Appendix D
Environmental Assessment Technical Memoranda

Red-Purple Bypass Project

Noise and Vibration

Technical Memorandum

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List of Acronyms and Abbreviations

API	area of potential impact
CTA	Chicago Transit Authority
dB	decibels
dBA	A-weighted decibels
EA	Environmental Assessment
FTA	Federal Transit Administration
Hz	hertz
L_{eq}	equivalent continuous sound level
L_{dn}	day-night average sound level
L_{max}	maximum noise level
L_v	vibration velocity level
MAP-21	The Moving Ahead for Progress in the 21st Century Act
NEPA	National Environmental Policy Act of 1969
OWL	one-way low-speed
PPV	peak particle velocity
RPM	Red-Purple Modernization Program
SEL	measure of sound energy
VdB	root mean squared vibration velocity in decibels relative to 1 microinch per second

Section 1
Summary

1.1 Purpose of this Technical Memorandum

This technical memorandum presents the assessment of the potential noise and vibration impacts associated with the Red-Purple Bypass Project. This project is one of the Phase One projects under the Red and Purple Modernization (RPM) Program that are undergoing Environmental Assessment (EA) in accordance with the National Environmental Policy Act (NEPA).

This section provides a summary of potential noise and vibration impacts. **Section 2** is an overall description of the project. **Section 3** describes the methods used in the noise and vibration analysis that are consistent with the Federal Transit Administration's (FTA) guidance for determining impacts. **Section 4** details the existing noise and vibration measurements within the affected environment. **Section 5** contains the results of the noise and vibration predictive models. **Section 6** describes the potential impacts associated with the Red-Purple Bypass Project. **Section 7** defines potential mitigation measures to minimize noise and vibration impacts. Technical details and background information are provided in **Appendices A through E**.

1.2 Construction Impacts

The No Build Alternative would not involve major construction and would therefore have no noise or vibration impacts as a result of construction activities.

The construction noise analysis considered temporary noise impacts that construction would cause. Construction of a modern closed-deck structure requires the use of heavy earth moving equipment, pneumatic tools, and other equipment. Pile driving is not currently proposed. The predicted construction noise levels exceed the FTA daytime impact thresholds for sensitive receivers within 50 feet of the construction activities and would result in adverse impacts on sensitive receivers.

High vibration activities during construction would include demolition of buildings, construction of aerial structures, pavement breaking, and ground compaction. Predicted vibration thresholds are the levels at which there would be a risk for damage, not the level at which damage would occur. The calculated impact threshold distances indicate that most of the equipment can be operated without risk of damage at distances of 15 feet or more from non-engineered timber and masonry buildings or at distances of 8 feet or more from reinforced concrete buildings.

1.3 Operational Impacts

1.3.1 No Build Alternative

The No Build Alternative would include all funded and committed projects within the project limits, as well as typical repairs required to keep the system within the project limits functional. No capital projects are currently proposed within the Red-Purple Bypass Project limits. Ongoing typical repairs include tie replacement and track maintenance. Under the No Build Alternative, travel patterns would remain the same.

No change is predicted in noise and vibration levels for the No Build Alternative. The noise levels for the No Build Alternative do not exceed the FTA impact thresholds and no noise impact is predicted. The existing vibration levels exceed the FTA impact thresholds for Category 2 land uses that are within 30 feet of the existing open-deck structure and 35 feet of the existing closed-deck structure for trains traveling 25 mph, and the condition would remain in the No Build Alternative.

1.3.2 Build Alternative

The Build Alternative for the Red-Purple Bypass project addresses two key passenger capacity needs: grade separation of the northbound Brown Line track from the Red Line and Purple Line tracks, and improving curves in the Red Line and Purple Line tracks between School Street and Newport Avenue to increase allowable train speeds. Major elements of the Build Alternative include the mainline track and construction of the new fifth track bypass.

There were 56 clusters of sensitive receivers identified within 350 feet of the alignment. Six of these are predicted to have a moderate permanent impact and four are predicted to have a severe permanent impact. These sensitive receivers have very high existing noise levels, which results in very low allowable noise increases using the FTA noise impact criteria.

Noise impacts before mitigation are predicted near where special trackwork would be installed (i.e., where crossovers would be installed to allow trains to move from one track to another) or where existing buildings would be removed as a result of the project. Removing buildings would cause noise levels to increase because acoustic shielding is removed. Wheel impacts at special trackwork are predicted to increase noise levels by up to 6 decibels (dB).

Six of the ten noise impacts are predicted at sensitive receivers located near turnouts that would be installed as part of the project. New turnouts are proposed where the bypass track would tie in with the existing mainline tracks on the existing Belmont station structure at the south end of the project area and on the Brown Line at the north end of the project area. Four of the ten noise impacts are predicted to result from the removal of intervening buildings to accommodate the new bypass structure.

Changes in the permanent vibration levels with the Build Alternative would result from a change in the track structure, the construction of the bypass structure closer to some receivers, and an increase in train speeds. Special trackwork can increase vibration levels by up to 10 decibels. Of the 56 clusters of sensitive receivers identified within 350 feet of the alignment, six are predicted to have vibration impacts which exceed the FTA impact threshold before mitigation.

1.4 Mitigation Measures

FTA's policy on noise mitigation is that mitigation measures should be considered when there are moderate impacts; noise mitigation should be implemented when there are severe impacts unless there are compelling reasons why mitigation measures are not feasible.

As discussed, a closed deck structure, noise barriers along the edges of the structure, and welded rail north of Belmont station are assumed to be part of the project. Lower noise levels associated with these features are taken into account in the predicted noise levels, therefore they are not considered as potential mitigation measures. Increasing the height of the noise barriers on the structure is also not considered as a potential mitigation measure because the majority of the noise impacts are at upper story sensitive receivers, and a higher noise barrier would not be effective in lowering noise levels. In addition, good wheel and track condition is assumed for both existing noise conditions and future noise conditions; therefore, changes in wheel or track maintenance are not considered as potential mitigation measures.

Several mitigation measures are possible, and measures to be implemented would be determined during final design. The options below are listed in order of their applicability and likelihood of implementation. One or more of the following mitigation measures could be incorporated in the project to reduce noise levels at sensitive receivers:

- Use flange-bearing frogs. A flange-bearing frog is designed with a ramp so the wheels transition onto the flange through the gap in the special trackwork, providing a smoother transition.

- Replace jointed rail with welded rail. At Belmont station and along the open-deck Brown Line track, the existing jointed rail would not be replaced as part of the project. Replacing the jointed rail with welded rail may be done to reduce noise levels at sensitive receivers near these locations.

- Apply an absorptive material on a concrete deck with direct fixation track. Although not common, there are several examples where this approach is used as a noise mitigation measure on Asian and European transit systems.

- Install high resilience (soft) fasteners on the remaining open-deck steel structure. Softer fasteners would reduce the noise radiated from the structure.

- Install residential sound insulation for upper story receivers or receivers without outdoor land uses. Assessment of the existing sound insulation at sensitive receivers may show that additional sound insulation is not warranted and no further mitigation measure is necessary.

Details for each of these options are explained in **Section 7**. The four severe impacts and six moderate impacts would be reduced to an acceptable threshold if one of the potential mitigation measures is implemented. The flange-bearing frog was deemed the appropriate measure to mitigate all but one of the predicted impacts; it may be mitigated using welded track. It is not likely that residential sound insulation would be considered a viable mitigation measure for the Build Alternative.

All of the sensitive receivers where a vibration impact is predicted are located near special trackwork. The gaps associated with special trackwork can cause vibration levels to increase by 10 decibels. The following mitigation measures could be incorporated into the project to reduce vibration levels at sensitive receivers:

- Use flange-bearing frogs. A flange-bearing frog is a low-impact frog that would reduce vibration levels from special trackwork. A flange-bearing frog is designed with a ramp so the wheels transition onto the flange through the gap in the special trackwork, providing a smoother transition. Alternative designs for low-impact frogs, such as monoblock frogs, may also be used to reduce vibration levels from special trackwork.

- Install rubber bearing pads on the top of the columns to reduce the vibration transmitted through the columns into the ground. The specific details of this approach would be investigated during the preliminary engineering phase. Based on experience with floating slab track systems to reduce levels of ground-borne vibration, this appears to be a practical approach for eliminating vibration impacts.

The analysis has demonstrated that applying a potential mitigation measure would mitigate the predicted vibratory impacts at three of the six affected locations. The flange-bearing frog was appropriate for the three locations where it reduced impacts. At the remaining three locations an alternative mitigation measure to reduce vibration levels, such as installing rubber bearing pads on top of the columns, should be considered in addition to or in place of flange-bearing frogs. Further study during preliminary engineering is required to predict the reduction in vibration that would result from installing rubber bearing pads on top of the columns. Deciding which mitigation measure to apply would be done in coordination with FTA and during detailed preliminary engineering to determine viability.

Section 2
Project Description

The Chicago Transit Authority (CTA), as project sponsor to the Federal Transit Administration (FTA), proposes to construct a fifth track bypass just north of Belmont station where the CTA rail system Red, Purple, and Brown line tracks converge at an existing flat junction. Improvements as part of this project would also reconstruct approximately 0.3 mile of the mainline Red and Purple line tracks from Belmont station in the south to the segment of track between Newport and Cornelia Avenues in the north. This project, known as the Red-Purple Bypass Project, would modernize infrastructure and expand capacity, reduce passenger travel times, and improve system mobility and safety at one of the largest bottlenecks in the CTA rail system. This memorandum describes the potential impacts of the Red-Purple Bypass Project with regard to noise and vibration.

Two alternatives are under consideration: the No Build Alternative and the Build Alternative.

2.1 No Build Alternative

The No Build Alternative is a required alternative as part of the NEPA environmental analysis and is used for comparison purposes to assess the relative benefits and impacts of implementing the Red-Purple Bypass Project. The No Build Alternative would maintain the status quo, and would not expand system capacity.

The No Build Alternative represents future conditions if the Red-Purple Bypass Project were not implemented. The alternative would include typical repairs to the existing flat junction and the associated mainline tracks based on historic funding levels needed to keep the lines functional. Capital expenditures would be minor compared to the Build Alternative. Functional improvements under the No Build Alternative would be insufficient to respond to ridership demand, and would not modernize the system. Some expenditure would be made to keep the system operating; however, service quality and effective capacity would decline over time, and maintenance costs would rise due to continued aging of the infrastructure. The No Build Alternative would not involve substantial changes to the existing infrastructure or major construction activities. Travel times would likely continue to increase and service reliability would continue to degrade in order to safely operate on deteriorating infrastructure.

2.2 Build Alternative

The Build Alternative consists of constructing a fifth track bypass for the northbound Brown Line and reconstructing approximately 0.3 mile of the mainline Red and Purple line tracks from Belmont station on the south to the segment of track between Newport and Cornelia Avenues on the north. The improvements would address current and increased ridership demands, decrease travel times, raise overall system reliability and safety, reduce noise levels, and provide a modern track structure with a renewed useful life of 60 to 80 years while supporting future growth and development in the project area and beyond. **Figure 2-1** provides a map of the project limits.

2.2.1 Fifth Track Bypass

Currently, northbound Brown Line trains must cross the north- and southbound Red Line tracks and the southbound Purple Line track at Clark Junction. This flat junction configuration causes signal delays because Red, Purple, and Brown line trains must wait for each other to pass through the junction before proceeding. The Build Alternative would provide a grade-separated junction allowing northbound Brown Line trains to cross unimpeded over and above the other tracks on a new aerial structure, resulting in increased capacity to all three lines while also improving travel time and overall system reliability and safety. A new track would be built to the east of the existing tracks, ramp up, and curve westward over the mainline tracks to merge onto the existing Brown Line track elevated structure just west of Sheffield Avenue. Based on conceptual engineering, the bypass track is expected to rise approximately 40 to 45 feet above the existing ground level (up to 22 feet above the existing tracks) at its highest point. **Figure 2-2** shows a picture of the existing four-track system at Belmont station facing north and an artistic conceptual rendering of the proposed bypass.

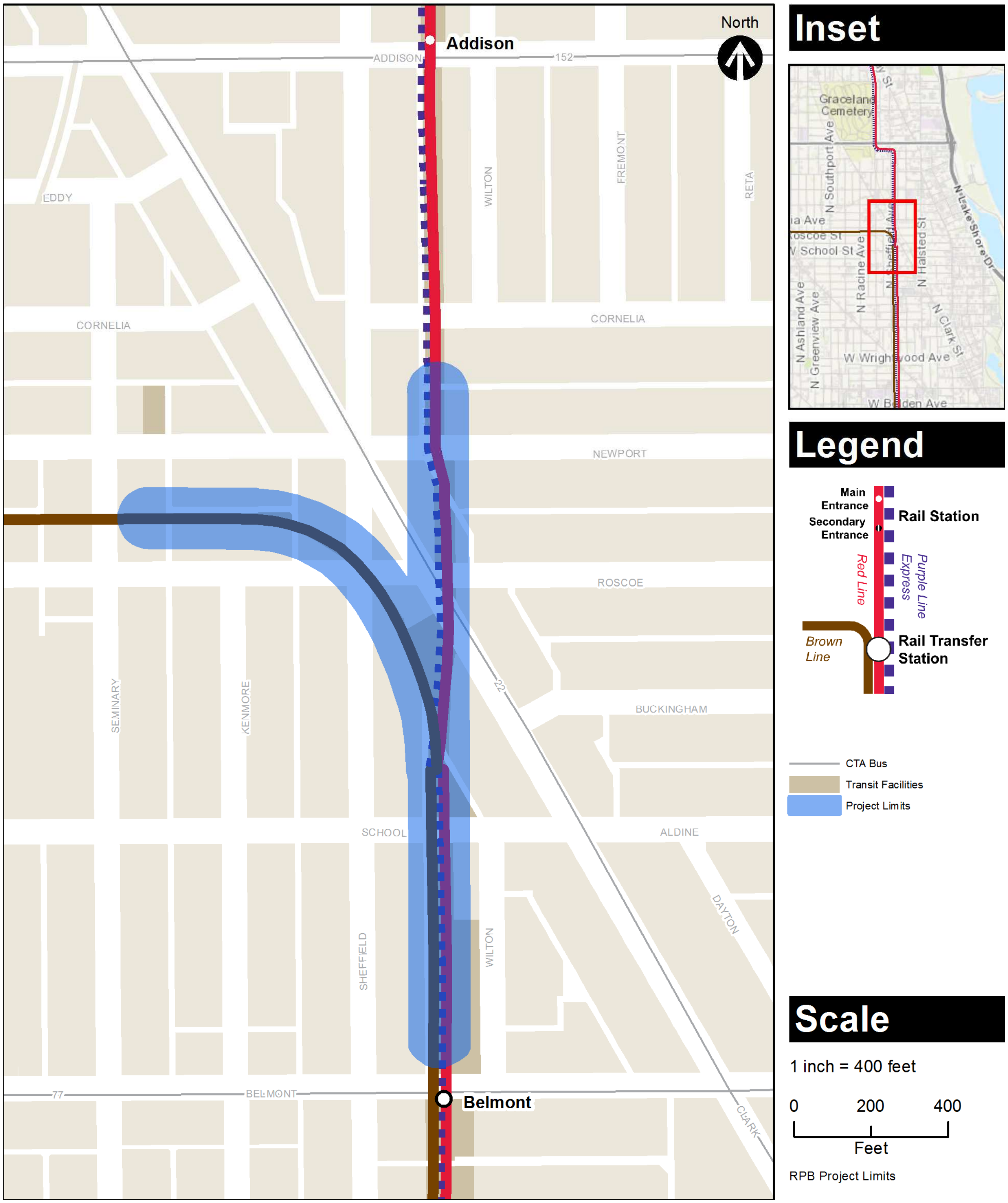


Figure 2-1: Red-Purple Bypass Project Limits

Figure 2-2: Photo and Artistic Conceptual Rendering of Proposed Red-Purple Bypass, Facing North from Belmont Station

2.2.2 Mainline Track

The existing mainline tracks are directly underneath the location of the proposed bypass. These tracks date back to the turn of the 20th century and have not been fully replaced since this time.

The existing track geometry north of Clark Junction requires Red and Purple line trains on all four tracks to maneuver through two short-radius curves between School Street and Newport Avenue, partly beneath the location of the proposed new bypass tracks. These short-radius curves restrict train speeds; increase travel time, noise levels, and rail wear; and reduce passenger comfort with undesirable side-to-side movements. As part of the Red-Purple Bypass Project, these existing short-radius curves would be realigned to eliminate unnecessary speed restrictions, improving train speeds, travel time, and ride quality. If not improved, these speed-restricted curves would limit speeds for the Red and Purple lines even after the flat junction capacity constraint is removed. The existing open-deck, steel structure with jointed rail, which is over 115 years old, would be modernized from Belmont station on the south to the segment of track between Newport and Cornelia Avenues on the north. The modernized track structure would be wider than the existing track structure to meet modern design standards, including provisions for worker safety. To minimize noise and vibration impacts from faster and more frequent trains, the proposed structure would use a closed-deck aerial structure with direct-fixation track and welded rail. Noise barriers (approximately 3 to 5 feet in height) are proposed on both sides of the track deck for the full length of the project limits to reduce noise transmission at and below track level. At specific locations special trackwork, signals, signal equipment, and relay houses would be included.

The project would be constructed with minimal service disruptions. Improvements in the area would lead to several building displacements in the vicinity to accommodate permanent right-of-way and construction needs. Portions of the land acquired for permanent right-of-way would be needed for the final track realignment; the remainder of property would become available for potential redevelopment after construction.

Section 3
Methods for Impact Evaluation

3.1 Regulatory Framework for Analysis

Procedures published by the FTA were used to evaluate the potential for noise and vibration impacts at sensitive receiver locations in the project area. The criteria are described in the FTA manual *Transit Noise and Vibration Impact Assessment* (FTA-VA-90-1003-06; May 2006), referred to as the Guidance Manual. In addition to the federal criteria, state and local noise ordinances were also reviewed to determine their applicability in assessing noise and vibration impacts from the proposed projects. All relevant federal, state, and local criteria are described below.

3.1.1 Federal

The noise and vibration analyses for the project were prepared in accordance with the FTA Guidance Manual. This technical memorandum sets forth the basic concepts, methods, and procedures for evaluating the extent and severity of the noise and vibration impacts from transit projects. All aspects of the noise and vibration analyses were coordinated with CTA and FTA.

The rail sections of the Guidance Manual were primarily written for analysis of new, modern rail transit projects. The noise analysis for this project (which consists of improvements to an aging, existing system) was based on the procedures in the Guidance Manual, but relied on measurements of the existing system as opposed to the reference noise levels provided in the Guidance Manual to establish a noise and vibration baseline for a system type not used in new construction scenarios.

