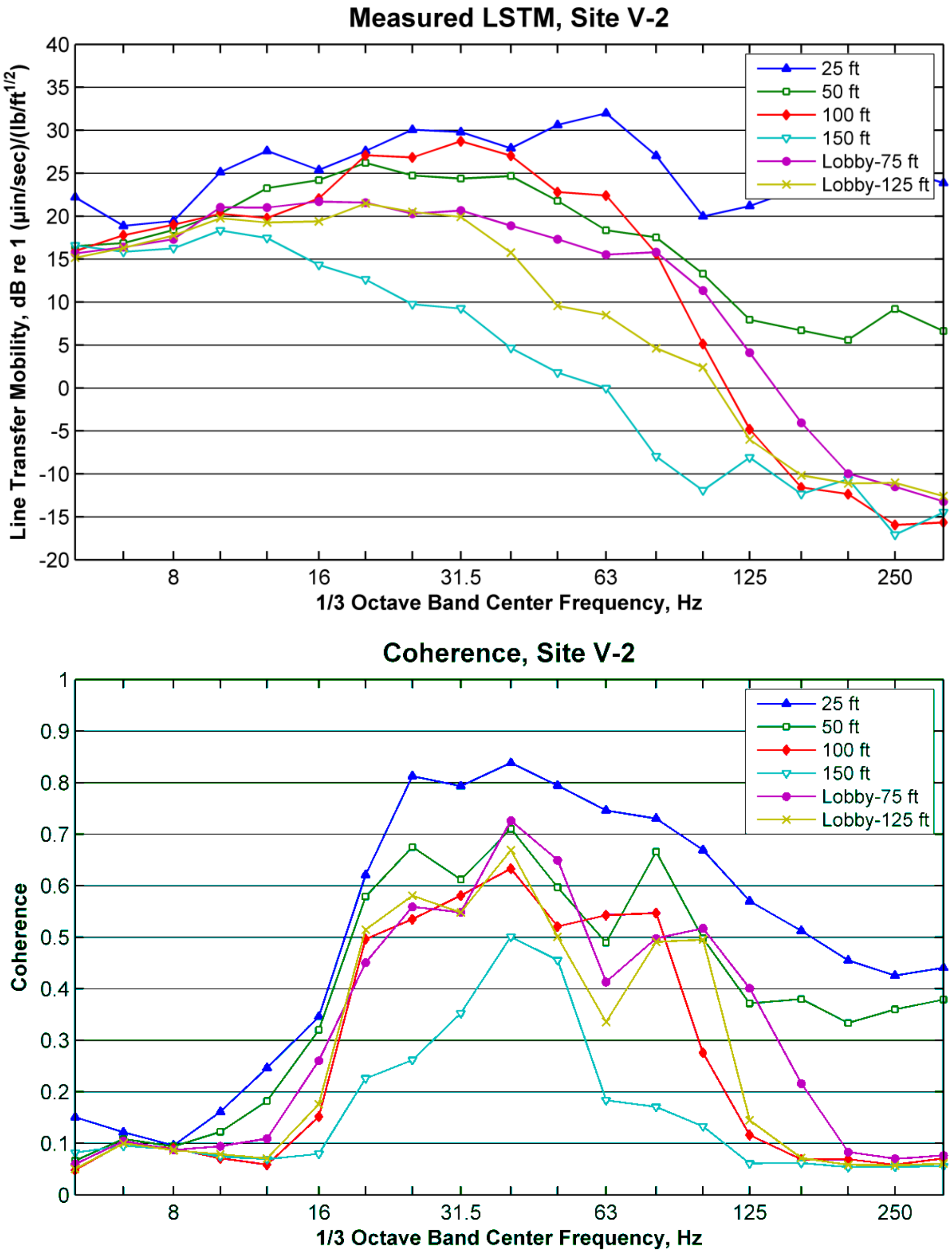



**Figure 8: Measured LSTM and Coherence, Site V-2**

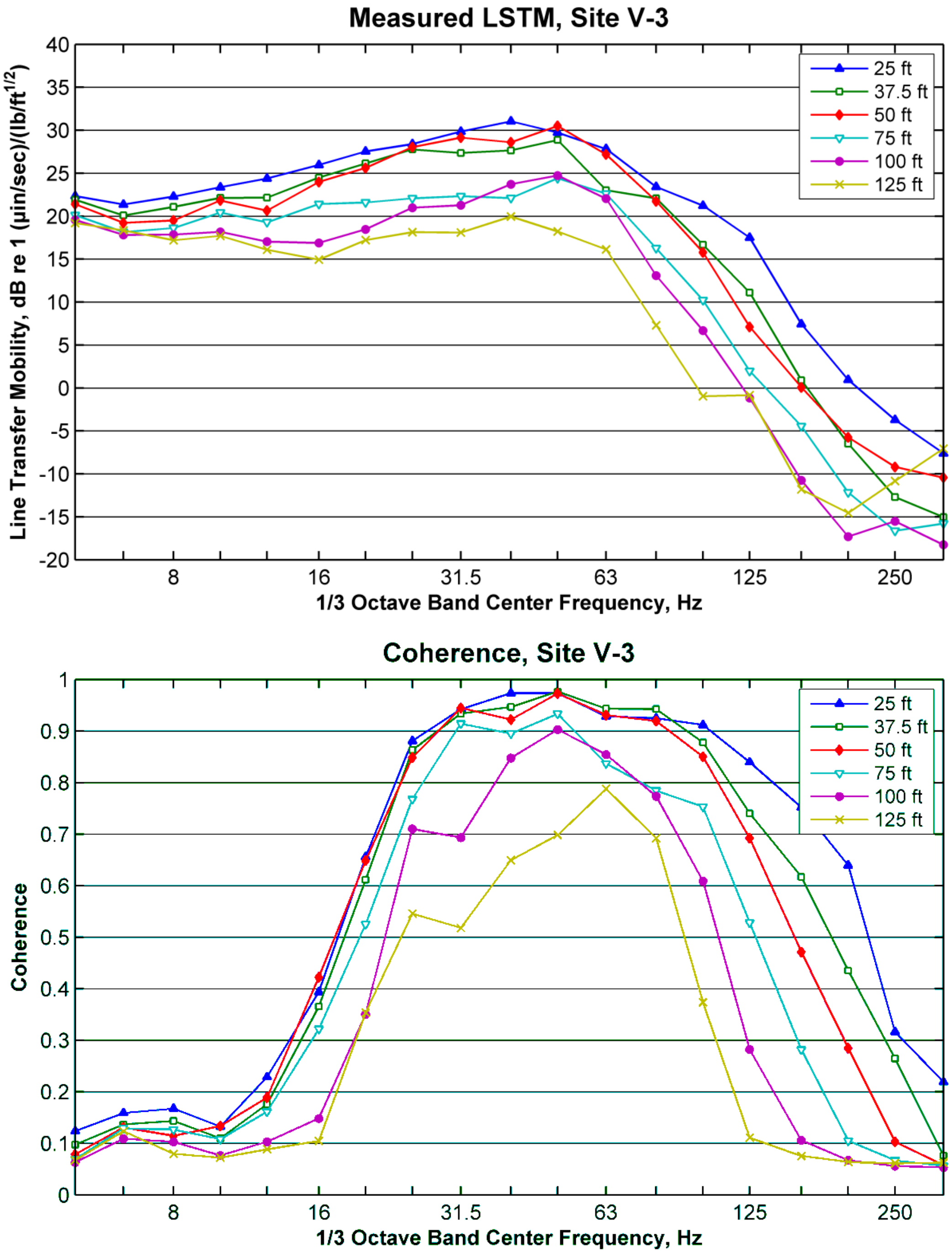
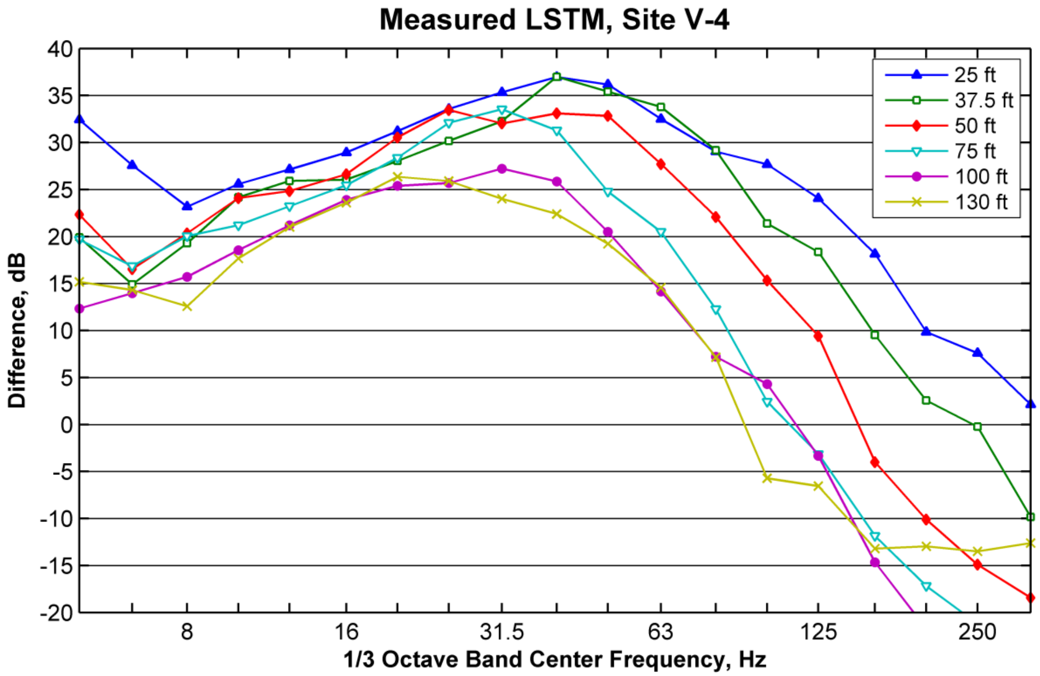



**Figure 9: Measured LSTM and Coherence, Site V-3**



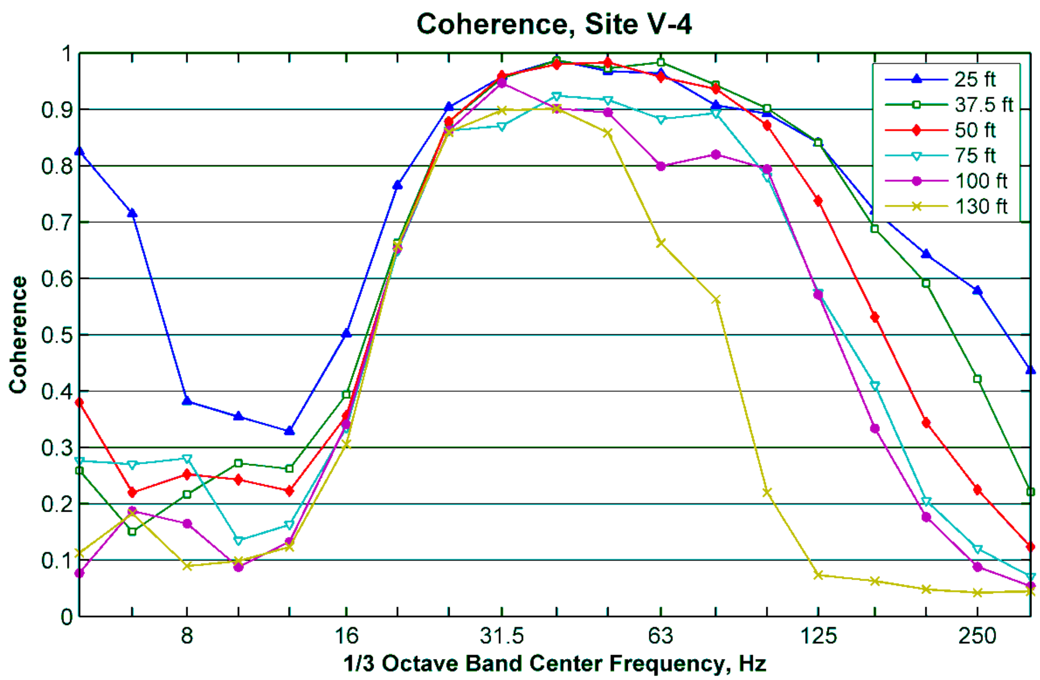




**Figure 10: Measured LSTM and Coherence, Site V-4**

### *5.2.4 Ambient Vibration*

The FTA vibration analysis procedure for streetcar projects is not based on existing vibration and does not require measurements of ambient vibration. However, because many of the sensitive receivers in the project area are within 15 to 20 ft of the street, ambient vibration was measured in the project area to document the existing vibration levels caused by vehicular traffic.

The ambient vibration measurements were performed at the short-term noise sites concurrent with the noise measurements. Table 9 summarizes the ambient vibration measurements. Description of the test locations are provided in Section 4.2. Some key points from the ambient vibration measurements are:

- The Leq at all sites was relatively low and did not exceed 60 VdB[1] at any site.
- The L1 at all test sites, except ST-6, was 60 VdB or higher. The L1 at ST-1, ST-3, and ST-5 exceeded 65 VdB. The L1 represents typical maximum vibration levels from trucks or buses passing on near the measurement position. The level of 65 VdB is important because the approximate threshold of perception for most humans ranges between 60 and 65 VdB.
- The measured Leq and L1 at sites ST-1, ST-3, and ST-5 were dominated by a few high-vibration events. The peaks in the 1/3 octave band spectra for these events were between 10 and 16 Hz, which is consistent with the vibration created by trucks and buses.
- The ambient vibration at ST-6 was relatively low because of the greater distance to the nearest road.

**Table 9: Ambient Vibration Measurement Results**

| Site [(a)] | Location | Type of Land Use | Duration | Start Time, hh:mm | Dist. from Center of Nearest Traffic Lane, ft [(b)] | Leq, VdB | L1,[(c)] VdB | L99, [(d)] VdB |
|---|---|---|---|---|---|---|---|---|
| ST-1 | 501 H Street | 2 | 1hr | 11:30 | 40 | 57 | 68 | 44 |
| ST-2 | H and 11th | 2 | 1hr | 13:40 | 25 | 50 | 60 | 40 |
| ST-3 | H and Florida | 2 | 1hr | 15:00 | 25 | 57 | 67 | 43 |
| ST-4 | Benning and 18th | 2 | 1hr | 10:40 | 45 | 53 | 63 | 43 |
| ST-5 | Benning and 20th | 2 | 1hr | 11:50 | 50 | 57 | 68 | 38 |
| ST-6 | 2500 Benning Road | 3 | 1hr | 09:30 | 330 | 45 | 55 | 33 |

Notes:

(a) Vibration measurements were performed concurrent to the short-term noise measurements at sites ST-1 through ST-6.

(b) The distance of the accelerometers from the centerline of the nearest traffic lane.

(c) L1 is the sound level exceeded 1 percent of the time. This typically represents high vibration peaks from events such as a heavy truck or bus.

(d) L99 is the sound level exceeded 99 percent of the measurement period. This represents the typical background vibration.

[1] All vibration levels in this report are in terms of rms vibration velocity in decibels using a decibel reference of 1 µin/sec. The abbreviation “VdB” is used for vibration velocity decibels to avoid confusion with sound decibels.

# 6. REGULATORY FRAMEWORK

## 6.1 State and Local Noise and Vibration Limits

The District of Columbia Municipal Regulations (DCMR) have established noise limits for railroad cars operated by Washington Metropolitan Area Transit Authority (WMATA) within residential, commercial and industrial zones (Ref. 2). The DC noise limits allow the WMATA railroad cars a maximum noise level of up to 75 dBA at 100 feet for residential land uses and does not take existing noise levels into account. The maximum noise from the streetcar vehicles proposed for the DC Streetcar projects will not exceed 75 dBA at 100 feet for the proposed maximum operation speeds and therefore this limit was not used as a criterion in the noise impact assessment.

For federally financed transit projects the noise impact criteria for use are defined in the FTA Guidance Manual (Ref. 1). This project does not use FTA funds however, the FTA analysis methods were used because the FTA method reflects the best available research on the topic.

## 6.2 FTA Noise Impact Criteria

The noise impact criteria for use on federally financed transit projects are defined in the FTA Guidance Manual (Ref. 1). Studies on which the FTA criteria are based show that characterizing the overall noise environment using measures of noise exposure provides the best correlation with human annoyance.

Table 10 lists the three land-use categories that FTA uses along with the applicable noise metric for each category. For Category 2 land uses, noise exposure is characterized using Ldn, while for Category 1 and Category 3 land uses, noise exposure is characterized using the maximum one-hour Leq. It is noteworthy that Category 2 land uses (residential) include residences, motels, hotels, and any other place where people typically sleep. Appendix A provides background information on the Ldn and Leq noise descriptors. The basic concept of the FTA noise impact criteria is that more project noise is allowed in areas where existing noise is higher, but that the decibel increase in total noise exposure (the decibel sum of existing noise and project noise) decreases.

FTA defines two levels of noise impact: ***moderate*** and ***severe***. In accordance with the FTA Guidance Manual, mitigation to eliminate noise impacts must be investigated for both degrees of impact. The manual also states that for severe impacts "…there is a presumption by FTA that mitigation is incorporated into the project unless there are truly extenuating circumstances which prevent it." In considering mitigation for severe impacts in this study, the goal has been to reduce noise levels to below the moderate impact threshold.

FTA allows more discretion for mitigation of moderate impacts based on the consideration of factors including cost, number of sensitive receivers affected, community views, the amount by which the predicted levels exceed the impact threshold, and the sensitivity of the affected receivers. The FTA noise impact criteria are given in tabular format in Table 11 with the thresholds rounded up to the nearest decibel. The criteria are shown graphically in Figure 11 for the different categories of land use along with an example of how the criteria are applied. The top two graphs are for nonresidential land uses where Leq(h) represents the noise exposure metric, and the bottom left graph is for residential land uses where Ldn represents the noise exposure metric. As shown in Figure 11, the impact threshold is a sliding scale and it typically increases with an increase in existing noise exposure. The existing noise appears on the horizontal axis, and the amount of new noise that the project can create is on the vertical axis. The lower curve (blue) defines the threshold for moderate impact and the upper curve (red) defines the threshold for severe impact. Figure 12 shows the mathematical equations for the curves shown in Figure 11.

| Table 10: FTA Land Use Categories and Noise Metrics | | |
|---|---|---|
| **Land Use Category** | **Noise Metric (dBA)** | **Description of Land Use Category** |
| 1 | Outdoor Leq (h)[a] | A tract of land where quiet is an essential element of their intended purpose. This category includes lands set aside for serenity and quiet and such land uses as outdoor amphitheaters and concert pavilions, as well as national historic landmarks with significant outdoor use. Also included are recording studios and concert halls. |
| 2 | Outdoor Ldn | Residences and buildings in which people sleep. This category includes homes, hospitals, and hotels, where a nighttime sensitivity to noise is assumed to be of utmost importance. |
| 3 | Outdoor Leq (h) [a] | Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, and churches, where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds, and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included. |

Source: FTA Guidance Manual, May 2006 (Ref. 1).
Notes:
(a) Leq for the noisiest hour of transit-related activity during hours of noise sensitivity.

The sample graph located in the bottom right corner of Figure 11 may help clarify the concept of a sliding scale for noise impact. Assume that the existing noise has been measured at 60 dBA Ldn. This is the total noise from all existing noise sources over a 24-hour period: traffic, aircraft, lawn mowers, children playing, birds chirping, etc. Starting at 60 dBA on the horizontal axis, follow the vertical line up to where it intersects the moderate and severe impact curves. Then refer to the left axis to see the impact thresholds. An existing noise of 60 dBA Ldn gives thresholds of 57.8 dBA Ldn for moderate impact and 63.4 dBA Ldn for severe impact. Note that the values are given in tenths of a decibel to avoid confusion from rounding off; in reality, one cannot perceive a tenth of a decibel change in sound level.

The project noise has thresholds of 57.8 dBA Ldn and 63.4 dBA Ldn. This is the new noise generated by operating the transit project. If the predicted project noise is greater than 57.8 dBA Ldn, there is moderate impact and noise mitigation must be considered. If the predicted project noise exceeds 63.4 dBA Ldn, then there is severe impact and, as discussed above, noise mitigation must be included in the project unless there are compelling reasons why mitigation is unfeasible.

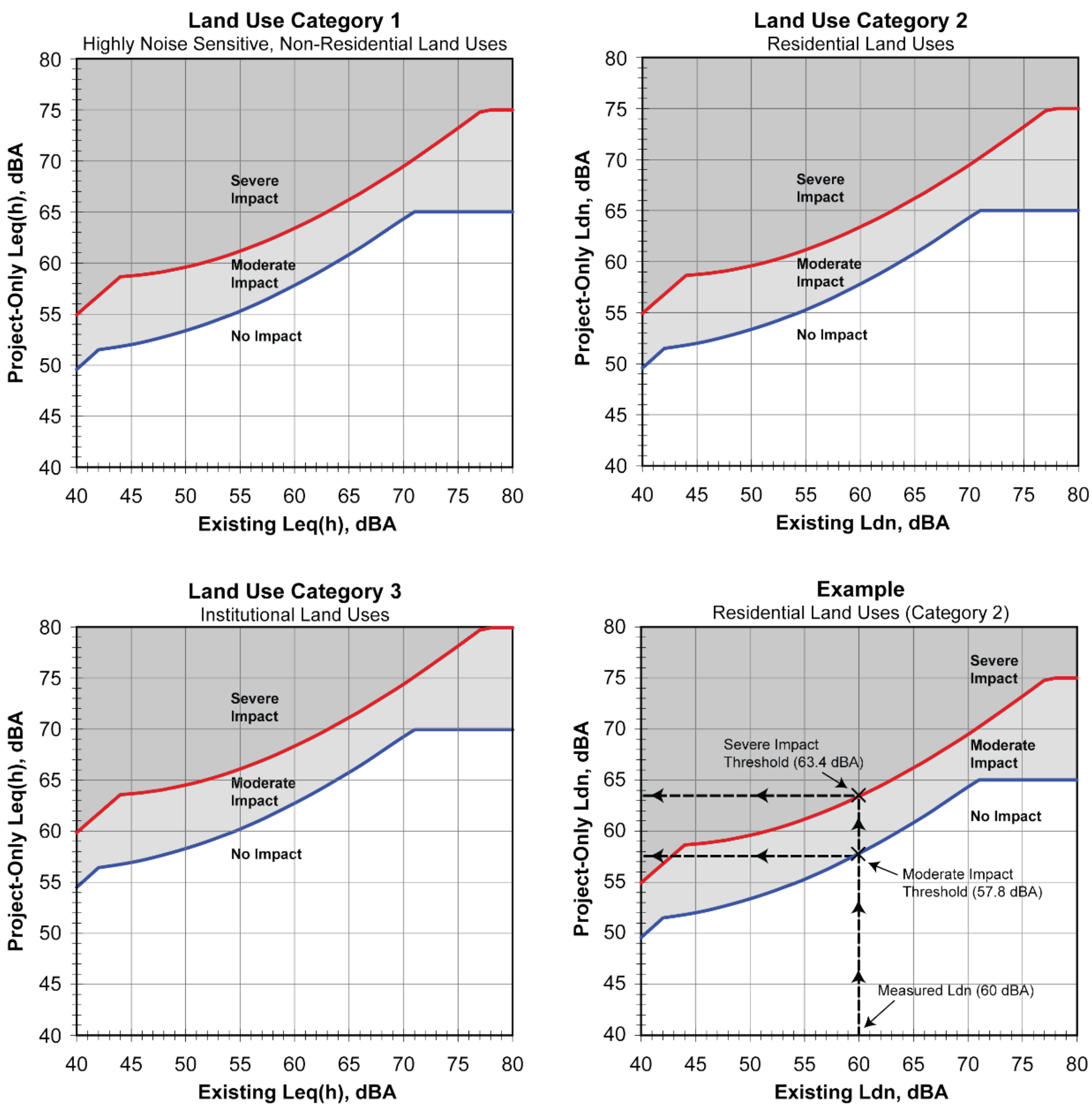



**Figure 11: FTA Noise Impact Criteria**

**Threshold of Moderate Impact**

**Category 1 and 2**

| | | | |
|---|---|---|---|
| $L_p$ | = | $11.450 + 0.953L_E$ | $L_E < 42$ |
| $Lp$ | = | $71.662 - 1.164L_E + 0.018L_E^2 - 4.088\times10^{-5}L_E^3$ | $42 \leq L_E \leq 71$ |
| $Lp$ | = | $65$ | $L_E > 71$ |

**Category 3**

| | | | |
|---|---|---|---|
| $L_p$ | = | $16.450 + 0.953L_E$ | $L_E < 42$ |
| $Lp$ | = | $76.662 - 1.164L_E + 0.018L_E^2 - 4.088\times10^{-5}L_E^3$ | $42 \leq L_E \leq 71$ |
| $Lp$ | = | $70$ | $L_E > 71$ |

**Threshold of Severe Impact:**

**Category 1 and 2**

| | | | |
|---|---|---|---|
| $L_p$ | = | $17.322 + 0.940L_E$ | $L_E < 44$ |
| $Lp$ | = | $96.725 - 1.992L_E + 3.02\times10^{-2}L_E^2 - 1.043\times10^{-4}L_E^3$ | $42 \leq L_E \leq 71$ |
| $Lp$ | = | $75$ | $L_E > 71$ |

**Category 3**

| | | | |
|---|---|---|---|
| $L_p$ | = | $22.322 + 0.940L_E$ | $L_E < 44$ |
| $Lp$ | = | $101.725 - 1.992L_E + 3.02\times10^{-2}L_E^2 - 1.043\times10^{-4}L_E^3$ | $42 \leq L_E \leq 77$ |
| $Lp$ | = | $80$ | $L_E > 77$ |

**where:**

$L_p$= impact threshold and $L_E$=Existing noise exposure

Source: Ref. 1

**Figure 12: Equations Used for the FTA Noise Impact Criteria**

**Table 11: FTA Noise Impact Criteria**

| Existing Noise Exposure, Leq or Ldn | Project Noise Exposure Impact Thresholds, Leq or Ldn (dBA) | | | |
|---|---|---|---|---|
| | Category 1 or 2 Land Uses | | Category 3 Land Uses | |
| Moderate Impact | Moderate Impact | Severe Impact | Moderate Impact | Severe Impact |
| <43 | Ambient+10 | Ambient+15 | Ambient+15 | Ambient+20 |
| 43 | 52 | 58 | 57 | 63 |
| 44 | 52 | 58 | 57 | 63 |
| 45 | 52 | 58 | 57 | 63 |
| 46 | 53 | 59 | 58 | 64 |
| 47 | 53 | 59 | 58 | 64 |
| 48 | 53 | 59 | 58 | 64 |
| 49 | 54 | 59 | 59 | 64 |
| 50 | 54 | 59 | 59 | 64 |
| 51 | 54 | 60 | 59 | 65 |
| 52 | 55 | 60 | 60 | 65 |
| 53 | 54 | 60 | 60 | 65 |
| 54 | 55 | 61 | 60 | 66 |
| 55 | 56 | 61 | 61 | 66 |
| 56 | 56 | 62 | 61 | 67 |
| 57 | 57 | 62 | 62 | 67 |
| 58 | 57 | 62 | 62 | 67 |
| 59 | 58 | 63 | 63 | 68 |
| 60 | 58 | 63 | 63 | 68 |
| 61 | 59 | 64 | 64 | 69 |
| 62 | 59 | 64 | 64 | 69 |
| 63 | 60 | 65 | 65 | 70 |
| 64 | 61 | 65 | 66 | 70 |
| 65 | 61 | 66 | 66 | 71 |
| 66 | 62 | 67 | 67 | 72 |
| 67 | 63 | 67 | 68 | 72 |
| 68 | 63 | 68 | 68 | 73 |
| 69 | 64 | 69 | 69 | 74 |
| 70 | 65 | 69 | 70 | 74 |
| 71 | 65 | 70 | 71 | 75 |
| 72 | 66 | 71 | 71 | 76 |
| 73 | 66 | 71 | 71 | 76 |
| 74 | 66 | 72 | 71 | 77 |
| 75 | 66 | 73 | 71 | 78 |
| 76 | 66 | 74 | 71 | 79 |
| 77 | 66 | 74 | 71 | 79 |
| >77 | 66 | 75 | 71 | 80 |

Source: FTA Guidance Manual, May 2006, Ref. 1.

Notes:

1. Ldn is used for land uses where nighttime sensitivity is a factor; maximum one hour Leq is used for land use involving only daytime activities. All values in this table are rounded up to the nearest integer.
2. Impact thresholds are rounded up to the nearest decibel.

## 6.3 FHWA Noise Abatement Criteria

For highway/transit projects, when both highway and transit cause significant noise, but at different times of the day, the FTA Guidance Manual specifies that noise impact from the project be determined using both FTA and FHWA methods. The primary difference between the FTA and FHWA noise assessment methods is that the FHWA procedure assesses only the loudest-hour noise levels, whereas the FTA procedure assesses the average 24 hour noise levels with a penalty of 10 decibels added to the nighttime hours. For most of the receivers located along the H/Benning Streetcar alignment, traffic noise would dominate during most of the daytime hours including peak commute hours, and the streetcar noise would dominate the rest of the time including the nighttime hours. Therefore, FHWA noise analysis has been performed for this project in addition to the FTA noise analysis. The rest of this section discusses the FHWA noise abatement criteria (NAC) as applicable to DDOT projects.

Because the current project includes a new alignment for the streetcar that includes restriping and/or major revamping of the existing roadway, this project would be classified by DDOT as an FHWA Type 1 noise project. Based on the DDOT interpretation, a project alternative will cause impacts if the project will cause the existing noise level to increase by at least 6 decibels or if the predicted traffic noise approaches or exceeds the NAC. Any sensitive receiver that would experience an impact as the term is defined by DDOT, is eligible for consideration of noise abatement.

The DDOT noise abatement criteria for highway projects are summarized in Table 12. Consistent with DDOT policy, noise abatement will be considered for land use categories B and C if exterior noise due to traffic is predicted to be 66 dBA or higher. For Category E land uses, noise abatement will be considered if the predicted exterior noise is 71 dBA or higher. Only the external land use categories B, C and E have been evaluated for the H/Benning Streetcar Project. For these land use categories, the noise impact criteria are applicable only when there are areas of frequent outdoor human activity at these receivers. For this project, interior land uses have not been evaluated for noise impacts.