3.1.2 State

3.1.2.1 Noise

The State of Illinois in Title 35: Environmental Protection; Subtitle H: Noise; Part 900 has established Sound Emission Standards and Limitations for Property Line Noise Sources for different land use classifications. Class A land uses include residences, hotels, hospitals, nursing homes, schools, and places of worship. Class B land uses include commercial and office buildings, and Class C land uses include industrial and manufacturing facilities. The State of Illinois indicates, however, that the noise limits do not apply to sound emitted from transit systems, or from equipment being used for construction.

3.1.2.2 Vibration

The State of Illinois does not address vibration in Title 35: Environmental Protection; Subtitle H: Noise; Part 900. There are no state vibration limits or regulations applicable to the project.

3.1.3 Local

3.1.3.1 Noise

The City of Chicago Municipal Code Article XXI: Environmental Noise and Vibration Control (also referred to as the Chicago Environmental Noise Ordinance) has established "noise disturbance" requirements. The City of Chicago noise requirements, however, do not apply to sounds generated in the operation of any mass transit system (Section 8-32-170(c)). In addition, these noise requirements do not apply to any construction, demolition, or repair work of an emergency nature or to work on public improvements authorized by a government body or agency (Section 8-32-170(e)).

3.1.3.2 Vibration

The City of Chicago Municipal Code Article XXI: Environmental Noise and Vibration Control does establish vibration limits in Section 8-32-160. The City of Chicago vibration requirements do not apply, however, to vibration generated in the operation of any mass transit system (Section 8-32-170(c)). In addition, the vibration limits do not apply to any construction, demolition, or repair work that is authorized by a government body or agency (Section 8-32-170(e)).

3.2 Significance Thresholds

Because the State of Illinois and City of Chicago noise limits do not apply to transit projects, the FTA's noise and vibration procedures were used for the technical analysis. Although the impact thresholds in the FTA Guidance Manual are most commonly used for new transit corridors, the procedures do take into account the noise and vibration levels from the existing rail infrastructure in the project area. Further details on the interpretation of the FTA's impact thresholds, the proposed approach to the noise and vibration analysis, and mitigation considerations are provided throughout the remainder of this technical memorandum.

3.2.1 Construction Noise

The proposed Red-Purple Bypass Project would require construction over an extended period of time, both for demolition of existing structures and construction of the new structures. The use of heavy equipment during construction has the potential to cause significant, yet temporary, increases in local noise levels in the project area. Because the City of Chicago Noise Ordinance does not provide limits appropriate for defining construction noise impacts, the impact thresholds provided in the Guidance Manual and shown in **Table 3-3** were used to assess potential construction noise impacts and the need for mitigation. The guidelines are based on an average 1-hour equivalent sound level (L_{eq}).

The construction impact thresholds presented in Table 3-3 are considered reasonable criteria for assessment during the environmental phase of the project to identify potential impacts before a contractor has been selected and the means and methods for construction have been defined. The FTA Guidance Manual recommends that the noise impact thresholds applied during the construction phase of the project should be developed on a project-specific basis and should take into account the existing noise environment, the absolute noise levels during construction activities, the duration of the construction, and the adjacent land use.

Table 3-1: Construction Noise Guidelines

Land Use	Noise Limit, 1 hr L_{eq} (dBA)	
	Daytime	Nighttime
Residential	90	80
Commercial	100	100
Industrial	100	100

Source: FTA 2006
L_{eq} = equivalent continuous sound level, dBA = A-weighted decibels

3.2.2 Construction Vibration

The City of Chicago Noise Ordinance does not provide limits appropriate for defining construction vibration impacts; the impact thresholds provided in the Guidance Manual and shown in **Table 3-2** were used to assess construction vibration impacts and the need for mitigation. It is important to note that the vibration limits in **Table 3-2** are the levels at which there is a risk for damage, not the level at which damage would occur. These limits should be viewed as criteria that should be used during the impact assessment phase to identify problem locations that must be addressed during final design.

The levels in **Table 3-2** were used to assess potential vibration impacts resulting from construction. The construction vibration impact assessment used the prediction methodology and the source levels for construction equipment recommended in the Guidance Manual. A mitigation measure for construction vibration would be to institute a vibration monitoring protocol. Recommendations for vibration monitoring during construction were developed based on the results of the analysis, and were drawn from CTA's specifications for vibration monitoring protocol from previous projects.

Table 3-2: Construction Vibration Damage Criteria

Building Category	PPV (in/sec)	Approximate L_v
I. Reinforced-concrete, steel or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

Source: FTA 2006
PPV = peak particle velocity; L_v = vibration velocity level

3.2.3 Operational Noise

Noise is a key concern in the environmental analysis of the impacts of mass transit improvements on surrounding communities. As such, a major goal of the noise impact assessment was to identify mitigation measures that prevent noise levels from exceeding the FTA moderate noise impact threshold. Given the context of this existing heavily used transit corridor, the allowable increase in noise levels before there are moderate or severe impacts for these projects was based on a survey of measured existing community noise levels at sensitive receivers that are representative of the different noise environments within the project areas.

The FTA identifies three different land use categories that are noise sensitive. Land uses that are not identified as noise sensitive are not assessed for impact. The noise sensitive land use categories are defined in **Table 3-3**.

Table 3-3: Land Use Categories for Transit Noise Impact Criteria

Land Use Category[1]	Noise Level[2]	Description
1	$L_{eq}(h)$	Tracts of land set aside for serenity and quiet, such as outdoor amphitheaters, concert pavilions, and historic landmarks.
2	L_{dn}	Buildings used for sleeping, including residences, hospitals, hotels, and other areas where nighttime sensitivity to noise is of utmost importance.
3	$L_{eq}(h)$	Institutional land uses with primarily daytime and evening uses including schools, libraries, churches, museums, theaters, cemeteries, historical sites and parks, and certain recreational facilities used for study or meditation.

Notes:

[1] Land use categories are based on sensitivity to noise intrusions.

[2] The threshold noise limits include an hourly equivalent noise level (or $L_{eq}(h)$) for Category 1 and 3 receivers and the day-night noise level (or L_{dn}) for Category 2 receivers. The FTA noise limits, which are based on the existing background levels, are determined using empirical formulas shown graphically in **Figure 3-1**.

The FTA thresholds for noise impact are sliding scales that are functions of the existing noise exposure. FTA defines two degrees of noise impact: *moderate impact* and *severe impact.* FTA's policy is that noise mitigation should be considered when there is moderate impact; when there are severe impacts, noise mitigation should be implemented unless there are very compelling reasons[1] why mitigation is not feasible. The analysis adopted the following approach for recommending mitigation for severe and moderate noise impacts:

- Severe Impacts: Mitigation would be recommended unless there are extenuating circumstances as described in the FTA Guidance Manual Section 3.2.5. Mitigation recommendations would aim to reduce noise to below the moderate impact threshold, if feasible.

[1] Compelling reasons used to determine whether mitigation is feasible and prudent include "noise reduction potential, the cost, the effect on transit operations and maintenance, and … any new environmental impacts which may be caused by the measure" (FTA 2006).

- Moderate Impacts: Mitigation options would be considered for moderate noise impacts; however, final mitigation recommendations would depend on cost, amount of noise reduction provided to receivers, number of receivers affected, and other factors as described in the FTA Guidance Manual Section 3.2.5.

For residential land uses, which represent the majority of noise sensitive receivers in the project area, noise exposure is characterized using the day-night sound level, L_{dn}.[2] The graphs in **Figure 3-1** illustrate the impact thresholds for Category 2 land uses, which include residences, hotels, and other buildings where people normally sleep. The graph on the left shows the impact threshold in terms of the amount of noise that can be generated by the transit project before there is moderate impact (the blue line) and severe impact (the red line). As shown in the left figure, as existing noise exposure increases the amount of new noise exposure that can be generated by the project increases up to limits of 65 dBA for moderate impact and 75 dBA for severe impact.

The graph on the right reconfigures the threshold in terms of the amount the project can cause noise exposure to increase before there is impact. Because this project would be modifying an existing noise source and is not a new noise source, it would be more appropriate to identify noise impacts by applying the FTA thresholds in terms of the allowable increase in noise exposure. As the figure on the right illustrates, as the existing noise exposure increases the amount the project can cause noise exposure to increase without impact is reduced. This sliding scale is illustrated in the two examples shown in **Figure 3-2**.

[2] L_{dn} is a measure of total noise exposure over a 24-hour period, with noise that occurs during nighttime hours (defined as 10 PM to 7 AM) assigned a weighting factor that makes one sound event during nighttime hours equivalent to ten of the same events during daytime hours.

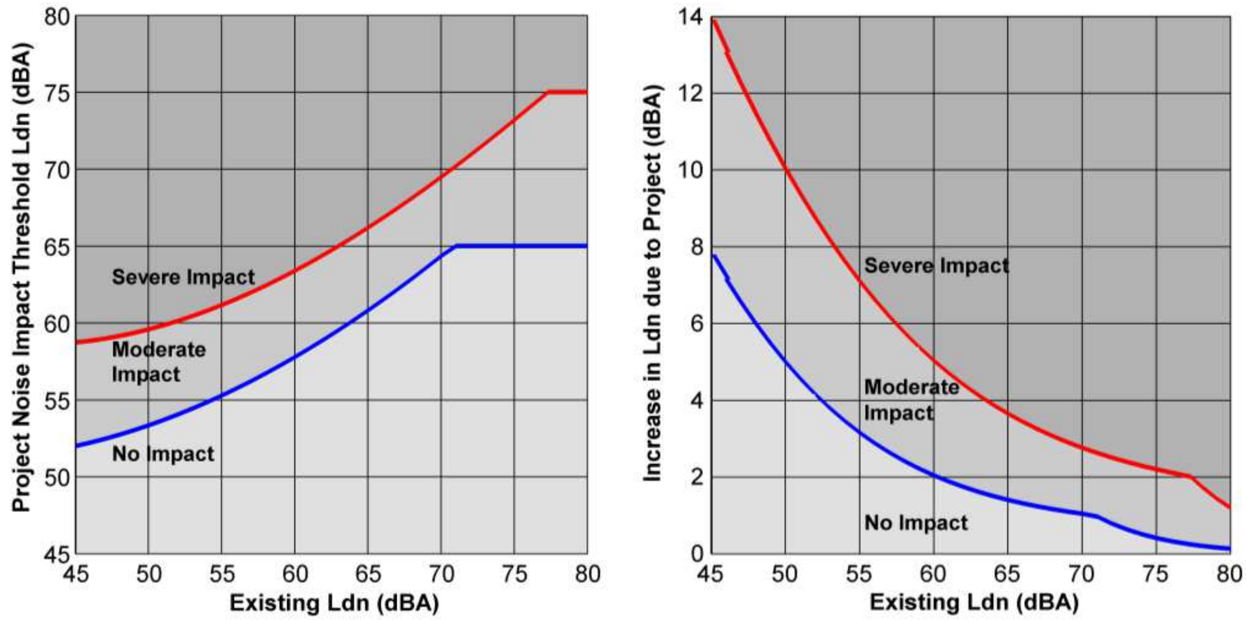


Figure 3-1: FTA Noise Impact Thresholds for Category 2 Land Uses

Consider the two cases illustrated in **Figure 3-2**. In Example 1, the measured existing noise exposure is L_{dn} 60 dBA, which represents noise environments at locations that are more than 200 to 300 feet from the existing track structure. With an existing L_{dn} of 60 dBA, increasing L_{dn} by 2 decibels to 62 dBA would be a moderate impact and increasing the L_{dn} by 5 decibels to 65 dBA would be a severe impact.

In example 2 the existing noise exposure is an L_{dn} of 75 dBA, which currently occurs at some residences that are within 25 feet of the existing track structure. For this example, if the project were to increase L_{dn} by 0.4 decibels to 75.4 dBA it would be a moderate impact, and if the project were to increase L_{dn} by 2.3 decibels to 77.3 dBA it would be a severe impact. This example illustrates that when existing noise exposure is high, as it is in much of the RPM corridor, a less than one decibel increase in the noise exposure may be considered a moderate impact under the FTA noise impact criteria. An increase of just over 2 decibels may represent a severe impact.

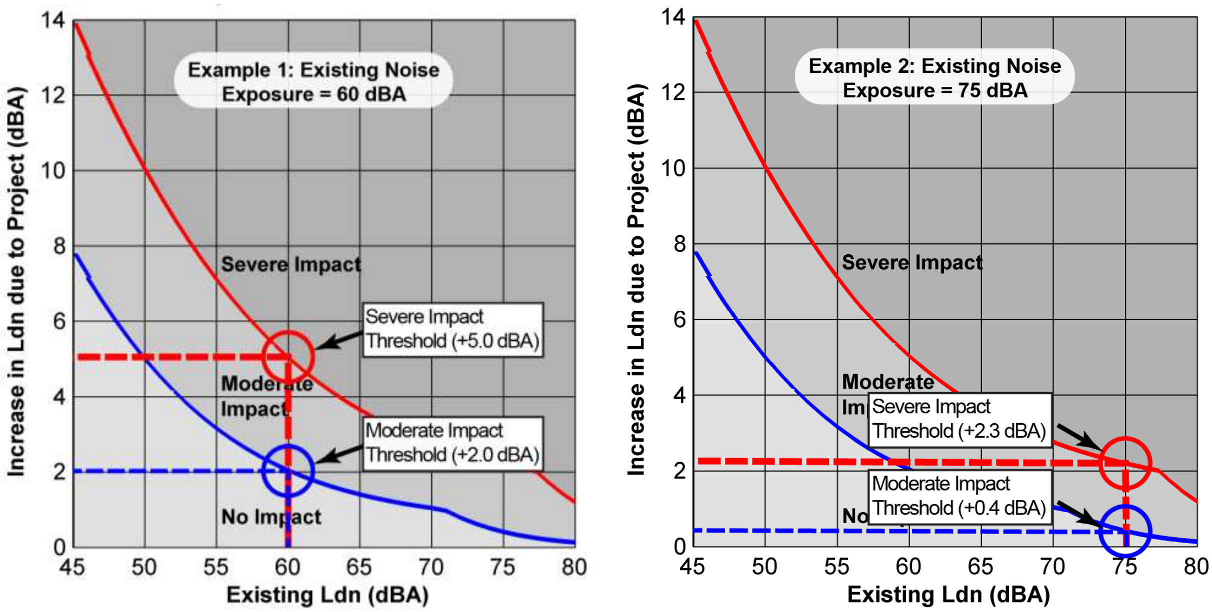


Figure 3-2: Two Examples of Impact Thresholds based on Increase in Noise Exposure

3.2.4 Operational Vibration

The FTA criteria for vibration impact were used to assess community annoyance to vibration from CTA operations. In contrast to the FTA noise impact criteria, which are based on cumulative outdoor noise exposure over a 24-hour period, the FTA vibration impact criteria are based on the maximum vibration levels generated in occupied indoor spaces as trains pass the sensitive receiver. The FTA impact threshold for residential land uses is 72 VdB[3] in any 1/3 octave band between 8 hertz (Hz) and 80 Hz. For new transit projects, the FTA impact threshold does not take into account existing vibration levels; however, for projects such as this one where the project consists of modifications to an existing vibration source, the FTA procedures do consider the existing vibration levels. The Guidance Manual provides several examples. The most applicable is when existing tracks would be moved, causing vibration levels to increase. FTA describes the impact as follows:

> "If the track relocation will cause higher vibration levels at sensitive receivers, then the projected vibration levels must be compared to the appropriate impact criterion to determine if there will be new impacts. If impact is judged to have existed before moving the tracks, new impact will be assessed only if the relocation results in more than a 3 VdB increase in vibration level."

[3] Measure of vibration velocity in decibels.

The FTA identifies three different land use categories that are vibration sensitive. Land uses that are not identified as vibration sensitive are not assessed for impact. The vibration sensitive land use categories are described in **Table 3-4**.

Table 3-4: Ground-Borne Vibration Impact Criteria

Land Use Category[1]	Description
1	Buildings where vibration would interfere with operations. This category includes vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations.
2	Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels.
3	Institutional land uses which include schools, churches, other institutions, and quiet offices that have the potential for activity interference. Note that offices are not considered a noise sensitive land use, but may be considered a vibration sensitive land use.
Special Use Buildings	Buildings that are very sensitive to vibration and warrant special attention during the environmental impact assessment. This category includes concert halls, TV and recording studios, and theaters.

Source: FTA 2006

[1] Land use categories are based on sensitivity to vibration intrusions.

The interpretation of the criteria relative to the project is as follows:

- If the existing and future vibration levels from CTA operations are below the impact threshold, there is no impact.
- If the existing vibration levels are below the impact threshold and the future vibration levels would be above the impact threshold, there is impact.
- If the existing vibration levels are above the impact threshold and future vibration levels would result in more than a 3 decibel increase, there is impact; if the increase is less than 3 decibels, there is no impact.

The FTA Guidance Manual also notes: "When the project will cause vibration more than 5 VdB greater than the existing source, the existing source can be ignored and the standard vibration criteria applied to the project." The analysis verified that the project would not cause vibration increases of more than 5 VdB before the vibration criteria described above is applied in the impact analysis.

It is important to note that vibration impacts would be based on the potential for human annoyance or the interference with sensitive receivers such as recording studios and vibration-sensitive research or medical equipment. Because the impact thresholds for annoyance and for sensitive equipment are well below the thresholds for minimizing risk of damage, it is not expected that the Red-Purple Bypass Project would generate vibration levels close to the thresholds used to determine the risk of building damage by environmental vibration.

3.3 Methods

The standard FTA methodology for analyzing noise and vibration for transit projects has three fundamental steps: Screening Assessment, General Assessment, and Detailed Assessment. The Screening Assessment consists of a review of the project area to identify locations where the potential for impacts exists. If none are identified, no further assessment is required. The next step is the General Assessment, where generalized noise and vibration models are used to identify specific receivers where there is potential for impact. In many cases the detail provided by a General Assessment is sufficient for an EA, particularly when relatively straightforward mitigation measures, such as noise barriers, are sufficient to eliminate the impacts. Detailed Assessments are used when the assessment requires specific information about the project's rolling stock, the track system, and the receivers to accurately define the potential impacts and to recommend measures that would mitigate the predicted impacts.

The RPM Phase One projects are relatively unique in that current measured noise and vibration levels from CTA operations are quite high. Noise and vibration impact analysis for this project was based on how noise and vibration levels would change as a result of the projects, and mitigation measures are likely to involve design modifications to the elevated structures. Because it is clear that the RPM Phase One projects have the potential for substantial noise and vibration impacts and the results of the noise and vibration assessment may directly influence the final design of RPM structures, a detailed noise and vibration assessment has been performed to identify potential impacts and feasible mitigation measures.

The basic steps in the noise and vibration assessments are:

1. Identify all noise and vibration sensitive receivers in the project area.
2. Characterize existing noise and vibration conditions in the project area through measurements at representative sensitive receivers. (**Section 4**)
3. Perform detailed measurements of the existing CTA elevated structures similar to the proposed replacement structures to use as reference noise levels in the prediction model. (**Section 5**)
4. Develop models of the noise and vibration that would be generated by the proposed structures. The models were based on the data generated in step 3. (**Section 5**)
5. Predict future noise and vibration levels at all sensitive receivers using the models developed in step 4. The predictions were performed for clusters of sensitive receivers when the receivers are similar distances from the existing and proposed future tracks and CTA operating conditions are similar. (**Section 6**)
6. Identify feasible mitigation measures and the reductions that would be achieved with the mitigation measures for all locations where the predicted levels exceed one or more of the FTA impact thresholds. The goal was to identify feasible noise mitigation measures that

would reduce noise levels to below the moderate impact threshold at all locations where the predicted noise levels exceed the moderate or severe FTA noise impact threshold. For predicted vibration impact, the goal was to reduce predicted vibration levels to below the applicable FTA vibration impact threshold. (**Section 7**)

3.3.1 Area of Potential Impact

The screening procedure provided in the Guidance Manual was used to define the area of potential impact (API) for potential noise and vibration impacts. The relevant screening distances for rapid transit systems such as CTA are shown in **Table 3-5.**

Table 3-5: Screening Distances for Noise and Vibration Impacts

Screening Distances for Noise Impact[1]	
Unobstructed Path	700 feet
Intervening Buildings	350 feet
Screening Distances for Vibration Impact[2]	
Residential Land Uses (FTA Vibration Category 2)	200 feet
Institutional Land Uses (FTA Vibration Category 3)	120 feet

1. Source: FTA 2006 (Table 4-1)
2. Source: FTA 2006 (Table 9-2)

The distances were measured from the right-of-way or property line of a transit project, which is the edge of the proposed elevated structures. Because the API is a dense urban environment, the noise screening distance assuming intervening buildings (350 feet) described in the Guidance Manual was used to define the API. The same API was used for both the noise and vibration analysis. For the Red-Purple Bypass Project, the Guidance Manual contains applicable screening distances for a rail station as well as rapid transit systems because the project would involve reconstruction of tracks and construction of a bypass. The greater screening distance (Rapid Rail Transit) was used for the noise and vibration analysis to account for the maximum impact of the project. Based on a maximum distance to potential noise or vibration impacts of 350 feet, **Figure 3-3** shows the API for the Red-Purple Bypass Project.

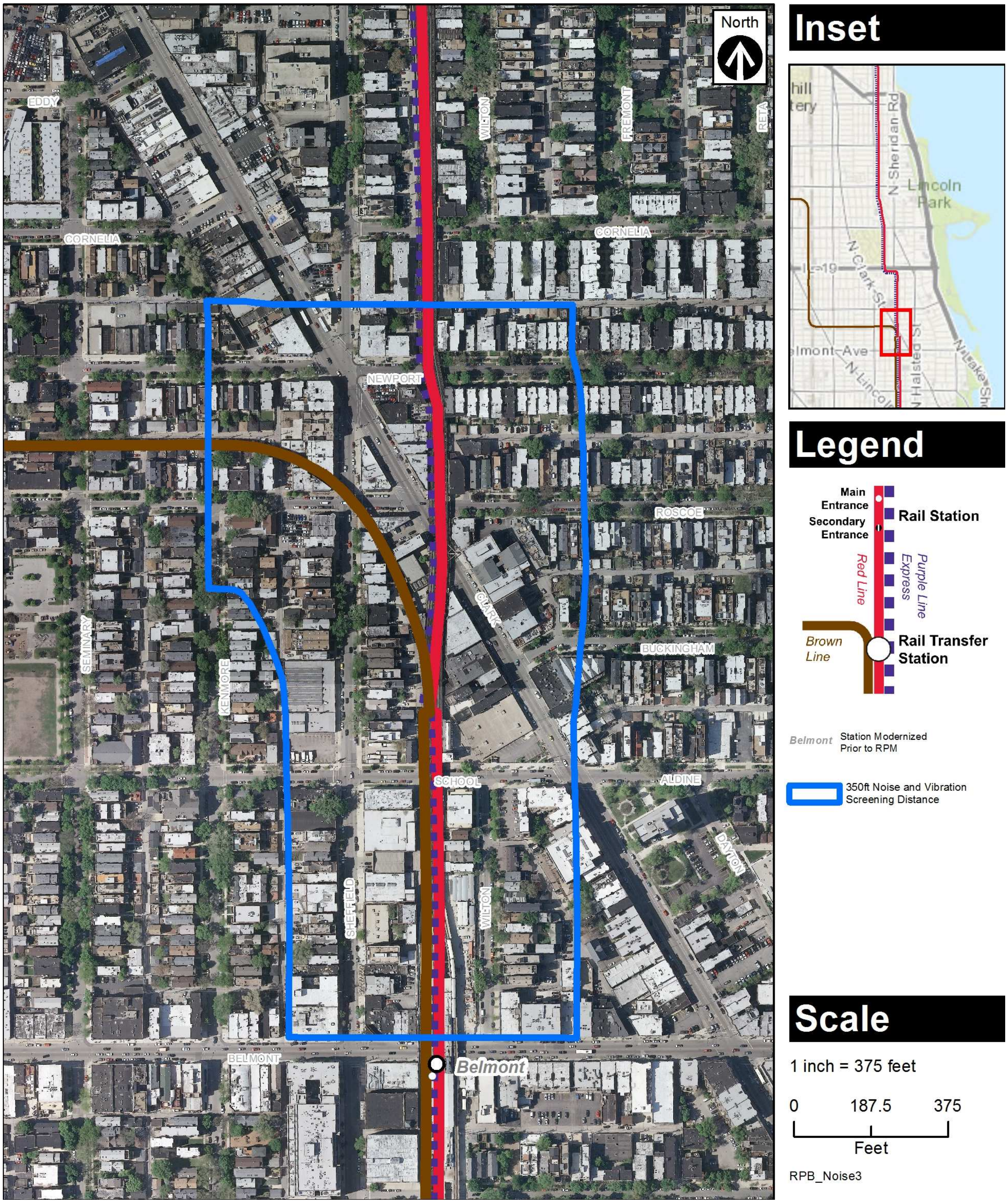


Figure 3-3: Noise and Vibration Area of Potential Impact for the Red-Purple Bypass Project

3.3.1.1 Identifying Noise and Vibration Sensitive Receivers

Noise and vibration sensitive receivers within the project areas include residences, one school (Truman College Lakeview Learning Center), and one church (North Side Mosque of Chicago). A complete list of the noise and vibration sensitive receivers is presented in **Appendix E**.

Noise and vibration sensitive land uses within the project area were identified through:

- A review of the project area using Google Earth.
- A review of all properties potentially displaced by each project.
- A review of the historic structures that have been identified as part of ongoing environmental analyses.
- Use of online resources, including review and use of:
  - City of Chicago online GIS application (https://gisapps.cityofchicago.org/mapchicago)
  - City of Chicago business license lookup (http://www.cityofchicago.org/city/en/depts/bacp/provdrs/bus/svcs/business_licenselook-up.html)
  - City of Chicago business license map (https://data.cityofchicago.org/Community-Economic-Development/Business-Licenses-Current-Active-Map/e4sp-itvq)
  - Cook County Assessor's office property search (http://cookcountyassessor.com/Property_Search/Property_Search.aspx)
- A second field review to confirm sensitive land uses that were identified using online tools.

3.3.2 Existing Noise and Vibration Measurements

Existing noise and vibration levels were measured within the project area. This data is important both for understanding the mechanisms that generate noise and vibration from the existing structures and for determining impact thresholds.

3.3.2.1 Characterizing Existing Noise Conditions

Two types of noise measurements were completed to document the existing conditions in the project area: long-term (24-hour) unattended measurements and short-term (1-hour) attended measurements. The FTA noise impact thresholds for Category 2 land uses, including residences, are based on the existing 24-hour day-night level, or L_{dn}. The 24-hour long-term measurements were conducted at eight representative sensitive receivers throughout the project area. Short-term measurements were conducted at an additional nine sites in the project area to help estimate existing noise levels at sensitive receivers where long-term measurements were not conducted. The short-term measurements were attended and the time, direction, track, and speed of each train event was logged. The logged information was used to better understand how existing train noise varies throughout the project area.

The combination of the 24-hour and short-term measurements were used to establish the existing noise baseline used in the FTA impact analysis. The existing noise measurement results are presented in **Section 4**.

3.3.2.2 Characterizing Existing Vibration Conditions

Measurements of existing vibration generated by CTA rail traffic were performed simultaneously with the short-term noise measurements. The vibration level was measured in the vertical direction at several distances from the existing track structure throughout the project area. The vibration measurements are all short-term measurements. Unlike noise impact for residential land uses, which is based on a cumulative measure of noise over a 24-hour period, FTA bases vibration impacts on the maximum vibration levels of trains as they pass sensitive land uses; therefore, it is not necessary to perform 24-hour vibration measurements to characterize existing vibration exposure. The existing vibration measurement results are presented in **Section 4**.

3.3.3 Impact Analysis

This section provides further details on the steps taken to evaluate the noise and vibration impacts. These steps include developing noise and vibration prediction models, determining how impact thresholds and impact assessments are established, and deciding when mitigation measures are recommended.

3.3.3.1 Modeling Project Noise and Vibration

3.3.3.1.1 Noise

The method for predicting future community noise levels after the project has been completed is to start with the procedures provided in the Guidance Manual, modify the reference levels provided in the Guidance Manual using reference levels based on measurements of existing CTA traffic on a structure similar to what would be constructed as part of the project, and then extend the predictions to all sensitive receivers in the project area using the formulas in the Guidance Manual. The formulas in the Guidance Manual take into account future operating characteristics including train volumes, train speeds, vehicle length, and vehicle type. The predicted noise and vibration levels were compared to the existing levels and the applicable FTA impact thresholds to determine the potential for moderate or severe impacts. Impact thresholds for assessing moderate or severe noise impacts and for assessing vibration impacts are discussed in **Section 3.2**. The noise prediction model is presented in more detail in **Section 5**.

3.3.3.1.2 Vibration

The method for predicting future vibration levels after the project has been completed is based on vibration level measurements conducted at a CTA structure similar to what would be built for the project, and on vibration decay versus distance curves measured in the project area. The vibration decay versus distance curves measured in the project area are used to account for the effect of ground conditions at sensitive receivers on vibration levels. The formulas in the FTA Guidance

Manual were used to account for operating characteristics including train speed, special trackwork, and welded rail. The vibration prediction model is presented in greater detail in **Section 5**.

3.3.3.2 Impact Assessment

3.3.3.2.1 Noise

The assessment of noise impact and the need to consider mitigation was based on the impact thresholds presented in the Guidance Manual. FTA defines two levels of noise impacts (moderate impact and severe impact) as discussed in **Section 3.2**. Mitigation options were evaluated wherever moderate or severe impacts are predicted. Mitigation measures were carefully considered for all severe noise impacts and were recommended unless there were extenuating circumstances. For predicted moderate noise impacts, noise mitigation measures were considered but, following FTA guidance, other project-specific factors such as the increase over existing noise levels and the number of noise sensitive sites affected were also taken into account.

3.3.3.2.2 Vibration

Because the project area already experiences vibration from the existing CTA traffic, mitigation of vibration impacts was evaluated and, if feasible, recommended for implementation at sensitive receivers where:

1. The existing vibration level is below the FTA impact criteria and the predicted future vibration level is above the FTA impact criteria, or

2. The existing vibration level is above the FTA impact criteria and the predicted future vibration level is 3 decibels above the existing vibration levels.

3.3.3.3 Mitigation Assessment

3.3.3.3.1 Noise

As discussed above, mitigation measures were carefully considered for all severe noise impacts and were recommended unless there were extenuating circumstances. For predicted moderate noise impacts, noise mitigation measures were considered but, following FTA guidance, other project-specific factors such as the increase over existing noise levels and the number of noise sensitive sites affected were also taken into account. The goal of the analysis was to provide design recommendations to avoid increases in noise levels at the sensitive receivers. Because of the high existing measured noise levels in the project area, any increase in noise level as a result of the project is likely to result in at least a moderate noise impact. If mitigating an impact is determined to be infeasible, a thorough analysis of why mitigation options would not be feasible is presented. The recommended mitigation measures are defined in **Section 7**.

3.3.3.3.2 Vibration

Vibration mitigation measures were recommended for all identified vibration impacts. Potential vibration mitigation measures include installing low-impact frogs, installing high-resilience direct-fixation fasteners, or installing resilient bearing pads at the top of the column. The recommended mitigation measures are defined in **Section 7**.

Section 4
Affected Environment

4.1 Noise Measurements

Noise measurements were obtained throughout the project area to determine the existing noise exposure at sensitive receivers. Determining the existing noise exposure at sensitive receivers is an important step in the noise impact assessment because the thresholds for noise impacts are based on existing noise. The noise impact thresholds are higher for areas with high existing noise and lower for areas with low existing noise.

The dominant noise source in the project area is existing train noise from the Red, Purple, and Brown lines. The trains currently run on an open-deck, steel elevated structure with jointed track throughout the project area, with the exception of the Belmont station area. The Belmont station is a closed-deck, aerial structure with direct fixation track and jointed rail. The closed-deck structure extends about 200 feet north of the station. Red Line trains operate 24 hours a day. Purple Line trains operate in the project area during weekday peak periods, between approximately 5:30 AM and 11:15 AM and 2:30 PM and 8:00 PM. Brown Line trains operate all day except between 2:30 AM and 4:00 AM.

Two types of noise measurements were completed to document the existing conditions in the project area: long-term (24-hour) unattended measurements and short-term (1-hour) attended measurements. The FTA noise impact thresholds for Category 2 land uses, including residences, are based on the existing 24-hour day-night level, or L_{dn}. The 24-hour long-term measurements were conducted at five representative sensitive receivers throughout the project area. Short-term measurements were conducted at an additional five sites in the project area to help estimate existing noise levels at sensitive receivers where long-term measurements were not conducted. The short-term measurements were attended and the time, direction, track, and speed of each train event were logged. The logged information was used to better understand how existing train noise varies throughout the project area.

The locations of the long-term and short-term measurement sites are shown in **Figure 4-1**.

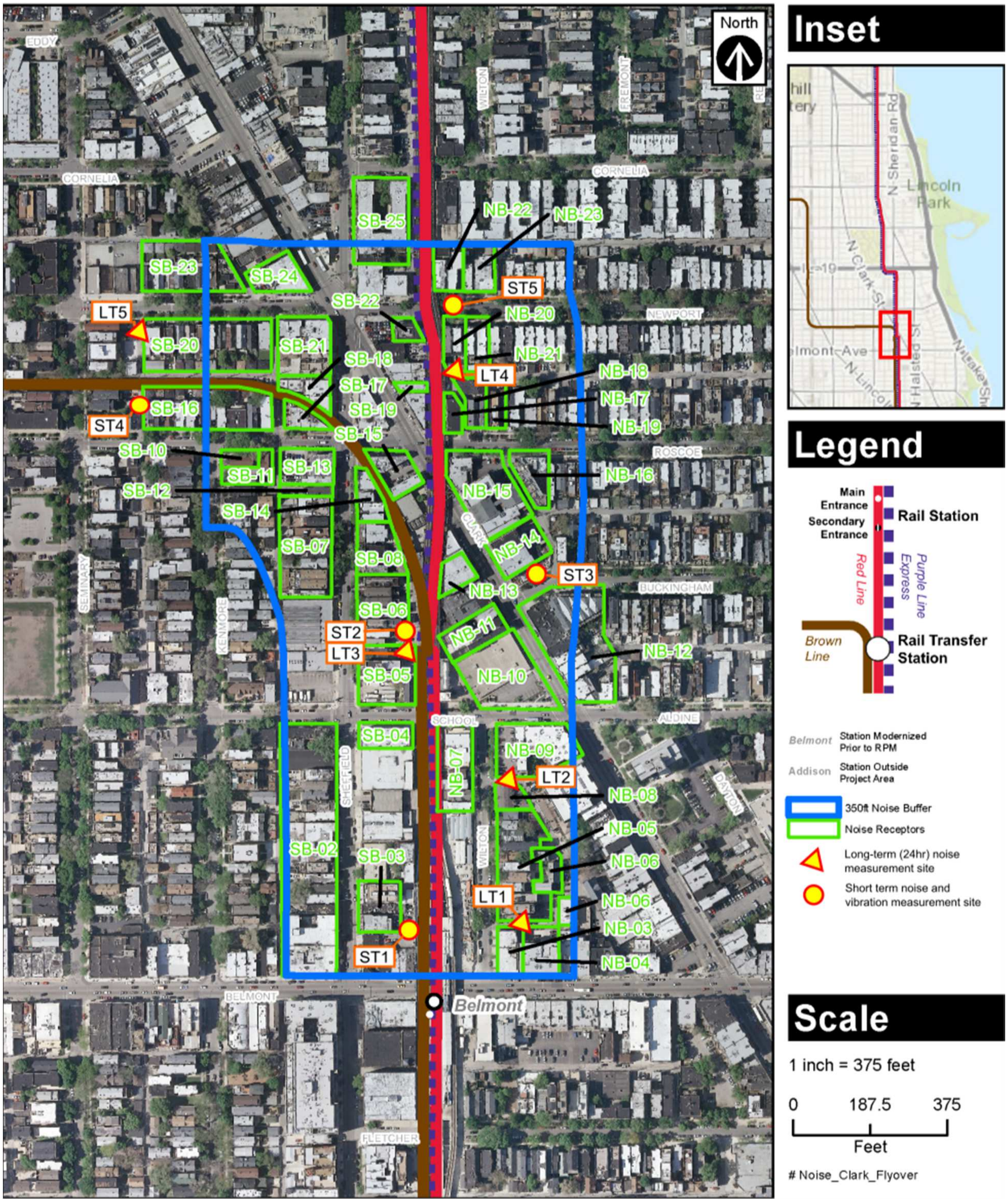


Figure 4-1: Noise and Vibration Measurement Locations

4.1.1 Long-Term Measurement Results

The long-term measurement results are presented in **Table 4-1**. The train noise was the dominant noise source at all measurement sites. The measurement sites were selected to represent five different train noise environments in the project area:

- LT1: Closed-deck concrete deck with direct fixation track near the Belmont station, four tracks (Red, Purple, and Brown lines)
- LT2: Open-deck steel structure with an intervening building row between the existing tracks and the receiver, four tracks (Red, Purple, and Brown lines)
- LT3: Open-deck steel structure with crossovers, four tracks (Red, Purple, and Brown lines)
- LT4: Open-deck steel structure without crossovers, four tracks (Red and Purple lines)
- LT5: Open-deck steel structure without crossovers, two tracks (Brown Line only)

Appendix A includes photographs of the long-term noise measurement sites and plots of the measured sound levels over the 24-hour measurement period.