The procedures used for assessing traffic noise impacts from the project are based on the FHWA procedures and include the following general steps:

1. Identify sensitive receivers and their land use category in the project corridor. Determine the sensitive land uses that have exterior areas where frequent human use occurs and are exposed to the project noise sources.
2. Measure the existing noise at representative sensitive receivers in the project corridor to determine the conditions at each noise-sensitive receiver.
3. Develop a model to predict traffic noise levels.
4. Where there is noise impact, consider noise abatement.
5. Evaluate the reasonableness and feasibility of the noise abatement.

More details on the traffic noise impact evaluation are provided in Section 8.4.

| Table 12: FHWA Noise Abatement Criteria | | | |
|---|---|---|---|
| **Land Use Category** | **Noise Metric (dBA)** | | **Description of Activities** |
| A | 57 | Exterior | Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities if the area is to continue to serve its intended purpose. |
| B | 67 | Exterior | Residential |
| C | 67 | Exterior | Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meetings rooms, public and nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings |
| D | 52 | 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 | Hotels, motels, offices, restaurants/bars, and other developed lands, properties, or activities not included in A-D or F. |

Source: FHWA 23 CFR 772, 2010.

## 6.4 District of Columbia Construction Noise Limits

The District of Columbia Municipal Regulations (DCMR) restrict the hours of construction and specifies noise limits for construction or demolition activities within a residential zone (Ref. 3 and 4). The limits on construction noise are summarized below:

- Construction activities are allowed on weekdays between 7 AM to 7 PM.
- Construction activities are not allowed on Sundays, holidays and between 7 PM to 7 AM on weekdays.
- Restrictions on construction hours are exempt for work performed by public utilities or WMATA or its subcontractors. Our understanding is that this exemption applies for the construction of the H/Benning Streetcar Project including the Car Barn and Training Center (CBTC).

The maximum allowed construction noise levels at residential land uses for public utilities and WMATA-related projects are:

- 7 AM to 7 PM: 80 dBA.
- 7 PM to 7 AM on weekdays: 55 dBA.

## 6.5 FTA Impact Criteria for Groundborne Vibration

As discussed in Appendix A, the potential adverse effects of rail transit groundborne vibration include perceptible building vibration, rattle noises, reradiated noise (groundborne noise), and cosmetic or structural damage to buildings. The vibration caused by modern streetcar operations is well below what is considered necessary to cause even minor cosmetic damage to buildings. Therefore, the criteria for building vibration caused by transit operations are only concerned with potential annoyance of building occupants.

One potential concern is historic buildings and other cultural resources that may be fragile and particularly susceptible to damage from ground motions. Several historic buildings and other resources have been identified in the study area. However, none of the structures appear to be unusually fragile. Therefore, the vibration assessment of these structures is based on the current use of the building. The potential for construction vibration to damage structures during construction is covered in Section 9.2 (Construction vibration).

The FTA vibration impact criteria are based on the maximum indoor vibration level as a train passes. There are no impact criteria for outdoor spaces such as parks. The FTA Guidance Manual provides two sets of criteria: one based on the overall vibration velocity level for use in General Vibration Impact Assessments and one based on the maximum vibration level in any 1/3 octave band (the band maximum level) for use with a Detailed Vibration Assessment, which was used for this project.

Table 13 shows the FTA General Assessment criteria for groundborne vibration from rail transit systems. As with the FTA noise criteria, there are three categories of sensitive land uses. However, the category definitions are different for noise and for vibration. The primary difference is in Category 1. For a noise assessment, Category 1 applies to land uses "…where quiet is an essential element of their intended purpose." For a vibration assessment, Category 1 applies to "Buildings where vibration would interfere with interior operations...," which primarily applies to spaces that house sensitive research and laboratory equipment such as scanning electron microscopes. There are no buildings in the H/Benning Streetcar Project corridor that qualify as Category 1 vibration sensitive land uses.

Unlike the FTA noise criteria, the vibration criteria do not incorporate any factor to account for the number of trains per day with one exception. The exception is that for "occasional service," the FTA impact thresholds are 3 VdB higher than for "frequent service" and for "infrequent service," the FTA impact thresholds are 8 VdB higher than for frequent service. FTA defines occasional service to be between 30 and 70 trains per day and infrequent service to be less than 30 trains per day. The frequent criteria are applicable to the H/Benning Streetcar Project as there would be more than 70 streetcars per day.

The FTA vibration thresholds do not specifically account for existing vibration. Although H Street and Benning Road have substantial volumes of vehicular traffic including buses and trucks, it is relatively rare that rubber-tired vehicles will generate perceptible ground vibration unless there are irregularities in the roadway surface such as potholes or wide expansion joints. Ambient vibration measurements along the corridor show that the vibration levels from vehicular traffic are typically below 60 VdB in the project corridor and are not always perceptible. Vibration levels from rare events such as a truck or a bus passing close to the receiver are perceptible, but are still below 70 VdB (see Section 5.2.4).

The refined criteria for use with Detailed Vibration Assessments are shown in Figure 13. For the Detailed Assessment, the predicted vibration levels in terms of the 1/3 octave band spectra are compared to the curves shown in Figure 13 to determine whether there is impact and the frequency range over which vibration mitigation is required. Impact occurs when any spectral values exceed the applicable curve. The FTA interpretation of how each of the curves shown in Figure 13 should be applied is given in Table 14. The VC-A through VC-E curves are used to specify acceptable vibration limits for sensitive equipment such as electron microscopes. Which curve to use depends on the sensitivity of the specific equipment that would be affected. With the exception of a few particularly sensitive pieces of equipment such as Transmission Electron Microscopes (TEM) or Atomic Force Microscopes (AFM), the VC-C curve is adequate to meet avoid interfering with the operation of most sensitive equipment.

The use of the Detailed Vibration Assessment criteria is illustrated by the example vibration spectrum (the blue dashed line) shown in Figure 13. The maximum level of the vibration spectrum exceeds the "Residential (Night)" curve in the 50 and 63 Hz 1/3 octave bands. For this example, impact would be predicted for residential land uses and vibration mitigation would need to be evaluated, even though all of the 1/3 octave band levels fall below the "Residential (Day)" curve. Typical sensitive equipment and their appropriate VC-curves are listed in Table 11. It may be noted that the FTA Manual does not provide a Detailed Vibration Assessment criteria for institutional land uses. However, where the General Assessment threshold is exceeded and the predicted vibration spectrum is available, it is reasonable to apply the Residential (Day) curve of the Detailed Vibration Assessment criteria to assess impacts. Because institutional land uses are used primarily during the day and the vibration level for annoyance would not be more stringent than residential land uses, this is a valid approach.

The approach used for this project is that the General Assessment criteria of Table 13 were used to identify potential vibration impacts. Then the Detailed Assessment criteria were applied to determine whether vibration mitigation would be warranted. The Detailed Vibration Assessment curve for the Residential (Day) was applied for institutional land uses and the Residential (Night) curve was used for residential land uses.

There are some buildings, such as concert halls, recording studios, and theaters, which can be very sensitive to vibration but do not fit into any of the three categories listed in Table 13 or can be associated with the curves in Figure 13. Due to the sensitivity of these buildings, they usually warrant special attention during the environmental evaluation of a transit project. Table 14 gives the FTA criteria for acceptable levels of groundborne vibration and groundborne noise for various categories of special buildings. The Atlas Theater and the H Street Playhouse are the only special buildings that have been identified in the project corridor. The Atlas Theater was evaluated as a concert hall and the H Street Playhouse was evaluated as a theater and the appropriate FTA thresholds listed in Table 15 were applied for the groundborne noise and vibration impact assessment.

**Table 13: FTA Impact Thresholds for Groundborne Vibration, General Impact Assessment**

| **Land Use Category** | **Groundborne Vibration (VdB re 1 micro inch/sec)** | | |
|---|---|---|---|
| | **Frequent Events** | **Occasional Events** | **Infrequent Events** |
| Category 1. Buildings where vibration would interfere with interior operations. Typically land uses include vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations. | 65 | 65 | 65 |
| Category 2. Residences and buildings where people normally sleep. | 72 | 75 | 80 |
| Category 3. Institutional land uses with primarily daytime use. | 75 | 78 | 83 |

Source: FTA Guidance Manual, May 2006 (Ref. 1).

Notes:

(a) Frequent events defined as more than 70 vibration events per day.
(b) Occasional events are defined as between 30 and 70 events per day.
(c) Infrequent events defined as less than 30 events per day.
(d) Vibration sensitive equipment is not sensitive to groundborne noise.

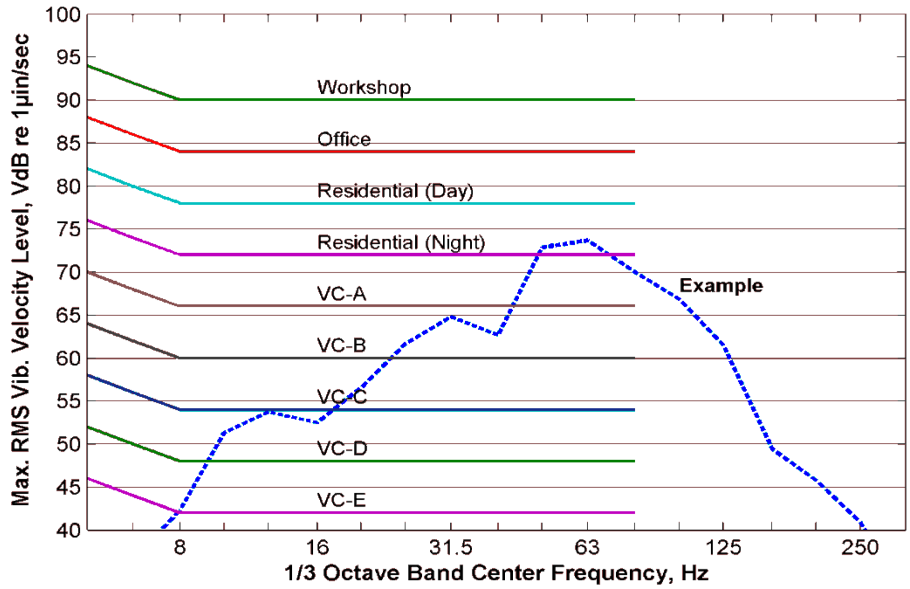



**Figure 13: FTA Criteria for Detailed Vibration Analysis**

**Table 14: Interpretation of Vibration Criteria for Detailed Analysis**

| Criterion Curves | Max Lv[a] (VdB) | Description of Uses |
|---|---|---|
| Workshop | 90 | Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas. |
| Office | 84 | Feelable vibration. Appropriate to offices and non-sensitive areas. |
| Residential Day | 78 | Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X). |
| Residential Night, Operating Rooms | 72 | Vibration not feelable, but groundborne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity. |
| VC-A | 66 | Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment. |
| VC-B | 60 | Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths. |
| VC-C | 54 | Appropriate for most lithography and inspection equipment to 1 micron detail size. |
| VC-D | 48 | Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability. |
| VC-E | 42 | The most demanding criterion for extremely vibration-sensitive equipment. |

Source: FTA Guidance Manual, May 2006 (Ref. 1).
Notes:
(a) Maximum allowed vibration velocity in any 1/3 octave band over the range of 8 to 80 Hz.

| Table 15: Groundborne Noise and Vibration Impact Criteria for Special Buildings | | |
|---|---|---|
| **Location** | **Groundborne Vibration Impact Levels (VdB re 1 micro-inch/sec)** | **Groundborne Noise Impact Levels (dB re 20 micro-Pascals)** |
| Concert Halls | 65 | 25 |
| TV Studios | 65 | 25 |
| Recording Studios | 65 | 25 |
| Auditoriums | 72 | 30 |
| Theaters | 72 | 35 |

Source: FTA Guidance Manual, May 2006 (Ref. 1).

# 7. NOISE AND VIBRATION PREDICTION MODELS

## 7.1 Noise Prediction Model

This section describes the models that were used to predict noise related to the modern streetcar operations.

### *7.1.1 Noise from Streetcar Operations*

For a well-maintained streetcar system, the general trend is that at speeds below 20 mph the noise from propulsion motors, air conditioning, and other auxiliary equipment on the vehicles dominates. Above 25 mph, the rolling noise due to metal to metal contact at the wheel-rail interface dominates. This is referred to as wheel/rail noise. The level of wheel/rail noise is generally considered to vary with speed by 30*log(speed). Between 15 and 25 mph a transition of the dominant noise source from the vehicle equipment to the wheel-rail interface occurs. Therefore, it is reasonable to expect the streetcar noise to have three regimes based on speed: a constant slope for speeds below 15 mph, a lower slope for speeds between 15 and 25 mph, and a higher slope above 25 mph.

Because the proposed vehicle and track design for the DC Streetcar system would be similar to the modern streetcar systems in Portland, OR and Seattle, WA, the noise predictions for the DC Streetcar system is based on measurements of the noise generated by the Portland and Seattle Streetcar systems (Ref. 5). Based on measurements in Portland and Seattle, reasonable speed adjustments for the maximum streetcar noise levels (Lmax) are:

- Speed-independent below 15 mph
- 12*log(speed) between 15 and 25 mph
- 30*log(speed) above 25 mph.

At a reference distance of 50 ft from the centerline of the track, the measured Lmax for streetcar noise was:

- 72 dBA at 15 mph
- 74.7 dBA at 25 mph.

Based on the measured Lmax at 25 mph and the 30*log(speed) adjustment, the streetcar Lmax at 40 mph is estimated to be 80.8 dBA (see Figure 14).

The reference levels used for this analysis are:

- Maximum sound level (Lmax) of a one-car streetcar operating at 25 mph on embedded track at a distance of 50 ft: 74.7 dBA
- Streetcar length: 66 ft
- Noise amplification from crossover frogs: +6 dB

These values were used with formulas included in the FTA Guidance Manual to predict the noise levels at each cluster of sensitive receivers. The principal formulas are:

**Relationship between Lmax and the Sound Exposure Level (SEL):**

$$SEL = L_{\max} - 10 \times \log\left[\frac{speed}{length}\left(2\alpha + \sin(2\alpha)\right)\right] + 3.3$$

where:

speed = Speed in mph

length = Length of streetcar in feet (e.g., 1 car = 66 ft)

α = $\tan^{-1}$(length/2y), where y is the distance from receiver to track centerline

**Change in sound level with speed:**

$$\Delta SEL = 2 \times \log\left( {speed_2}/{speed_1} \right)$$

where:

$speed_1$ = Initial speed

$speed_2$ = New speed

ΔSEL = Change in SEL for speed change from $speed_1$ to $speed_2$

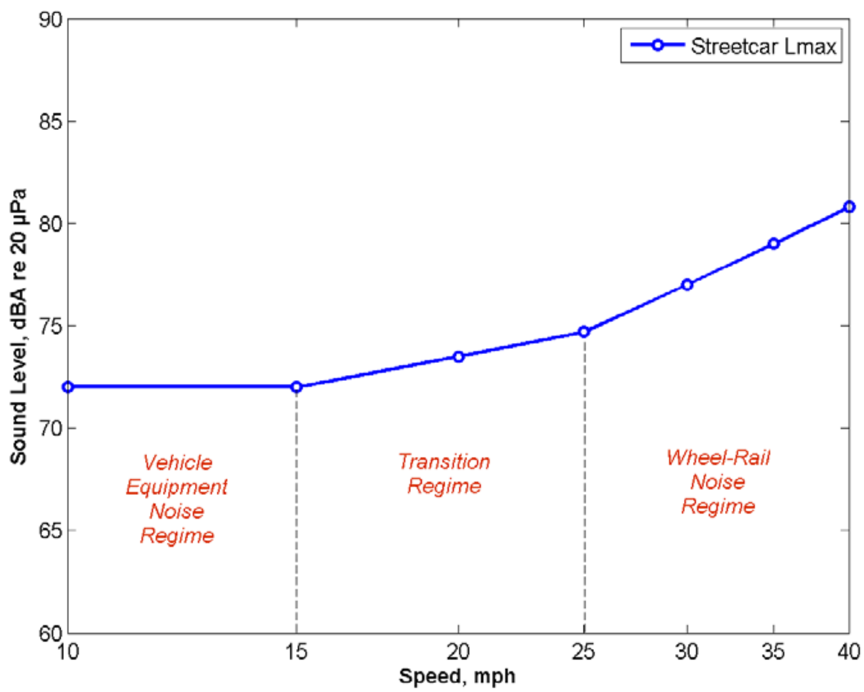



**Figure 14: Speed Dependence of Modern Streetcar Reference Noise Levels**

**Calculation of Ldn and hourly Leq from SEL:**

$$L_{DN} = SEL + 10 \times \log\left( NTrain_{DAY} + 10 \times NTrain_{NIGHT} \right) - 49.4$$

$$L_{EQ}(Hour) = SEL + 10 \times \log\left( NTrain_{HOUR} \right) - 35.6$$

where:

$NTrain_{DAY}$ = Number of streetcars during daytime hours

| | | |
|---|---|---|
| $NTrain_{NIGHT}$ | = | Number of streetcars during nighttime hours |
| $NTrain_{HOUR}$ | = | Number of streetcars during one hour |

The assumed operating schedule is 10 minute headways except between 12 AM and 6 AM when no operations are assumed. This assumed schedule has a total of 108 streetcars in each direction per day: 90 during the daytime hours (7 AM to 10 PM) and 18 during the nighttime hours (10 PM to 7 AM).

Figure 15 shows the predicted streetcar sound level vs. the distance from the near track centerline in terms of Ldn and the maximum sound level (Lmax) assuming a streetcar speed of 25 mph. A separation distance of 30 ft between the near and far tracks was used to generate the curve.


**Figure 15: Streetcar Sound Levels (Ldn) Vs. Distance from Track Centerline**
(Streetcars operating on embedded track at 25 mph)

### *7.1.2 Squeal Noise*

Squeal noise occurs when steel-wheel transit vehicles traverse tight curves with radii less than 400 ft. It is difficult to predict whether squeal noise will occur at any given curve. The general approach is to assume that the squeal noise will occur at tight radius curves and add +10 decibels to the project noise. For the H/Benning Streetcar Project we added an adjustment of +10 dB to the train noise for all receivers located within 100 ft of the curved track at the "star" intersection of H Street and Benning Road.

### *7.1.3 Prediction Model, Noise from Audible Warnings*

Bells and horns are the only audible signals that would be installed in the streetcar vehicles. The bells would be installed at both ends of the streetcar vehicles and may be activated at the front or both front and rear ends. The noise from bells is modeled assuming that the bells are point sound sources. The bell reference sound level is assumed to be a maximum sound level (Lmax) of 80 dBA at a distance of 50 ft from the bell. Although the bells are mounted on the trains, the bells are modeled as a point sound source because it is expected that in normal use they will be sounded in one short interval only 1) when starting from the streetcar stops and 2) at the driver's discretion at the stoplights to signal to pedestrians and traffic that the streetcar is moving after stopping for the signals. A reasonable assumption is that approximately half of the trains would sound the bell at signaled intersections because the bells would only be sounded when the signal requires the streetcar to stop at an intersection. The bell noise model also assumes that the bells will be sounded by all trains when starting from streetcar stops.

The principal formulas used for this analysis are:

**Relationship between Lmax and SEL:**

$$SEL = L_{\max} + 10 \times \log[T]$$

where:

T = duration of the maximum bell noise

**Calculation of Ldn and hourly Leq from SEL:**

$$L_{DN} = SEL + 10 \times \log(NTrain_{DAY} + 10 \times NTrain_{NIGHT}) - 49.4$$

$$L_{EQ}(Hour) = SEL + 10 \times \log(NTrain_{HOUR}) - 35.6$$

where:

$NTrain_{DAY}$ = Number of trains during daytime hours

$NTrain_{NIGHT}$ = Number of trains during nighttime hours

$NTrain_{HOUR}$ = Number of trains during one hour

**Calculation of bell noise at individual receiver:**

$$Lp = Lp_{ref} + 20 \times \log(D/D_{ref})$$

where:

$D$ = Distance to receiver from the centerline of the tracks

$D_{ref}$ = Reference distance from the bells (50 ft)

$Lp$ = Level of bell noise at receiver

$Lp_{ref}$ = Bell noise level at reference distance (50 dBA)

### *7.1.4 Prediction Model, Noise from Audible Warnings*

The only ancillary equipment expected to have the potential of causing noise impacts are the Transit power substations (TPSS) units. The primary noise from the TPSS units is from  transformer hum and the cooling system. On most modern TPSS units the transformer hum is minimal so only the ventilation and cooling system has potential to cause noise impacts.

A recent noise measurement of a TPSS unit used in a residential area along the Los Angeles Metro Gold Line showed that the ventilation fan generated a sound level of 51 dBA at a distance of 40 feet from the fan. This is equivalent to an Leq of 49 dBA at a distance of 50 feet (the measurement was not done at 50 feet because of obstructions), which is equivalent to an Ldn of 54 dBA at 50 feet. The measured noise level is consistent with the limit of 50 dBA at 50 feet from any side of the TPSS that has been included in the purchase specifications for TPSS units on several recently completed light rail systems. It has been assumed that similar units will be used on the H/Benning Streetcar Project.

The following formula has been use to estimate TPSS noise for this project:

$$Lp = Lp_{ref} + 20 \times \log\left(D/D_{ref}\right)$$

where:

$D$ = Distance to receiver from the TPSS unit cooling fan

$D_{ref}$ = Reference distance from the TPSS unit cooling fan (50 ft)

$Lp$ = Level of TPSS noise at receiver

$Lp_{ref}$ = TPSS noise level at reference distance (50 dBA)

### *7.1.5 Yard and Shops, Noise from Maintenance and Storage Activities*

The primary noisy activities at the Car Barn and Training Center (CBTC) are maintenance work inside the shops and the movement of the streetcars inside the storage tracks. The movement in the storage tracks will be characterized by banging noise caused by the wheel impacts at the crossover frogs. This impact noise is a point noise source and is modeled to attenuate with distance as 20*log(Distance). The reference levels used for this noise are the same as for streetcars on the mainline and are discussed in Section 7.1.1.

The noise from the shops will be similar to facilities in other rail systems such as the MTA Green Line Maintenance Shops in Los Angeles. The reference noise level used for the shops is 58 dBA at a reference distance of 50 ft when the doors are open. The formula used for the attenuation with distance is 20*log(Distance).

### *7.1.6 Traffic Noise Model*

The FHWA computer program “Traffic Noise Model” (TNM) version 2.5 was used to predict traffic noise levels at sensitive receivers with outdoor areas where frequent human use occurs. TNM 2.5 is the highway noise prediction model approved by DDOT for traffic noise analysis. Key inputs to the traffic noise models are the locations of roadways, receiver locations, ground cover, traffic volumes, traffic mix and traffic speeds.

## 7.2 Vibration Prediction Model

The predictions of groundborne vibration for this study follow the Detailed Vibration Assessment procedure of the FTA Guidance Manual (Ref. 1). This is an entirely empirical method based on testing of the vibration propagation characteristics of the soil in the project corridor and measurements of the vibration characteristics of a similar streetcar vehicle. As discussed in Section 4.2, vibration propagation tests were performed at four locations in the proposed corridor for the H/Benning Streetcar Project. The quantity derived from the propagation tests is referred to as the line source transfer mobility (LSTM). The results of the propagation tests are presented in Section 4.2. The basic relationship used for the vibration predictions is:

Lv = FDL + LSTM

where:

Lv = Train vibration velocity measured at the ground surface

LSTM = Measured line source transfer mobility

FDL = Force density function that characterizes the vibration forces generated by the train and track

(All quantities are expressed in decibels using a consistent set of decibel reference values)

FDL is derived by measuring Lv and LSTM at a site where there are streetcar operations. For this project, the FDL is based on measurements at the Portland and Seattle streetcar systems that were performed as part of the Tempe Streetcar Project (Ref. 5). The streetcar FDL at 25 mph is shown in Figure 16. The FDL does not show any remarkable peaks across the spectrum. A low force density can be maintained in streetcar systems through a program that maintains the desired wheel and rail profiles and pro-actively eliminates wheel flats.

The LSTM results are discussed in Section 5.2.3. In general, the LSTM at sites V-1 through V-3 were comparable at 25 ft. At 50 ft, there were subtle variations between the three sites due to differences in attenuation rates and spectral shapes. The LSTM at site V-2 attenuated at a faster rate compared to V-1 and V-3 resulting in lower levels at 100 ft. The LSTM at site V-4 was substantially different from the rest of the sites. At distances less than 75 ft, the LSTM was approximately 5 decibels higher than at the other three sites. This is important because the first row of sensitive receivers is generally less than 50 ft from the proposed location of the streetcar tracks.

The predictions for the H/Benning Streetcar vibration include an adjustment factor of +5 dB to each 1/3 octave band in order to account for potential amplification effects and provide a small safety factor for other sources of uncertainty in the predictions. For the combined effect of coupling loss and floor amplification, FTA Guidance Manual recommends a net adjustment of +1 dB for the vibration inside a typical residence. A recent TCRP study based on 35 outdoor-indoor vibration measurements in several cities in North America showed an average outdoor-indoor amplification of 0 dB with a standard deviation of approximately 5 dB (Ref. 6 and 7). Therefore, an adjustment factor of +5 dB is a conservative approach that ensures that in the majority of cases the predicted vibration levels are higher than what will occur after the proposed project is operational.

The approach used for predicting vibration from the operations of the H/Benning Streetcar system was to use the LSTM measurement from the site that is closest to the sensitive receiver. Although only site V-4 showed distinctly different vibration characteristics, applying the vibration curve from the closest test site ensures consistency in the approach.

Figure 18 shows the predicted overall vibration velocity level as a function of distance from the tracks for streetcar speeds of 25 mph. This figure shows that vibration from streetcar operations using the LSTM curves from sites V-1, V-2 and V-3 are below the FTA General Assessment threshold.

Figure 18 through Figure 21 show the 1/3 octave band spectra of the predicted vibration at distances of 25, 38, 50, and 100 ft from the track centerline. The curves are used as the basis for Detailed Impact Assessment for residential and institutional land uses. These curves show that:

- The predicted overall vibration level for Category 2 (residential) land uses exceed the FTA General Assessment impact threshold at 25 ft from the near track centerline for site V-2 and at distances below 35 ft for site V-4 (See Figure 17).
- The predicted vibration spectrum for Category 2 (residential) land uses is below the FTA Detailed Assessment impact threshold at 25 ft from the near track centerline for all sites (See Figure 18).
- As shown in Figure 17, the FTA General Assessment impact threshold for Category 3 (institutional) land uses is exceeded at distances below 40 ft for site V-4. However, the 1/3 octave levels are below the FTA Detailed Vibration impact threshold at V-4(see Figure 18).

The curves in Figure 18 and Figure 17 were used as the basis for the vibration predictions. Figure 17 was used for the general assessment and Figure 18 through Figure 21 were used as appropriate for the detailed vibration assessment. For any given vibration sensitive receiver, the LSTM curve from the closest test site was used as the basis and then the following adjustments were applied to estimate vibration levels in occupied spaces of buildings:

- Speed Adjustment: The planned maximum operational speed for the H/Benning Streetcar Project is 25 mph. Although the streetcars would operate at slower speeds near streetcar stops, they could accelerate to top speeds at short distances. The speed assumptions for the vibration analysis were conservative and 25 mph was applied for the entire alignment. Therefore, no speed adjustment was required for the vibration predictions.
- Special Trackwork: The additional vibration at special trackwork was accounted for by adding 10 decibels to the predicted vibration levels when a special trackwork frog would be located less than 100 feet from a sensitive receiver.

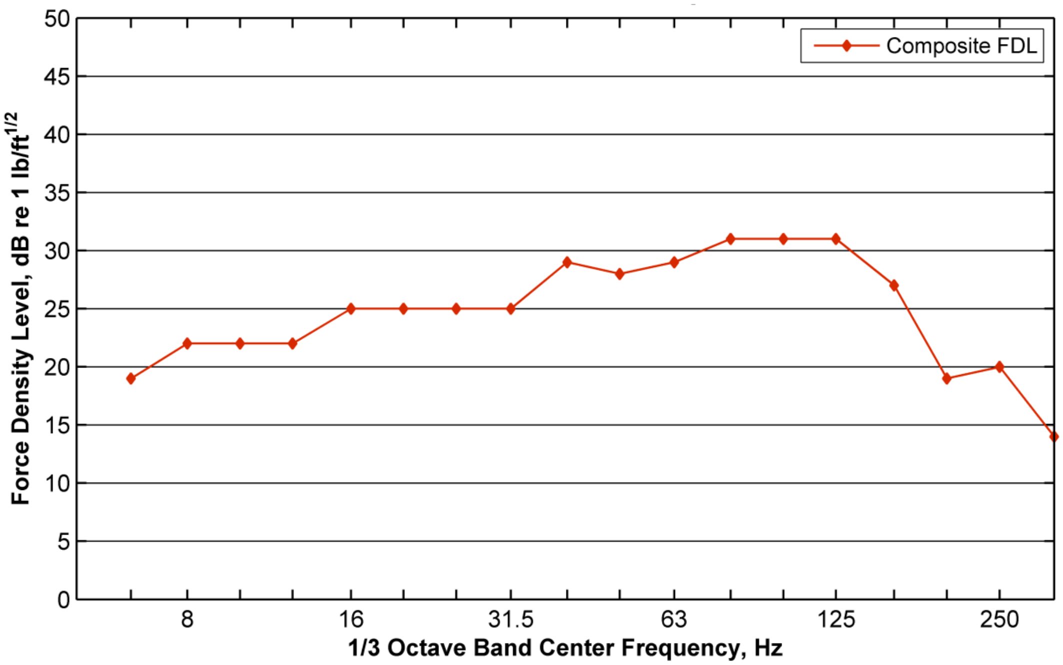



**Figure 16: Streetcar Force Density Level at 25 mph**

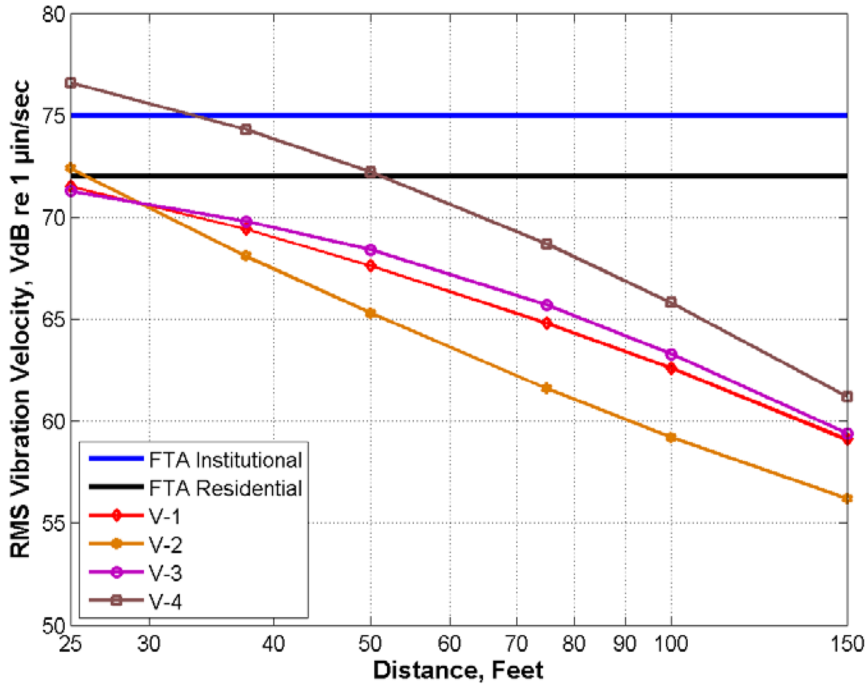



**Figure 17: Predicted Streetcar Vibration versus Distance**
(Curves include +5 dB adjustment for floor amplification and a safety factor)

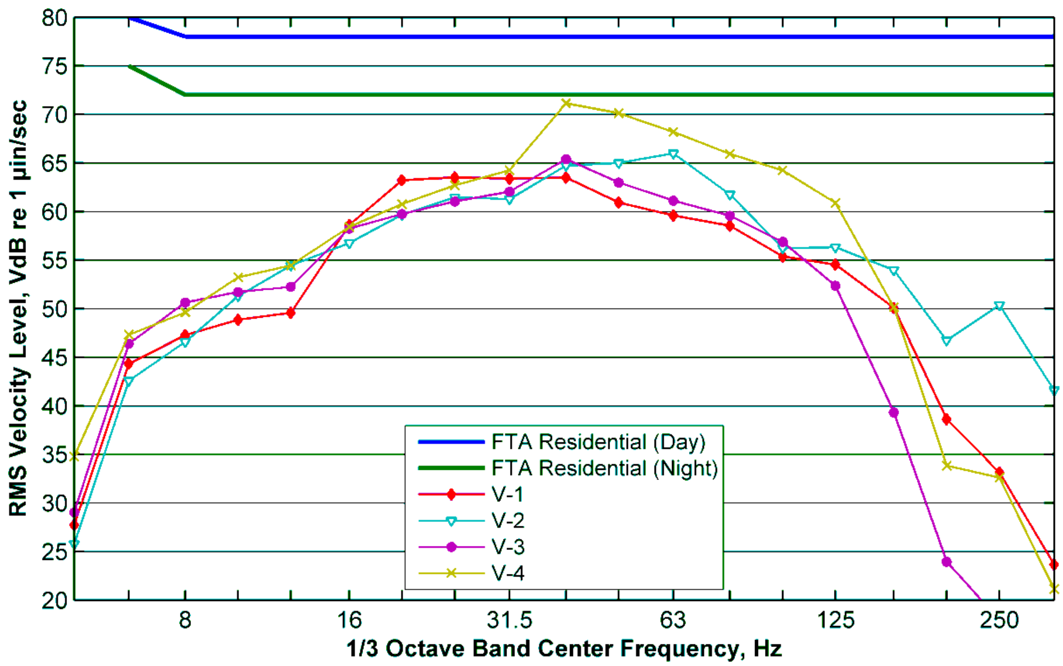



**Figure 18: Predicted Streetcar Vibration Spectrum, 25 ft**
(Curves include +5 dB adjustment for floor amplification and a safety factor)

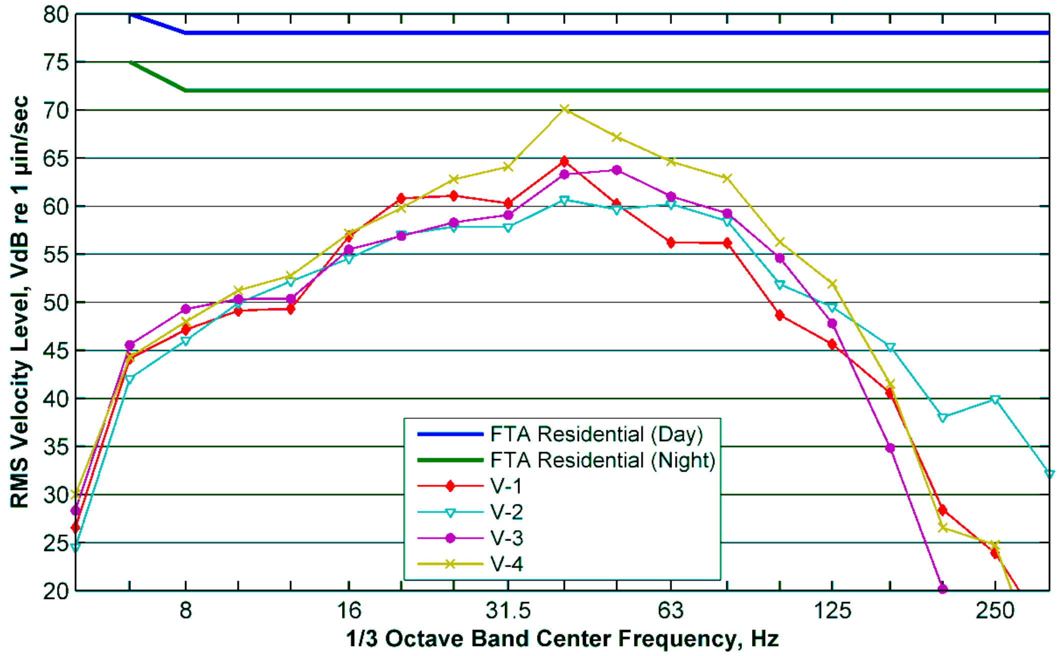



**Figure 19: Predicted Streetcar Vibration Spectrum, 38 ft**
(Curves include +5 dB adjustment for floor amplification and a safety factor)

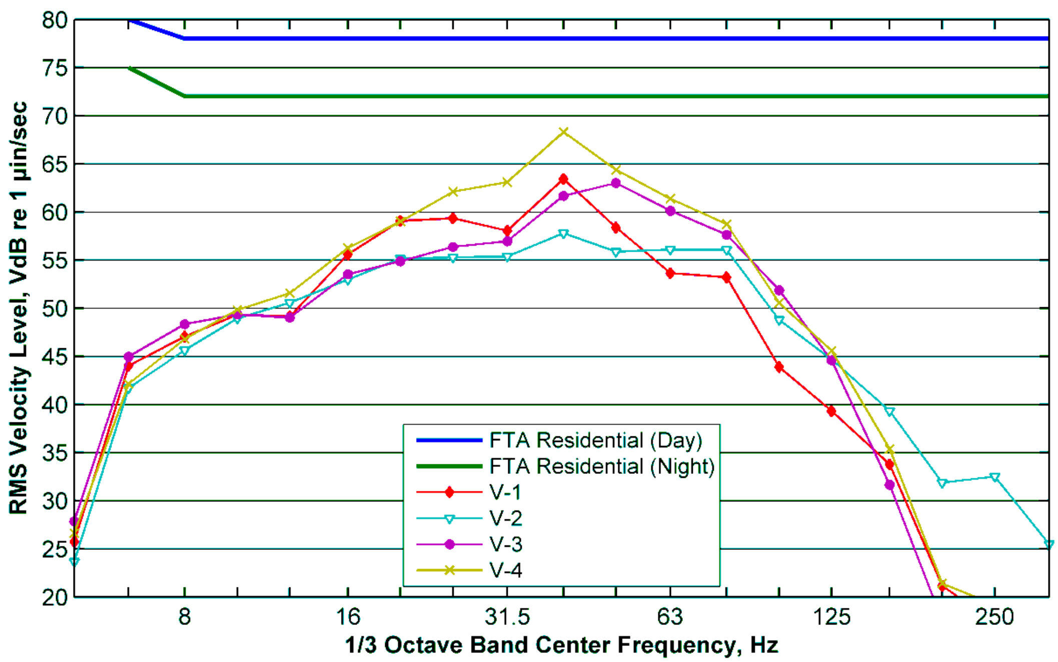



**Figure 20: Predicted Streetcar Vibration Spectrum, 50 ft**
(Curves include +5 dB adjustment for floor amplification and a safety factor)

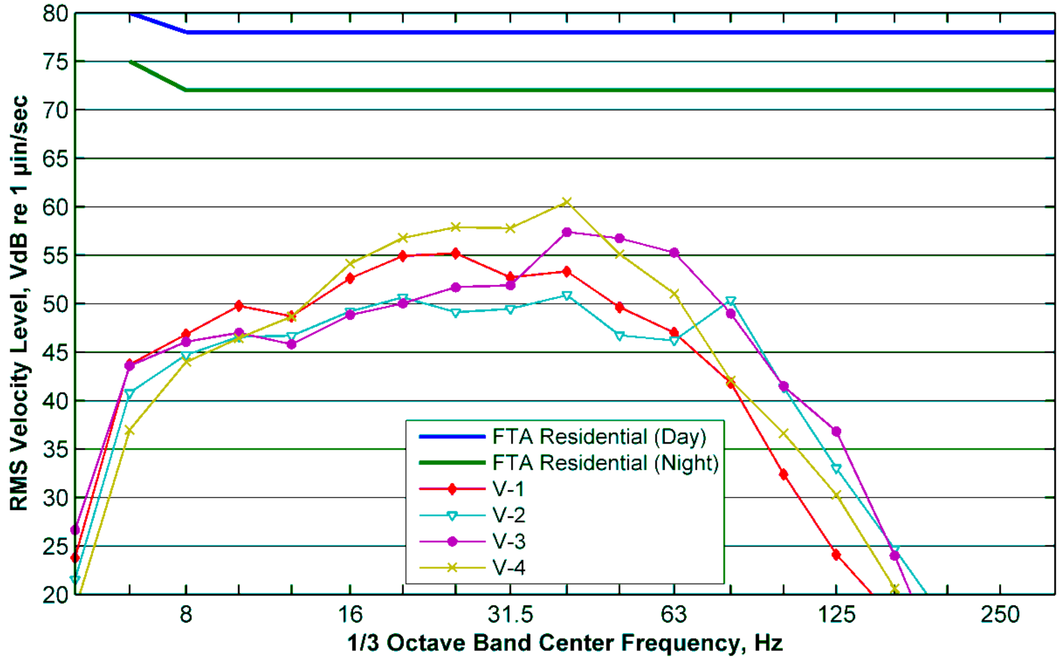



**Figure 21: Predicted Streetcar Vibration Spectrum, 100 ft**
(Curves include +5 dB adjustment for floor amplification and a safety factor)

# 8. POTENTIAL OPERATIONAL NOISE AND VIBRATION IMPACTS AND MITIGATION

## 8.1 Streetcar Related Noise

### *8.1.1 Operational Noise*

This section discusses the noise impacts from streetcar operations at FTA Category 1, 2 and 3 noise sensitive receivers. The residential land uses (FTA Category 2) along the H/Benning Streetcar Project were grouped into clusters as discussed in Section 4. All other FTA noise sensitive receivers were numbered individually. Consistent with the FTA Guidelines (Ref. 1), restaurants, barber shops and other commercial businesses were not evaluated for noise impacts from streetcar operations. Table 16 , Table 17 and Table 18 show the predictions of noise from streetcar operations for Category 1, Category 2, and Category 3 land uses, respectively.

The columns in Table 16 and Table 18 include the following information:

- Cluster: Cluster numbers were used for Category 2 land uses (Table 17). Because the Category 1 and 3 land uses were not clustered, receiver numbers were used (Table 16 and Table 18).
- Desc. or Receiver Name: The type of land use or name of the receiver.
- Adjacent Street: Identifies the street closest to the cluster for Category 2 land uses.
- Near Track Dist: Distance in feet from the near track centerline to the closest location of the noise sensitive receiver or cluster.
- Train Speed: Maximum expected train speed on the track closest to the receiver or cluster. The speeds were based on the projected speed profile.
- Existing: Existing noise level (Ldn) at each cluster based on the measured Ldns for Category 2 land uses (Table 17). Existing Leq was used at Category 1 and 3 land uses (Table 16 and Table 18).
- Project: Predicted future noise levels from train operations. This is Ldn for residential land uses and maximum hourly Leq for non-residential land uses. The noise predictions include bell noise from the streetcars. The streetcar bell noise is included for all sensitive receivers that are located within 200 feet of a streetcar stop or an intersection where streetcars will stop.
- Impact Threshold: The FTA impact thresholds for moderate and severe impact based on the existing noise levels.
- Impact (Yes/No): Whether there are noise impacts at Category 1 and 3 land uses (Table 16 and Table 18).
- Number of Impacts: The number of dwelling units where the predicted levels of streetcar noise exceed the Moderate (Mod) and Severe impact thresholds (Table 17).

Following is a summary of the noise impact assessment for FTA Category 1 land uses shown in Table 16:

- The Atlas Theater is the only FTA Category 1 land use in the project area.
- The predicted streetcar noise at the Atlas Theater is below the applicable impact threshold.

The summary of the noise impact assessment for FTA Category 2 land uses shown in Table 17 is as follows:

- A total of 16 residential clusters were evaluated for noise impacts from streetcar operations.
- Based on the evaluation, there is potential for moderate noise impact from streetcar operations at residential land use clusters R6 and R7. This would affect approximately 40 dwelling units located near the intersection of the H/Benning Streetcar alignment with Maryland Avenue. The primary reason for the predicted noise impacts at these receivers is the potential for wheel squeal noise from the sharp track curvature at the Maryland Avenue intersection.

Following is a summary of the noise impact assessment for FTA Category 3 land uses shown in Table 18:

- A total of 28 Category 3 receivers were evaluated for noise impacts from streetcar operations.
- As discussed in Section 4, H Street Playhouse is classified as FTA Category 3 noise sensitive receiver for airborne noise. However for groundborne noise and vibration, it is evaluated as a FTA "Special Building."
- No noise impacts are predicted at any FTA Category 3 land uses.

**Table 16: Summary of Noise Impact Assessment for Category 1 Land Uses**

| Receiver # | Receiver Name [(a)] | NT Dist.[(a)] (ft) | Speed (mph) | Existing Noise Site | Leq[(b)] (dBA) | | | | Impact (Yes/No) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Existing | Project [(c)] | Imp. Thresh. | | | |
| | | | | | | | Mod | Severe | Mod | Severe |
| T1 | Atlas Theater | 25 | 25 | ST-2 | 70 | 56 | 64.3 | 69.5 | No | No |

Notes:

(a) Distance to the near track is rounded off to the nearest 5 ft.

(b) Leq values are rounded off to the nearest whole number unless shown otherwise.

(c) Project Leq is the additional noise that would be created by streetcar operations.

| Table 17: Summary of Noise Impact Assessment for Category 2 Land Uses | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cluster #** | **Desc [(a)]** | **NT Dist.[(b)] (ft)** | **Adj. Street** | **Speed (mph)** | **Existing Noise Site** | **Ldn[(c)] (dBA)** | | | | **# of Impacts[(e)]** | |
| | | | | | | **Existing** | **Project[(d)]** | **Imp. Thresh.** | | | |
| | | | | | | | | **Mod** | **Severe** | **Mod** | **Severe** |
| R1 | MFR | 45 | 3rd St. | 25 | LT-1 | 75 | 63[(f), (g)] | 65.0 | 73.2 | -- | -- |
| R2 | MFR | 100 | 3rd St. | 25 | LT-1 | 71 | 60[(f), (g)] | 65.0 | 70.2 | -- | -- |
| R3 | MFR | 140 | 4th St. | 25 | LT-1 | 69 | 52[(f)] | 64.0 | 69.1 | -- | -- |
| R4 | MFR | 120 | 4th St. | 25 | LT-1 | 70 | 54[(f)] | 64.5 | 69.6 | -- | -- |
| R5 | MFR | 150 | 12th St. | 25 | LT-1 | 69 | 52[(f)] | 63.7 | 68.9 | -- | -- |
| R6 | MFR | 50 | Florida Ave. | 25 | LT-2 | 77 | 66[(f), (h)] | 65.0 | 74.5 | 20 | -- |
| R7 | MFR | 45 | 15th St. | 25 | LT-2 | 78 | 67[(f), (h)] | 65.0 | 75.0 | 20 | -- |
| R8 | MFR | 45 | 16th St. | 25 | LT-3 | 78 | 57[(f)] | 65.0 | 72.5 | -- | -- |
| R9 | MFR | 45 | 17th St. | 25 | LT-3 | 78 | 57[(f)] | 65.0 | 72.5 | -- | -- |
| R10 | SFR | 65 | 18th St. | 25 | LT-3 | 75 | 55[(f)] | 65.0 | 70.2 | -- | -- |
| R11 | MFR | 45 | 19th St. | 25 | LT-3 | 78 | 57[(f)] | 65.0 | 72.5 | -- | -- |
| R12 | MFR | 45 | 19th St. | 25 | LT-3 | 78 | 57[(f)] | 65.0 | 72.5 | -- | -- |
| R13 | MFR | 45 | 20th St. | 25 | LT-3 | 78 | 57[(f)] | 65.0 | 72.5 | -- | -- |
| R14 | MFR | 75 | 21st St. | 25 | LT-4 | 69 | 55[(f)] | 63.7 | 68.9 | -- | -- |
| R15 | SFR | 65 | 24th St. | 25 | LT-4 | 70 | 61[(f), (g)] | 64.4 | 69.5 | -- | -- |
| R16 | SFR | 65 | 25th St. | 25 | LT-4 | 70 | 55[(f)] | 64.4 | 69.5 | -- | -- |

Notes:
(a) Desc. = Type of land use, SFR = single-family residence, MFR = multi-family residence.
(b) Distance to the near track (NT) is rounded off to the nearest 5 ft.
(c) Ldn values are rounded off to the nearest whole number unless shown otherwise.
(d) Project Ldn is the additional noise that would be created by streetcar operations.
(e) Number of impacts. This is a count of the number of SFR in the cluster plus the estimated number of residential units in MFR buildings.
(f) Includes streetcar bell noise at the stoplights and streetcar stops.
(g) Includes +6 dB for impact noise from the crossover frogs.
(h) Includes +10 dB for potential wheel squeal at tight radius curves.

| Table 18: Summary of Noise Impact Assessment for Category 3 Land Uses | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Receiver # | Receiver Name [(a)] | NT Dist.[(b)] (ft) | Speed (mph) | Existing Noise Site | Leq[(b)] (dBA) | | | | Impact (Yes/No) | |
| | | | | | Existing | Project[(c)] | Imp. Thresh. | | | |
| | | | | | | | Mod | Severe | Mod | Severe |
| I1 | Necomb Child Development & Care | 25 | 25 | ST-1 | 73 | 56[(d)] | 70.0 | 76.3 | No | No |
| I2 | Institute of Behavioral Change & Research Inc. | 25 | 25 | ST-1 | 73 | 56[(d)] | 70.0 | 76.3 | No | No |
| I3 | Community Development Center | 50 | 25 | ST-1 | 69 | 53[(d)] | 68.3 | 73.5 | No | No |
| I4 | EBT Training Center | 25 | 25 | ST-1 | 73 | 56 | 70.0 | 76.3 | No | No |
| I5 | 24-Hour Protection Govt Building | 25 | 25 | ST-1 | 73 | 56 | 70.0 | 76.3 | No | No |
| I6 | DC Community Services | 25 | 25 | ST-1 | 73 | 56[(d)] | 70.0 | 76.3 | No | No |
| I7 | Adnoi Church | 25 | 25 | ST-1 | 73 | 56[(d)] | 70.0 | 76.3 | No | No |
| I8 | DC Govt.: Animal Disease Control Division | 25 | 25 | ST-1 | 73 | 56[(d)] | 70.0 | 76.3 | No | No |
| I9 | Douglas Church | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I10 | Temple of Praise | 25 | 25 | ST-1 | 73 | 56[(d)] | 70.0 | 76.3 | No | No |
| I11 | The Red Palace (Museum of Oddities) | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I12 | Pentecostal Church | 25 | 25 | ST-2 | 70 | 56 | 69.3 | 74.5 | No | No |
| I13 | Comprehensive Community Health | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I14 | RL Christian Library | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I15 | United House of Prayer for All People | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I16 | St. John's Church of God | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I17 | Joy of Motion Dance Center | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |
| I18 | Trinidad Baptist Church | 45 | 25 | ST-4 | 73 | 54[(d)] | 0.0 | 76.6 | No | No |
| I19 | Benning Street Medical Clinic | 45 | 25 | ST-4 | 73 | 54[(d)] | 70.0 | 76.6 | No | No |
| I20 | Church of God in Christ | 45 | 25 | ST-5 | 74 | 54[(d)] | 70.0 | 77.4 | No | No |
| I21 | St. Elmo Crawford Dental Clinic | 45 | 25 | ST-5 | 74 | 54[(d)] | 70.0 | 77.4 | No | No |
| I22 | Northeast Academy of Dance | 45 | 25 | ST-5 | 74 | 54[(d)] | 70.0 | 77.4 | No | No |
| I23 | Prevention Works (Non-Profit) | 45 | 25 | ST-6 | 68 | 54[(d)] | 67.9 | 73.1 | No | No |
| I24 | Spingarn Senior High School | 350 | 25 | ST-6 | 56 | 46[(d)] | 60.7 | 66.5 | No | No |
| I25 | G C Langston Country Club | 160 | 25 | ST-6 | 60 | 49[(d)] | 62.6 | 68.2 | No | No |
| I26 | Langston Golf Course | 45 | 25 | ST-6 | 68 | 60[(d)] | 67.9 | 73.1 | No | No |
| M1 | Greater Northeast Medical Center | 45. | 25 | ST-4 | 73 | 54[(d), (e)] | 70.0 | 70.6 | No | No |
| T2 | H Street Playhouse | 25 | 25 | ST-2 | 70 | 56[(d)] | 69.3 | 74.5 | No | No |

Notes:
(a) Distance to the near track is rounded off to the nearest 5 ft.
(b) Leq values are rounded off to the nearest whole number unless shown otherwise.
(c) Project Leq is the additional noise that would be created by the streetcar operations.
(d) Includes streetcar bell noise at stoplights and streetcar stops.
(e) Includes +6 dB for impact noise from the frogs at special trackwork.

### *8.1.2 Ancillary Equipment*

Traction power substation (TPSS) units are the only ancillary equipment associated with the proposed project that has the potential to cause noise impacts. Three TPSS units are planned for the H/Benning Streetcar alignment. All TPSS units would be located approximately 100 ft from the closest residence. The locations of the TPSS units are:

- Under the Hopscotch Bridge between 2nd and 3rd Streets

- Southwest corner of H Street and 12th Street
- Southwest corner of the planned Car Barn and Training Center

It is common to include noise limits in the purchase specifications for TPSS units to minimize the potential for noise impacts from TPSS noise. The specifications generally include maximum noise limits for potential noise generators, such as the transformer hum and any cooling systems. The cooling fans are the major noise source on many modern TPSS units and the transformer hum is usually inaudible except very close to the TPSS unit.

The typically adopted design goal for noise from TPSS units is at least 5 decibels lower than the nighttime ambient level (Leq). This is lower than the FTA noise impact criteria, but is appropriate because controlling TPSS noise usually is straightforward and rarely adds more than marginally to the cost. The first step in controlling TPSS noise is to include a noise limit in the purchase specifications for TPSS units. The recommended limit is that the maximum noise level not exceed 50 dBA at a distance of 50 feet from any part of a TPSS unit.

Table 19 shows the predicted levels of TPSS noise at the residence nearest to each of the sites being considered along with the measured nighttime Leq for the site. A noise impact is indicated when the predicted TPSS nighttime Leq noise level exceeds the existing nighttime Leq minus 5 decibels. This approach for assessing TPSS noise impact is more stringent than the FTA impact criteria and ensures no impacts are overlooked. As seen in Table 19, impacts from the TPSS units are not predicted at any of the potential sites.

If the locations of the TPSS units are revised in final design such that the TPSS units will be closer than 50 ft to any residential land use and the TPSS noise at a residence would exceed the nighttime Leq minus 5 decibels, mitigation should be considered. The mitigation can be as simple as arranging for the ventilation fans to be on the side of the TPSS building that is farthest from noise sensitive receptors. Other mitigation options include building a sound wall or partial enclosure around the TPSS.

**Table 19: Predicted TPSS Noise**

| TPSS Unit Site | Location | Distance to Closest Residence, ft | Existing Noise Level, dBA | | Predicted TPSS Noise(b), dBA | | Impacts (Yes/No) |
|---|---|---|---|---|---|---|---|
| | | | Nighttime Leq(a) | Ldn | Leq | Ldn | |
| 1 | Hopscotch Bridge | 100 | 68 | 75 | 50 | 44 | No |
| 2 | SW Corner of H & 12th Streets | 100 | 63 | 69 | 50 | 44 | No |
| 3 | Car Barn Training Center | 100 | 63 | 69 | 50 | 44 | No |

Notes:

(a) Average noise levels (Leq) measured between 10 PM and 7 AM.

(b) The predicted TPSS noise levels are based on a maximum noise level of 50 dBA at a distance of 50 ft from any side of the TPSS units.

### *8.1.3 Car Barn and Training Center (CBTC) Noise*

The proposed location for the Car Barn and Training Center (CBTC) facility is just west of the eastern terminus of the H/Benning Streetcar alignment at the northwest corner of the Benning Road and 26th Street intersection. Our assumptions of the noise producing activities at the proposed CBTC are based on the Transportation and Maintenance Operations Plan (TMOP) Final Report prepared by DDOT and dated July 12, 2012.

The storage facility will have a single ingress/egress point via a lead track on the western end of the property. The facility's lead track transitions to the revenue track via turnouts in both directions. There is a future proposed track on 26th Street that would serve as a potential second ingress/egress point. The CBTC facility will serve as the operations and maintenance facility and operations control center. The three storage tracks immediately north of the CBTC building will accommodate up to six vehicles. Four additional shop tracks will serve the CBTC's three maintenance bays and vehicle wash/service bay. Each maintenance bay will be able to accommodate two vehicles. In addition, at least one bay will be equipped with a mezzanine level to enable streetcar vehicle roof maintenance.

The equipment that will be contained at the CBTC is typical to similar maintenance facilities at other rail transit systems in the US, and it is assumed that noise from the CBTC maintenance activities would be similar to other facilities. Although CBTC will have capacity to accommodate up to 15 streetcar vehicles, only 3 vehicles are expected to be housed in this facility during the opening year of the project. The maximum capacity of 15 vehicles is not expected to be in service before many years after the system opens. A reasonable projection is that the facility will house fewer than 10 cars in the foreseeable future.

Figure 22 shows the key noise sources from the activities at the CBTC facility. The seven crossovers are shown as X1 through X7. The two sharp curves that have the potential to cause wheel squeal are the primary noise sources from the streetcar movements within the facility. The maintenance shop noise, TPSS noise, and the movement of trains through the lead tracks are the other potential CBTC noise sources and are described below:

- Transit Power Substation: We assume that the TPSS will operate for 24 hours a day and will meet the specification for noise levels. The analysis is based on a maximum TPSS noise level of 50 dBA at 50 feet from any part of the TPSS units.
- Car Wash: The car wash will include one vehicle wash bay and servicing area for daily cleaning. Because the car wash is planned to be a hand cleaning facility, it is expected to be an insignificant noise source.
- Noise from Maintenance Shops: It is expected that the shop access doors often will be open for vehicles to enter and exit the facility. During this time, noise from ongoing shop activities could radiate out the doors. The doors may be open for shorter periods during the winter months than the rest of the year. Noise from the maintenance facility could include hammering for minor body work or repair of other components; noise from machines such as the wheel truer, air compressor and metal working equipment; and noise from the HVAC system. Forklift backup alarms and general repair tools could also be intermittent noise sources. For the noise assessment, we have based our predictions on measurements made at the MTA Green Line shops in Los Angeles. The Green Line maintenance and storage facility is for a light rail line with considerably more activity than would occur at the CBTC. As a worst case we assumed that the shop will be in operation 24 hours per day and the doors will be open. These are conservative assumptions that ensure that potential noise impacts are not overlooked.
- Traffic on Lead Tracks: The number of trains entering and exiting the storage facility will peak during the hours starting at 6 AM and 11 PM, respectively. In addition, there is potential for heightened activity during the day when there are shift changes and/or trains are pulled out or fed into the mainline through the lead tracks. We assumed that the peak activity during the daytime would occur starting at 12 noon. For the 3 hours of peak activity between the main line and the CBTC, the number of trains that will enter and exit the facility was assumed to be 2 for the opening year and 8 when the maximum fleet capacity of 15 cars would be reached.
- Crossovers: There are seven crossovers located within the CBTC facility that will be sources of impact noise from the wheel banging on the crossover frogs. The crossovers will experience differing amounts of traffic depending on their location. Crossover X1 shown in Figure 22 is expected to be the busiest crossover during peak entrance and exit times. For the full fleet of 15 streetcar vehicles, we assumed that 8 trains will pass over X1 during each of the 3 peak hours. Two trains per hour were assumed to pass over X1 for the remaining operation hours. During the opening year, we assumed that the number of trains that will pass over X1 would be two trains for the peak hour and one train for the remaining hours.

- Vehicular Traffic Into/Out of Facility: Twenty parking spaces are planned for the facility. The vehicles would enter the facility from the 26th Street. When the facility opens it is expected to have fewer staff due to the small fleet size. Therefore, for the opening year we have assumed movement of 10 motor vehicles per hour during three shift changes (1 daytime peak hour and 2 nighttime peak hours) when workers arrive and leave, and 5 motor vehicles/hour during 6 daytime off-peak hours and 3 nighttime off-peak hours. When the maximum fleet capacity is reached at the facility, we have assumed movement of 20 motor vehicles per hour during the shift changes and 10 motor vehicles per hour during the off-peak hours. Based on FHWA's algorithm used in the TNM model, the reference sound level at 50 ft for autos and SUVs moving at 50 mph ranges from 72 to 76 dBA depending on the pavement type. We assumed a reference sound level (Leq) of 75 dBA at 50 feet for autos and SUVs moving at 10 to 30 mph. This is a conservative reference level because at low speeds the vehicle noise is dominated by the engine noise, and not the tire-pavement noise.