Table 4-1: Long-term Noise Measurement Results

Site Label	Measurement Locations	Site Description	Distance from Nearest Track	Sound Level, L_{dn} (dBA)
LT1	3213 N. Wilton Avenue	Closed-deck structure at Belmont station	150 feet	66.9[1]
LT2	3245 N. Wilton Avenue	Open-deck steel structure, shielded by intervening buildings	150 feet	69.9
LT3	3319 N. Sheffield Avenue	Open-deck steel structure with crossovers	20 feet	87.5
LT4	937 W. Newport Avenue	Open-deck steel structure	25 feet	81.9
LT5	1043 W. Newport Avenue	Open-deck steel structure (2 tracks)	100 feet	71.3

L_{dn} = day-night average sound level, dBA = A-weighted decibels

[1]Noise at site LT1 was heavily affected by many loud events during the nighttime hours. The L_{dn} excludes these loud events.

4.1.2 Short-Term Measurement Results

Short-term noise measurements within the project area are used to supplement the data from the long-term noise measurements and better characterize the train noise. Short-term noise measurements were conducted at five measurement sites, shown in **Figure 4-1**.

4.1.2.1 Train Noise Decay with Distance

At site ST5, train noise was measured at 25 feet, 50 feet, 100 feet, 200 feet, and 300 feet from the existing open-deck steel structure. The microphones were located on the south sidewalk of Newport Avenue. The data from this measurement site was used to determine how noise levels decay with distance in the built-up urban environment.

Figure 4-2 shows the A-weighted noise levels versus distance for trains running northbound on Track 3. The slope of the line describes how rapidly noise decreases with distance. The noise levels down Newport Avenue decrease with the relationship 20*log(distance). In a flat, open area noise levels typically decrease with a relationship of 10*log(distance). The data show that noise levels decrease more rapidly with distance down Newport Avenue. This is likely because the buildings along Newport Avenue are providing some acoustic shielding.

Figure 4-3 shows the spectra of the A-weighted noise levels (SEL) for trains running northbound on Track 3. The spectra show that at low frequencies below 100 Hz, the noise does not decay as rapidly with distance. The low frequency noise is the noise radiated from the steel structure. It is not clear why the noise at low frequencies shows a slower decrease with distance.

The train noise levels from Tracks 1, 2, and 4 showed decay with distance similar to Track 3. The noise measurement results from these three tracks are shown in **Appendix A**.

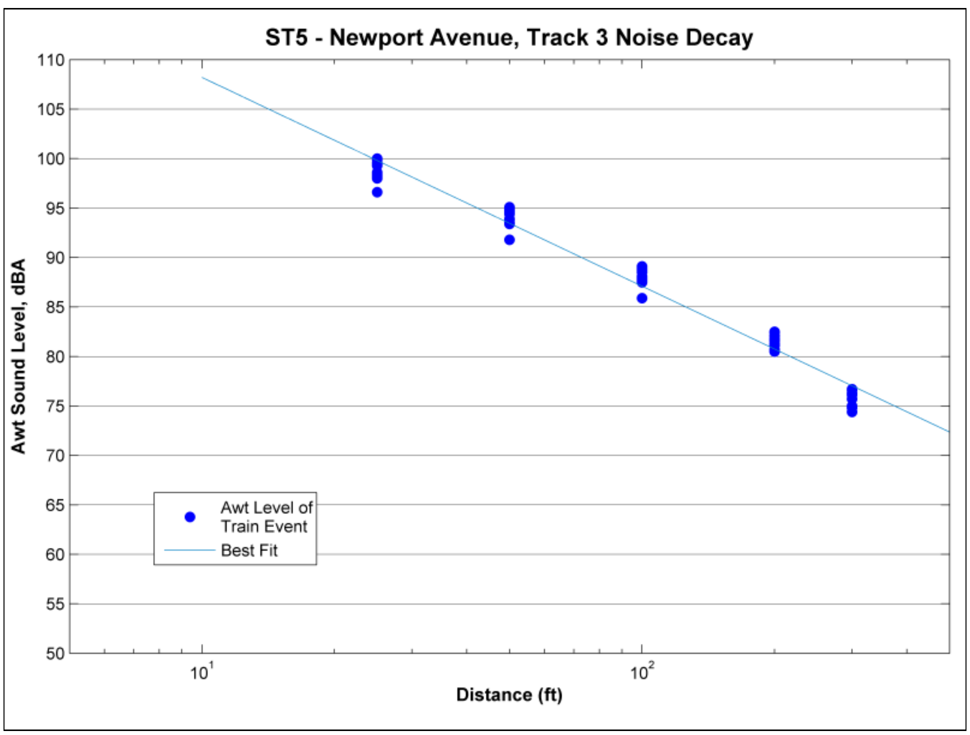


Figure 4-2: Train SEL Versus Distance at Site ST5 Track 3

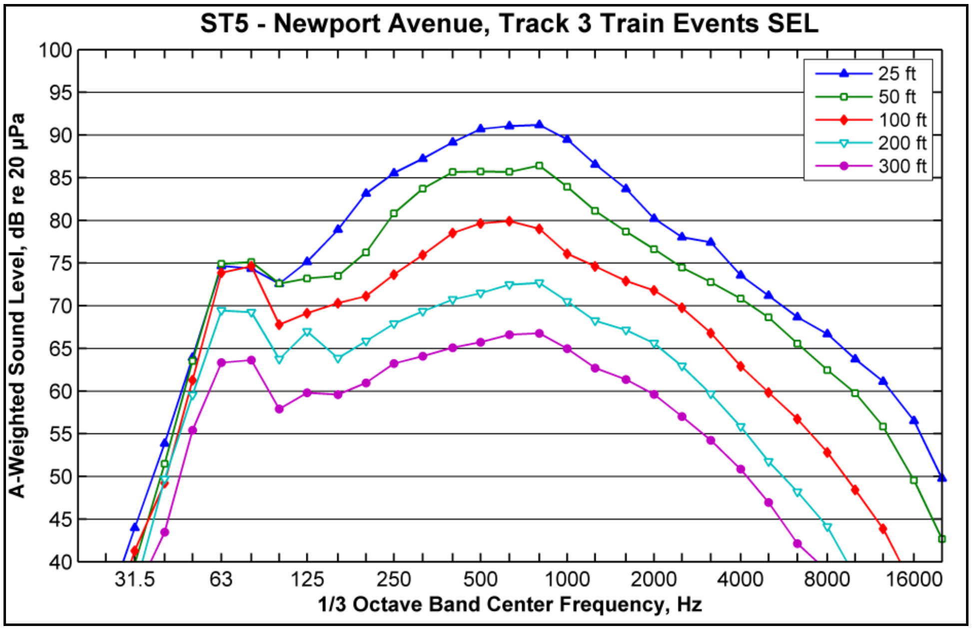


Figure 4-3: Spectra of Train SEL at Site ST5 Track 3

4.1.2.2 SEL of Existing Train Noise

Table 4-2 and **Figure 4-4** through **Figure 4-6** show the average SEL from the trains at each of the short-term sites. SEL is a measure of sound energy generated by one train event and is useful for comparing train noise measured at different locations. The SEL levels in **Table 4-2** and **Figure 4-4** through **Figure 4-6** have been normalized for distance, speed, and train length so they are directly comparable. Key observations from the table and the figures include the following:

- The SEL for site ST1 Track 1 is about 5.8 dB higher than the SEL for Track 3. This is likely due to the gap in the track deck adjacent to Track 1. An average SEL for the closed-deck structure is not presented because the SEL varies with track location.

- The SELs for site ST1 (the closed-deck structure) are 10 to 15 dB lower than the SELs for the open-deck steel structure.

- The average SEL for sites near a crossover is 1.4 dB higher than for sites near the open-deck steel structure sites but not adjacent to a crossover. Crossovers typically increase noise levels by 5 to 6 dB; however, the jointed rail at sites without crossovers results in a lower than typical increase.

- The SEL for site ST5 Track 1 is about 6 dB lower than the SEL measured for other tracks. There is insufficient information to determine why the noise level from this track is lower. The data from Track 1 is not included in the average SEL for open-deck structure without crossovers.

Figure 4-6 shows high levels at high frequencies for site ST5 Track 4. This is due to intermittent wheel squeal as trains travel through the curve at Newport Avenue.

Figure 4-5 shows high low-frequency levels for site ST3. The high low-frequency noise levels are an artifact of the distance normalization; site ST3 is 200 feet away from the tracks. As described in **Section 4.1.2.1**, the low frequency noise does not decay as rapidly with distance as noise at higher frequencies.

Table 4-2: Short-Term Noise Measurement Results

Site Label	Measurement Locations	Track Description	Track	SEL[1] (dBA)
ST1	Belmont Station	Closed-deck	Track 1	96.4
			Track 3	90.6
ST2	School Street	Open-deck, crossovers	Track 1	102.6
			Track 2	104.9
			Track 3	102.1
			Track 4[2]	102.9
ST3	Buckingham Place and Clark Street	Open-deck, crossovers	Track 1	104.2[3]
			Track 2	105.5[3]
			Track 3	103.7[3]
			Track 4[2]	102.5[3]
ST4	Roscoe Avenue	Open-deck, no crossovers	Track 1	103.4
			Track 4	101.4
ST5	Newport Avenue	Open-deck, no crossovers	Track 1[4]	96.3
			Track 2	103.1
			Track 3	100.2
			Track 4	102.5
Average SEL, Closed-Deck				**N/A**
Average SEL, Open-deck with crossovers				**103.7**
Average SEL, Open-deck no crossovers				**102.3**

dBA = A-weighted decibels; N/A = not applicable; SEL = measure of sound energy

[1]The SEL is normalized to 50 feet, 40 mph, and eight-car trains measured at 5 feet above ground level.

[2]T4 trains are completing a diverting movement and crossing over Tracks 2 and 3 to continue on the Brown Line.

[3]Train noise from site ST3 was normalized using a 10*log distance adjustment because the building between the measurement site and the existing tracks was destroyed by fire in 2013, so there is limited acoustic shielding from buildings. The noise level at all other sites used a 20*log distance adjustment to reflect the data shown in Section 4.1.2.1.

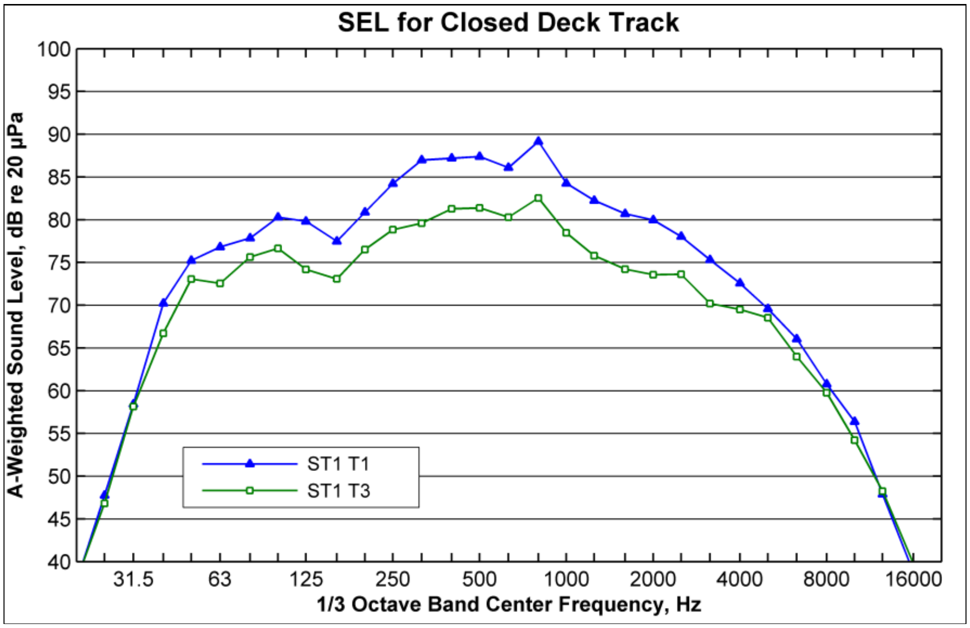


Figure 4-4: Spectra of Train SEL from Short-term Measurement Site at Closed-Deck Structure, Normalized to 50 feet, 40 mph, and eight-car trains

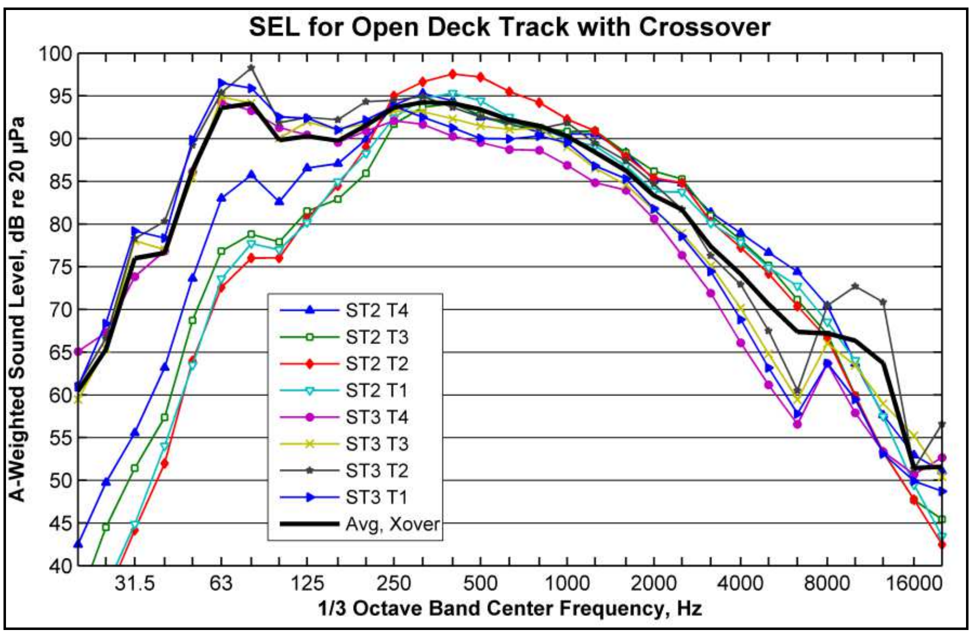


Figure 4-5: Spectra of Train SEL from Short-term Measurement Sites at Open-Deck Structure with Crossovers, Normalized to 50 feet, 40 mph, and eight-car trains

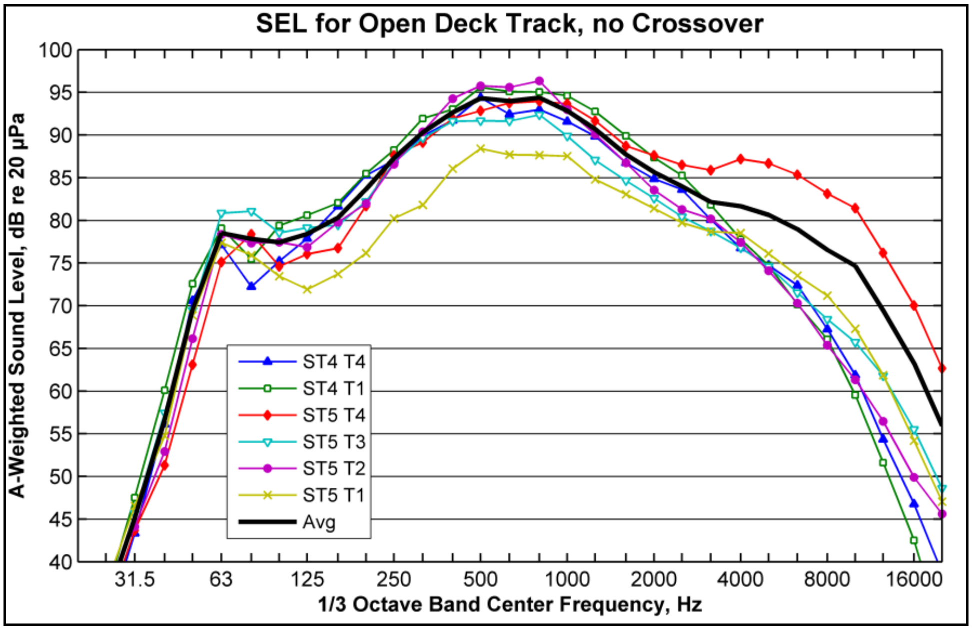


Figure 4-6: Spectra of Train SEL from Short-term Measurement Sites at Open-Deck Structure, No Crossovers, Normalized to 50 feet, 40 mph, and eight-car trains

4.1.3 Estimating Existing Noise Levels

The measurement results show that existing train noise is the dominant noise source in the project area, and that other existing environmental noise sources are insignificant contributors to the cumulative L_{dn} that includes all community noise sources.

The existing noise level was estimated for all sensitive receivers using the SEL measured at the short-term measurement sites and the formulas provided in the FTA Guidance Manual to calculate L_{dn} and account for distance to the track and train speed. The estimated existing noise level at each long-term measurement site is compared to the measured noise level in **Table 4-3**.

The estimated existing train noise level is within one decibel of the measured train noise level at all but one of the long-term measurement sites. The estimated noise level overestimates the measured noise level at site LT2 by 2.2 dB because of an intervening building row blocking the line-of-sight to the tracks. Based on the results in **Table 4-3**, the following assumptions are used to estimate the existing noise levels at all sensitive receivers in the project area:

- Use the SEL measured at the short-term sites with similar track conditions (closed-deck, open-deck with crossover, or open-deck without crossover) shown in **Table 4-2**.
- Adjust for distance to the track using a 20*log(distance) adjustment for all receivers closer than 50 feet to the tracks and all receivers that have partial shielding from buildings. For receivers farther than 50 feet from the tracks where there are no intervening buildings, use an adjustment of 10*log(distance).

- At sensitive receivers where there is no line-of-sight to the tracks, include a shielding adjustment of -2.2 dB. This adjustment is based on the shielding measured at LT2.

- At upper story receivers near the closed-deck structure, add an adjustment of +5.5 dB because those receivers do not benefit from the sound wall on the structure. This adjustment is based on the measurements performed at Fullerton station, which are presented in **Section 5**.

- Calculate the L_{dn} using the formulas provided in the FTA Guidance Manual and the existing train volumes shown in **Table 5-3**.

Table 4-3: Estimated Existing Noise Levels

Site Label	Measurement Locations	Track Description	Estimated Noise Level, L_{dn} (dBA)	Measured Noise Level, L_{dn} (dBA)	Difference in Noise Level (dBA)
LT1	3213 Wilton Avenue	Closed-deck structure at Belmont station	67.0[1]	66.9	0.1
LT2	3245 Wilton Avenue	Open-deck steel structure, shielded by intervening buildings	72.1	69.9	+2.2
LT3	3319 N. Sheffield Avenue	Open-deck steel structure with crossovers	87.4	87.5	-0.1
LT4	937 W. Newport Avenue	Open-deck steel structure	82.1	81.9	0.2
LT5	1043 W. Newport Avenue	Open-deck steel structure (2 tracks)	70.7	71.3	-0.6

dBA = A-weighted decibels; L_{dn} = day-night average sound level

[1]A 10*log distance adjustment was used for LT1. The 10*log distance adjustment was used for this site because the row of intervening buildings was removed when the Belmont station was constructed.