Two residential land use clusters and two institutional land uses will be exposed to noise from activities related to CBTC. The locations of the land uses are shown in Figure 22. The land uses are:

- R14: Apartments located west of the proposed facility
- R15: Multifamily residences located across Benning Road
- I24: Spingarn Senior High School located north of the facility
- I25: G C Langston Country Club

Table 20 shows the results of the noise analysis for the residential land uses and Table 21 shows the results for the institutional land uses. No noise impacts are predicted at any noise sensitive receiver for the opening year when a 5-car fleet will be in operation. When the size of the fleet stored and serviced at the CBTC reaches its maximum capacity of 15 vehicles, noise from activities at the CBTC is predicted to exceed the FTA noise impact thresholds at cluster R14. A sound barrier on the west side of the CBTC property line would be needed to eliminate the noise impacts for all the first floor residences at R14. The location of the potential soundwall is shown in Figure 22. Noise mitigation was not considered for the second and third floor residential units of R14 because the FTA Guidance Manual generally considers mitigation only for the first floor units. For the 2nd and 3rd floor units, noise mitigation would be considered only if there were outdoor use areas such as balconies or patios that would be exposed to the noise sources. In conclusion, we recommend that a noise study of the yard activities be performed when the fleet size is expanded to greater than 10 cars to determine whether a sound barrrier would be required.

| Table 20: CBTC Noise for Residential Land Uses | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Activity** | **Potential Outdoor Noise Sources** | **Reference Noise Level, dBA** | | **Distance from Noisy Activity, ft** | | **Estimated Ldn for Opening Year [(a)], dBA** | | **Estimated Ldn for Max Capacity [(b)], dBA** | | |
| | | **Opening Year** | **Design Year** | **R14** | **R15** | **R14** | **R15** | **R14** | **R15** | |
| 1. | Train Movements on Shop and Yard Tracks | | | | | | | | | |
| | 1a. Mainline | 48.2 | 54.9 | 105 | 130 | 47 | 47 | 51 | 50 | |
| | 1b. Crossover frogs 1 (X1) | 54.2 | 60.9 | 140 | 145 | 48 | 48 | 51 | 51 | |
| | 1c. Crossover frogs 2 (X2) | 54.2 | 59.8 | 165 | 165 | 46 | 46 | 49 | 49 | |
| | 1d. Crossover frogs 3 (X3) | 47.4 | 53.4 | 185 | 205 | 40 | 39 | 43 | 42 | |
| | 1e. Crossover frogs 4 (X4) | 47.4 | 50.4 | 225 | 250 | 38 | 37 | 41 | 40 | |
| | 1f. Crossover frogs 5 (X5) | 52.4 | 54.2 | 260 | 290 | 37 | 41 | 40 | 44 | |
| | 1g. Crossover frogs 6 (X6) | 49.4 | 52.4 | 175 | 160 | 45 | 46 | 48 | 49 | |
| | 1h. Crossover frogs 7 (X7) | 49.4 | 55.4 | 235 | 180 | 42 | 45 | 45 | 48 | |
| | 1i. Squeal Source 1 | 53.4 | 59.4 | 310 | 350 | 31 | 31 | 33 | 33 | |
| | 1j. Squeal Source 2 | -- | 53.4 | 440 | 425 | -- | -- | 30 [(c)] | -- | |
| | Total | | | | | **54** | **54** | **57** | **57** | |
| 2. | Maintenance Shops | 58.0 | 58.0 | 290 | 225 | **49** | **46** | **49** | **46** | |
| 3. | TPSS | 50.0 | 50.0 | 105 | 190 | **50** | **46** | **50** | **46** | |
| 4. | Vehicular Traffic Into/Out of Parking | 51.2 | 54.2 | 120 | 200 | **31** | **30** | **33** | **32** | |
| **Total Yard and Shop Noise** | | | | | | **57** | **56** | **60** [(d)] | **59** | |
| **Existing Leq** | | | | | | **64** | **70** | **64** | **70** | |
| **FTA Threshold for Moderate Noise Impact** | | | | | | **60** | **64** | **60** | **64** | |
| **Impact (Yes/No)** | | | | | | **No** | **No** | **Yes** | **No** | |

Notes:

(a) A 5-car fleet is assumed for the opening year of the CBTC.

(b) The CBTC will have a maximum capacity of 15 cars. The Ldn estimates for the maximum capacity are based on a 15-car fleet.

(c) The future lead track on the east end of the property is not part of the initial plans. Receiver R14 would be exposed to the squeal noise from this section of the tracks but receiver R15 would be shielded by the CBTC structure.

(d) Bold red fonts indicate that the predicted noise levels from the Yard and Shop activities at the CBTC exceed the FTA impact thresholds.

| Table 21: CTBC Noise for Institutional Land Uses | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Activity** | **Potential Outdoor Noise Sources** | **Reference Noise Level, dBA** | | **Distance from Noisy Activity, ft** | | **Estimated Leq for Opening Year [(a)], dBA** | | **Estimated Leq for Max Capacity [(b)], dBA** | |
| | | **Opening Year** | **Design Year** | **I24** | **I25** | **I24** | **I25** | **I24** | **I25** |
| 1. | Train Movements on Shop and Yard Tracks | | | | | | | | |
| | 1a. Mainline | 48.2 | 54.9 | 290 | 230 | 41 | 40 | 39 | 43 |
| | 1b. Crossover frogs 1 (X1) | 54.2 | 60.9 | 285 | 470 | 39 | 40 | 38 | 43 |
| | 1c. Crossover frogs 2 (X2) | 54.2 | 59.8 | 250 | 425 | 40 | 39 | 39 | 42 |
| | 1d. Crossover frogs 3 (X3) | 52.4 | 53.4 | 215 | 390 | 40 | 33 | 40 | 36 |
| | 1e. Crossover frogs 4 (X4) | 52.4 | 50.4 | 180 | 350 | 41 | 31 | 41 | 34 |
| | 1f. Crossover frogs 5 (X5) | 52.4 | 54.2 | 145 | 310 | 43 | 30 | 43 | 33 |
| | 1g. Crossover frogs 6 (X6) | 49.4 | 52.4 | 260 | 415 | 35 | 38 | 38 | 41 |
| | 1h. Crossover frogs 7 (X7) | 49.4 | 55.4 | 265 | 360 | 35 | 36 | 38 | 39 |
| | 1i. Squeal Source 1 | 53.4 | 59.4 | 105 | 260 | 50 | 46 | 53 | 49 |
| | 1j. Squeal Source 2 | -- | 53.4 | 110 | 95 | -- | -- | 50[(c)] | 51[(c)] |
| | Total | | | | | **53** | **49** | **57** | **55** |
| 2. | Maintenance Shops | 58.0 | 58.0 | 175 | 120 | **47** | **50** | **47** | **50** |
| 3. | TPSS | 50.0 | 50.0 | 150 | 395 | **40** | **32** | **40** | **32** |
| 4. | Vehicular Traffic Into/Out of Parking | 51.2 | 54.2 | 125 | 70 | **47** | **50** | **50** | **53** |
| **Total Yard and Shop Noise** | | | | | | **54** | **55** | **58** | **58** |
| **Existing Leq** | | | | | | **56** | **60** | **56** | **60** |
| **FTA Threshold for Moderate Noise Impact** | | | | | | **61** | **63** | **61** | **63** |
| **Impact (Yes/No)** | | | | | | **No** | **No** | **No** | **No** |

Notes:

(a) A 5-car fleet is assumed for the opening year of the CBTC.

(b) The CBTC will have a maximum capacity of 15 cars. The Leq estimates for the maximum capacity are based on a 15-car fleet.

(c) The future lead track on the east end of the property is not part of the initial plans. Receivers I24 and I25 could be exposed to the squeal noise from this section of the tracks.

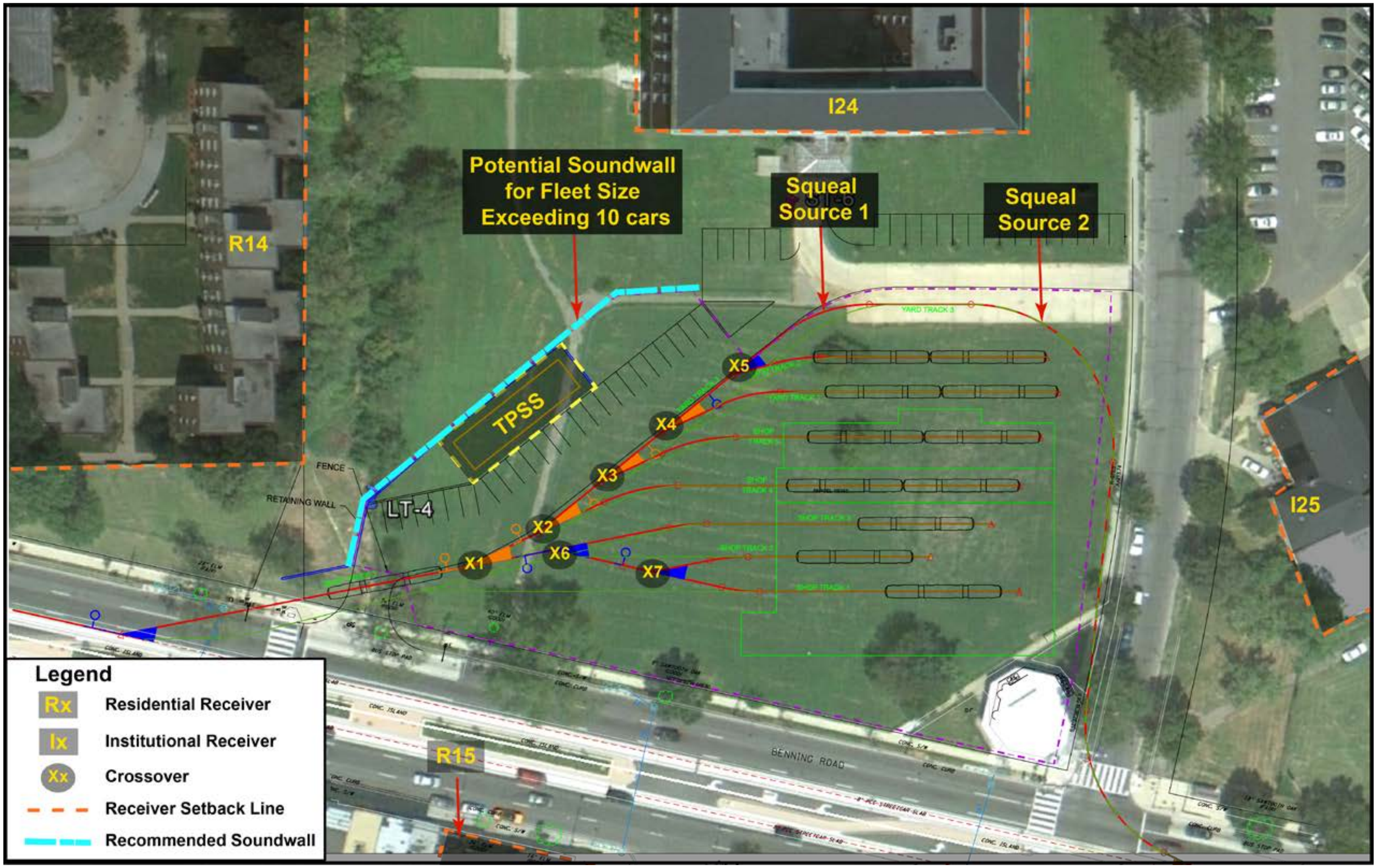



**Figure 22: Car Barn and Training Center Noise Sources and Recommended Mitigation**

## 8.2 Traffic Noise

Traffic noise from the project was modeled using the FHWA's TNM® 2.5 software as discussed in Section 7.1.6. The key features of the noise models are:

- Traffic was considered to flow freely on Benning Road and H Street without stoppage. Because the average vehicle speeds are low, stops at the intersections will not result in more than a small change to the noise levels. Therefore, free flow traffic is a reasonable approximation.
- Fleet mix assumptions were based on traffic counts conducted during the noise measurements. Table 22 is a summary of traffic counts at the six short-term noise measurement sites. At each site, simultaneous counts of westbound and eastbound traffic were made for 15 minutes.
- The noise prediction models were calibrated using the noise measurements at the six short-term sites and the traffic counts performed at the same time as the noise measurements. The difference between the measured and predicted noise was less than 2 decibels at all sites (see Table 23). Therefore, no calibration factors were necessary for the noise prediction models.
- The noise predictions were based on traffic for the base condition (2013) and the design year (2040). Traffic levels for each segment were based on the peak hour traffic levels from the traffic study. The fleet mix assumptions for the traffic model were based on the traffic counts taken during the short-term noise measurements and are summarized in Table 24.
- Traffic on cross streets was assumed to be insignificant compared to traffic on H Street and Benning Road. The only exception was Florida Avenue at the intersection with Benning Road.
- Normal atmospheric conditions and a flat topography were assumed for all receivers. As appropriate, pavement or lawn was used for the ground conditions at each receiver.
- Following DDOT procedures, only first row sensitive receivers where there was evidence of exterior activities were modeled.

**Table 22: Traffic Counts at the Short-term Noise Measurement Sites**

| Site | Location | Duration[(a)] | Traffic Direction[(b)] | Cars | Medium Trucks | Heavy Trucks | Buses |
|---|---|---|---|---|---|---|---|
| ST-1 | 501 H Street | 15 min | WB | 119 | 3 | 3 | 1 |
| | | | EB | 83 | 5 | 6 | 7 |
| ST-2 | H and 11th | 15 min | WB | 123 | 2 | 0 | 2 |
| | | | EB | 132 | 2 | 5 | 1 |
| ST-3 | H and Florida | 15 min | WB | 79 | 1 | 1 | 2 |
| | | | EB | 360 | 6 | 5 | 1 |
| ST-4 | Benning and 18th | 15 min | WB | 236 | 7 | 4 | 1 |
| | | | EB | 169 | 7 | 5 | 2 |
| ST-5 | Benning and 20th | 15 min | WB | 212 | 5 | 4 | 1 |
| | | | EB | 168 | 6 | 6 | 1 |
| ST-6 | 2500 Benning Road | 15 min | WB | 294 | 4 | 3 | 3 |
| | | | EB | 153 | 3 | 8 | 3 |

Notes:
(a) Duration of traffic counts in each direction. Traffic counts for both directions were performed simultaneously with the noise measurements.
(b) Direction of the traffic. WB = Westbound, EB = Eastbound.

| Table 23: Calibration of Traffic Noise Model | | | | |
|---|---|---|---|---|
| **Site** | **Location** | **Measured Leq, dBA[(a)]** | **Predicted TNM Leq, dBA[(b)]** | **Difference, dB** |
| ST-1 | 501 H Street | 68.3 | 68.7 | -0.4 |
| ST-2 | H and 11th | 68.2 | 66.3 | 1.9 |
| ST-3 | H and Florida | 68.9 | 68.2 | 0.7 |
| ST-4 | Benning and 18th | 69.6 | 69.2 | 0.4 |
| ST-5 | Benning and 20th | 69.9 | 68.1 | 1.8 |
| ST-6 | 2500 Benning Road | 54.9 | 56.7 | -1.8 |

Notes:
(a) The measured Leq's over the 15-minute duration of the traffic counts.
(b) Noise predicted using the TNM model with the traffic counts.
(c) Difference between the measured and predicted noise levels (Measured Leq minus TNM Predicted Leq).

| Table 24: Traffic Fleet Mix | | |
|---|---|---|
| **Vehicle Type** | **Percentage of Total Vehicles** | **Speed** |
| Cars | 94.6% | 35 |
| Medium Trucks | 2.2% | 30 |
| Heavy Trucks | 2.1% | 30 |
| Buses | 1.1% | 30 |

The land uses along the alignment fall into FHWA activity categories B, C and E. Traffic noise impacts were assessed for the 2040 project build condition based on the DDOT noise abatement criteria. Table 25 summarizes the traffic noise assessment for single- and multi-family residences. There was evidence of frequent human activity in outdoor areas at all the residential receivers. The predicted noise levels for existing and future conditions with and without the streetcar project exceed the NAC at all residential clusters except R2 through R5 and R14. Also, the predicted levels of traffic noise with the project are less than 1 decibel greater or lesser than the levels without the project at all of the residential receivers.

Table 26 shows the traffic noise assessment for Category C land uses. Land uses in Table 26 include churches, clinics, non-profit and government offices, training centers, a country club and other institutional receivers. Because outdoor human activity areas were limited to 4 of the 29 Category C sensitive receivers, only these four receivers were modeled using TNM. The predicted levels at two of these receptors approach or exceed the NAC. As for the residential receivers, the predicted levels of traffic noise with and without the project are virtually identical.

A total of 40 FHWA Category E clusters were identified along the corridor. These receivers consist of restaurants, bars, offices and other businesses. Traffic noise impact assessment was not performed for the Category E receivers because no areas of frequent outdoor human activity were identified at any of these receivers.

| Table 25: Summary of Traffic Noise Impact Assessment for FHWA Category B | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cluster ID | Desc.[(a)] | Dist.[(b)] (ft) | Adjacent Street | Leq[(c)] (dBA) | | | | NAC[(d)] | Approach/ Exceed[(e)] | # of Units [(f)] | Abate. Feas/Reas |
| | | | | No Build 2013 | Build 2013 | No Build 2040 | Build 2040 | | | | |
| R1 | MFR | 30 | 3rd St. | 68 | 68 | 69 | 69 | 66 | Yes | 10 | No[(g)] |
| R2 | MFR | 85 | 3rd St. | 60 | 60 | 61 | 61 | 66 | No | -- | -- |
| R3 | MFR | 110 | 4th St. | 60 | 60 | 61 | 61 | 66 | No | -- | -- |
| R4 | MFR | 120 | 4th St. | 60 | 60 | 60 | 60 | 66 | No | -- | -- |
| R5 | MFR | 140 | 12th St. | 58 | 58 | 59 | 59 | 66 | No | -- | -- |
| R6 | MFR | 40 | Florida Ave. | 68 | 66 | 69 | 69 | 66 | Yes | 20 | No[(g)] |
| R7 | MFR | 25 | 15th St. | 70 | 70 | 71 | 71 | 66 | Yes | 20 | No[(g)] |
| R8 | MFR | 30 | 16th St. | 69 | 69 | 70 | 70 | 66 | Yes | 4 | No[(g)] |
| R9 | MFR | 30 | 17th St. | 67 | 67 | 68 | 68 | 66 | Yes | 21 | No[(g)]) |
| R10 | SFR | 40 | 18th St. | 72 | 72 | 73 | 73 | 66 | Yes | 48 | No[(g)] |
| R11 | MFR | 25 | 19th St. | 71 | 71 | 72 | 72 | 66 | Yes | 10 | No[(g)] |
| R12 | MFR | 30 | 19th St. | 71 | 71 | 71 | 71 | 66 | Yes | 4 | No[(g)] |
| R13 | MFR | 25 | 20th St. | 70 | 70 | 71 | 71 | 66 | Yes | 3 | No[(g)] |
| R14 | MFR | 85 | 21st St. | 63 | 64 | 64 | 64 | 66 | No | -- | -- |
| R15 | SFR | 30 | 24th St. | 69 | 69 | 70 | 70 | 66 | Yes | 4 | No[(g)] |
| R16 | SFR | 40 | 25th St. | 70 | 70 | 71 | 71 | 66 | Yes | 6 | No[(g)] |

Notes:

(a) Desc. = Type of land use, SFR = single-family residence, MFR = multi-family residence.
(b) Distance to the near lane is rounded off to the nearest 5 ft.
(c) Leq values are rounded off to the nearest whole number unless shown otherwise.
(d) NAC is the noise abatement criteria, which is 67 dBA for Category B land uses. DDOT assesses impact when traffic noise is within 1 dB of the NAC.
(e) Indicates whether the predicted 2040 Build noise level approaches or exceeds the NAC.
(f) Number of dwelling units where the 2040 Build noise level is predicted to approach or exceed the NAC.
(g) Noise abatement is not feasible because the sensitive receiver property line abuts the H Street/Benning Road sidewalk.

| Table 26: Summary of Traffic Noise Impact Assessment for FHWA Category C | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receiver ID | Desc.[(a)] | Dist.[(b)] (ft) | Adjacent Street | Exterior Use | Receiver Modeled | Leq[(c)] (dBA) | | | | NAC[(d)] | Impacts[(e)] (Yes/No) | Abate Feas or Reas |
| | | | | | | No Build 2013 | Build 2013 | No Build 2040 | Build 2040 | | | |
| M1 | Hospital | 30 | 16th St. | No | No | 70 | 70 | 71 | 71 | 66 | Yes | No[(f)] |
| I14 | Library | 85 | 13th St. | Yes | Yes | 60 | 60 | 62 | 62 | 66 | No | -- |
| I15 | Church | 140 | 13th St. | Yes | Yes | 59 | 59 | 60 | 60 | 66 | No | -- |
| I24 | School | 325 | 26th St. | Yes | Yes | 54 | 55 | 55 | 55 | 66 | No | -- |
| I25 | Institute | 170 | 26th St. | Yes | Yes | 59 | 59 | 59 | 60 | 66 | No | |
| I26 | Golf Course | 40 | 26th St. | Yes | Yes | 69 | 69 | 70 | 70 | 66 | Yes | No[(f)] |

Notes:

(a) Desc. = Type of land use.
(b) Distance to the near lane is rounded off to the nearest 5 ft.
(c) Leq values are rounded off to the nearest whole number unless shown otherwise.
(d) NAC is the noise abatement criteria, which is 67 dBA for Category C land uses. DDOT assesses impact when traffic noise is within 1 dB of the NAC.
(e) Indicates whether the predicted 2040 Build noise level approaches or exceeds the NAC.
(f) Noise abatement is not feasible because the sensitive receiver property line abuts the H Street/Benning Road sidewalk.

## 8.3 Operational Noise Mitigation

The potential sources of noise impacts along the proposed streetcar alignments are: 1) special trackwork and 2) squeal noise from tight curves located within 100 ft of residential land uses. Using a “well-designed" flange-bearing frog for the crossovers located within 100 ft of noise-sensitive receivers will be sufficient to eliminate the noise impacts from proximity to crossovers. If wheel squeal occurs that is sufficient to cause community noise levels to exceed the applicable FTA moderate impact thresholds, measures to reduce wheel squeal, such as rail or wheel lubrication should be sufficient to eliminate the impacts.

## 8.4 Traffic Noise Abatement

The NAC for traffic noise would be approached or exceeded at 150 residential units, a hospital and a golf course. Traffic noise is expected to change by less than 1 dB in the 2040 due to the project. However, because these sensitive receivers require access to H Street/Benning Road, noise abatement in the form of sound barriers is not feasible. Therefore, no abatement is recommended for traffic noise from the project.

## 8.5 Streetcar Operational Vibration

As discussed in Section 6.5, FTA guidelines provide two sets of criteria for assessing vibration impacts. The first is based on the overall vibration velocity level and is intended for use with a general impact assessment. The second is for use with a detailed impact assessment when the predictions include the 1/3 octave band spectra. The approach used for this assessment is:

1. The predicted overall vibration velocity level is compared to the applicable General Assessment threshold. The thresholds are 72 VdB for residential land uses (FTA Category 2) and 75 VdB for institutional land uses (FTA Category 3).
2. If the predicted level is below the General Assessment threshold, no additional analysis is performed.
3. If the predicted level is above the General Assessment threshold, the predicted 1/3 octave band spectrum is compared to the threshold for a Detailed Impact Assessment. Over the 8 to 80 Hz range, the thresholds are a maximum in any 1/3 octave band of 72 VdB for residential land uses and 75 VdB for institutional land uses. This level is referred to as the ***band maximum*** level.
4. Mitigation is evaluated if the predicted vibration levels exceed both the General and Detailed Assessment thresholds.

For special land uses such as theaters and concert halls, the FTA impact criteria do not have a separate threshold for detailed impact assessments. Mitigation is evaluated for land uses that fall into one of the FTA special land uses when the predicted vibration level exceeds the applicable General Assessment impact threshold.

The vibration impact assessment for residential land uses is presented in Table 27 and for institutional land uses is presented in Table 28. Included in Table 28 are land uses such as schools, churches, medical clinics, and community centers. However, because outdoor activities are generally not affected by groundborne vibration, land uses such as parks and golf courses are not included Table 28.

As shown in Table 27, there are six clusters where the predicted vibration levels at residential land uses exceed the General Assessment impact threshold. At two of these clusters the predicted indoor vibration levels also exceed the Detailed Assessment impact threshold. The conclusion is that there is potential for impacts from groundborne vibration at 14 dwelling units. All the predicted vibration impacts are due to sensitive receptors being within 100 feet of special trackwork, which is assumed to amplify vibration levels by up to 10 decibels.

The predicted vibration levels for Category 3 land uses are shown in Table 28. As can be seen in Table 28, all of the predicted vibration levels are below the General Assessment impact threshold.

The two buildings in the H/Benning Streetcar corridor that are covered by the FTA "special" category are the Atlas Theater and the H Street Playhouse. The vibration impact assessment for these two buildings is summarized in Table 29. Both buildings are relatively large buildings. The predictions for both buildings are based on the LSTM measurements inside the Atlas Theater lobby during the vibration propagation tests at site V-2. The auditorium area of the Atlas Theater is setback from the future near track centerline by approximately 130 ft; therefore the measurement at the 125 ft lobby position was used for the Atlas Theater.

Vibration propagation tests were not performed the H Street Playhouse. However, the building appears to be of a similar construction to the Atlas Theater lobby area and is located approximately 350 ft east of the Atlas Theater. Therefore, the indoor vibration tests at the Atlas Theater will provide a reasonable estimate of the vibration levels at the H Street Playhouse. The 75 ft data from the Atlas Theater lobby was used to estimate the vibration levels inside the H Street Playhouse that are presented in Table 29.

For both the Atlas Theater and the H Street Playhouse the predicted groundborne noise and vibration levels are below the applicable FTA impact thresholds. The predictions are conservative because they include a +5dB safety factor for any potential floor amplification and prediction uncertainty.

Although no impacts are predicted at the Atlas Theater, the predicted groundborne noise level inside the Atlas Theater is less than 1 dB below the impact threshold. Therefore, it is recommended that the groundborne noise and the groundborne vibration levels inside the auditorium area should be measured when the streetcars are in operation to verify that no mitigation measures are required. Should the groundborne noise levels be high enough to interfere with performances at the Atlas Theater, retrofit vibration mitigation measures applied to the building should be sufficient to reduce groundborne noise to below the impact threshold.

**Table 27: Summary of Vibration Impact Assessment for Category 2 Land Uses**

| Cluster | Desc.[(a)] | NT Dist.[(b)] (ft) | Adjacent Street | Speed (mph) | General Impact Assessment | | | Detailed Impact Assessment | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lv (VdB) | Thresh. (VdB) | Impact (Yes/No) | Band Max[(c)] (VdB) | Impact Yes/No | # of Units [(d)] |
| R1 | MFR | 45 | 3rd St. | 25 | 78[c] | 72 | Yes | 74.1 | Yes | 10 |
| R2 | MFR | 100 | 3rd St. | 25 | 73 | 72 | Yes | -- | No | -- |
| R3 | MFR | 140 | 4th St. | 25 | 60 | 72 | No | -- | No | -- |
| R4 | MFR | 120 | 4th St. | 25 | 61 | 72 | No | -- | No | -- |
| R5 | MFR | 150 | 12th St. | 25 | 56 | 72 | No | -- | No | -- |
| R6 | MFR | 50 | Florida Ave. | 25 | 65 | 72 | No | -- | No | -- |
| R7 | MFR | 45 | 15th St. | 25 | 66 | 72 | No | -- | No | -- |
| R8 | MFR | 45 | 16th St. | 25 | 69 | 72 | No | -- | No | -- |
| R9 | MFR | 45 | 17th St. | 25 | 69 | 72 | No | -- | No | -- |
| R10 | SFR | 65 | 18th St. | 25 | 67 | 72 | No | -- | No | -- |
| R11 | MFR | 45 | 19th St. | 25 | 73 | 72 | Yes | -- | No | -- |
| R12 | MFR | 45 | 19th St. | 25 | 73 | 72 | Yes | -- | No | -- |
| R13 | MFR | 45 | 20th St. | 25 | 73 | 72 | Yes | -- | No | -- |
| R14 | MFR | 75 | 21st St. | 25 | 69 | 72 | No | -- | No | -- |
| R15 | SFR | 65 | 24th St. | 25 | 80[(e)] | 72 | Yes | 79.1 | Yes | 4 |
| R16 | SFR | 65 | 25th St. | 25 | 70 | 72 | No | -- | No | -- |

Notes:

(a) Desc. = Type of land use, SFR = single-family residence, MFR = multi-family residence.

(b) Distance to the near track (NT) is rounded off to the nearest 5 ft.

(c) Maximum 1/3 octave band level in 8 to 80 Hz frequency range.

(d) Number of impacted dwelling units based on Detailed Assessment vibration criteria. Note that only units that are within the impact distance and where people sleep are counted for the vibration impacts.

(e) Includes +10 dB for vibration amplification due to wheel impacts at the crossover frogs.

| Table 28: Summary of Vibration Impact Assessment for Category 3 Land Uses | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cluster | Receiver Name | NT Dist.[(a)] (ft) | Speed (mph) | General Impact Assessment | | | Detailed Impact Assessment | | |
| | | | | Lv (VdB) | Thresh. (VdB) | Impact (Yes/No) | Band Max[(b)] (VdB) | Impact Yes/No | # of Units |
| I1 | Necomb Child Development & Care | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I2 | Institute of Behavioral Change & Research Inc. | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I3 | Community Development Center | 50 | 25 | 68 | 75 | No | -- | No | -- |
| I4 | EBT Training Center | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I5 | 24-Hour Protection Govt Building | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I6 | DC Community Services | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I7 | Adnoi Church | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I8 | DC Govt.: Animal Disease Control Division | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I9 | Douglas Church | 25 | 25 | 71 | 75 | No | -- | No | -- |
| I10 | Temple of Praise | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I11 | The Red Palace (Museum of Oddities) | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I12 | Penthacostal Church | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I13 | Comprehensive Community Health | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I14 | RL Christian Library | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I15 | United House of Prayer for All People | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I16 | St. John's Church of God | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I17 | Joy of Motion Dance Center | 25 | 25 | 72 | 75 | No | -- | No | -- |
| I18 | Trinidad Baptist Church | 45 | 25 | 69 | 75 | No | -- | No | -- |
| I19 | Benning Street Medical Clinic | 45 | 25 | 69 | 75 | No | -- | No | -- |
| I20 | Church of God in Christ | 45 | 25 | 73 | 75 | No | -- | No | -- |
| I21 | St. Elmo Crawford Dental Clinic | 45 | 25 | 73 | 75 | No | -- | No | -- |
| I22 | Northeast Academy of Dance | 45 | 25 | 73 | 75 | No | -- | No | -- |
| I23 | Prevention Works (Non-Profit) | 45 | 25 | 73 | 75 | No | -- | No | -- |
| I24 | Springarn Senior High School | 350 | 25 | 49 | 75 | No | -- | No | -- |
| I25 | G C Langston Country Club | 160 | 25 | 60 | 75 | No | -- | No | -- |
| M1 | Greater Northwest Medical Center | 45 | 25 | 69 | 75 | No | -- | No | -- |
| T2 | H Street Playhouse | 25 | 25 | 72 | 75 | No | -- | No | -- |

Notes:

(a) Distance to the near track (NT) is rounded off to the nearest 5 ft.

(b) Maximum 1/3 octave band level in 8 to 80 Hz frequency range.

| Table 29: Summary of Vibration Impact Assessment for Special Buildings | | | | | |
|---|---|---|---|---|---|
| Receiver # | Receiver Name | Groundborne Vibration, VdB | | Groundborne Noise, dBA | |
| | | Threshold | Predicted | Threshold | Predicted |
| T1 | The Atlas Theater | 65 | 58.6[c] | 25 | 24.7 |
| T2 | H Street Playhouse | 72 | 61.1 | 35 | 33.4 |

## 8.6 Operational Vibration Mitigation

A number of different approaches have been used by light rail and streetcar systems to reduce the levels of groundborne vibration. These measures range from very simple approaches such as stiffening the floors at the receivers to the very expensive such as placing the entire track system on a concrete slab that is supported by springs (a floating slab) or constructing a building so that the entire building is supported by rubber or coil springs. The most common measure used to mitigate train vibration consists of placing some sort of resilient layer between the track and the soil. Some common approaches for installing standard vibration mitigation measures with embedded track are:

- Resilient mat under Track Slab: Resilient mats are similar to ballast mats that are designed to be placed under ballast and tie track. Some embedded track designs have used resilient mats under a concrete slab as a vibration mitigation measure. A resilient mat consists of a three- to six-centimeter-thick elastomeric pad that is placed under the concrete track slab. In essence, the resilient mat is used to create a floating slab. This approach has the advantage of putting a continuous layer under the concrete slab, which reduces the potential for litter and other fouling material to get under the slab and short circuit the vibration isolation provided by the resilient layer.
- QTrack Embedded Track: QTrack is a proprietary embedded track system supplied by CDM-Novitec. It is a fastenerless continuously-supported track with rubber profiles decoupling the whole rail from its environment. QTrack consists of a high-resilient pad underneath the rail base that acts as the spring and a rubber boot that encompasses the rail. The potential concerns for lateral stability of these fastenerless systems are addressed through careful design to ensure stability that is comparable to mechanically fixed rail. The supplier claims that QTrack can provide effective isolation above 25 Hz and can be engineered to provide attenuation that is comparable to ballast mats.
- High-resilience boot: A common embedded track system is to place the rails in a rubber “boot”, position the rails, and then pour concrete around the boot. The rubber boot provides electrical isolation of the rails and provides enough resilience that movement of the rail during operations and movement resulting from thermal expansion and contraction does not cause the concrete to crack. In the standard configuration, the rail boot results in a fairly stiff track system. It is sometimes feasible to reduce the track stiffness by using a thicker and softer material for the boot. However, it is unlikely that a softer boot would provide sufficient vibration isolation except for segments where the predicted vibration levels exceed the impact threshold only at frequencies of 60 Hz and higher. Alternative approaches to increase the resilience of embedded track include using poured materials (e.g., Icoset) and the equivalent of booted track using three separate pieces to enclose the track instead of a single “boot”.
- Tire Derived Aggregate (shredded tires): This approach consists of building the track on top of a layer of tire derived aggregate (TDA). This is an innovative approach for recycling old automobile tires. Although this approach has not been used for embedded track, it has been successfully used by light rail systems in Denver and San Jose to reduce vibration from sections of ballast and tie track. A 12 inch layer of TDA was used for both the Denver and San Jose installations and all indications are that those designs are functioning as intended.
- Floating slab track: A floating slab consists of a concrete slab supported by elastomer or steel-coil springs. For embedded track the rails would be embedded in the spring-supported slab using the same basic design as used for standard embedded track. The frequency range at which a floating slab is effective depends on the thickness of the slab and the stiffness of the springs. Most North American floating slab systems use rubber pads that are 12 to 18 inches in diameter supporting a concrete slab that is 12 to 24 inches thick. Floating slabs are very effective at reducing vibration levels; however, they are also very expensive and may not be suitable for shared right-of-way systems such as streetcars.

The predicted attenuation for the various mitigation options are shown in Figure 23. The recommended vibration mitigation measures for the sensitive receivers that are predicted to be impacted by the H/Benning Streetcar Project are shown in Table 30. Because the only vibration impacts are caused by the special trackwork, where there would be special trackwork located within 200 ft of vibration sensitive receivers, "well-designed" flange-bearing frogs are recommended.

Although predicted groundborne noise from the streetcar operations does not exceed the FTA impact threshold inside the Atlas Theater auditorium, it is within 1 decibel of the impact threshold based on the measurements performed in the lobby. Therefore, we recommend vibration measurements inside the theater during the pre-revenue testing of the streetcar system. If the groundborne noise levels exceed the FTA impact threshold inside the theater auditorium, it should be feasible to eliminate the impact with building modifications. These modifications could be as simple as stiffening floors.

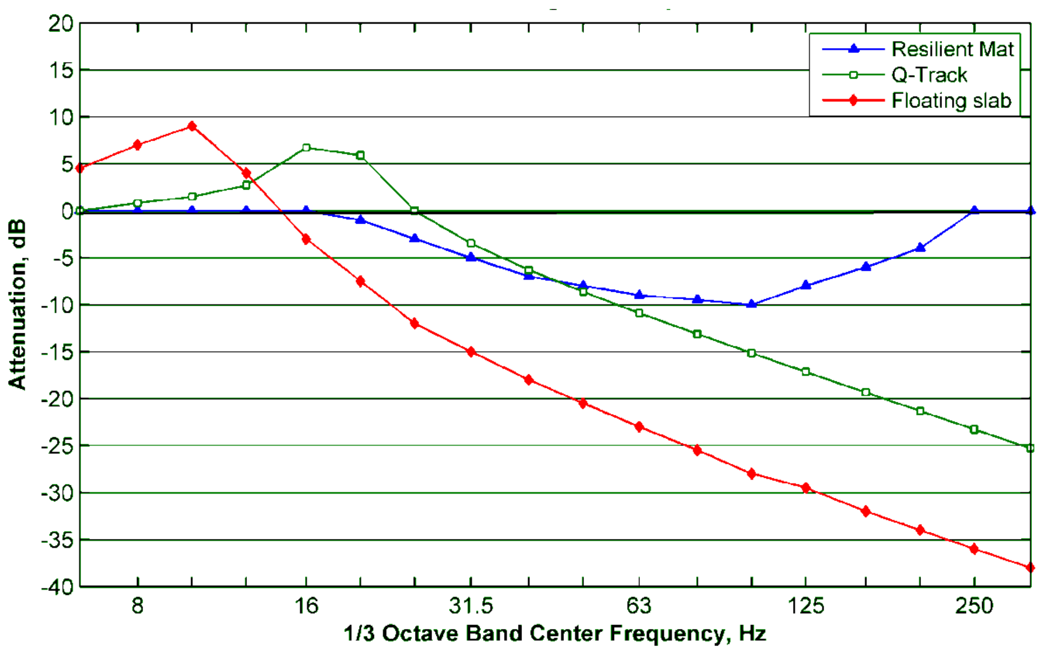



**Figure 23: Predicted Attenuation for Various Vibration Mitigation Options**

**Table 30: Recommended Locations for Vibration Mitigation**

| Location | Number of Impacts Before Mitigation[(a)] | Recommended Mitigation | Residual Impacts[(b)] |
|---|---|---|---|
| R1 | 10 | "well-designed" flange bearing frogs | 0 |
| R15 | 4 | | 0 |

Notes:

(a) Number of impacts represents the number of residential units and/or institutional spaces at which the levels from streetcar vibration exceed the FTA Detailed Vibration Impact Criteria.

(b) Residual impacts represent the number of indoor vibration sensitive spaces at which the predicted levels of streetcar vibration exceed the FTA Detailed Vibration Impact Criteria after mitigation.

## 9. POTENTIAL CONSTRUCTION NOISE AND VIBRATION IMPACTS AND MITIGATION

### 9.1 Construction Noise

Significant sections of the streetcar alignment had already been built at the time of this study. Therefore, this section applies to the unfinished portions of the project and the CBTC that is currently in the preliminary design stage.

At the first stage of construction it may be necessary to relocate, modify, or protect in place all utilities and underground structures that would conflict or interfere with excavation for street level concrete pavement and trackwork. Equipment typically used for utility relocation work includes diamond saws, pavement breakers, jackhammers, excavators, compressors, dump trucks, and welding machines.

During construction the installation of the embedded streetcar trackbed would require excavation of the existing roadway. Equipment used for construction of the tracks would typically be similar to what is required for relocation of the utilities with the addition of track-laying equipment paving machines, concrete mixers, and concrete finisher.

The use of this equipment during project construction has the potential to result in substantial, yet temporary, increases in local noise levels along the project alignments. The District of Columbia (DC) allows construction from 7AM to 7 PM on any weekday with the requirement that noise levels resulting from construction or demolition (excluding pile driver devices) shall not exceed a 1-hour Leq of 80 dBA at 25 feet from the outermost limits of the construction site. From 7 PM to 7AM the maximum noise levels in Table 1 shall apply. The sound level shall be measured at the property line of the property on which the noise source is located, or as close as is practicable if there is an obstruction.

**Table 31: District of Columbia Nighttime Construction Noise Limits**

| Zone | Maximum Noise Level (dBA) |
|---|---|
| | Weekday 7 PM to 7AM |
| Residential, special purpose or waterfront zone | 55 |
| Commercial or light manufacturing zone | 60 |
| Industrial zone | 65 |

Source: Ref. 3.

Construction noise levels depend on the number of pieces and type of equipment, their general condition, the amount of time each piece operates per day, the presence or lack of noise attenuating features such as walls, and the location of the construction activities relative to the sensitive receivers. The majority of these variables are left to the discretion of the contractor. Therefore, it is not feasible to accurately estimate construction noise levels until the contractor’s means and methods have been defined.

Table 32 shows the equipment likely to be used during the noisiest periods of utility relocation and track construction, the maximum noise generated by this equipment at 50 feet, the estimated usage factors, and the estimated work-shift Leq at a distance of 25 feet from the edge of the construction area. This analysis shows that most of the equipment likely to be used by a contractor would be likely to exceed the noise limits in the DC noise limit of a maximum 1-hour Leq of 80 dBA at 25 ft from the construction site. Furthermore, because much of the construction will be located within 25 feet to 50 feet of noise sensitive receptors, there is a high probability that the construction activities will generate noise levels that exceed a one-hour Leq of 80 dBA at sensitive receptors. Approaches to mitigating the noise impacts are discussed in Section 9.2.

| Table 32: Predicted Construction Noise | | | | |
|---|---|---|---|---|
| **Equipment** | **Maximum Sound Level @ 50 ft under full Load** | **Source Usage Factor (% Time under Full Load)** | **One-Hour Leq at 25 ft** | **Likely to Exceed DC Noise Limit** |
| Pavement breakers | 89 dBA | 20% | 88 dBA | YES |
| Concrete diamond saws | 90 dBA | 20% | 89 dBA | YES |
| Jackhammers | 89 dBA | 20% | 88 dBA | YES |
| Excavators | 81 dBA | 40% | 83 dBA | YES |
| Compressor | 78 dBA | 40% | 80 dBA | YES |
| Dump trucks | 77 dBA | 40% | 79 dBA | NO |
| Welding machines | 74 dBA | 40% | 76 dBA | NO |
| Paving machines | 77 dBA | 50% | 80 dBA | NO |
| Concrete mixers | 78 dBA | 40% | 81 dBA | YES |
| Compactors | 83 dBA | 20% | 82 dBA | YES |

## 9.2 Construction Noise Mitigation

Listed below are some typical approaches to reducing noise levels associated with the construction phase of major projects. Requiring the contractor to employ these methods should leave the contractor with enough flexibility to perform the work without undue financial or logistical burdens while protecting adjacent noise sensitive receivers from excessive construction noise levels.

- Because construction during nighttime hours is likely to exceed the DC noise limits, avoid nighttime construction unless a variance is issued by the District of Columbia.
- Use specialty equipment with enclosed engines and/or high-performance mufflers.
- Locate equipment and staging areas as far from noise-sensitive receivers as possible.
- Limit unnecessary idling of equipment.
- Install temporary noise barriers. This approach can be particularly effective for stationary noise sources such as compressors and generators.
- Reroute construction related truck traffic away from local residential streets.
- Avoid impact pile driving where possible. Where geological conditions permit, the use of drilled piles or a vibratory pile driver is generally quieter.

Specific measures to be employed to mitigate construction noise impacts would be developed by the contractor and presented in the form of a Noise Control Plan. Because many of the construction activities will be located in close proximity to noise sensitive receivers, staging the construction to minimize the amount of time that noise producing activities affect specific receivers may be an alternative to using quieter equipment that may extend the exposure to construction activities.

## 9.3 Construction Vibration

Some activities, such as compaction, pavement breaking, and the use of excavators, could result in perceptible levels of groundborne vibration. However, these activities would be limited in duration and the vibration levels are likely to be well below thresholds for minor cosmetic building damage. However because the project study area has several historic buildings that may be well over 100 years old, further analysis would be required to manage structural and architectural damage risk to these buildings.

Typical damage risk vibration limits are shown in Table 33. The planned construction would include a limited number of activities expected to generate vibration that approaches the lowest limit in Table 33.

**Table 33: Construction Vibration Limits**

| Equipment | Maximum PPV (in/sec) | Source |
|---|---|---|
| Typical construction | 2.0 | Bureau of Mines Bulletin 656, 1971 |
| Extremely fragile buildings | 0.2 | FTA, 2006 |
| Historic and ancient buildings | 0.12 | German Standard DIN 4150 |

## 9.4 Construction Vibration Mitigation

Construction related vibration activities are unlikely to exceed the impact thresholds shown in Table 33. However, the following precautionary vibration mitigation strategies are recommended to minimize the potential for damage to any structures in the corridor:

1. Pre-Construction Survey: The survey should include inspection of building foundations and taking photographs of pre-existing conditions. The survey can be limited to the first row of buildings along the selected alignment. The only exception is if an important and potentially fragile historic resource is located within approximately 200 feet of the construction zone, in which case it should be included in the survey. In the case of the CBTC, the survey should be performed at receivers R14, I24 and I25.
2. Vibration Limits: The FTA guidance manual (Ref. 1) suggests vibration limits in terms of peak particle velocity (PPV) ranging from 0.12 in/sec for “buildings extremely susceptible to vibration damage” to 0.5 in/sec for “Reinforced-concrete, steel or timber” buildings. The contract specifications should establish appropriate damage risk vibration limits for each of the historic properties that are within 200 feet of the construction.
3. Vibration Monitoring: The contractor should be required to monitor vibration at any buildings where the lower vibration limit is applicable and at any location where complaints about vibration are received from building occupants.

If the contractor’s plan calls for high-vibration construction activities being performed close to structures, it may be necessary for the contractor to use alternative procedures that produces lower vibration levels. Examples of high-vibration construction activities include the use of vibratory compaction and hoe rams next to sensitive buildings. Alternative procedures would be to use of non-vibratory compaction in limited areas and concrete saws in place of a jackhammers or pavement breakers for demolition.

## 10. REFERENCES


1. Federal Transit Administration Office of Planning and Environment, *Transit Noise and Vibration Impact Assessment*. Document FTA-VA-90-1003-06, May 2006.
2. District of Columbia Municipal Regulations, Chapter 27, Noise Control, Section 2703, "Exemptions: Vehicles Using only Rails and Tracks."
3. District of Columbia Municipal Regulations, Chapter 27, Noise Control, Section 2701, "Maximum Sound Levels."
4. District of Columbia Municipal Regulations, Chapter 28, Noise Control, Section 2803, "Construction in Residential Zones."
5. "Tempe Streetcar Environmental Assessment, Noise and Vibration Technical Report", Appendix D and Appendix E, February 2012.
6. Jeffery Zapfe, Hugh Saurenman, Sanford Fidell, *Groundborne Noise and Vibration in Buildings Caused by Rail Transit*, prepared for Transit Cooperative Research Program, Transportation Research Board of the National Academies, Project D-12, November 2009.
7. Shannon McKenna, "A Study of Building Amplification from Groundborne Vibration", Noise-Con 2011, Portland, Oregon, 25-27 July 2011.

# APPENDIX A: FUNDAMENTALS OF NOISE AND VIBRATION

## A.1 Noise Fundamentals

Sound is mechanical energy transmitted by pressure waves in a compressible medium such as air. Typically, noise is defined as unwanted or excessive sound. Sound can vary in intensity by over one million times within the range of human hearing. Therefore, a logarithmic scale, known as the decibel scale (dB), is used to quantify sound intensity and compress the scale to a more convenient range.

Sound is characterized by both its amplitude and frequency (or pitch). The human ear does not hear all frequencies equally. In particular, the ear deemphasizes low and very high frequencies. The A-weighted decibel scale (dBA) better approximates the sensitivity of human hearing. On this scale, the human range of hearing extends from approximately 3 dBA to around 140 dBA. As a point of reference, Figure 24 includes examples of A-weighted sound levels from common indoor and outdoor sounds.

Using the decibel scale, sound levels from two or more sources cannot be directly added together to determine the overall sound level. Rather, the combination of two sounds at the same level yields an increase of 3 dB. The smallest recognizable change in sound level is approximately 1 dB. A 3 dB increase in the A-weighted sound level is considered generally perceptible, whereas a 5 dB increase is readily perceptible. A 10 dB increase is judged by most people as an approximate doubling of the perceived loudness.

The two primary factors that reduce levels of environmental sounds are (1) increasing the distance between the sound source and the receiver and (2) having intervening obstacles such as walls, buildings, or terrain features that block the direct path between the sound source and the receiver. Factors that act to make environmental sounds louder include moving the sound source closer to the receiver, sound enhancements caused by reflections, and focusing caused by various meteorological conditions.

The following are brief definitions of the measures of environmental noise used in this report:

***Maximum Sound Level (Lmax):*** Lmax is the maximum sound level that occurs during an event such as a streetcar passing. For this analysis, Lmax is defined as the maximum sound level using the slow setting on a standard sound level meter.

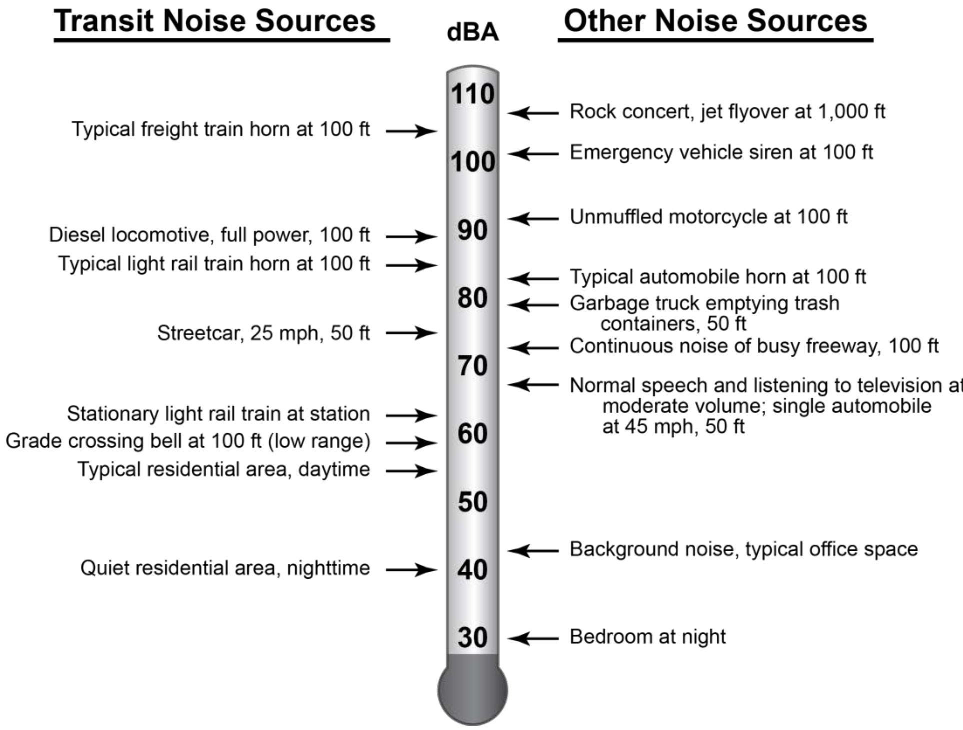
***Equivalent Sound Level (Leq):*** Environment sound fluctuates constantly. The equivalent sound level (Leq) is the most common means of characterizing community noise. Leq represents a constant sound that, over a specified period of time, has the same sound energy as the time-varying sound. Leq is used by FTA to evaluate noise impacts at institutional land uses, such as schools, churches, and libraries, from proposed transit projects.

***Day-Night Sound Level (Ldn):*** Ldn is a 24-hour Leq with an adjustment to reflect the greater sensitivity of most people to nighttime noise. The adjustment is a 10 dB penalty for all sound that occurs between the hours of 10:00 PM to 7:00 AM. The effect of the penalty is that, when calculating Ldn, any event that occurs during the nighttime is equivalent to ten occurrences of the same event during the daytime. Ldn is the most common measure of total community noise over a 24-hour period and is used by FTA to evaluate residential noise impacts from proposed transit projects.

***Lxx:*** This is the percent of time a sound level is exceeded during the measurement period. For example, the L99 is the sound level exceeded 99 percent of the measurement period. For a one hour period, L99 is the sound level exceeded for all except 36 seconds of the hour. L1 represents typical maximum sound levels, L33 is approximately equal to Leq when free-flowing traffic is the dominant noise source, L50 is the median sound level, and L99 is close to the minimum sound level.

***Sound Exposure Level (SEL):*** SEL is a measure of the acoustic energy of an event such as a train passing. In essence, the acoustic energy of the event is compressed into a one second period. SEL increases as the sound level of the event increases and as the duration of the event increases. It is often used as an intermediate value in calculating overall metrics such as Leq and Ldn.

***Sound Transmission Class (STC):*** STC ratings are used to compare the sound insulating effectiveness of different types of noise barriers, including windows, walls, etc. Although the amount of attenuation varies with frequency, the STC rating provides a rough estimate of the transmission loss from a particular window or wall.




*Source: FTA, 2006*

**Figure 24: Typical Outdoor and Indoor Noise Levels**

## A.2 Vibration Fundamentals

One potential community impact from the proposed project is vibration that is transmitted from the tracks through the ground to adjacent houses. This is referred to as groundborne vibration. When evaluating human response, groundborne vibration is expressed in terms of decibels using the root mean square (RMS) vibration velocity. RMS is defined as the average of the squared amplitude of the vibration signal. To avoid confusion with sound decibels, the abbreviation VdB is used for vibration decibels. All vibration decibels in this report use a decibel reference of 1 micro-inch/second (μin/sec.).2

The potential adverse impacts of rail transit groundborne vibration are as follows:

- ***Perceptible Building Vibration:*** The vibration of the floor or other building surfaces that the occupants feel. Experience shows that the threshold of human perception is around 65 VdB and that vibration that exceeds 75 to 80 VdB is perceived as intrusive and annoying to occupants.
- ***Rattle:*** The building vibration can cause rattling of items on shelves and hangings on walls, and various rattle and buzzing noises from windows and doors.

[2] One μin/sec= $10^{-6}$ in/sec.

- ***Reradiated Noise:*** The vibration of room surfaces radiates sound waves that are audible to humans (groundborne noise). Groundborne noise sounds like a low-frequency rumble. Usually, for a surface rail system such as the proposed streetcar, the groundborne noise is masked by the normal airborne noise radiated from the transit vehicle and the rails.
- ***Damage to Building Structures:*** Although it is conceivable that vibration from a streetcar system can damage fragile buildings, the vibration from rail transit systems is one to two orders of magnitude below the most restrictive thresholds for preventing building damage. Hence the vibration impact criteria focus on human annoyance, which occurs at much lower amplitudes than does building damage.

Vibration is an oscillatory motion that is described in terms of the displacement, velocity, or acceleration of the motion. The response of humans to vibration is very complex. However, the general consensus is that for the vibration frequencies generated by streetcars, human response is best approximated by the vibration velocity level. Therefore, this study uses vibration velocity to describe streetcar-generated vibration levels.

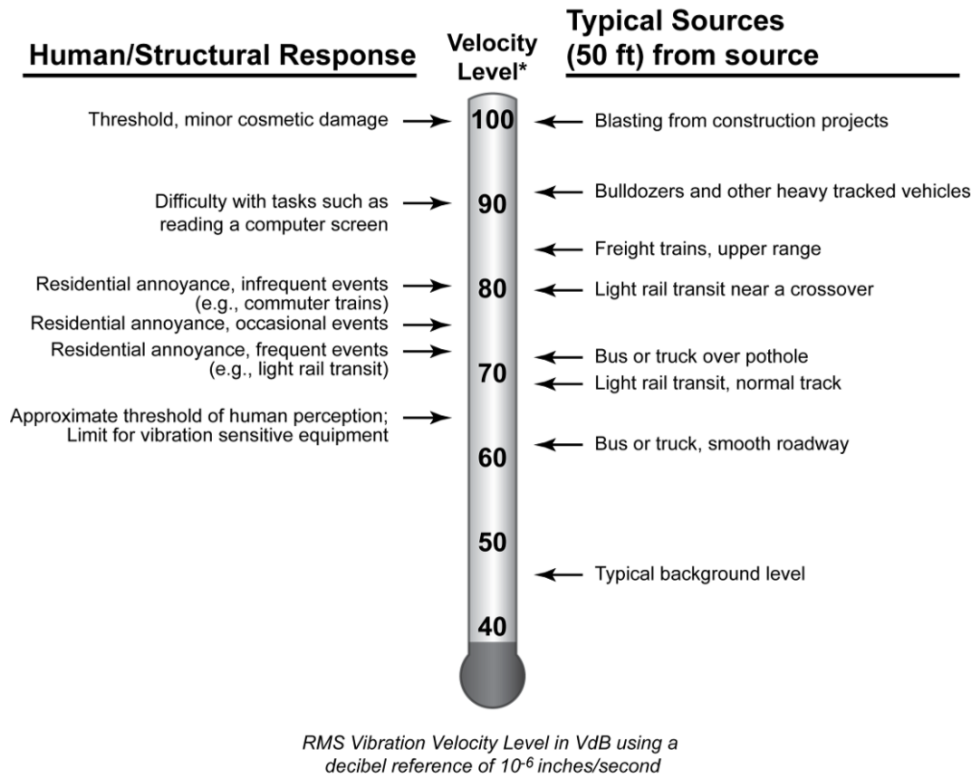
Figure 25 shows typical vibration levels from rail and non-rail sources as well as the human and structure response to such levels.

Although there is relatively little research into human and building response to groundborne vibration, there is substantial experience with vibration from rail systems. In general, the collective experience indicates that:

It is rare that groundborne vibration from transit systems results in building damage (even minor cosmetic damage). Therefore, the primary consideration is whether or not the vibration is intrusive to building occupants or interferes with interior activities or machinery.

The threshold for human perception is approximately 65 VdB. Vibration levels in the range of 70 to 75 VdB often are noticeable but acceptable. Beyond 80 VdB, vibration levels are considered unacceptable.

For human annoyance, there is a relationship between the number of daily events and the degree of annoyance caused by groundborne vibration. The FTA Guidance Manual includes an 8 VdB higher impact threshold if there are fewer than 30 events per day and a 3 VdB higher threshold if there are fewer than 70 events per day.




*Source: FTA, 2006*

**Figure 25: Typical Vibration Levels**

Often it is necessary to determine the contribution at different frequencies when evaluating vibration or noise signals. The 1/3-octave band spectrum is the most common procedure used to evaluate frequency components of acoustic signals. The term *octave* is borrowed from music, where it refers to a span of eight notes. The ratio of the highest frequency to the lowest frequency in an octave is 2:1. For a 1/3-octave band spectrum, each octave is divided into three bands, where the ratio of the lowest frequency to the highest frequency in each 1/3-octave band is $2^{1/3}$:1 (1.26:1). An octave consists of three 1/3 octaves.

The 1/3-octave band spectrum of a signal is obtained by passing the signal through a bank of filters. Each filter excludes all components except those that are between the upper and lower range of one 1/3-octave band (Ref. 1).

## APPENDIX B: AMBIENT NOISE AND VIBRATION MEASUREMENT RESULTS

This appendix shows maps and photos of the ambient noise and vibration measurement sites and provides the detailed results of the measured data. Unusual noise from sources such as sirens, leaf-blowers and construction equipment were removed from the ambient data. The removed events are shown and highlighted in red in the time history plots of long-term and short-term noise measurements.