4.2 Vibration Measurements

Vibration measurements were performed throughout the project area to determine the existing vibration levels at sensitive receivers. In contrast to the FTA noise impact criteria, which are based on cumulative outdoor noise exposure over a 24-hour period, the FTA vibration impact criteria are based on the maximum vibration level generated from a single train event in an occupied indoor space. Existing vibration levels were measured over a period of one hour at five locations in the project area. Determining the existing vibration levels at sensitive receivers is an important step in the vibration impact assessment because a higher vibration impact threshold is adopted for sensitive receivers where existing vibration levels exceed the FTA impact threshold.

4.2.1 Existing Vibration Measurement Results

Train vibration was measured at five sites throughout the project area during short-term (1-hour) measurements. The measurement locations are shown in **Figure 4-1**. The measurements were attended and the time, track, and speed of each train event were logged. At measurement site

ST5, vibration was measured at several distances from the existing tracks to determine the rate at which vibration decreases with distance.

The existing vibration measurement results are presented in **Table 4-4**. For a detailed vibration impact assessment, FTA impact criteria apply to the vibration level measured in each 1/3 octave band over the frequency range of 8 to 80 Hz; therefore, **Table 4-4** presents the vibration level in the maximum 1/3 octave band (the band maximum) for each measurement site and the 1/3 octave band that corresponds to the maximum level. The value in the table is the band maximum of the average of the 1/3 octave band spectra for all train events on a single track. The spectra of the individual train events for all measurement sites and aerial photographs showing the location of the measurement sites are included in **Appendix B**.

Key observations from **Table 4-4** include the following:

- The FTA impact threshold for Category 2 land uses, including residences, is 72 VdB. Existing vibration levels exceed this threshold at most measurement locations 30 feet or closer to the nearest track, including ST1, ST4, and ST5. The level at site ST2, which is 25 feet from the nearest track, is only 1 decibel below the impact threshold.

- Existing vibration was measured at two sites (ST3 and ST5) at a distance of 200 feet from the structure. The existing vibration levels at these two sites show good agreement, indicating vibration levels decay with distance at a comparable rate at both measurement locations.

- Two of the measurement sites (ST2 and ST3) were adjacent to existing crossovers. The vibration levels at these two sites did not show higher vibration levels compared to other sites. This indicates that the higher vibration levels caused by special trackwork at crossovers are approximately equal to the higher vibration levels caused by the jointed track for the open-deck structure.

- Existing vibration at site ST5 was measured at five different distances from the tracks. These data are used to develop vibration level versus distance curves to estimate existing vibration levels at sensitive receivers where vibration measurements were not performed.

Table 4-4: Existing Vibration Measurement Results

Site Label	Location	Distance[2] to Near Track,[3] (feet)	Track 1		Track 2		Track 3		Track 4	
			L_v Max (VdB)	Frequency (Hz)	L_v Max (VdB)	Frequency (Hz)	L_v Max (VdB)	Frequency (Hz)	L_v Max (VdB)	Frequency (Hz)
ST1	Belmont Station	30	73	40 Hz	NA[2]	NA[2]	66	40	NA[2]	NA[2]
ST2	School Street[1]	25	70	35 Hz	71	20 Hz	62	10 Hz	66	20 Hz
ST3	Buckingham Place and Clark Street[1]	200	62	12.5 Hz	62	12.5 Hz	64	12.5 Hz	NA[3]	NA[3]
ST4	Roscoe Avenue	30	79	40 Hz	NA[4]	NA[4]	NA[4]	NA[4]	78	40 Hz
ST5	Newport Avenue	25	67	31.5 Hz	72	12.5 Hz	78	40 Hz	74	31.5 Hz
		50	60	12.5 Hz	69	12.5 Hz	65	12.5 Hz	66	12.5 Hz
		100	60	12.5 Hz	65	12.5 Hz	67	12.5 Hz	64	12.5 Hz
		200	58	12.5 Hz	61	12.5 Hz	64	12.5 Hz	61	12.5 Hz
		300	55	12.5 Hz	60	10 Hz	62	12.5 Hz	60	16 Hz

Hz = hertz; Lv = vibration velocity level; VdB = root mean squared vibration velocity in decibels relative to 1 microinch per second

[1]Sites ST2 and ST3 are adjacent to existing crossovers and special trackwork.

[2]At site ST1, it was not possible to distinguish on which track trains were traveling due to limited visibility. Southbound trains were assumed to be on Track 1 and northbound trains were assumed to be on Track 3.

[3]At site ST3, no Purple Line trains traveled on Track 4 during the measurement period and the Brown Line trains had already diverted off of Track 4.

[4]Site ST4 is adjacent to the open-deck structure with only 2 Brown Line tracks (Track 1 and Track 4). There is no Track 2 or Track 3 at this location.

4.2.2 Estimating Existing Vibration Levels

The existing vibration levels at all sensitive receivers in the project area are estimated using a vibration level versus distance curve that was derived from the measurement results. **Figure 4-7** shows the vibration level versus distance curve for vibration from each of the four tracks at site ST5. The slopes of the curves describe how quickly vibration levels decay with distance. The measured vibration levels from the other measurement sites near the open-deck structure, where vibration was measured at a single distance from the structure, are also shown in **Figure 4-7**. **Figure 4-8** shows the average vibration spectra for trains operating on the near track from each of the open-deck structure measurement sites.

Key observations from **Figure 4-7** and **Figure 4-8** are as follows:

- The vibration level versus distance curves from all four tracks at site ST-5 show a similar decay rate with distance. Trains were traveling about 25 mph on all four tracks. Note that Track 1 is the farthest track from the accelerometers.

- The vibration level at sites near crossovers (ST2 and ST3) do not show higher vibration levels compared to the sites where there are no crossovers. The data show that the crossovers do not result in higher vibration levels compared to jointed rail for the open-deck structure.

- The vibration levels measured at site ST4 near the Brown Line track show higher vibration levels compared to the other sites. This may be due to poor wheel condition of Brown Line trains, particularly severe track joints at the measurement site, or increased vibration levels due to the curve in the track. There is not enough information to determine the source of the high vibration levels, so the data is not included in the existing vibration prediction model.

- The vibration levels measured near two of the tracks at ST2 show lower vibration levels compared to the other sites and the other tracks at ST2. The lower vibration levels are from slow train speeds, which did not exceed 15 mph because there was a work crew on the tracks during the measurement.

- The spectra of the vibration levels (**Figure 4-8**) show that vibration attenuates much more rapidly at frequencies above 30 Hz. Below 30 Hz, there is very slow attenuation with distance.

- There was significant train-to-train variation in vibration levels. This variation is shown in the plots of the vibration spectra in **Appendix B**. The variation in levels is due to varying wheel condition and train speed, among other factors.

- The decay with distance curve measured at ST5 Track 2, shown as the heavier dashed line in **Figure 4-7**, has been used to estimate existing vibration levels at sensitive receivers in the project area that are near the existing open-deck structure. The data from ST5 Track 2 generally shows good agreement with the other measurement locations and less train-to-train variation, which indicates that trains on this track were traveling at consistent speeds and had relatively consistent wheel condition. The reference speed of the level versus distance curve is 25 mph.

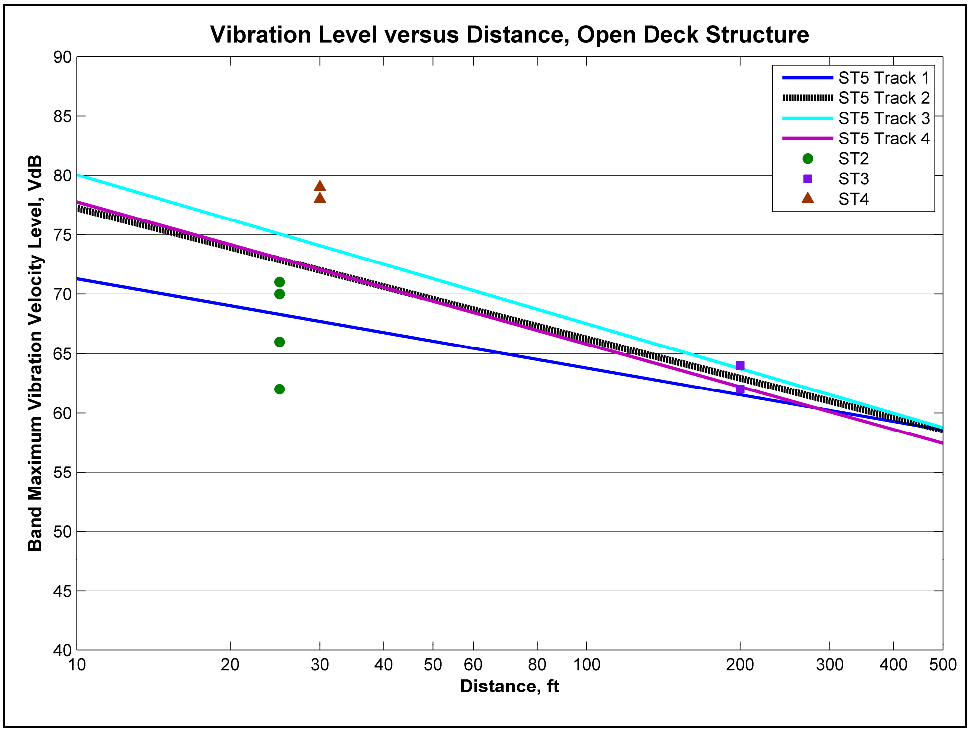


Figure 4-7: Plot of Vibration Level versus Distance for Measurement Sites at Open-Deck Structure (multiple points for sites ST2-ST4 represent different tracks)

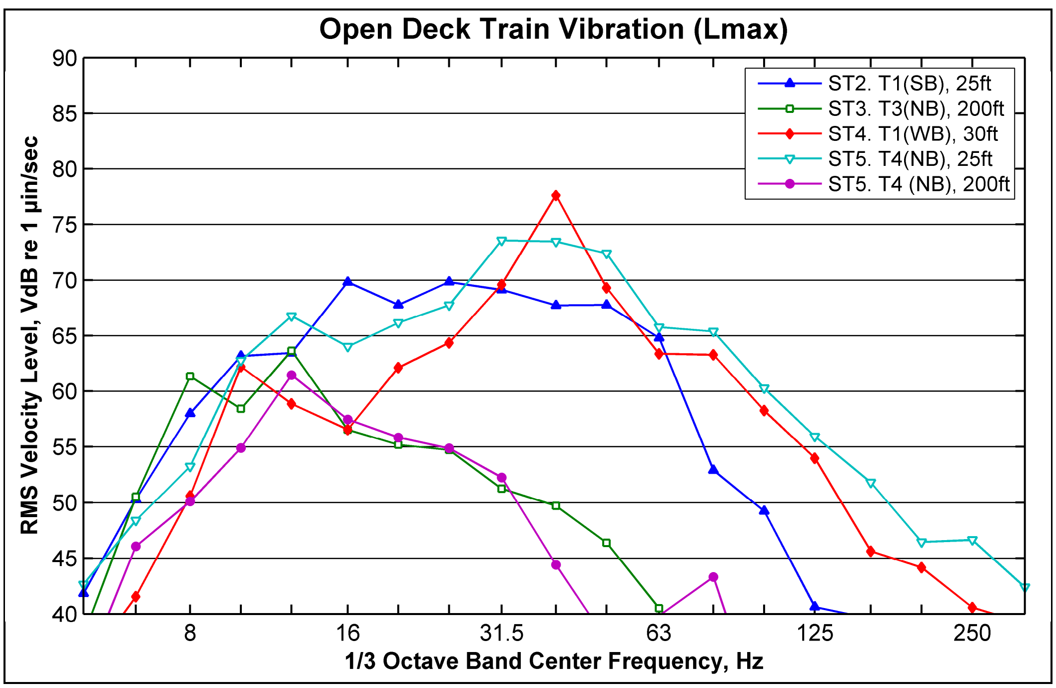


Figure 4-8: Spectra of Train Vibration for Measurement Sites at Open-Deck Structure

The existing vibration levels at sensitive receivers near the closed-deck structure at Belmont station are based on the measured vibration levels from site ST1. At site ST1, the vibration level was measured at a single distance from the track structure. The measurements completed at ST5 are used to model the vibration decay rate. The distance versus level curve for estimating existing vibration levels near the closed-deck structure at Belmont station is shown in **Figure 4-9**. The data point at 30 feet shows the average measured vibration level from Track 1 at Belmont station.

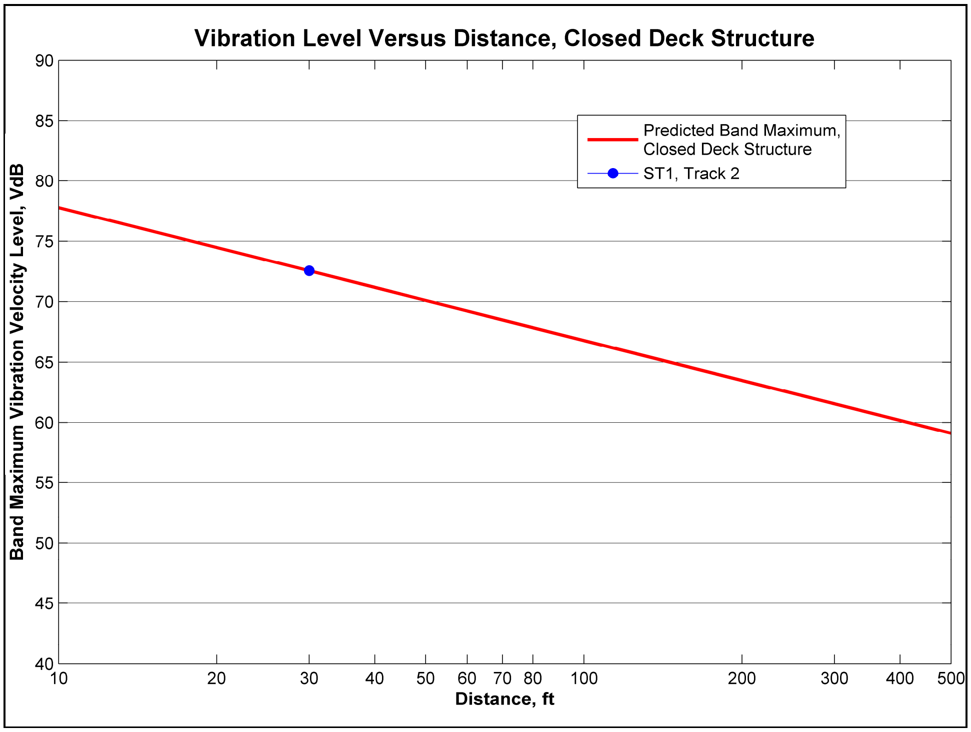


Figure 4-9: Plot of Vibration Level versus Distance for Existing Closed-Deck Structure

The FTA impact threshold for Category 2 land uses is 72 VdB. Using the methods described above, the existing vibration levels would exceed the FTA impact threshold for Category 2 land uses that are within 30 feet of the existing open-deck structure and within 35 feet of the existing closed-deck structure for trains traveling 25 mph. The locations where existing vibration exceeds FTA thresholds are shown on **Figure 4-10**.

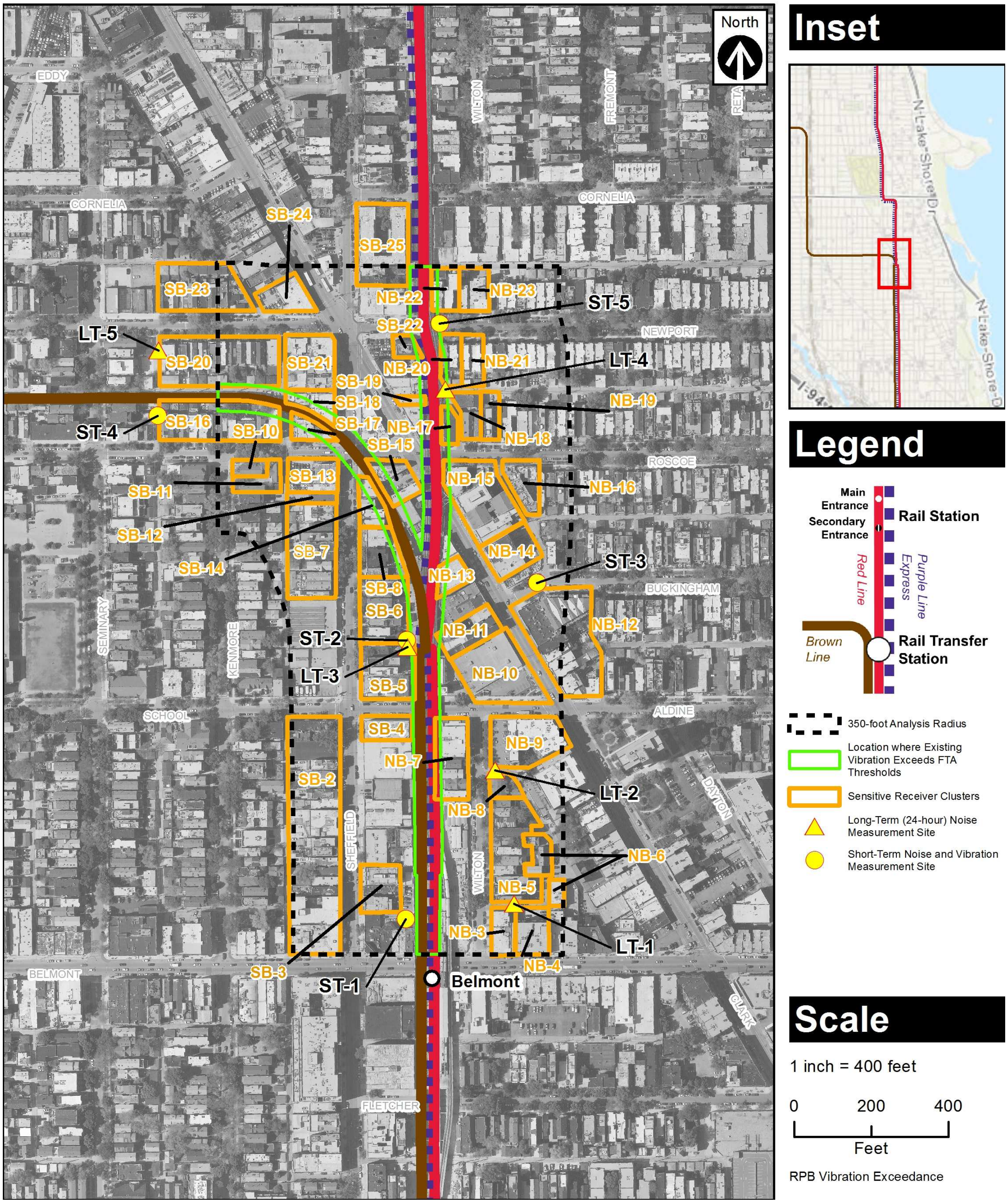


Figure 4-10: Locations Where Existing Vibration Levels Exceed FTA Thresholds

Section 5
Noise and Vibration Prediction Models

5.1 Train Noise Prediction Model

The train noise prediction model is based on reference noise level measurements conducted at a CTA structure similar to what would be built for the project, and on modeling equations provided in the FTA Guidance Manual to account for train speed, distance to the tracks, and number of train events. The noise from trains carrying passengers is the only significant operational noise source associated with the project. The train noise is primarily caused by the steel wheels of the vehicles rolling on the steel rails.