### B.1 Long-Term Noise Measurement Site LT-1

Measured Ldn:

Ldn with unusual events removed:

**Figure 26: Long-Term Noise Measurement Site, LT-1**

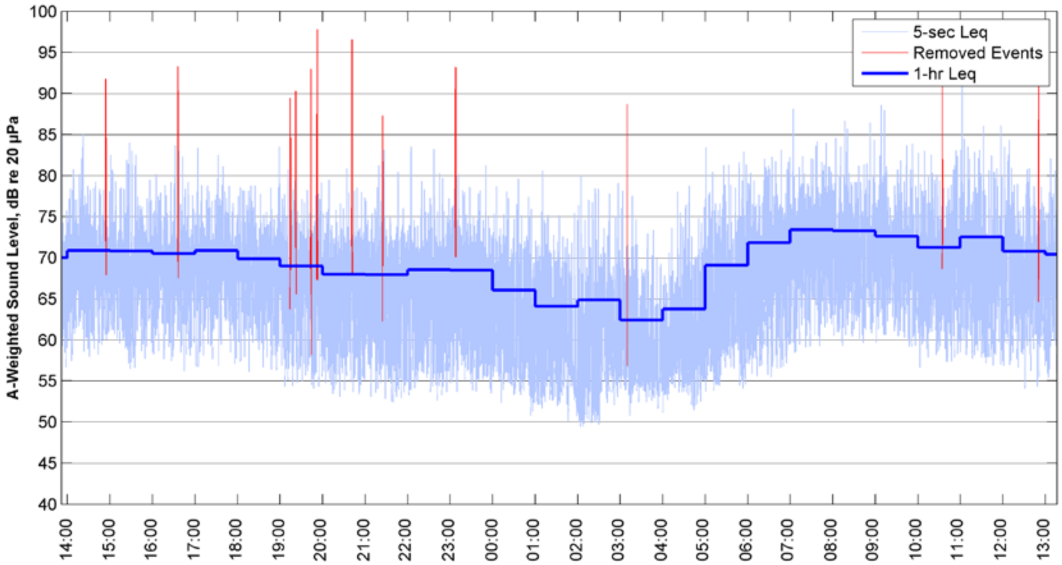



**Figure 27: Time History of Long-Term Noise Measurement at Site LT-1**

| Table 34: Summary of Hourly Noise Levels, Site LT-1 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Day** | **Start Hour, hh:mm** | **Leq** | **Lmax** | **Lmin** | **L1** | **L10** | **L50** | **L90** | **L99** | **Leq (w/o Unusual Events)** |
| 28 June, 2012 | 13:00 | 70.0 | 85.4 | 56.6 | 85.4 | 72.4 | 65.9 | 60.4 | 57.4 | 70.0 |
| 28 June, 2012 | 14:00 | 71.6 | 91.9 | 57.5 | 79.7 | 73.7 | 68.6 | 62 | 58.2 | 70.9 |
| 28 June, 2012 | 15:00 | 70.8 | 83.8 | 56.5 | 81.3 | 73.6 | 68 | 61.8 | 57.7 | 70.8 |
| 28 June, 2012 | 16:00 | 71.8 | 93.4 | 56.2 | 79.1 | 73.7 | 68.4 | 61.8 | 58.2 | 70.5 |
| 28 June, 2012 | 17:00 | 70.9 | 83.4 | 56.7 | 78.8 | 74.1 | 68.8 | 62.8 | 58.1 | 70.9 |
| 28 June, 2012 | 18:00 | 69.9 | 83.5 | 56.1 | 78.4 | 73.3 | 68.1 | 61.6 | 57.4 | 69.9 |
| 28 June, 2012 | 19:00 | 75.4 | 97.8 | 54.1 | 89.6 | 73.3 | 66.7 | 57.7 | 55.0 | 69.0 |
| 28 June, 2012 | 20:00 | 72.6 | 96.5 | 53.1 | 79 | 72.0 | 65.5 | 56.5 | 54.0 | 68.0 |
| 28 June, 2012 | 21:00 | 68.4 | 87.4 | 52.4 | 76.9 | 71.5 | 64.6 | 56.5 | 52.9 | 67.9 |
| 28 June, 2012 | 22:00 | 68.5 | 83.4 | 52.6 | 79.2 | 71.9 | 64.5 | 56.3 | 53.7 | 68.5 |
| 28 June, 2012 | 23:00 | 71.5 | 93.2 | 53.5 | 81 | 72.4 | 64.7 | 56.8 | 54.6 | 68.5 |
| 29 June, 2012 | 0:00 | 66.0 | 79.7 | 50.8 | 76.3 | 69.9 | 60.6 | 54.6 | 52.0 | 66.0 |
| 29 June, 2012 | 1:00 | 64.0 | 80.6 | 50.1 | 74.9 | 68.1 | 57.4 | 53.1 | 51.3 | 64.0 |
| 29 June, 2012 | 2:00 | 64.9 | 80.2 | 49.4 | 77 | 68.1 | 57.3 | 50.8 | 49.8 | 64.9 |
| 29 June, 2012 | 3:00 | 64.9 | 88.7 | 50.7 | 73.8 | 66.1 | 56.5 | 54 | 51.7 | 62.4 |
| 29 June, 2012 | 4:00 | 63.8 | 78.8 | 51.2 | 75.9 | 66.8 | 57.2 | 53.8 | 51.7 | 63.8 |
| 29 June, 2012 | 5:00 | 69.1 | 83.5 | 53.7 | 80.9 | 73 | 62.5 | 56.1 | 54.5 | 69.1 |
| 29 June, 2012 | 6:00 | 71.8 | 83.1 | 55.4 | 81.2 | 75.8 | 67.4 | 59 | 56.7 | 71.8 |
| 29 June, 2012 | 7:00 | 73.4 | 88.1 | 58.4 | 82.1 | 76.7 | 70.6 | 63.6 | 59.5 | 73.4 |
| 29 June, 2012 | 8:00 | 73.2 | 86.7 | 59.3 | 83.5 | 76.3 | 70.3 | 63.7 | 60.6 | 73.2 |
| 29 June, 2012 | 9:00 | 72.6 | 88.5 | 59.1 | 81.2 | 75.6 | 69.7 | 63 | 60 | 72.6 |
| 29 June, 2012 | 10:00 | 72.3 | 92.5 | 56.6 | 82.6 | 74.8 | 67.9 | 61.2 | 57.9 | 71.2 |
| 29 June, 2012 | 11:00 | 72.5 | 91 | 56.9 | 83.1 | 75.1 | 68.4 | 61.1 | 57.9 | 72.5 |
| 29 June, 2012 | 12:00 | 72.1 | 94.8 | 54.1 | 80.9 | 74.3 | 68 | 60.7 | 56.6 | 70.8 |

## B.2 Long-Term Noise Measurement Site LT-2

Figure 28: Long-Term Noise Measurement Site, LT-2

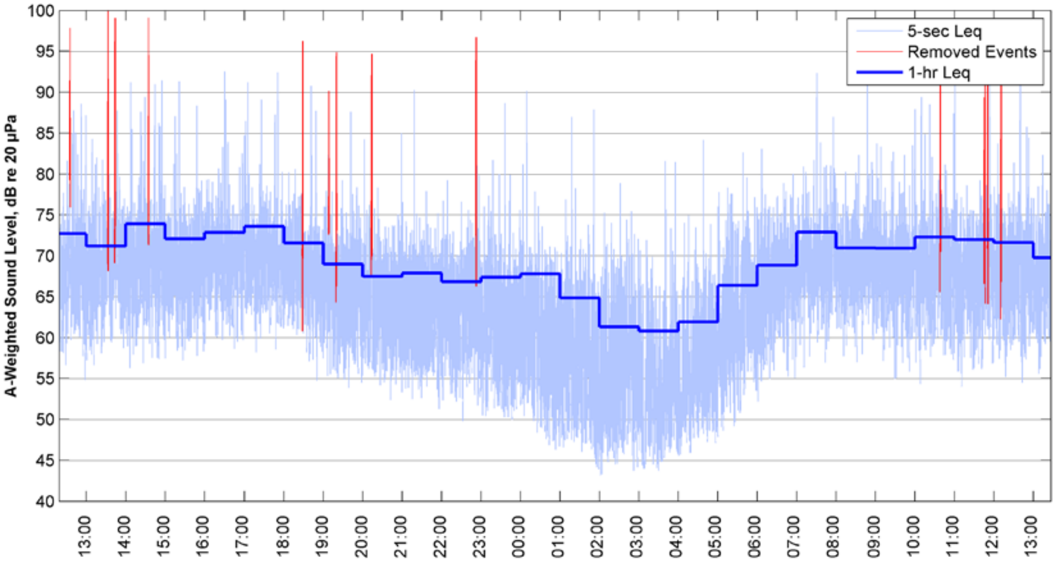



Figure 29: Time History of Long-Term Noise Measurement at Site LT-2

| Table 35: Summary of Hourly Noise Levels, Site LT-2 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Day** | **Start Hour, hh:mm** | **Leq** | **Lmax** | **Lmin** | **L1** | **L10** | **L50** | **L90** | **L99** | **Leq (w/o Unusual Events)** |
| 27 June 2012 | 12:00 | 76.3 | 97.9 | 54.8 | 88.6 | 74.7 | 67.9 | 61.5 | 58.3 | 72.7 |
| 27 June 2012 | 13:00 | 81.8 | 108.0 | 56.7 | 89 | 74.7 | 68.5 | 62.4 | 58.9 | 71.2 |
| 27 June 2012 | 14:00 | 76.2 | 99.1 | 56.3 | 89.3 | 75.4 | 68.2 | 62.4 | 57.9 | 73.9 |
| 27 June 2012 | 15:00 | 72.1 | 91.3 | 57.3 | 82.5 | 73.7 | 68.5 | 62.7 | 58.8 | 72.1 |
| 27 June 2012 | 16:00 | 72.9 | 92.5 | 58.6 | 83.7 | 73.9 | 69.6 | 64.3 | 60.1 | 72.9 |
| 27 June 2012 | 17:00 | 73.6 | 92.5 | 58.2 | 86.3 | 74.6 | 69.6 | 64.5 | 61.0 | 73.6 |
| 27 June 2012 | 18:00 | 73.4 | 96.2 | 54.7 | 83.2 | 73.0 | 68.4 | 62.5 | 58.2 | 71.6 |
| 27 June 2012 | 19:00 | 73.0 | 94.9 | 53.9 | 83.6 | 72.0 | 65.5 | 59.1 | 55.6 | 69.0 |
| 27 June 2012 | 20:00 | 71.0 | 94.7 | 52.4 | 79.1 | 70.4 | 63.9 | 57.7 | 54.9 | 67.5 |
| 27 June 2012 | 21:00 | 67.9 | 90.3 | 51.3 | 75.1 | 69.8 | 63.1 | 57.1 | 53.8 | 67.9 |
| 27 June 2012 | 22:00 | 71.4 | 96.7 | 49.8 | 79.3 | 70.4 | 63.5 | 55.7 | 52.6 | 66.8 |
| 27 June 2012 | 23:00 | 67.4 | 88.7 | 50.0 | 77.2 | 68.8 | 60.6 | 54.0 | 51.1 | 67.4 |
| 28 June 2012 | 0:00 | 67.8 | 90.2 | 46.3 | 77.9 | 67.3 | 57.7 | 50.2 | 47.6 | 67.8 |
| 28 June 2012 | 1:00 | 64.8 | 87.8 | 43.9 | 73.7 | 65.4 | 54.5 | 48.0 | 44.4 | 64.9 |
| 28 June 2012 | 2:00 | 61.3 | 78.9 | 43.1 | 72.1 | 65.2 | 53.7 | 46.7 | 43.7 | 61.3 |
| 28 June 2012 | 3:00 | 60.8 | 81.7 | 43.7 | 70.7 | 62.3 | 51.2 | 45.0 | 44.0 | 60.8 |
| 28 June 2012 | 4:00 | 61.9 | 84.2 | 45.5 | 72.2 | 63.4 | 54.0 | 48.6 | 47.0 | 61.9 |
| 28 June 2012 | 5:00 | 66.3 | 82.6 | 48.6 | 77.6 | 69.3 | 61.3 | 54.1 | 50.0 | 66.4 |
| 28 June 2012 | 6:00 | 68.8 | 83.1 | 52.2 | 77.4 | 72.1 | 66.2 | 59.5 | 55.2 | 68.8 |
| 28 June 2012 | 7:00 | 72.9 | 92.4 | 56.4 | 86.0 | 74.1 | 68.6 | 63.9 | 59.0 | 72.9 |
| 28 June 2012 | 8:00 | 70.9 | 91.6 | 57.0 | 79.7 | 73.2 | 68.1 | 63.7 | 60.1 | 71.0 |
| 28 June 2012 | 9:00 | 70.9 | 84.4 | 55.0 | 82.3 | 73.3 | 68.2 | 62.7 | 57.6 | 70.9 |
| 28 June 2012 | 10:00 | 74.1 | 95.5 | 54.3 | 87.1 | 74.5 | 67.8 | 61.2 | 57.7 | 72.3 |
| 28 June 2012 | 11:00 | 74.8 | 95.5 | 54 | 89.7 | 73.9 | 67.1 | 60.4 | 56.2 | 72.0 |

## B.3 Long-Term Noise Measurement Site LT-3

**Figure 30: Long-Term Noise Measurement Site, LT-3**

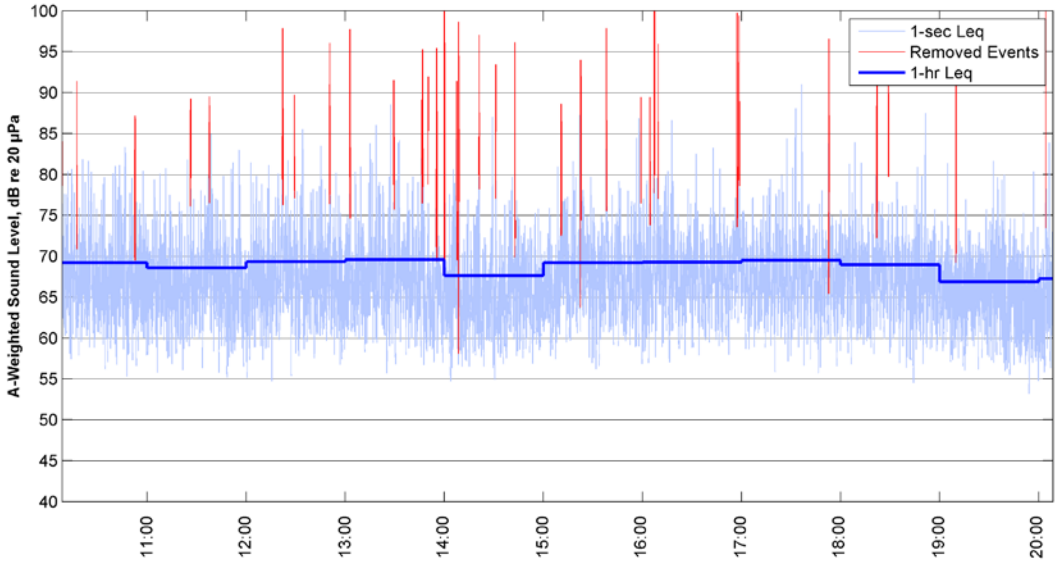



**Figure 31 Time History of Long-Term Noise Measurement at Site LT-3**

| Table 36: Summary of Hourly Noise Levels, Site LT-3 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Day** | **Start Hour, hh:mm** | **Leq** | **Lmax** | **Lmin** | **L1** | **L10** | **L50** | **L90** | **L99** | **Leq (w/o Unusual Events)** |
| 26 June 2012 | 10:00 | 70.7 | 93.8 | 55.3 | 80.3 | 72.4 | 66.4 | 61.8 | 57.9 | 55.3 |
| 26 June 2012 | 11:00 | 69.4 | 89.4 | 55.2 | 79.1 | 71.2 | 66 | 61.4 | 57.3 | 55.2 |
| 26 June 2012 | 12:00 | 72.7 | 97.8 | 54.7 | 82.2 | 72.5 | 66.7 | 61.6 | 57.8 | 54.7 |
| 26 June 2012 | 13:00 | 75.4 | 101.7 | 55.7 | 87.0 | 72.6 | 66.5 | 61.3 | 58 | 55.7 |
| 26 June 2012 | 14:00 | 73.8 | 98.6 | 54.8 | 84.6 | 70.7 | 64.3 | 59.9 | 57.1 | 54.8 |
| 26 June 2012 | 15:00 | 72.2 | 97.8 | 56.2 | 83.1 | 72.1 | 66.8 | 62.1 | 58.2 | 56.2 |
| 26 June 2012 | 16:00 | 77.8 | 104.4 | 56.9 | 83.8 | 72.5 | 67.2 | 62.2 | 58.7 | 56.9 |
| 26 June 2012 | 17:00 | 71.4 | 96.6 | 55.7 | 78.1 | 72.0 | 66.9 | 61.9 | 57.9 | 55.7 |
| 26 June 2012 | 18:00 | 71.8 | 99.0 | 54.5 | 80.9 | 71.5 | 66.8 | 61.7 | 57.8 | 54.5 |
| 26 June 2012 | 19:00 | 69.6 | 96.6 | 53.3 | 74.8 | 69.8 | 65.2 | 59.8 | 56.6 | 53.3 |

## B.4 Long-Term Noise Measurement Site LT-4

**Figure 32: Long-Term Noise Measurement Site, LT-4**

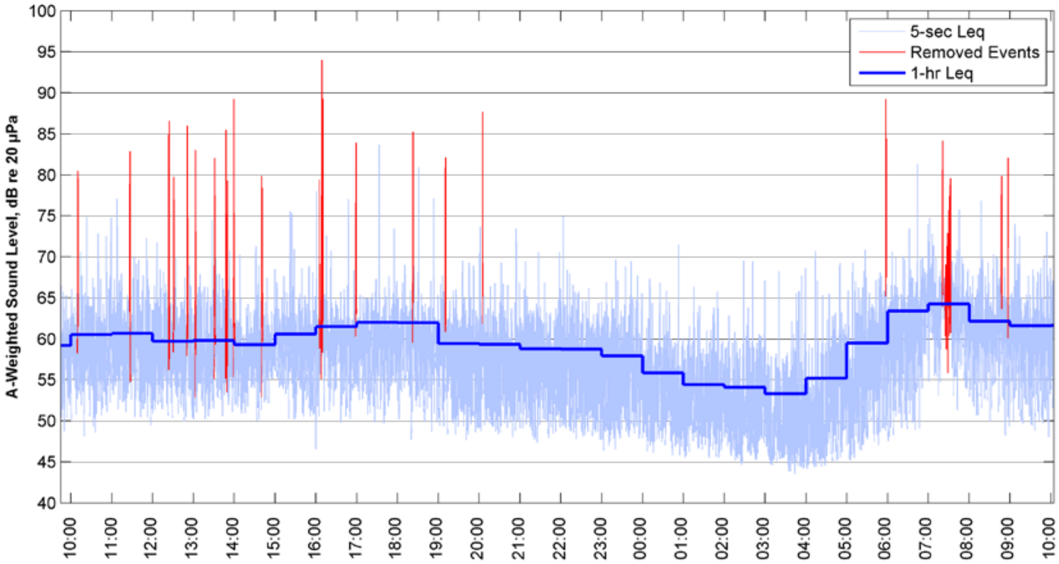



**Figure 33: Time History of Long-Term Noise Measurement at Site LT-4**

| Table 37: Summary of Hourly Noise Levels, Site LT-4 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Day** | **Start Hour, hh:mm** | **Leq** | **Lmax** | **Lmin** | **L1** | **L10** | **L50** | **L90** | **L99** | **Leq (w/o Unusual Events)** |
| 26 June 2012 | 9:00 | 59.2 | 66.0 | 48.8 | 66.0 | 61.9 | 58.5 | 53.0 | 50.4 | 59.2 |
| 26 June 2012 | 10:00 | 61.6 | 80.5 | 48.2 | 71.1 | 63.5 | 58.5 | 53.9 | 50.6 | 60.5 |
| 26 June 2012 | 11:00 | 62.6 | 82.9 | 49.5 | 72.3 | 63.8 | 57.6 | 53.3 | 51.0 | 60.7 |
| 26 June 2012 | 12:00 | 66.0 | 86.6 | 50.0 | 79.8 | 63.8 | 57.7 | 52.9 | 50.8 | 59.7 |
| 26 June 2012 | 13:00 | 67.4 | 89.1 | 50.2 | 82.4 | 65 | 57.1 | 53.7 | 51.1 | 59.8 |
| 26 June 2012 | 14:00 | 61.2 | 80.2 | 50.0 | 70.6 | 62.2 | 58.1 | 53.8 | 51.4 | 59.3 |
| 26 June 2012 | 15:00 | 60.6 | 75.6 | 46.5 | 69.3 | 62.8 | 58.8 | 54.3 | 50.6 | 60.6 |
| 26 June 2012 | 16:00 | 69.5 | 94 | 49.8 | 79.6 | 64.0 | 59.6 | 54.7 | 51.6 | 61.5 |
| 26 June 2012 | 17:00 | 62.0 | 83.7 | 49.7 | 67.9 | 63.6 | 59.7 | 54.6 | 51.4 | 62.0 |
| 26 June 2012 | 18:00 | 64.6 | 85.2 | 47.7 | 76.9 | 63.6 | 59.6 | 53.7 | 49.9 | 62.0 |
| 26 June 2012 | 19:00 | 61.2 | 82.1 | 47.7 | 68.6 | 62.5 | 58.2 | 51.3 | 49.1 | 59.4 |
| 26 June 2012 | 20:00 | 63.9 | 87.7 | 48.0 | 70.4 | 62.1 | 57.0 | 50.9 | 48.9 | 59.3 |
| 26 June 2012 | 21:00 | 58.8 | 70.6 | 47.4 | 66.4 | 61.9 | 57.1 | 50.8 | 48.4 | 58.8 |
| 26 June 2012 | 22:00 | 58.7 | 75.0 | 47.7 | 66.6 | 61.7 | 56.5 | 50.4 | 48.3 | 58.7 |
| 26 June 2012 | 23:00 | 57.9 | 69.6 | 46.4 | 67.2 | 61.4 | 54.9 | 49.4 | 47.6 | 57.9 |
| 27 June 2012 | 0:00 | 55.8 | 71.4 | 45.8 | 65.4 | 58.6 | 53.4 | 48.4 | 46.7 | 55.9 |
| 27 June 2012 | 1:00 | 54.4 | 66.3 | 45.5 | 63.4 | 57.9 | 51.4 | 47.2 | 45.8 | 54.4 |
| 27 June 2012 | 2:00 | 54.1 | 69.6 | 44.7 | 63.8 | 57.3 | 50.3 | 45.9 | 44.9 | 54.1 |
| 27 June 2012 | 3:00 | 53.3 | 68.5 | 43.6 | 65.5 | 56.3 | 48.3 | 45.1 | 44.0 | 53.3 |
| 27 June 2012 | 4:00 | 55.2 | 70.7 | 44.2 | 65.3 | 58.8 | 50.2 | 45.3 | 44.5 | 55.2 |
| 27 June 2012 | 5:00 | 63.9 | 89.2 | 45.2 | 69.3 | 63.6 | 55.9 | 48.3 | 45.6 | 59.5 |
| 27 June 2012 | 6:00 | 63.4 | 81.3 | 47.5 | 71.3 | 65.9 | 61.1 | 51.8 | 49.0 | 63.4 |
| 27 June 2012 | 7:00 | 66.8 | 84.2 | 51.3 | 78.7 | 68.7 | 63.6 | 57.2 | 53.2 | 64.3 |
| 27 June 2012 | 8:00 | 63.6 | 82.0 | 48.3 | 75.3 | 65.2 | 60.7 | 53.7 | 50.6 | 62.2 |

### B.5 Short-Term Noise and Vibration Measurement Site ST-1


**Figure 34: Short-Term Noise Measurement Site ST-1 and Transfer Mobility Measurement Site V-1**

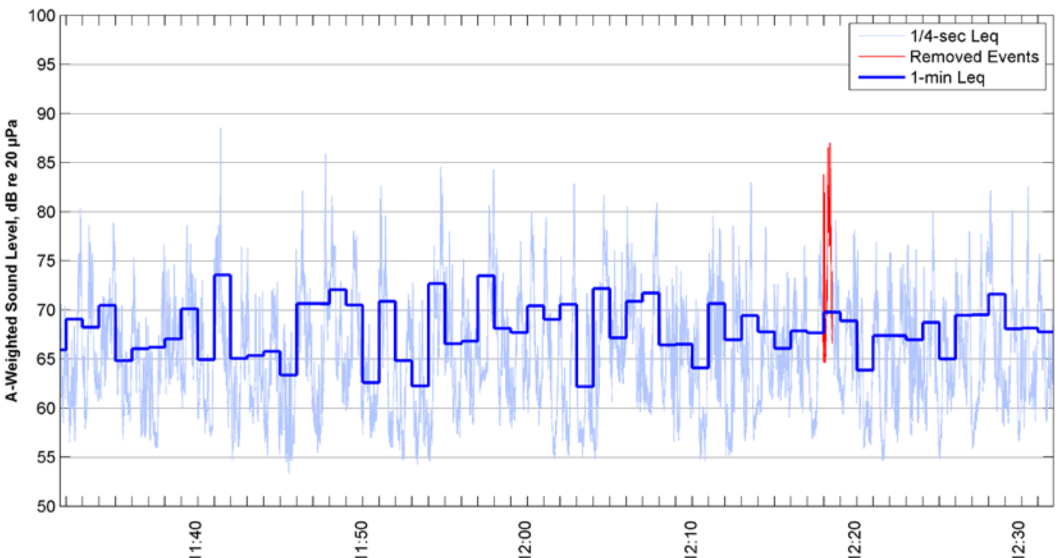



**Figure 35: Time History of Short-Term Noise Measurement Site ST-1**

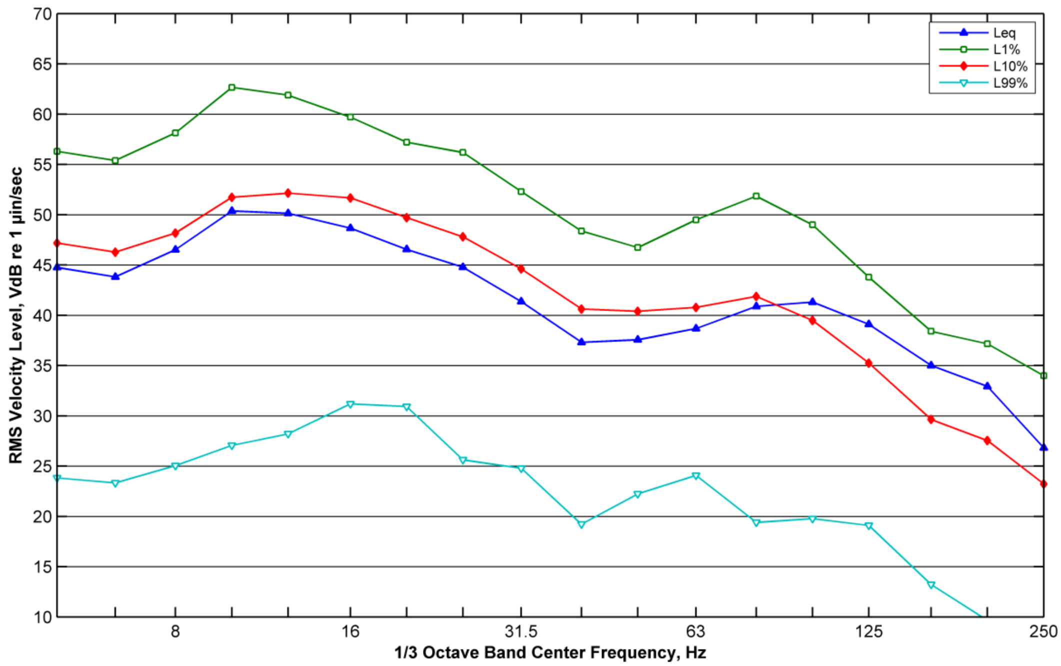



**Figure 36: Ambient Vibration at Site ST-1**

## B.6 Short-Term Noise and Vibration Site ST-2

**Figure 37: Short-Term Noise Measurement Site, ST-2**

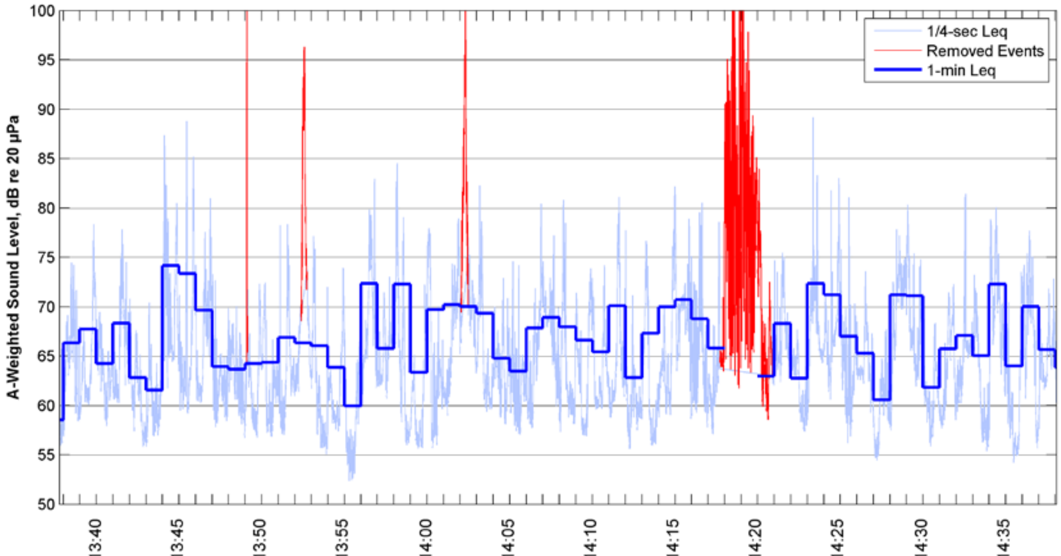



**Figure 38: Time History of Short-Term Noise Measurement at Site ST-2**

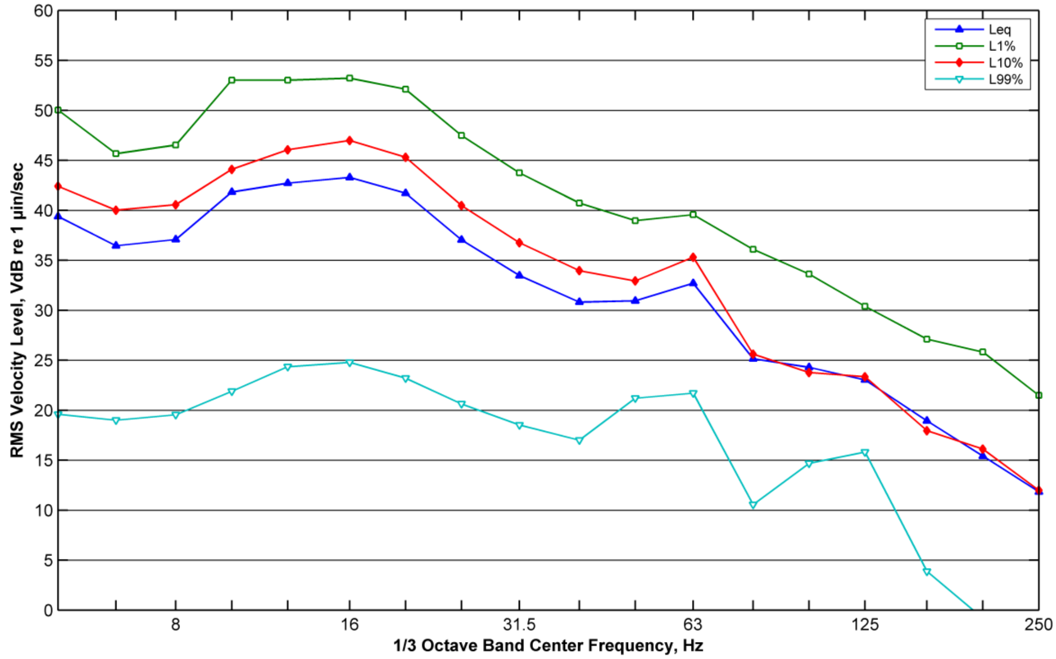



**Figure 39: Ambient Vibration Spectrum at Site ST-2**

## B.7 Short-Term Noise and Vibration Site ST-3


**Figure 40: Short-Term Noise and Vibration Measurement Site, ST-3**

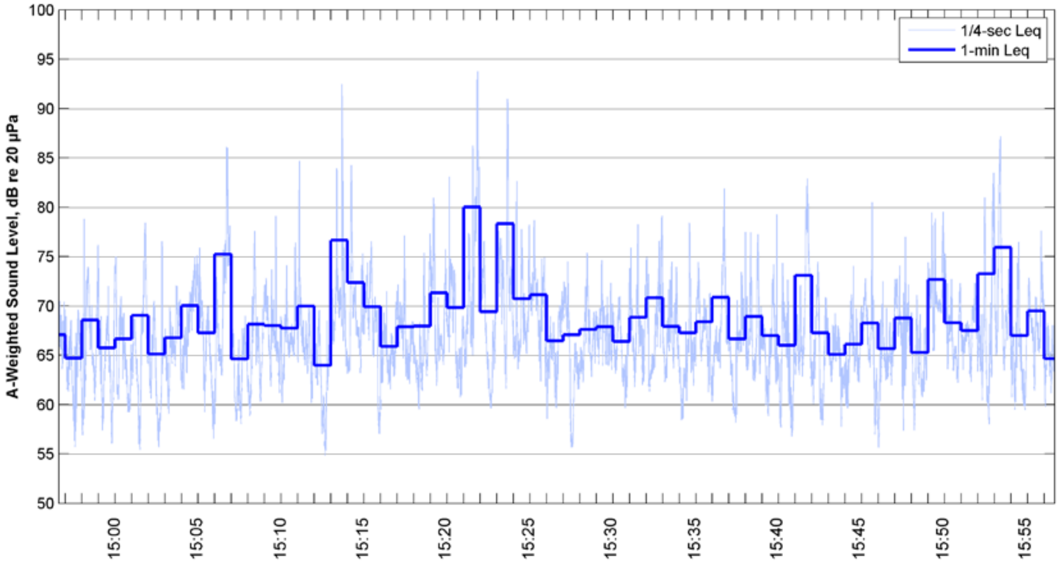



**Figure 41: Time History of Short-Term Noise Measurement at Site ST-3**

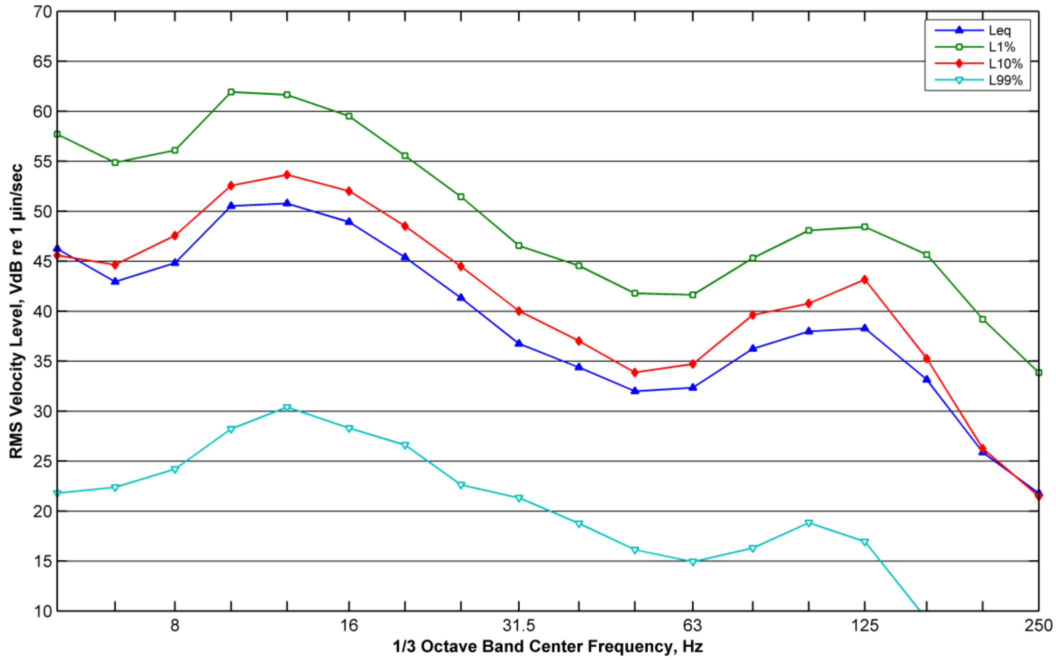



**Figure 42: Ambient Vibration Spectrum at Site ST-3**

## B.8 Short-Term Noise and Vibration Site ST-4

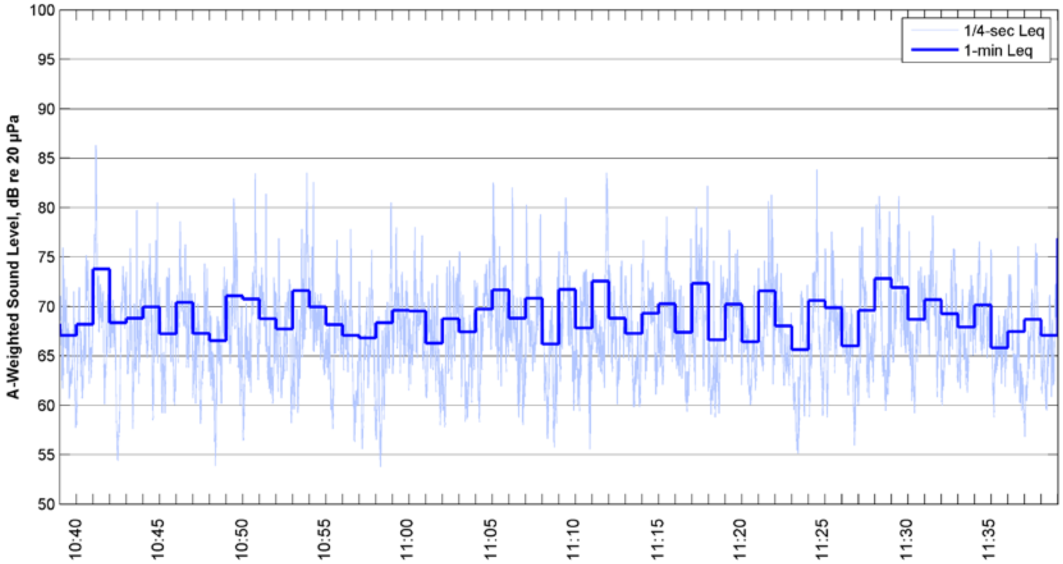



**Figure 43: Time History of Short-Term Noise Measurement at Site ST-4**

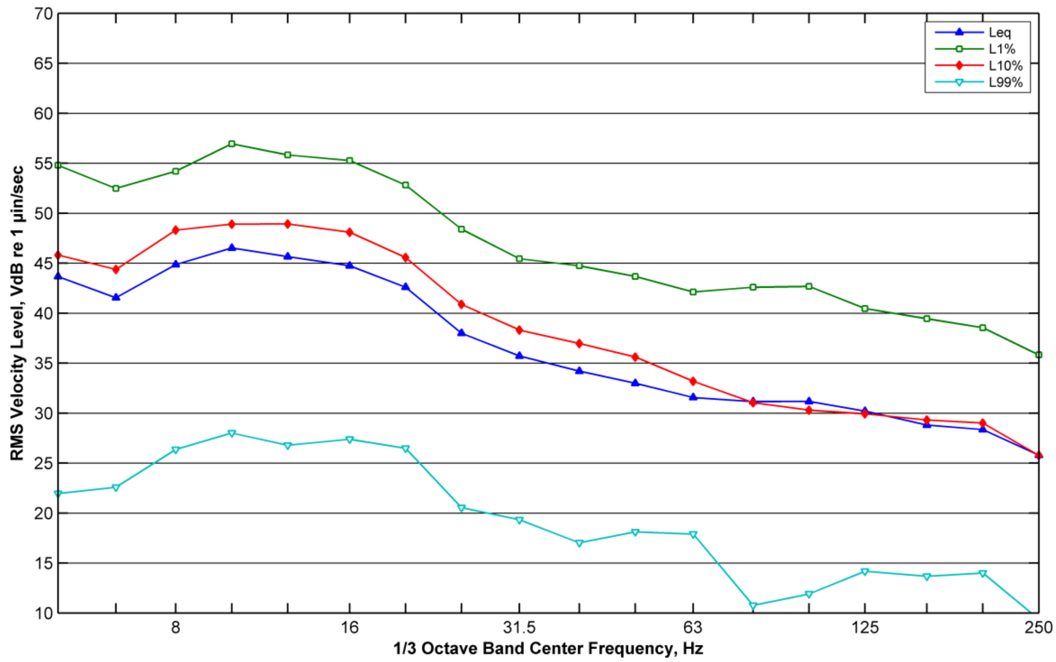



**Figure 44: Ambient Vibration Spectrum at Site ST-4**

## B.9 Vibration Propagation Test Site V-3 and Short Term Measurement Site ST-5


**Figure 45: Short-Term Noise Measurement Site ST-5 and Transfer Mobility Measurement Site V-3**

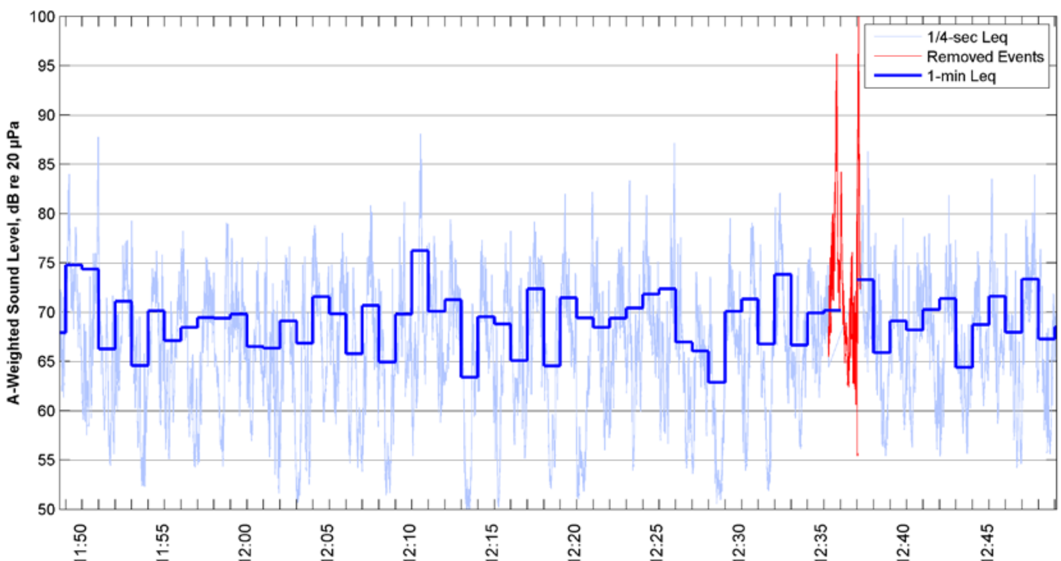



**Figure 46: Time History of Short-Term Noise Measurement at Site ST-5**

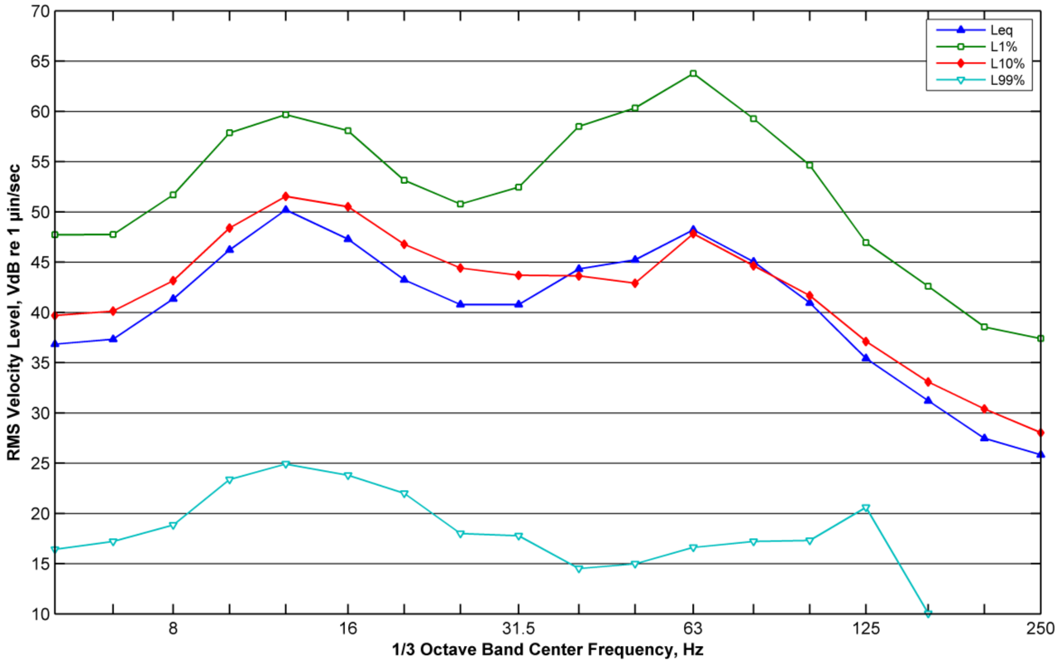



**Figure 47: Ambient Vibration Spectrum at ST-5**

### B.10 Short-Term Noise and Vibration Site ST-6

**Figure 48: Short-Term Noise and Vibration Measurement Site, ST-6**

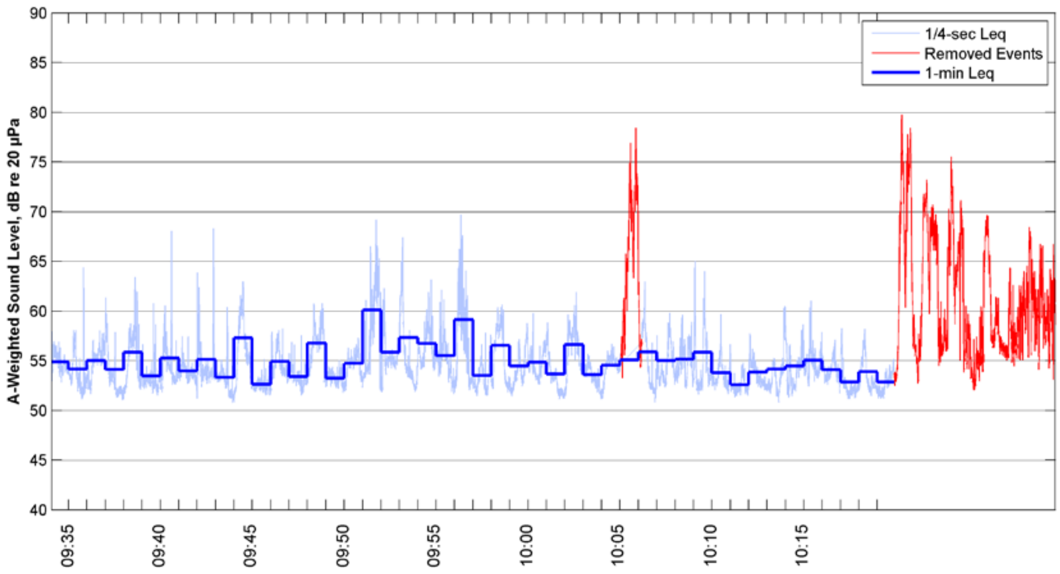



**Figure 49: Time History of Short-Term Noise Measurement at Site ST-6**

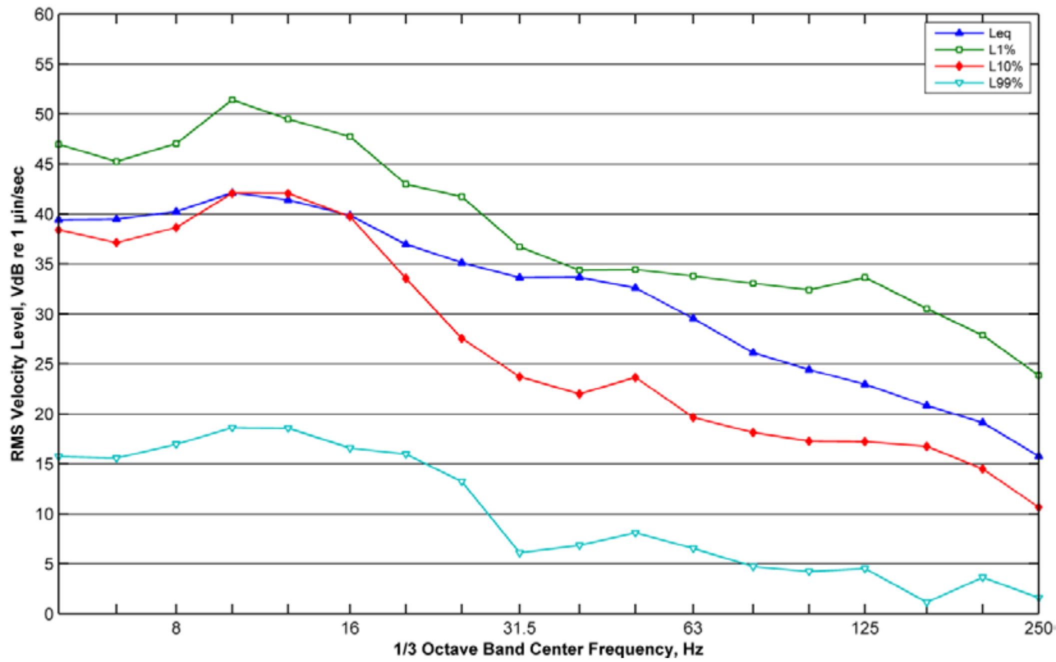



**Figure 50: Ambient Vibration Spectrum at Site ST-6**

## APPENDIX C: VIBRATION PROPAGATION BEST FIT COEFFICIENTS

Table 38 provides the best fit coefficients of the line source transfer mobility curves for each 1/3 octave band. A, B, and C in Table 38 are coefficients in the equation:

$$LSTM\ (X) = A + B\times\log_{10}(X) + C\times\log_{10}(X)^2$$

where X is the distance between the source and receiver in feet. The coefficients were calculated using the measured LSTM curves and least squares fit regression.

**Table 38: Line Source Transfer Mobility Best Fit Coefficients**

| Freq. | Site V1 | | | Site V2 | | | Site V3 | | | Site V4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C |
| 5 Hz | 31.8 | -6.5 | | 30.6 | -7 | | 29.6 | -4 | | 67.7 | -27.1 | |
| 6.3 Hz | 21.7 | -1 | | 22.7 | -3 | | 28.9 | -4.7 | | 47.3 | -17.2 | |
| 8 Hz | 21.3 | -0.7 | | 23.9 | -3.1 | | 34.2 | -7.6 | | 35.7 | -9.4 | |
| 10 Hz | 19.7 | 1.5 | | 35.1 | -7.8 | | 35.7 | -7.8 | | 42 | -11.3 | |
| 12 Hz | 24.6 | -1.5 | | 45.5 | -12.9 | | 40.2 | -10.7 | | 40.9 | -9.6 | |
| 16 Hz | 42.5 | -9.9 | | 44.3 | -12.5 | | 50.1 | -15.6 | | 38.4 | -7.1 | |
| 20 Hz | 52.5 | -13.8 | | 50.6 | -15 | | 52.3 | -16.1 | | 32.8 | 2.1 | -2.6 |
| 25 Hz | 52.8 | -13.8 | | 60.1 | -20.5 | | 52.7 | -15.5 | | -12.1 | 60 | -20 |
| 31.5 Hz | 58.2 | -17.7 | | 58.7 | -19.6 | | 55.6 | -16.9 | | -15.2 | 67.7 | -23.1 |
| 40 Hz | -101.9 | 171.5 | -55.4 | 62.9 | -23 | | 41.3 | -2.7 | -3.1 | -15.1 | 75.9 | -27.6 |
| 50 Hz | -41.7 | 97.8 | -34.3 | 74.4 | -30.4 | | -52.3 | 107.2 | -34.6 | 17.5 | 41.3 | -19.5 |
| 63 Hz | 43.8 | -7.5 | -4 | 78 | -32.9 | | -19 | 62.9 | -21.4 | 20 | 37.2 | -19.3 |
| 80 Hz | -32.8 | 86.6 | -33.7 | 52.2 | -18.9 | | -56 | 108.9 | -37.2 | -61 | 138.2 | -52.3 |
| 100 Hz | 72.7 | -38.2 | | 54.7 | -24.7 | | -26.9 | 76 | -29.9 | 88.5 | -41.3 | -1.3 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 Hz | 89.2 | -50.5 | | 74.4 | -38.7 | | 52.4 | -25.8 | | 96 | -50.8 | |
| 200 Hz | 93.9 | -54.2 | | 90 | -48.7 | | 42.9 | -25.5 | | 86.8 | -49.1 | |
| 315 Hz | 95.8 | -58 | | 91.7 | -49.3 | | 29.9 | -21.4 | | 67.7 | -41.4 | |