Section 5.1.1 presents a summary of the train noise measurements and the derived reference levels used for prediction. **Section 5.1.2** presents the operational assumptions used for the predictions including train speed and number of train events.

5.1.1 Train Noise Reference Level

5.1.1.1 Train Noise Measurement Location

A train noise measurement was conducted at the existing Fullerton station structure. Fullerton station is an existing Red, Brown, and Purple line station located 1 mile south of the project area. The structure has a closed concrete deck with direct fixation track that extends 200 feet north and south of the station platform, and is similar in construction to the aerial structure proposed for the project. A photograph of the structure is shown in **Figure 5-1**. Characteristics of the Fullerton structure that influence noise levels are:

- Four tracks (numbered from west to east)
- Jointed track
- Concrete deck with direct fixation track
- Steel I-beam girders
- Sound wall along the east and west edges of the structure
- A gap in the concrete deck between Tracks 1 and 2

An aerial photograph of the measurement location is shown in **Figure 5-2**. The train noise was measured 50 feet east of the structure at two microphone positions: 5 feet above ground level and 30 feet above ground level. The four tracks on the structure are labeled T1 to T4 in the figure. Southbound (SB) trains travel on Tracks 1 and 2 and northbound (NB) trains travel on Tracks 3 and 4. During the measurement, eight-car Red Line trains passed on T2(SB) and T3(NB) and four-car Brown Line trains and six-car Purple Line trains passed on T1(SB) and T4(NB).

Figure 5-1: Photograph of the Fullerton Structure Track Deck

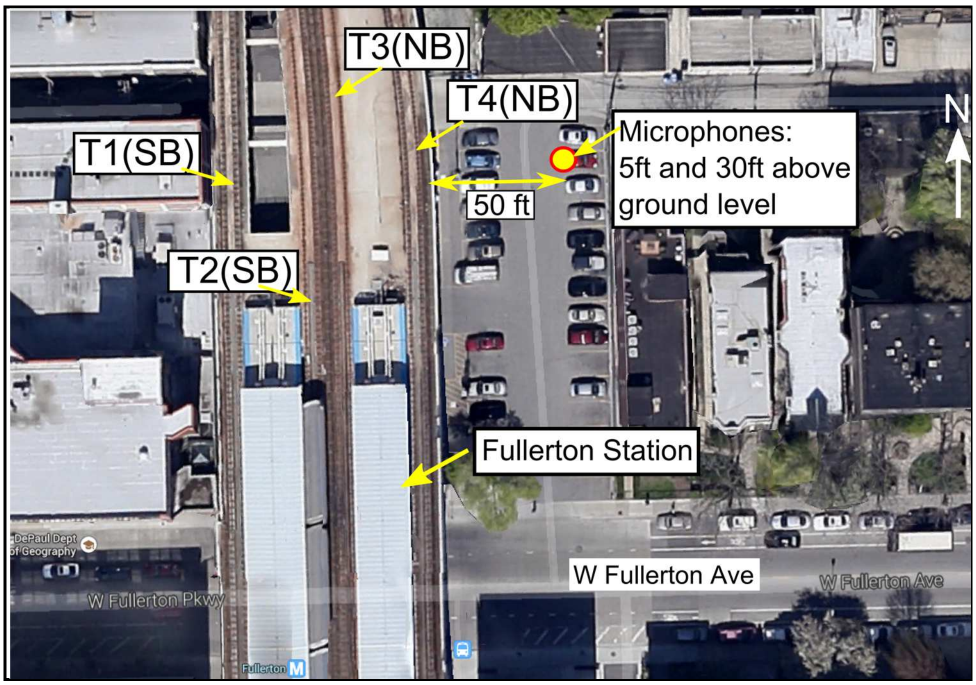


Figure 5-2: Aerial Photograph Showing Measurement Location at Fullerton Structure

5.1.1.2 Train Noise Measurement Results

The train noise measurement results were examined to determine typical noise levels from a closed-deck structure with direct fixation track. The measurements at 30 feet above ground level and 5 feet above ground level were compared to determine the noise reduction provided by the sound wall and closed-deck structure. The 1/3 octave band spectra of all train events during the measurement are shown in **Appendix A**. **Figure 5-3** shows the average SEL at 30 feet above ground level for all four tracks. **Table 5-1** shows the overall A-weighted SEL for the four tracks at 30 feet above ground level and 5 feet above ground level. The noise levels in both the table and the figure have been normalized to 50 feet, 40 mph, and eight-car trains using formulas in the FTA Guidance Manual, so the noise levels from the four tracks are directly comparable.

Key observations from the measured train noise levels are as follows:

- There were track joints on all four tracks near the measurement position. Due to the limited length of the closed-deck structure, it was not possible to measure train noise at a location that was not influenced by jointed track. **Figure 5-4** shows a vertically misaligned track joint from NBT3 and a wide-gap joint from NBT4.
- For NBT3, the train noise at ground level (5-foot elevation) is 5.5 dB less than the train noise measured at the 30-foot elevation. The noise reduction is due to acoustic shielding provided by the concrete deck and the sound wall.
- The noise reduction provided by the concrete deck and sound wall for SBT1 and SBT2 could be increased if the gap in the track deck were eliminated.
- The microphone 30 feet above ground level did not have direct line-of-sight to NBT4. The data from NBT4 cannot be used to directly estimate the acoustic shielding of trains on this track due to the structure and the sound wall. Adjustments are required to estimate noise levels from trains on NBT4 at receivers that are high enough to have a direct line-of-sight to the track.
- Measurements indicate that the noise radiated from the steel I-beam girders are contributing to noise in the 40 to 60 Hz range. Using concrete girders in place of steel I-beam girders would change the character of the noise, but would have a marginal effect on the A-weighted noise level. The A-weighted level is dominated by noise in the 400 to 1250 Hz range.
- The noise levels from all four tracks at 30 feet above ground level generally show good agreement.

Table 5-1: Train Noise Measured at Fullerton Structure

Track	SEL[1] (dBA) (50 feet, 40 mph, eight-car trains)	
	30-foot mic elevation	5-foot mic elevation
SBT1 (Brown Line Trains)	93.6	93.7
SBT2 (Red Line Trains)	93.1	90.0
NBT3 (Red Line Trains)	94.7	89.2
NBT4 (Brown Line Trains)	93.8	91.5

dBA = A-weighted decibels; SEL = measure of sound energy

[1] Results for all tracks were normalized to 50 feet, 40 mph, and eight-car trains. No adjustments were made for differences in shielding.

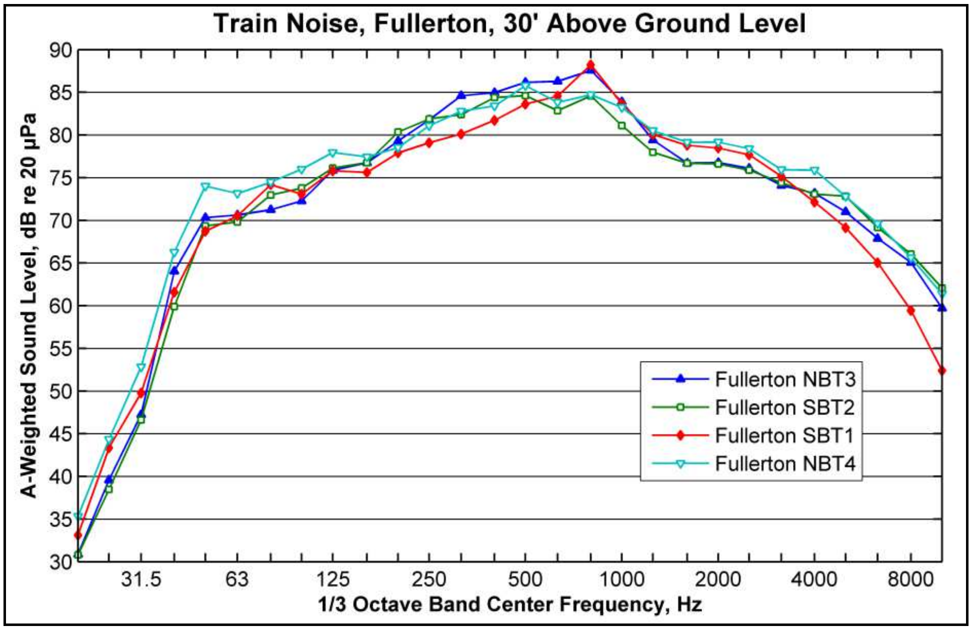


Figure 5-3: Train Noise Measured at 30 Feet above Ground Level at the Fullerton Structure, normalized to 50 feet, 40 mph, and eight-car trains

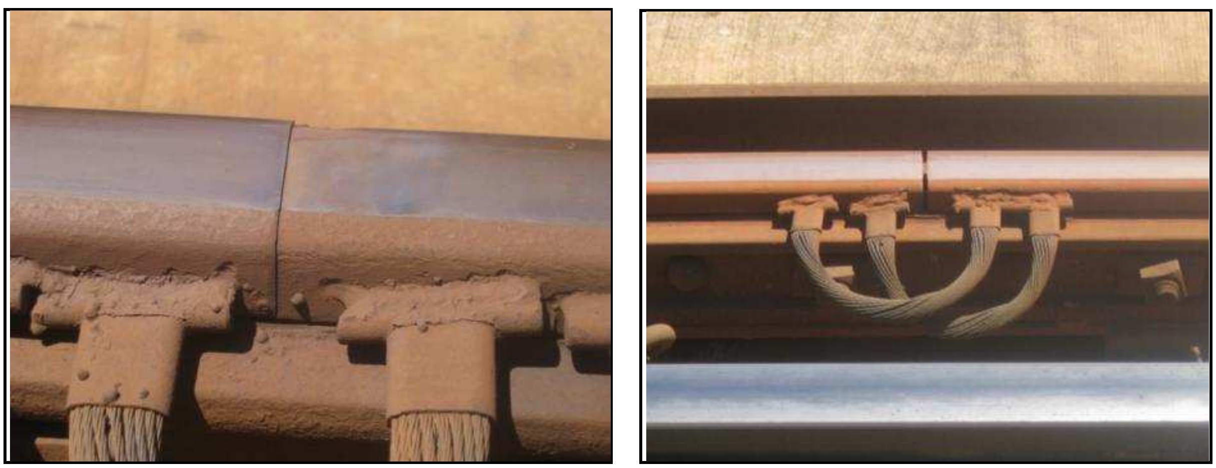


Figure 5-4: Photograph of a Misaligned Track Joint on NBT3 (left) and a Wide-Gap Track Joint on NBT4 (right)

5.1.1.3 Reference Level Assumptions and Prediction Procedure

The noise level measurements from the Fullerton structure have been used to predict future train noise. The Fullerton structure has jointed rail and a gap in the concrete deck. The future structure would have welded rail and a completely closed deck. The reference noise levels used in the predictions are shown in **Table 5-2**. These noise levels are normalized to 50 feet, 40 mph, and eight-car trains. The following method was used to determine the reference train noise levels based on the noise measurement results:

- The measured SEL at 30 feet above ground level for NBT3 was assumed to represent a closed-deck structure with direct fixation track with jointed rail at upper story receivers. The SEL is 94.7 dBA.

- A -4 dB adjustment was applied to the NBT3 SEL to adjust for welded rail. This is a conservative assumption. The FTA Guidance Manual recommends a -5 dB adjustment for welded rail and previous experience indicates track joints can increase noise levels by 4-6 dB. The reference SEL used in the predictions for upper story receivers assuming welded rail is 90.7 dBA.

- The measured noise reduction provided by shielding from the sound wall and closed deck for train noise from NBT3 is 5.5 dB. The gap in the track deck reduces the effectiveness of the sound wall.

- The noise reduction provided by shielding from the proposed structure and sound wall is assumed to be 6.5 dB in the prediction model. This is one decibel greater than the measured noise reduction to account for the gap in the Fullerton structure track deck. The same noise reduction is assumed for all tracks.

- The noise reduction provided by intervening buildings with no direct line-of-sight to the tracks is assumed to be -2.2 dB, based on the measurement results from measurement site LT2.

- The noise level decreases with distance at a rate of 20*log(distance). This relationship was measured using multiple microphone positions at site ST5.

Table 5-2: Reference Noise Levels for Closed-Deck Aerial Structure with Direct Fixation Track

	Closed-deck Aerial Structure, Direct Fixation Track (dBA)
SEL[1], ground floor	84.2
Upper story adjustment[2]	+6.5
SEL[1], upper story	90.7

dBA = A-weighted decibels; SEL = measure of sound energy

[1]SEL is for train noise at 50 feet from tracks, 40 mph, and eight-car trains.

[2]The upper story adjustment is the adjustment used to account for noise shielding from the structure. The upper story SEL is equal to the ground floor SEL plus the upper story adjustment.

The Belmont station structure located within the project area is also similar in construction to the aerial structure proposed for the project. Noise levels were measured adjacent to the Belmont station structure at short-term noise measurement site ST1 at 5 feet above ground level. The measured noise levels from ST1 are not used as the reference noise level for future predictions because of the close proximity to crossovers and an additional gap in the concrete deck between

Tracks 3 and 4; also, no data was obtained at 30 feet above ground level to characterize noise exposure at upper story receivers. A comparison of the measured noise levels from the Fullerton station structure and the Belmont station structure showed higher noise levels at Belmont station for the closest track caused by the additional gap in the track deck and comparable noise levels for the other tracks.

5.1.2 Operational Assumptions and Prediction Formulas

The reference train noise level is adjusted using formulas presented in the FTA Guidance Manual to calculate the L_{dn} and account for train speed and number of trains.

Existing and forecasted train speed and number of train events have been provided by CTA. Plots showing the existing and future train speeds are included in **Appendix D**. The existing and future train volumes for the Red, Purple, and Brown lines are shown in **Table 5-3** for daytime hours (7 AM to 10 PM), nighttime hours (10 PM to 7 AM), and the peak hour of operation (4 PM to 5 PM).

Table 5-3: Existing and Future Number of Train Events

	Existing Train Events (2013)	Future Train Events (2021)
Red Line, daytime, (7 AM-10 PM), eight-car trains	155.7	176.7
Red Line, nighttime (10 PM-7 AM), eight-car trains	25.6	25.7
Red Line, nighttime (10 PM-7 AM), four-car trains	32.2	34.3
Purple Line, daytime (7 AM-10 PM), six-car trains	59.3	67.4
Purple Line, nighttime (10 PM-7 AM), six-car trains	8.1	8.1
Brown Line, daytime (7 AM-10 PM), eight-car trains	133.5	146.7
Brown Line, daytime (7 AM-10 PM), four-car trains	3.0	3.0
Brown Line, nighttime (10 PM-7 AM), eight-car trains	7.2	6.9
Brown Line, nighttime (10 PM-7 AM), four-car trains	29.7	29.7
Red Line, peak hour (4 PM-5 PM), eight-car trains	16.0	20.0
Purple Line, peak hour (4 PM-5 PM), six-car trains	8.7	14.8
Brown Line, peak hour (4 PM-5 PM), eight-car trains	12.5	16.5

Source: CTA 2014

The train noise is predicted for all of the tracks and the predicted total future noise is the logarithmic sum of the noise from all of the tracks. The formula used to predict train noise for each track is:

$$Ldn = SEL_{ref} + 10\log(events_{day} + events_{night}x10) - 10\log\left({}^{Dist}/_{Dist_{ref}}\right) + 20\log\left({}^{V}/_{V_{ref}}\right) + Shielding - 49.4$$

where:

L_{dn}	=	Day-night sound level in A-weighted decibels (dBA)
SEL_{ref}	=	Reference SEL in dBA at 50 feet, 40 mph, and eight-car train
$events_{day}$	=	The number of train events during daytime hours (7 AM to 10 PM) normalized to eight-car trains
$events_{night}$	=	The number of train events during nighttime hours (10 PM to 7 AM) normalized to eight-car trains
Dist	=	The distance from the facade of the sensitive receiver to the track centerline
$Dist_{ref}$	=	The reference SEL distance (50 feet)
V	=	The speed of the train as it passes the sensitive receiver
V_{ref}	=	The reference SEL speed (40 mph)
Shielding	=	The shielding adjustment applied when the sensitive receiver does not have direct line-of-sight to the tracks

An additional adjustment has been applied to sensitive receivers near special trackwork. At turnouts and crossovers, there is a gap in the rail where the two rails cross. The wheels striking the ends of the gap increase noise levels near the special trackwork, similar to the increase in noise levels occurring from a wide-gap or misaligned joint. An adjustment of +6 dB is applied when special trackwork would be located within 300 feet of sensitive receivers.

There are alternatives to typical frogs that could result in lower impact forces and lower noise level increases at sensitive receivers near special trackwork. Examples of low-impact frogs include flange-bearing frogs and monoblock frogs. Flange-bearing frogs are designed with a ramp so the wheels transition onto the flange through the gap in the special trackwork, providing a smoother transition. For a flange-bearing frog to be effective at reducing noise, the ramp must provide smooth transition of load from the wheel tread to the wheel flange and then back from the flange to the tread. The general consensus is that the ramps should have a grade of 1:20 or possibly 1:40. Monoblock frogs are designed without bolted joints and rails which would result in a smoother running surface compared with traditional frogs. The mitigated noise level analysis assumes a +3 dB increase from flange-bearing or monoblock frogs, half the increase assumed for typical frogs. Low-impact frogs also provide maintenance benefits due to the lower impact forces as the trains travel through the frog.

The FTA Guidance Manual also presents formulas to account for ground absorption and shielding effects, although they have not been used in this analysis. The FTA Guidance Manual recommends ground absorption be zero for areas with hard ground, such as pavement. We assume the entire project area has hard ground; therefore, it would not be appropriate to include a ground absorption adjustment in this analysis. Adjustments for effects from noise shielding from the sound wall on the structure and from intervening building rows are based on measurement results.

5.1.3 Comparison of Prediction Models

Prediction models have been presented for estimating noise levels from the existing closed-deck structure at Belmont station, the existing open-deck structure, and for the proposed closed-deck aerial structure with direct fixation track with welded rail. **Table 5-4** presents a comparison of the reference noise levels used in each prediction model.

Key observations from the table include the following:

- At upper and lower story receivers, replacing the open-deck structure with an aerial structure with direct fixation track would decrease noise levels by more than 10 dB.
- The existing closed-deck aerial structure at Belmont station has higher noise levels than the proposed closed-deck aerial structure due to jointed rail and gaps in the track deck.