## APPENDIX D: CLUSTER DIAGRAMS

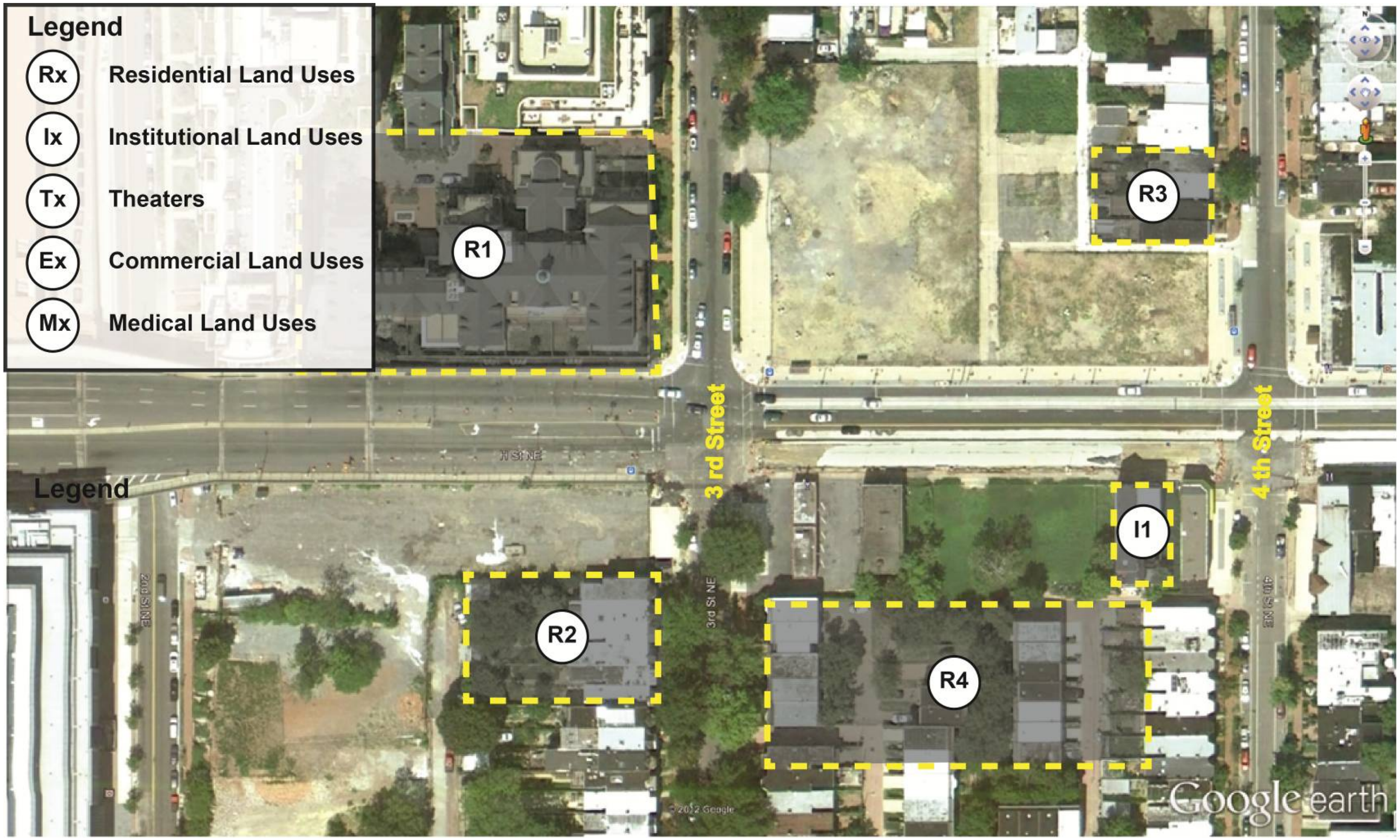



**Figure 51: Cluster Diagram 1**


**Figure 52: Cluster Diagram 2**

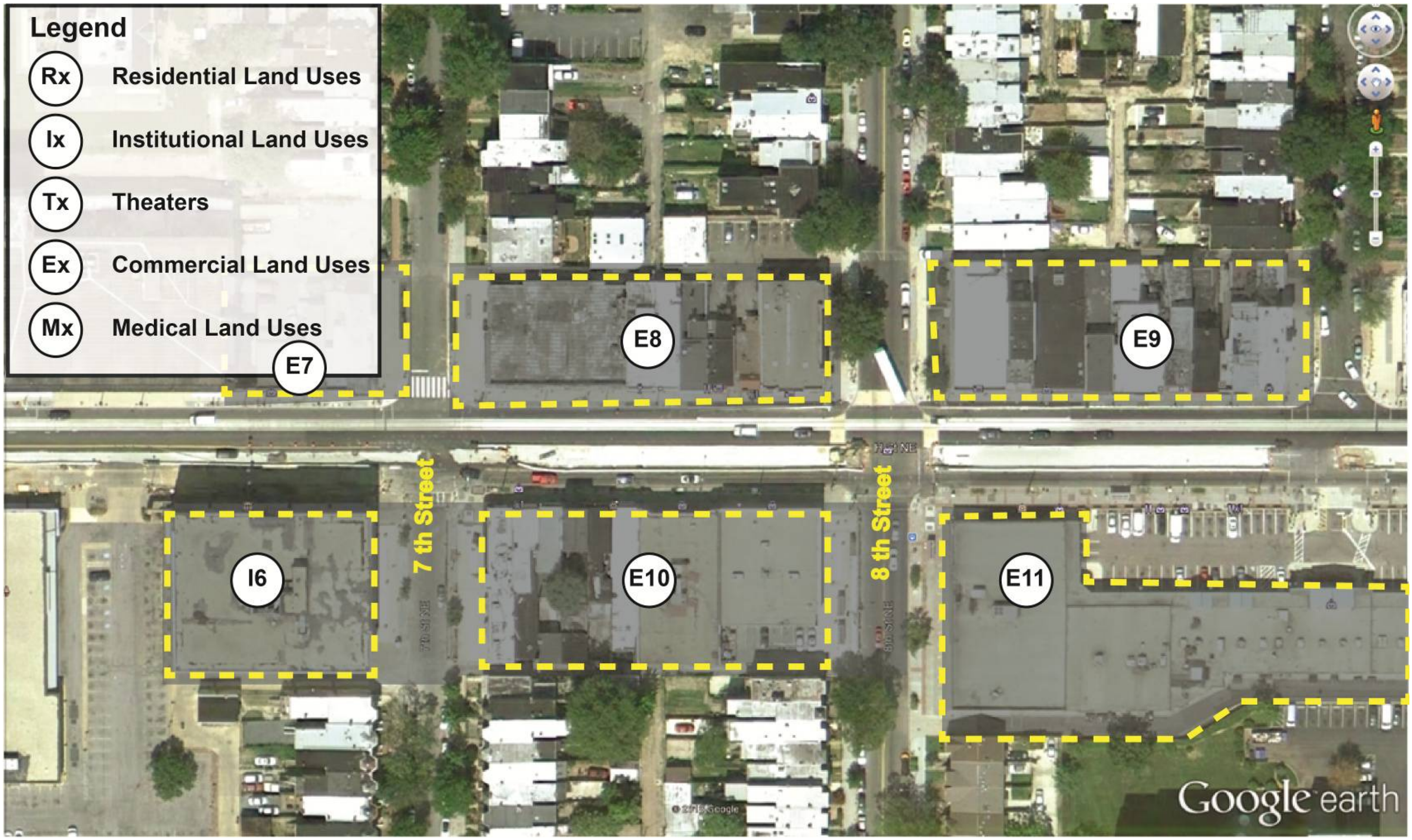



**Figure 53: Cluster Diagram 3**

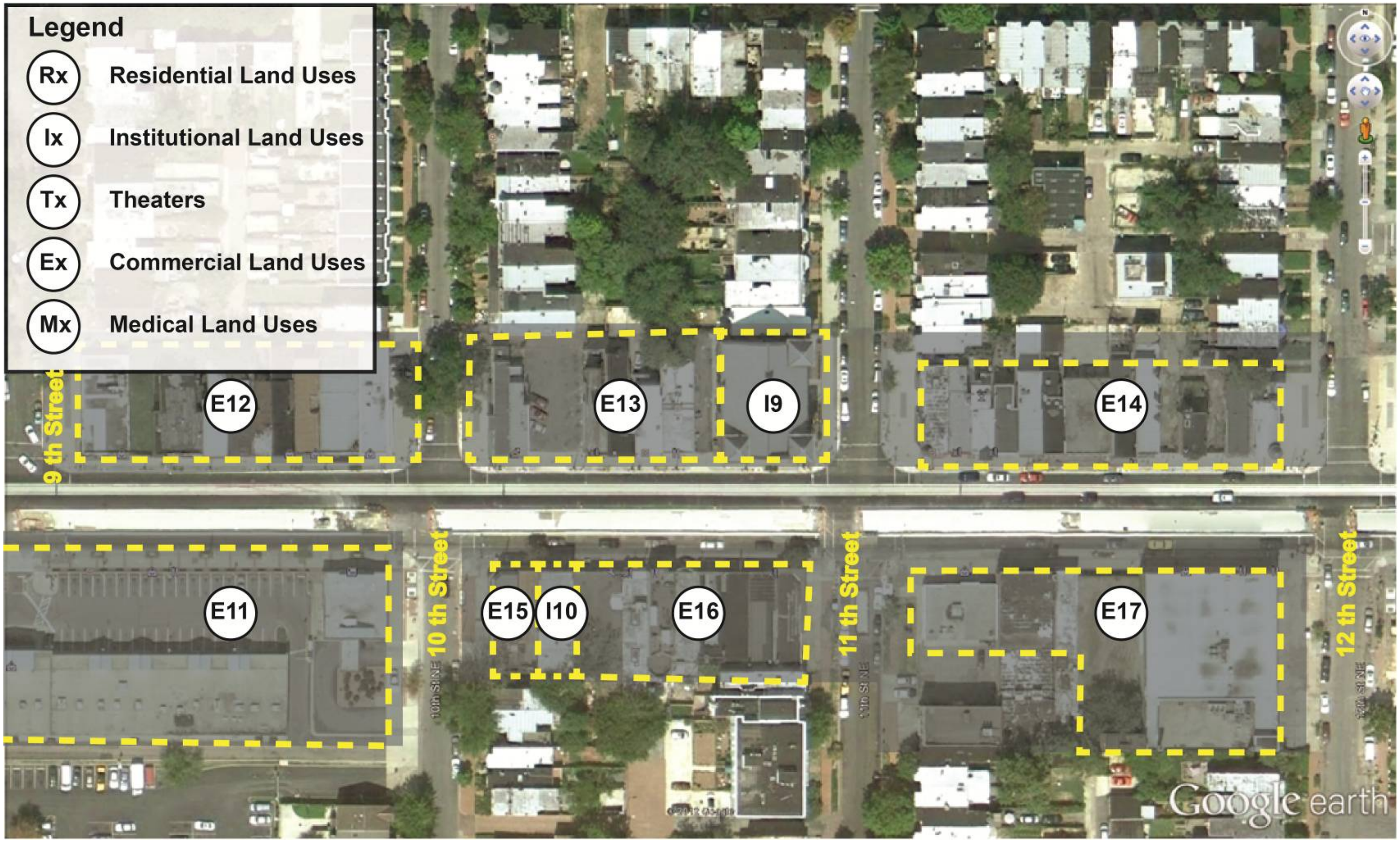



Figure 54: Cluster Diagram 4

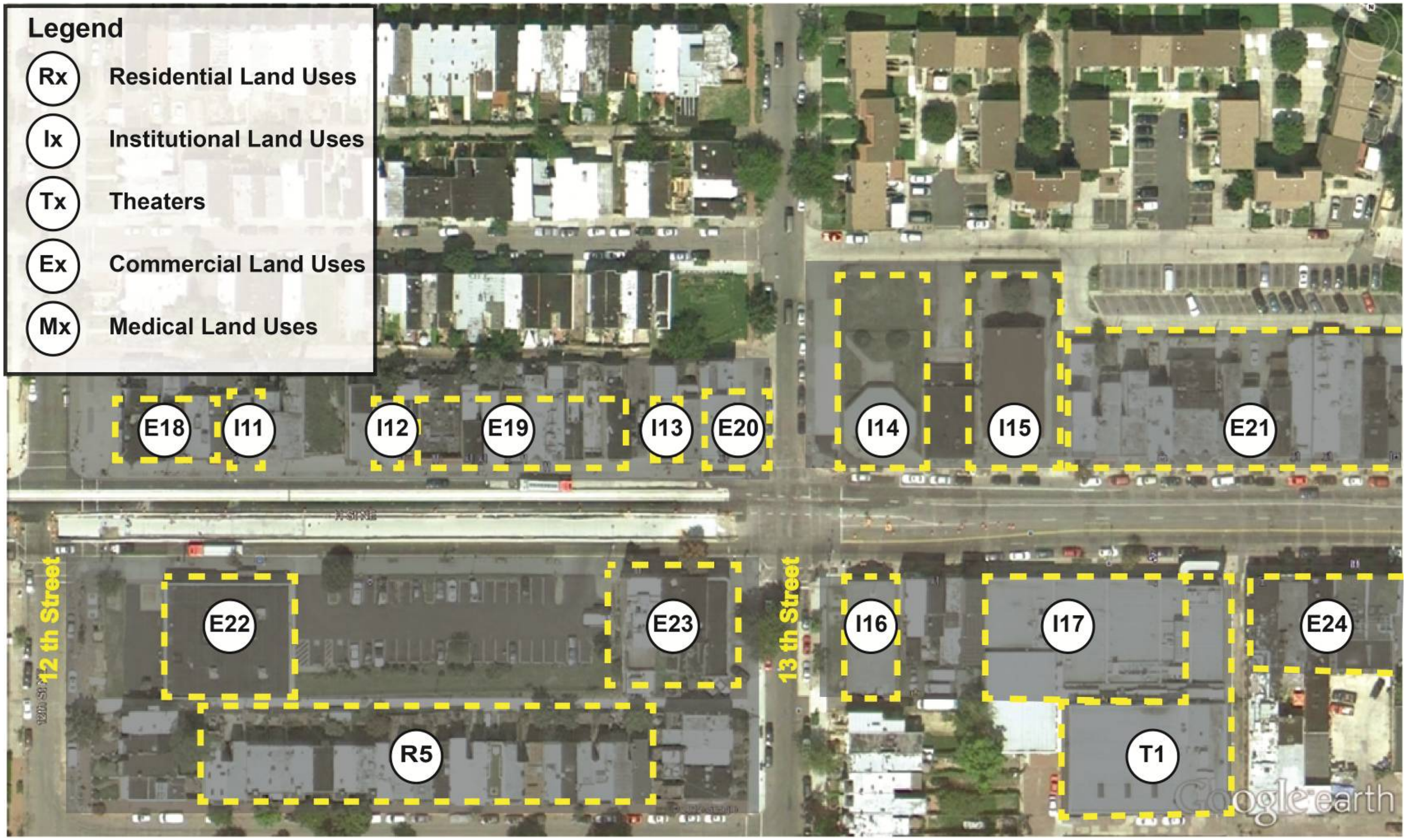



**Figure 55: Cluster Diagram 5**

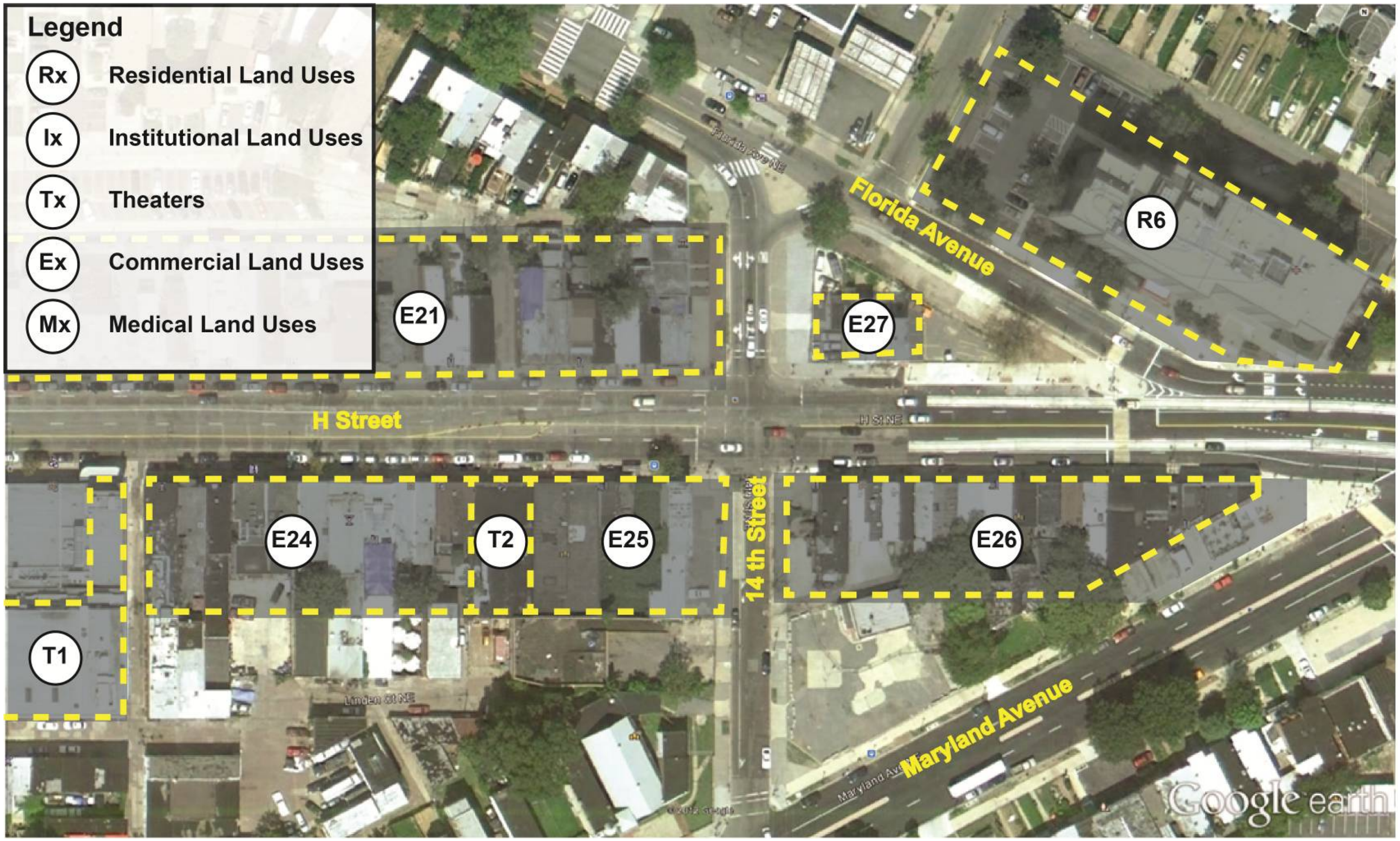



**Figure 56: Cluster Diagram 6**

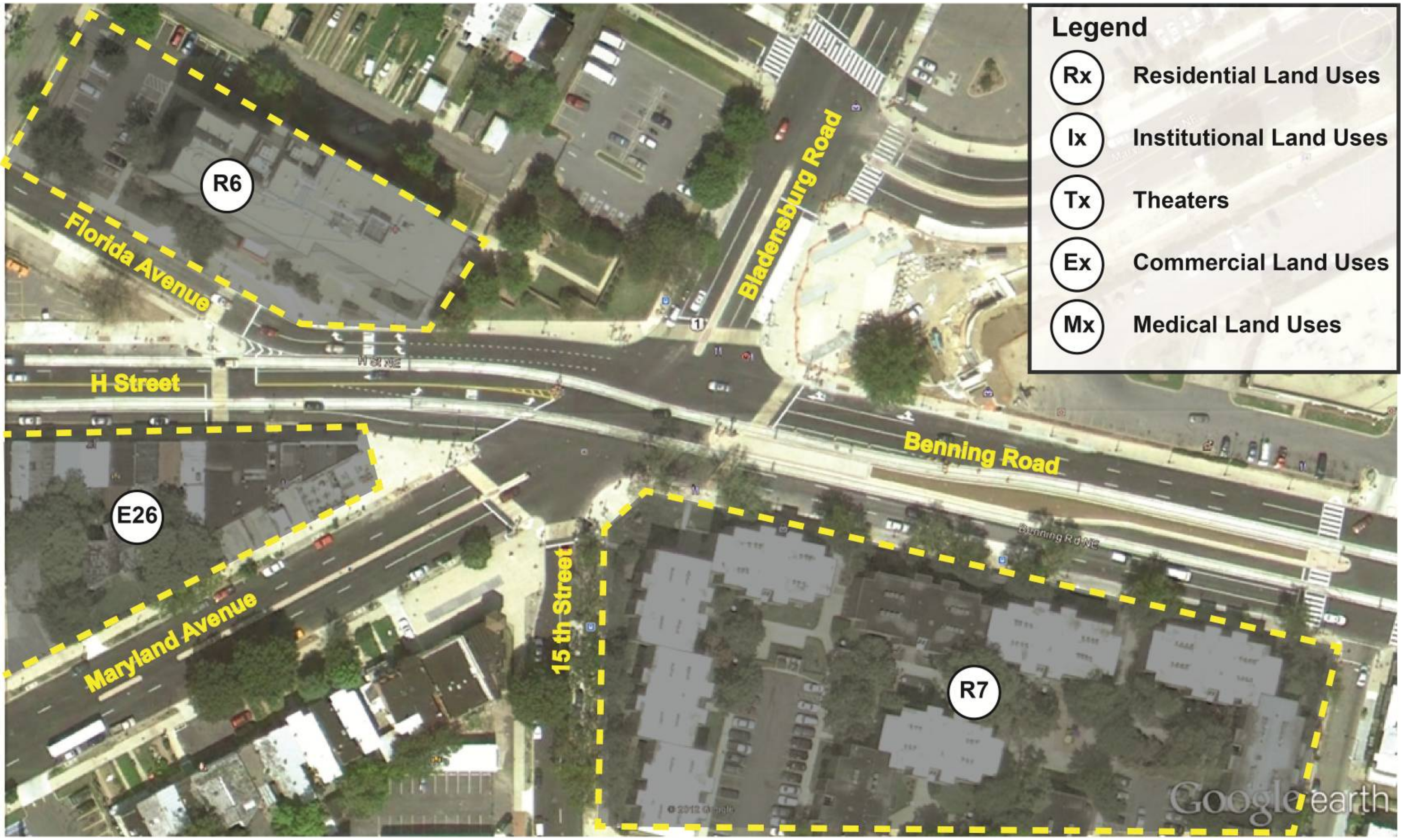



**Figure 57: Cluster Diagram 7**

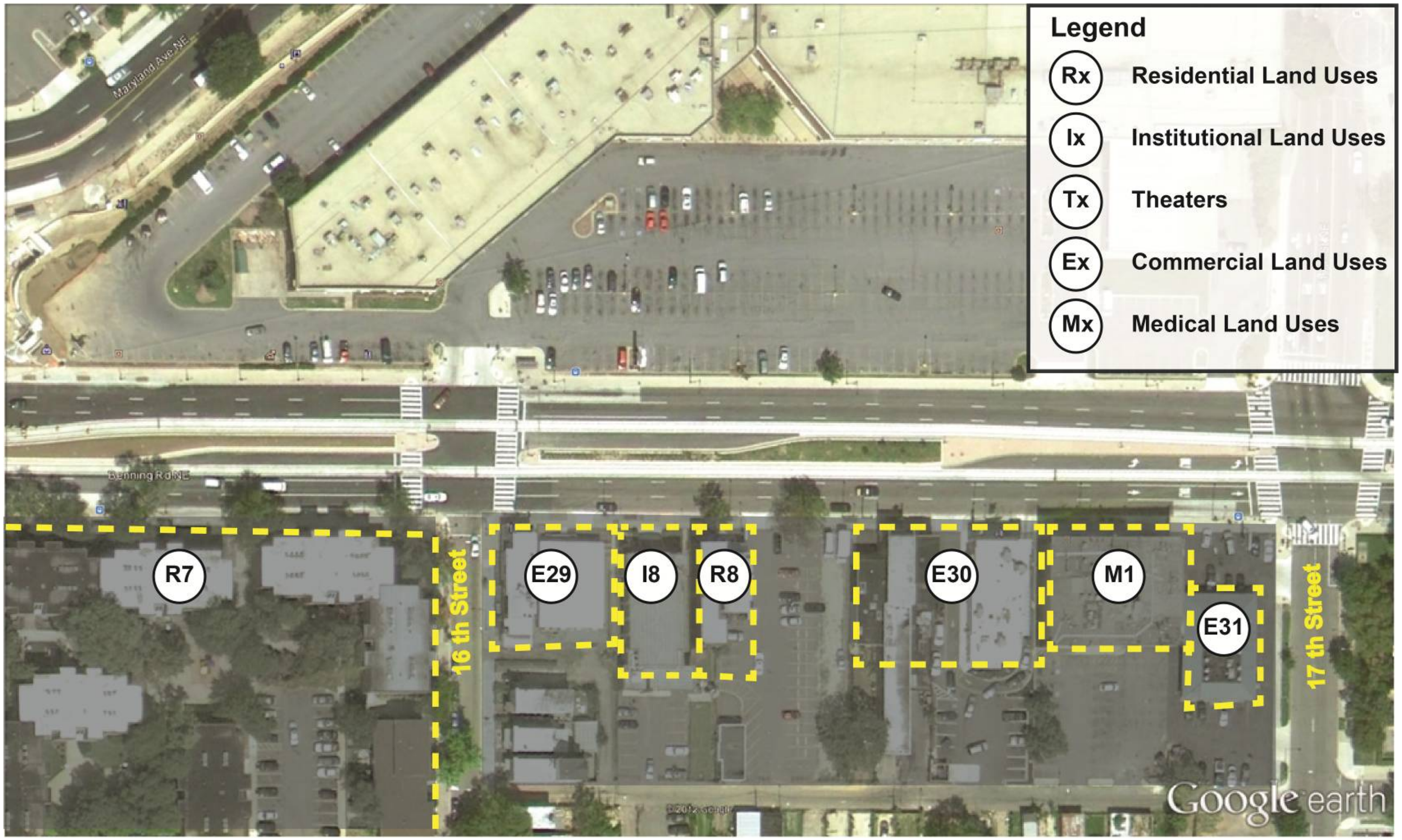



Figure 58: Cluster Diagram 8

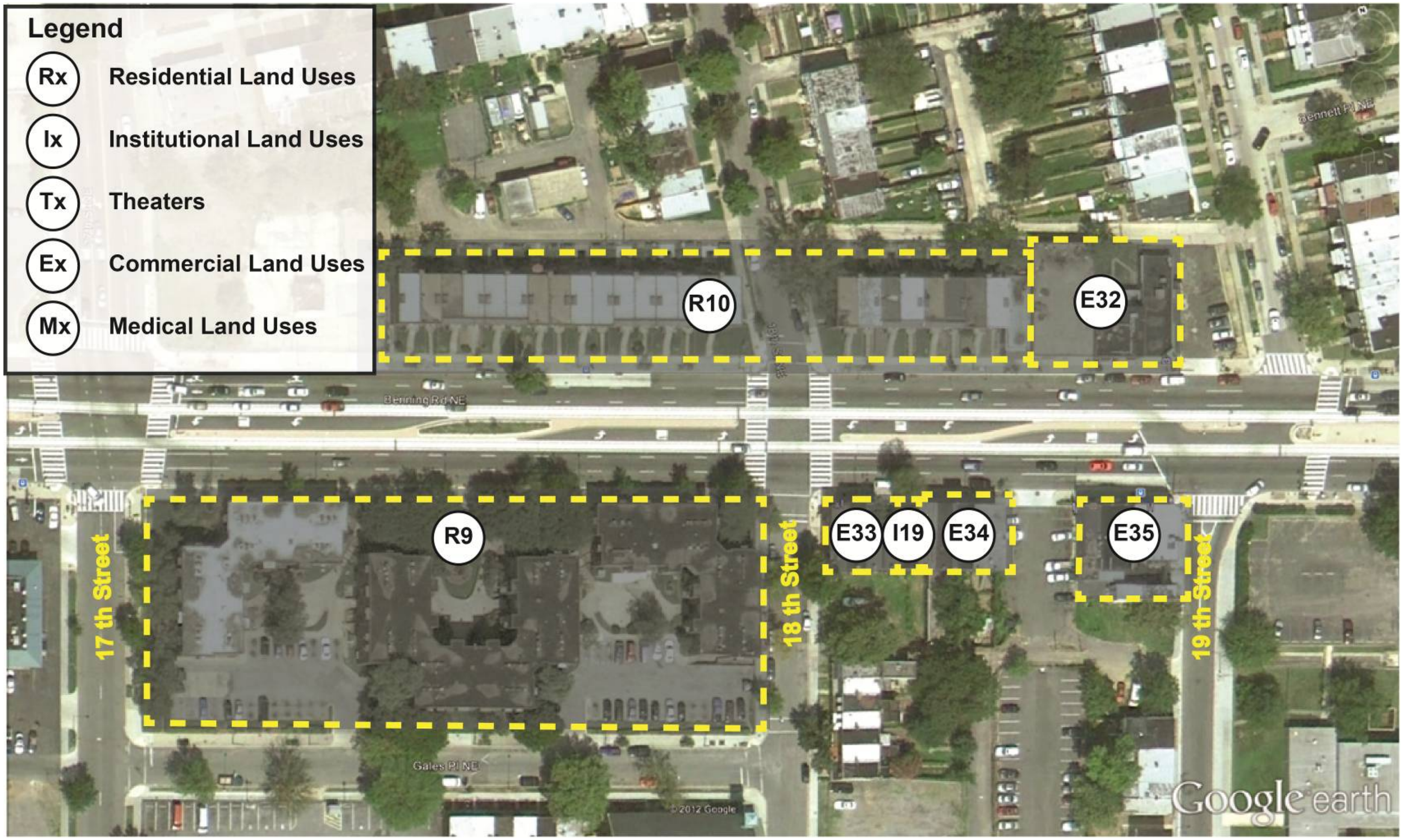



**Figure 59: Cluster Diagram 9**

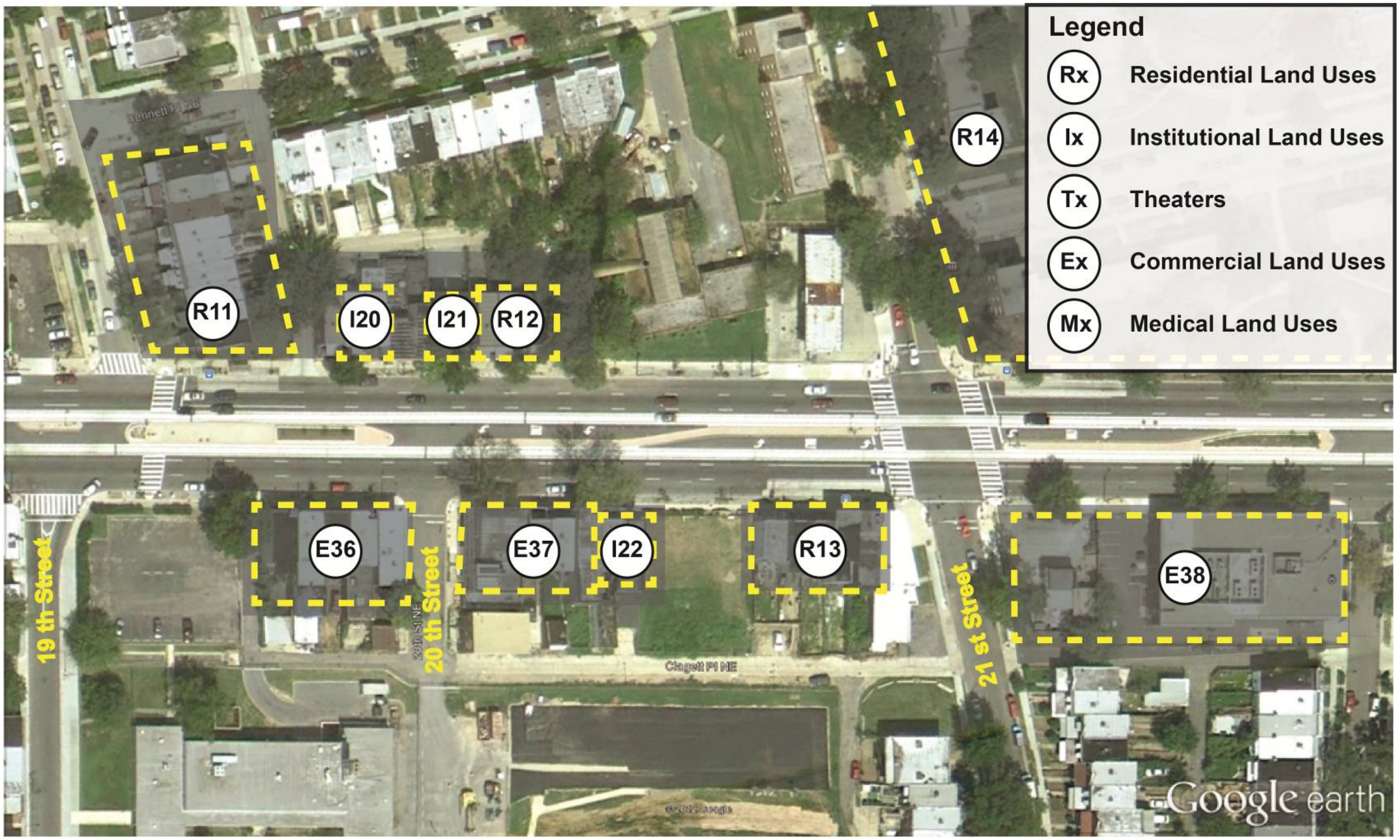



**Figure 60: Cluster Diagram 10**

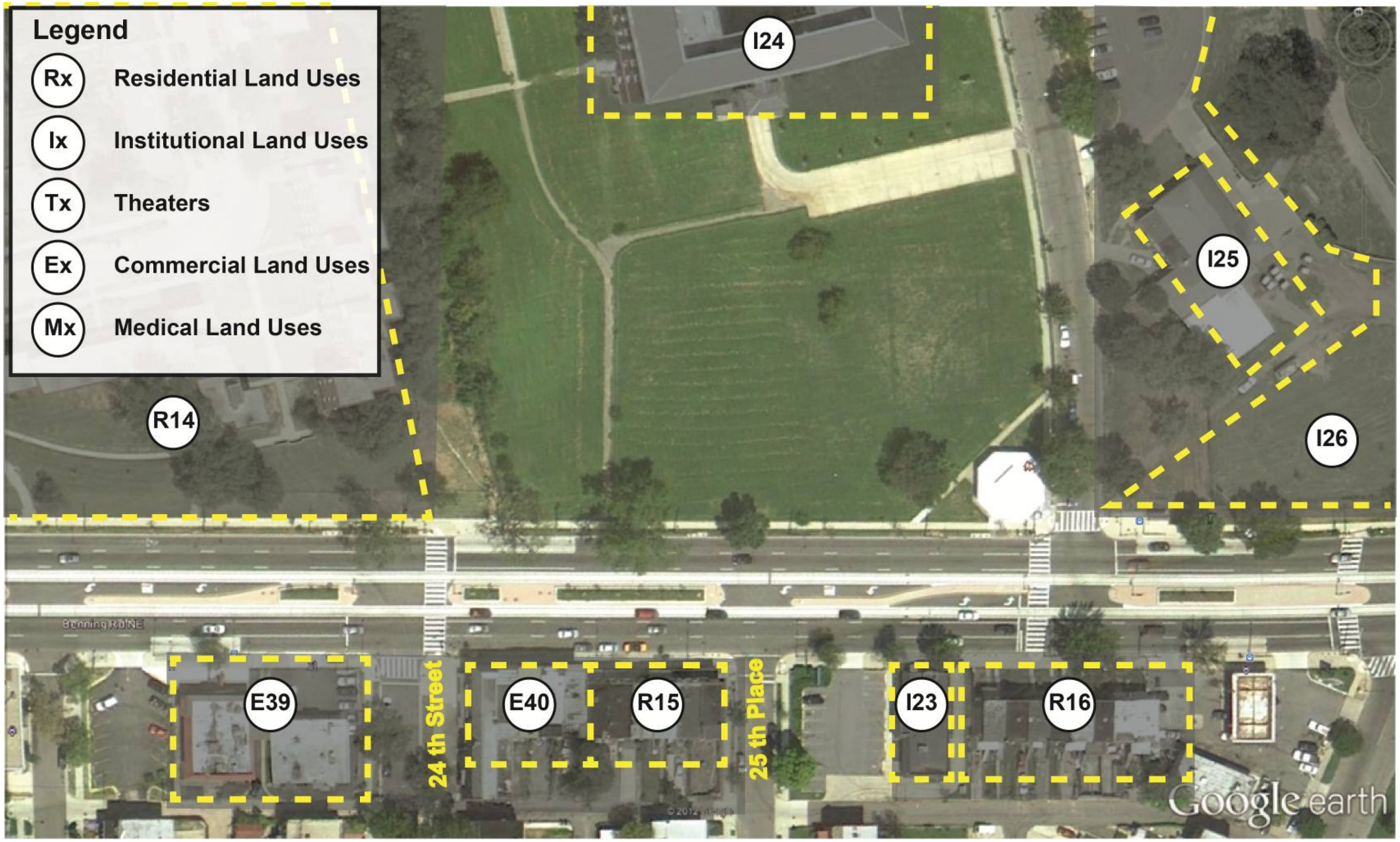



**Figure 61: Cluster Diagram 11**