Table 5-4: Comparison of Reference Noise Levels From Different Track Structures

	Existing Closed-Deck Structure at Belmont	Existing Open-Deck Structure	Proposed Closed-Deck Structure
SEL[1] (dBA), ground floor	90.6	102.3	84.2
Upper story adjustment (dBA)[2]	+5.5	+0	+6.5
SEL[1] (dBA), upper story	96.1	102.3	90.7
Difference from future, ground floor (dBA)	-6.4	-18.1	--
Difference from future, upper story (dBA)	-5.4	-11.6	--

dBA = A-weighted decibels; SEL = measure of sound energy

[1]SEL is for train noise at 50 feet from tracks, 40 mph, and eight-car trains.

[2]The upper story adjustment is the adjustment used to account for noise shielding from the structure. The upper story SEL is equal to the ground floor SEL plus the upper story adjustment.

5.2 Train Vibration Prediction Model

The train vibration prediction model is based on vibration level measurements conducted at a CTA structure similar to what would be built for the project, and on the vibration level versus distance curves measured in the project area. Adjustments for train speed, special trackwork, and welded rail are based on information in the FTA Guidance Manual. The vibration from trains carrying passengers is the only significant operational vibration source associated with the project.

Section 5.2.1 presents a summary of the train vibration measurements. **Section 5.2.2** describes the prediction model.

5.2.1 Train Vibration Measurements

5.2.1.1 Train Vibration Measurement Location

Vibration from trains was measured at the existing Fullerton station structure at the same location as the noise measurement. Fullerton station is an existing Red, Brown, and Purple line station located 1 mile south of the project area. The structure has a closed concrete deck with direct fixation track that extends 200 feet north and south of the station platform.

An aerial photograph indicating the accelerometer positions is shown in **Figure 5-5**. There are four tracks on the structure, labeled T1 to T4. Southbound trains travel on Tracks 1 and 2 and northbound trains travel on Tracks 3 and 4. During the measurement, eight-car Red Line trains operated on T2(SB) and T3(NB) and four-car Brown Line trains and six-car Purple Line trains operated on T1(SB) and T4(NB). Vibration was measured both east and west of the structure at the following locations:

- Column under T1(SB) track
  - 1 foot from column under T1
  - 30 feet west of column under T1
  - 50 feet west of column under T1
  - 18 feet south of column under T1 (between two columns)
- Column under T4(NB) track
  - 1 foot from column under T4
  - 25 feet east of column under T4
  - 31 feet east of column under T4
  - 50 feet east of column under T4

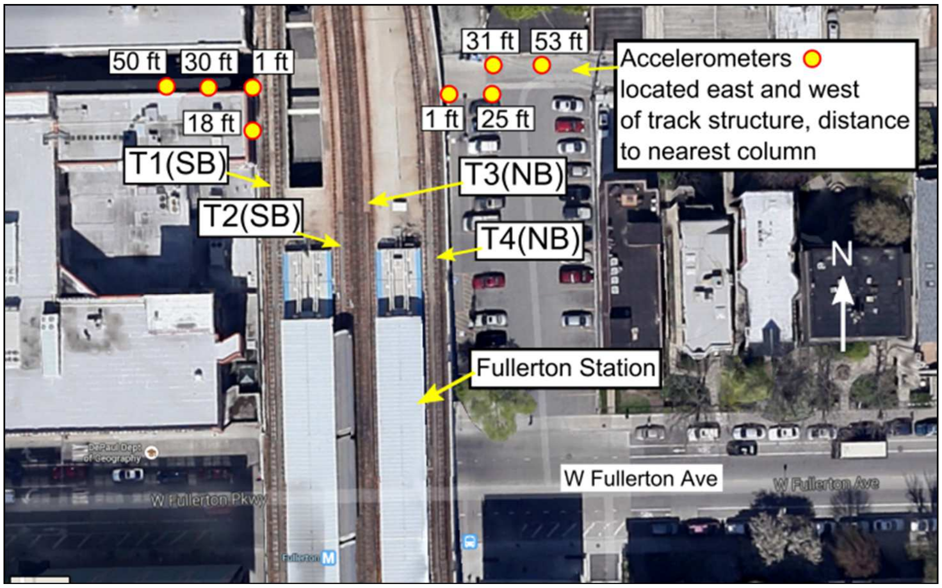


Figure 5-5: Aerial Photograph Showing Vibration Measurement Locations at the Fullerton Structure

5.2.1.2 Train Vibration Measurement Results

The train measurement results from Fullerton station were examined to determine typical vibration levels from a closed-deck structure with direct fixation track. The highest measured vibration levels were from trains running on Track 1 and Track 4, closest to the measurement locations. Because the FTA impact thresholds for vibration are based on maximum vibration levels, only the vibration levels from Tracks 1 and 4 are presented in this section. The measured vibration levels from all train events are presented in **Appendix B**.

Figure 5-6 shows the measured band maximum level at each measurement location from each train event. Key observations from **Figure 5-6** are as follows:

- The vibration levels measured at 25 feet east of the structure were abnormally high compared to the other measurement locations, including the measurement located nearby at 31 feet east of the structure. The nearby measurement sites did not have the same high vibration levels. This implies the high levels at the 25-feet location were due to a localized ground condition that is an anomaly and is not representative of the structure.
- The vibration levels measured at 50 feet west of the structure were abnormally low compared to all other measurement locations. This may be due to attenuation from the large building located directly adjacent to the measurement location.
- A best-fit level versus distance curve was derived from the measurement results, excluding the abnormally high vibration levels at 25 feet and the low vibration levels at 50 feet.

The data plotted in **Figure 5-6** includes trains traveling on track T1 at approximately 40 mph and on track T4 at approximately 25 mph. The vibration levels were similar at the two speeds. Based on the guidance provided in the FTA Guidance Manual, the vibration levels at 40 mph are expected to be 4 decibels higher than the vibration levels at 25 mph. The lack of an apparent correlation between vibration level and speed can be attributed to the large variation in vibration levels that appear to be due to variable wheel condition and track condition at CTA. In addition, the correlation between vibration level and train speed is a complex function of speed, track resonance, wheel condition, rail corrugation, and other factors.

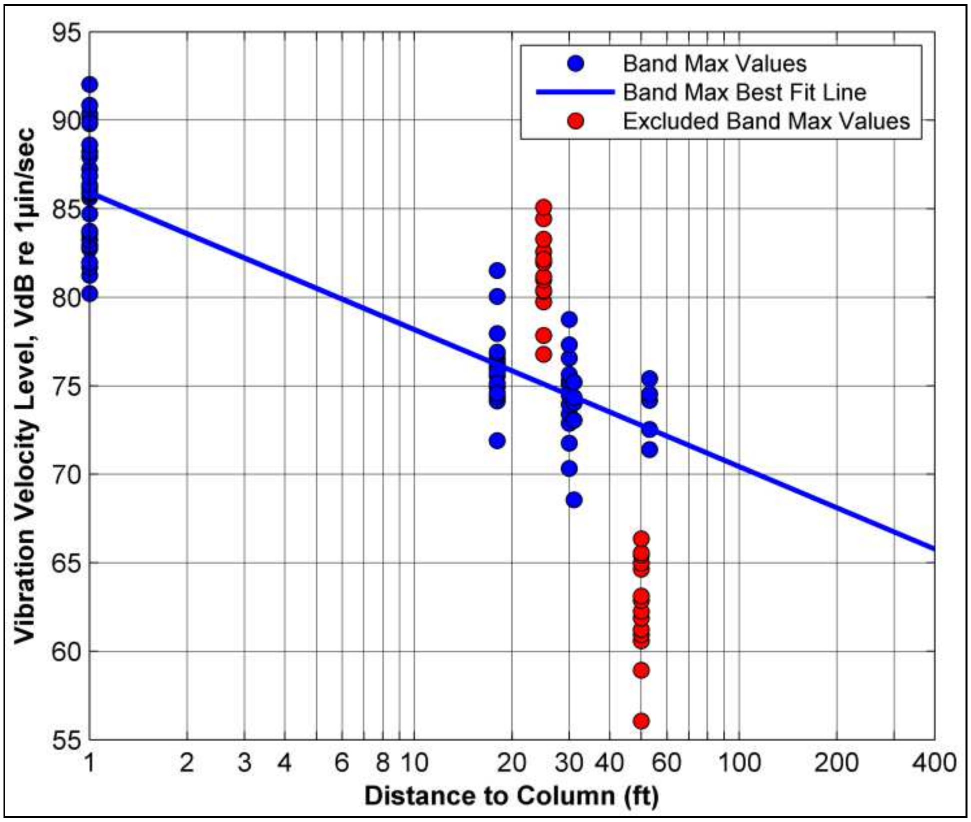


Figure 5-6: Vibration Levels versus Distance at Fullerton Structure

5.2.2 Train Vibration Prediction Model

The future vibration levels at sensitive receivers have been predicted by combining the train vibration levels measured at Fullerton station with the vibration decay with distance relationship measured in the project area and presented in **Section 4.2.** Measurements completed in the project area have been used to model the vibration decay rate in place of the measurements taken at the Fullerton structure because the vibration decay rate depends on local soil conditions.

One factor that must be accounted for is that the vibration level in the existing project area was not measured at distances closer than 25 feet from the elevated structure. At distances closer to the structure, the vibration levels likely decay at a slower rate. To account for this, the observed vibration amplitudes and decay rate close to the Fullerton structure columns were used to model future vibration levels within 30 feet of a column. The decay rate measured at the existing open-deck structure was used to estimate vibration levels at greater distances from the column.

The curves used to develop the prediction model are shown in **Figure 5-7**. Following is a summary of the steps taken to develop the vibration prediction model:

- The Fullerton structure has jointed rail; however, the future structure would have welded rail. A -4 dB adjustment was applied to the vibration levels measured at Fullerton to adjust for welded rail. The FTA Guidance Manual recommends a -5 dB adjustment. A -4 dB adjustment was used because it is consistent with the adjustment used in the noise analysis, and because it is more likely to err on the side of over-predicting future vibration levels.

- The vibration versus distance curve measured at Fullerton after adjustment for welded rail was used to estimate vibration levels for receivers that would be located 3 feet to 30 feet from a future column.

- The vibration versus distance slope used to predict the existing vibration level was applied for sensitive receivers located farther than 30 feet from a column. This decay rate is expected to produce a reasonable estimate of how the ground conditions at sensitive receivers would affect vibration levels.

- The Newport curve in **Figure 5-7** has been adjusted to 40 mph using a $15 \times log(speed/speed_{ref})$ adjustment, so it is comparable to the data measured at Fullerton. The prediction model has a reference speed of 40 mph.

- The FTA impact threshold for category 2 land uses is 72 VdB. The predicted vibration level exceeds the threshold at any receivers located closer than 20 feet from the nearest column for a train traveling 40 mph.

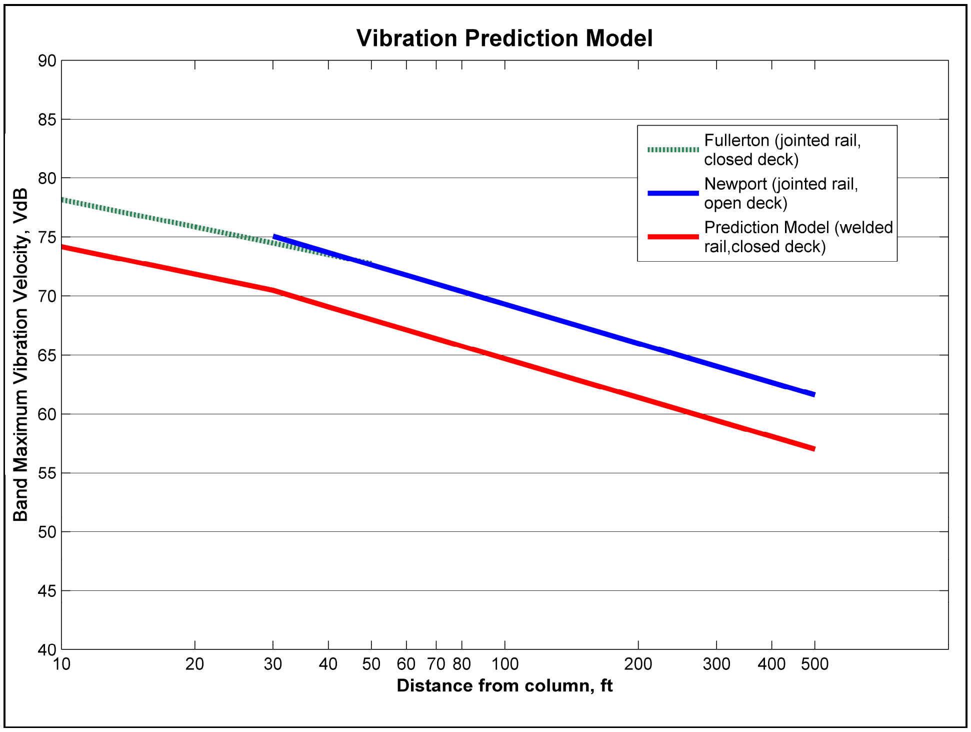


Figure 5-7: Vibration-vs-Distance Curve Used to Predict Future Vibration Levels

The distance versus vibration level curve presented in **Figure 5-7** applies to welded track for trains traveling at 40 mph. A speed adjustment of $20 \times log(speed/speed_{ref})$ is recommended in the FTA Guidance Manual when no other information is available regarding level variations with speed. Experience with other transit systems indicates that vibration level is a complex function of speed, and is often closer to $15 \times log(speed/speed_{ref})$. To ensure train vibration levels are not underestimated, a speed adjustment of $20 \times log(speed/speed_{ref})$ is applied when trains are traveling faster than 40 mph and a speed adjustment of $15 \times log(speed/speed_{ref})$ is applied when trains are traveling slower than 40 mph.

An additional adjustment is applied to vibration predictions for sensitive receivers near special trackwork. Similar to noise, train wheels striking the gaps in the rail at special trackwork increase vibration. An adjustment of +10 dB is applied to sensitive receivers located within 50 feet of special trackwork. At sensitive receivers located farther than 50 feet from special trackwork, the increase in vibration levels is assumed to be $+10 - 11 \times log(distance/50)$. The vibration decay rate is based on the vibration level versus distance curves measured at site ST5. If the turnout is placed on the Belmont structure, which has jointed rail that would not be replaced as part of the project, an adjustment of +6 dB is applied to the prediction in place of a +10 dB adjustment because a +4 dB adjustment is already included for the jointed rail.

5.3 Construction Noise Prediction Model

The construction noise prediction model follows the methodology described in the FTA Guidance Manual for a general construction noise assessment. A general construction noise assessment is appropriate for projects in the early assessment stage when the equipment roster and schedule are still undefined.

The construction noise prediction model includes the following assumptions:

- The predicted level includes only the two noisiest pieces of equipment expected to be used in each construction phase.
- The equipment would operate continuously for a period of one hour.
- The emission levels of the equipment at 50 feet are taken from **Table 5-5**.
- Free-field conditions are assumed and ground effects are ignored.

Table 5-5: Noise Levels for Typical Construction Equipment

Equipment	Expected Project Use	L_{max}[1] (dBA)
Air compressors	Pneumatic tools and general maintenance (all phases)	81
Backhoe	General construction and yard work	80
Compactor	Soil compaction	82
Concrete Mixer	Mixing concrete	82
Concrete Pump	Pumping concrete	82
Concrete Vibrator	Ensuring good pours of concrete	76
Crane	Materials handling: removal and replacement	83
Dozer	General construction and materials handling	85
Generator	Powering electrical equipment	81
Jackhammers	Pavement removal	88
Loader	General construction and materials handling	85
Pile-drivers	Support for structures and hillsides	101
Power plants	General construction use: nighttime work	72
Pumps	General construction use: water removal	76
Pneumatic tools	Miscellaneous construction work	85
Spike Driver	Putting spikes in railroad	77
Tie Cutter	Cuts railroad ties	84
Tie Handler	Moves and inserts railroad ties	80
Truck	Materials handling: general hauling	88

dBA = A-weighted decibels; L_{max} = maximum noise level

[1] Typical maximum noise level under normal operation as measured at 50 feet from the noise source.

Source: FTA 2006

5.4 Construction Vibration Prediction Model

The construction vibration prediction model follows the methodology described in the FTA Guidance Manual for a construction vibration damage assessment. The primary concern from construction activities is potential for damage to buildings. Because construction vibration is temporary, it is not usually a major concern for annoyance.

The major pieces of high-vibration construction equipment likely to be used during construction are listed in **Table 5-6**. The reference peak particle velocity (PPV) levels presented in the table are from reference levels provided in the FTA Guidance Manual and from measurements performed during the construction of the D-to-M Street Rail project in Tacoma, Washington.

The propagation adjustment used to predict vibration at different distances from the equipment is:

$$PPV_{equip} = PPV_{ref} x \left(D_{ref}/D\right)^{1.5}$$

where:

PPV_{equip}	=	peak particle velocity in inches per second of the equipment adjusted for distance
PPV_{ref}	=	reference vibration level in inches per second at distance D_{ref} taken from **Table 5-6**
D	=	distance from the equipment to the receiver

Table 5-6: Vibration Levels for Typical Construction Equipment

Equipment	PPV Ref Level at 100 feet (in./sec.)
Vibratory pile-driver	0.140
Impact pile-driver	0.200
Sonic pile-driver	0.213
Auger drill rig	0.011
Cranes	0.001
Dozer	0.011
Dump truck	0.010
Front-end loader	0.011
Jackhammer	0.003
Mounted hammer hoe ram	0.190

PPV = peak particle velocity

Source: FTA 2006; D-to-M Street Rail Project, Tacoma, WA 2009

Section 6
Impacts

6.1 Construction Impacts

6.1.1 Construction Noise

The construction noise analysis considers the temporary noise impacts that construction would cause in the project vicinity. These impacts would end when project construction is complete. Construction of a modern closed-deck structure requires the use of heavy earth moving equipment, pneumatic tools, pile drivers, and other equipment.

Table 6-1 shows the predicted construction noise levels for three different construction phases. The three different phases are:

1. **Demolition, Site Preparation, and Utilities Relocation:** Major noise-producing equipment expected to be used during the demolition phase of the project includes trucks and jackhammers. The predicted L_{eq}(1hr) is 91 dBA at residences 50 feet away. Other noise sources are likely to include air compressors, backhoes, cranes, dozers, generators, loaders, pumps, and power plants.

2. S**tructures Construction, Track Installation, and Paving Activities:** The loudest noise sources during construction of the aerial structure would include loaders, trucks, and cranes. Concrete mixers, concrete pumps, and concrete vibrators would be required to construct the structure itself. The predicted L_{eq}(1hr) is 90 dBA at a distance of 50 feet. Note that while pile driving may take place during this phase of construction, it is not included in this part of the analysis because pile driving is an impulse noise source rather than a continuous noise source. It does not accurately represent construction noise over time and is therefore treated separately.

3. **Miscellaneous Activities:** This phase occurs after the heavy construction of the structure and tracks and includes the installation of railings and signs as well as other activities. The predicted L_{eq}(1hr) is 90 dBA at a distance of 50 feet from the site. Construction noise from this phase would likely be for a short period of time due to the less intensive nature of the work.

The predicted construction noise levels in **Table 6-1** exceed the FTA daytime impact thresholds for sensitive receivers located within 50 feet of the construction activities. A map of sensitive receiver clusters within this 50-foot boundary are provided in **Figure 6-1**.

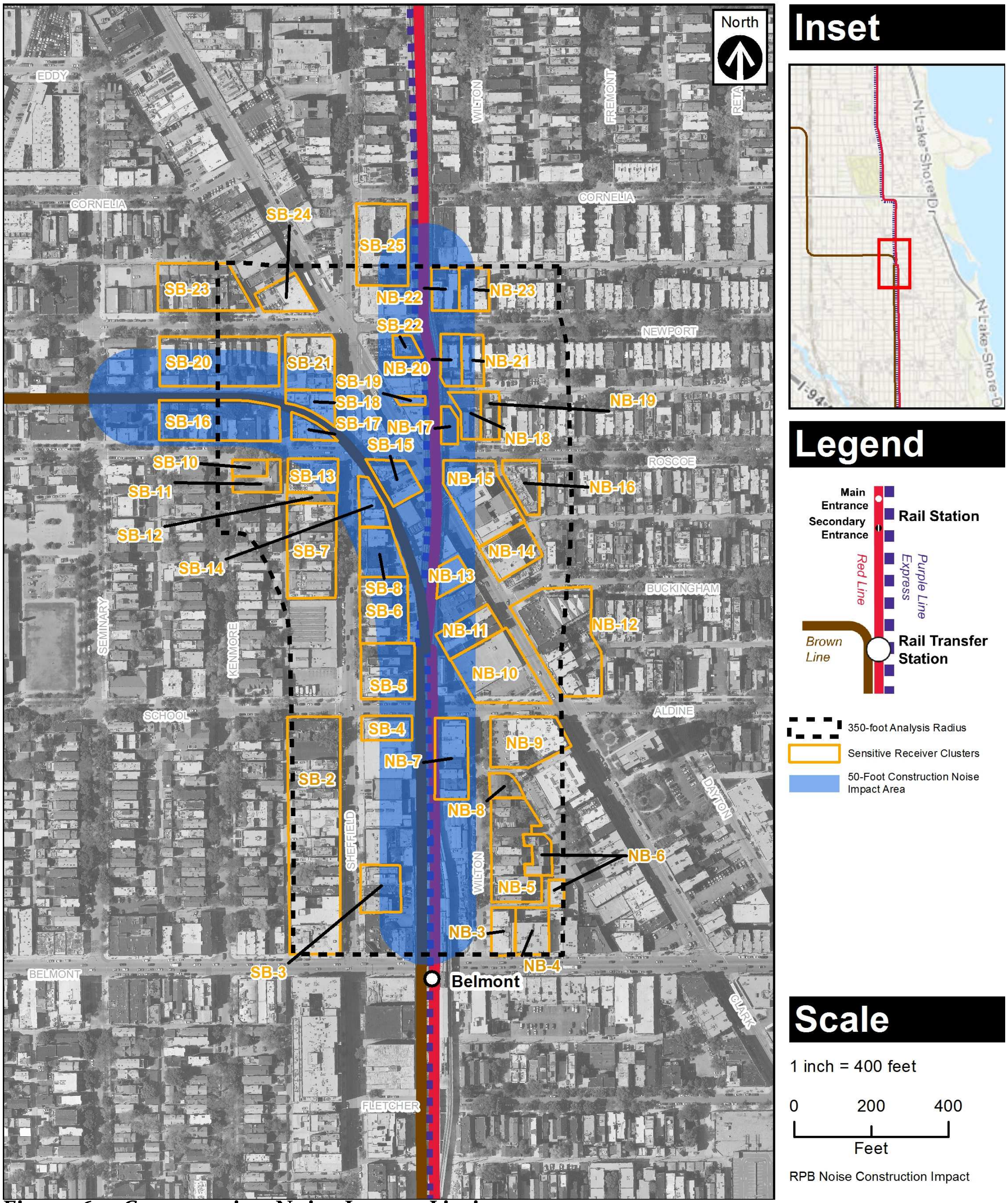


Figure 6-1: Construction Noise Impact Limits

Table 6-1: Predicted Noise Levels for Typical Construction Phases

Scenario[1]	Equipment[2]		Predicted L_{eq}(1hr)[3] (dBA)		Impact threshold L_{eq}(1hr) (dBA)	
	Two Loudest Pieces	Additional Equipment	10 feet	50 feet	Day	Night
Demolition, site preparation, and utilities relocation	Trucks, jackhammers	Air compressors, backhoes, cranes, dozers, generators, loaders, pumps, power plants	105	91	90	80
Structures construction, track installation	Trucks, loaders	Air compressors, backhoes, cement mixers, concrete pumps, concrete vibrators, cranes, generators, pumps, power plants	104	90	90	80
Miscellaneous activities	Trucks, loaders	Air compressors, backhoes, cranes, pneumatic tools, pumps	104	90	90	80

dBA = A-weighted decibels; L_{eq} = equivalent continuous sound level
[1] Operational conditions under which the noise levels are projected.
[2] Normal equipment in operation under the given scenario.
[3] L_{eq} is the combined noise of the two loudest pieces of equipment. This is a worst case scenario in which the equipment is being used continuously for an hour.

In addition to the construction activities presented in **Table 6-1**, pile driving may be required to support permanent structures such as the aerial track structure. Pile driving can produce maximum short-term noise levels of 101 dBA at 50 feet. Actual levels vary, depending on the distance and topographical conditions between the pile-driving location and the receiver location. An alternative to impact pile driving is to drill holes and use impact only to set piles. Pile driving is not currently proposed for this project.

6.1.2 Construction Vibration

High vibration activities during construction include demolition of buildings, construction of aerial structures, pavement breaking, ground compaction, and pile driving. Pile-drivers may be used to drive the piles into soil to provide support to columns of elevated structures.

Table 6-2 presents the distance beyond which the damage risk criteria would not be expected to be exceeded for the major vibration-generating pieces of equipment. It is important to note that the vibration limits are the levels at which there is a risk for damage, not the level at which damage would occur. The distance to the impact threshold is calculated for the four different building categories presented in **Table 6-2**.

Key results from **Table 6-2** are as follows:

- Most of the equipment can be operated without risk of damage at distances of 15 feet or greater from non-engineered timber and masonry buildings or at distances of 8 feet or greater from reinforced concrete buildings. The exceptions are the mounted hammer hoe ram and pile-drivers.

- Predicted vibration levels from pile-driving are likely to exceed the damage thresholds at the closest receivers. Alternate pile-driving methods can reduce vibration levels. For example, sonic pile-drivers at lower settings or pre-drilled holes can be used closer to buildings without exceeding the damage thresholds.

Table 6-2: Distance to Construction Vibration Impact Thresholds

Equipment	PPV Ref Level at 100 feet (in./sec.)	Distance to Impact Thresholds (feet)			
		Damage Criteria 0.5 in./sec. PPV[1]	Damage Criteria 0.3 in./sec. PPV[2]	Damage Criteria 0.2 in./sec. PPV[3]	Damage Criteria 0.12 in./sec. PPV[4]
Vibratory pile-driver	0.140	43	60	79	111
Impact pile-driver	0.200	54	76	100	141
Sonic pile-driver	0.213	57	80	104	147
Auger drill rig	0.011	8	11	14	20
Cranes	0.001	2	2	3	4
Dozer	0.011	8	11	14	20
Dump truck	0.010	7	10	14	19
Front-end loader	0.011	8	11	14	20
Jackhammer	0.003	3	5	6	9
Mounted hammer hoe ram	0.190	52	74	97	136

PPV = peak particle velocity
[1] The impact threshold for reinforced concrete, timber, or steel buildings (no plaster) is 0.5 in./sec. PPV.
[2] The impact threshold for engineered concrete and masonry buildings (no plaster) is 0.3 in./sec. PPV.
[3] The impact threshold for non-engineered timber and masonry buildings is 0.2 in./sec. PPV.
[4] The impact threshold for buildings extremely susceptible to vibration damage is 0.12 in./sec. PPV.

6.2 Operation Impacts

Noise and vibration impacts were identified using the prediction models presented in **Section 5**. Recommended mitigation measures for all sensitive receivers where impact is predicted are included in **Section 7**.

6.2.1 No Build Alternative

6.2.1.1 Noise

There is no predicted change in noise levels for the No Build Alternative. The noise levels for the No Build Alternative do not exceed the FTA impact thresholds and no noise impact is predicted.

6.2.1.2 Vibration

The vibration levels for the No Build Alternative are expected to remain the same as under existing conditions. The vibration levels for the No Build Alternative to do not exceed the FTA impact thresholds and no vibration impact is predicted.

6.2.2 Build Alternative

6.2.2.1 Noise

Changes in noise levels as a result of the build alternative would result from an increase in the number of train trips, the construction of the bypass track closer to some receivers, the change in track structure, installation of special trackwork, and the increase in train speeds. The Build Alternative assumes a closed-deck aerial structure with direct fixation track, welded rail, and a sound wall on the east and west edges of the structure.

Figure 6-2 provides a summary of noise impacts resulting from the Build Alternative.

Table 6-3 presents the existing noise levels, predicted future noise levels, and the FTA allowable noise increase for moderate and severe noise impacts. The far right column indicates the sensitive receivers where moderate or severe impact is predicted. Of the 56 clusters of sensitive receivers within 350 feet of the alignment, six are predicted to have a moderate impact and four are predicted to have a severe impact before mitigation.

At approximately 90 percent of the sensitive receiver clusters, noise levels would be significantly reduced as a result of the project because the existing open-deck steel structure would be replaced with a quieter closed-deck structure. These sensitive receiver clusters are bolded and in red text on **Table 6-3** to note locations where noise would be significantly reduced.

Noise impacts are predicted at six residential clusters where special trackwork would be installed and four residential clusters where buildings would be removed as a result of the project. Removing buildings would cause noise levels to increase because acoustic shielding is removed. Wheel impacts at special trackwork locations are predicted to increase noise levels by up to 6 dB. The following paragraphs provide further details on these ten sensitive receiver clusters where moderate or severe impacts are predicted.

Impacts are predicted at six sensitive receivers located near turnouts that would be installed as part of the project. New turnouts are proposed where the bypass track would tie in with the existing mainline tracks on the existing Belmont station structure at the south end of the project area and on the Brown Line at the north end of the project area. The clusters where noise levels are predicted to increase above the impact threshold because a turnout would be installed are clusters NB-3 through NB-6, SB-2, and SB-16 (located immediately east and west of the tracks between Belmont Avenue and School Street). Sensitive receiver clusters surrounding four of these receivers (NB-3, NB-4, NB-6, and SB-2) would experience a moderate impact before mitigation and two sensitive receiver clusters (NB-5 and S-16) would experience a severe impact before mitigation.

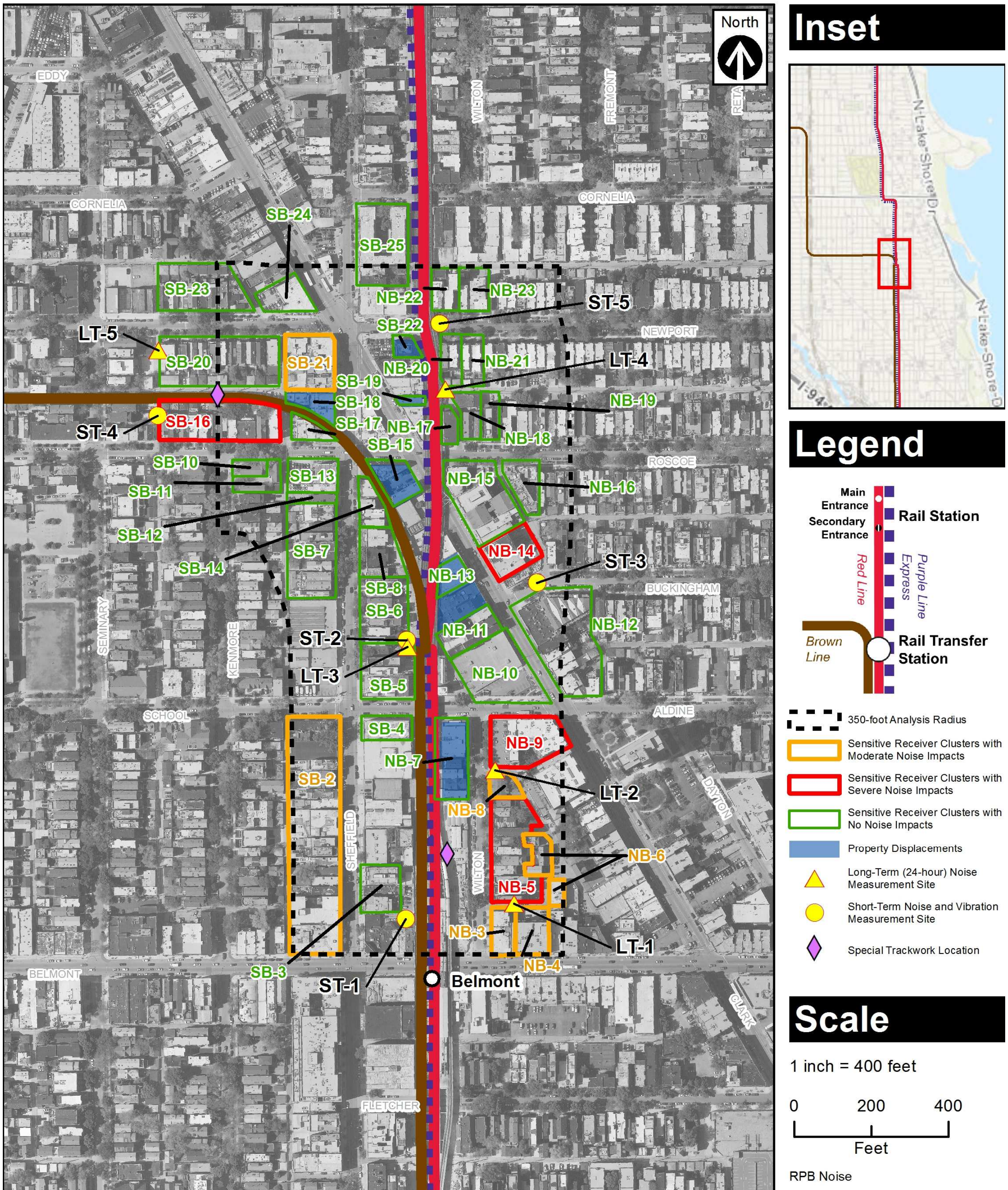


Figure 6-2: Permanent Noise Impacts Before Mitigation

Impacts are also predicted at four sensitive receivers where train noise levels would increase due to the removal of intervening buildings to accommodate the new bypass structure. The clusters where noise levels are predicted to increase above the impact threshold due to the removal of a building include NB-8, NB-9, NB-14, and SB-21. NB-8 and NB-9 are located immediately west of the tracks and south of School Street, NB-14 is located on Clark Street between School Street and Roscoe Street, and SB-21 is located south of Newport Avenue and west of Sheffield Avenue. Clusters surrounding NB-8 and SB-21 would experience a moderate impact before mitigation and clusters surrounding NB-9 and NB-14 would experience a severe impact before mitigation.

Table 6-3: Predicted Noise Levels at Sensitive Receivers

No.	Receiver Description	Existing Noise Level	Predicted Build	Increase	FTA Allowable Noise Increase		Impact?
		(L_{dn} in dBA)	(L_{dn} in dBA)	(dB)	Moderate Impact (dB)	Severe Impact (dB)	
Category 2 (Residential) Land Uses							
NB-1	MFR	73.2	71.6	-1.5	0.6	2.4	--
NB-2	MFR	64.5	63.8	-0.7	1.5	3.8	--
NB-3	MFR	65.9	68.0	2.1	1.3	3.5	Moderate
NB-4	MFR	69.5	71.8	2.2	1.1	2.8	Moderate
NB-5a	MFR	72.6	75.5	2.9	0.7	2.4	Severe
NB-5b	MFR	78.7	74.0	-4.7	0.2	1.5	--
NB-6	MFR	68.2	70.5	2.3	1.2	3.0	Moderate
NB-7	MFR	94.2	Property take	--	0.0	0.1	--
NB-8	MFR	71.9	73.7	1.8	0.8	2.5	Moderate
NB-9	MFR	70.2	73.8	3.7	1.0	2.7	Severe
NB-11	MFR	76.5	74.4	-2.1	0.3	2.1	--
NB-12	MFR	69.1	66.6	-2.4	1.1	2.9	--
NB-13	MFR	92.1	Property take	--	0.0	0.1	--
NB-14	MFR	72.8	75.7	2.8	0.7	2.4	Severe
NB-15	MFR	87.0	76.4	-10.6	0.0	0.3	--
NB-16	MFR	68.5	61.7	-6.8	1.1	3.0	--
NB-17	MFR	87.0	75.7	-11.3	0.0	0.3	--
NB-18	MFR	79.0	70.4	-8.6	0.2	1.4	--
NB-19	MFR	72.3	64.6	-7.7	0.7	2.5	--
NB-20	MFR	87.0	74.3	-12.7	0.0	0.3	--
NB-21	MFR	76.4	67.3	-9.1	0.3	2.1	--
NB-22	MFR	89.4	78.6	-10.9	0.0	0.2	--
NB-23	MFR	76.9	66.1	-10.9	0.3	2.0	--
NB-24	MFR	89.9	78.6	-11.4	0.0	0.1	--

No.	Receiver Description	Existing Noise Level	Predicted Build	Increase	FTA Allowable Noise Increase		Impact?
		(L_{dn} in dBA)	(L_{dn} in dBA)	(dB)	Moderate Impact (dB)	Severe Impact (dB)	
NB-25	MFR	77.7	66.3	-11.4	0.2	1.9	--
NB-26	MFR	89.9	78.6	-11.4	0.0	0.1	--
NB-27	MFR	72.1	60.8	-11.4	0.8	2.5	--
SB-1	MFR	60.8	60.7	-0.1	1.9	4.8	--
SB-2a	MFR	65.2	67.6	2.4	1.4	3.6	Moderate
SB-2b	MFR	73.4	67.3	-6.1	0.6	2.3	--
SB-3	MFR	82.9	75.4	-7.4	0.1	0.7	--
SB-4	MFR	83.2	81.2	-2.0	0.1	0.6	--
SB-5	MFR	92.1	90.6	-1.5	0.0	0.1	--
SB-6	MFR	84.3	82.5	-1.9	0.1	0.5	--
SB-7	MFR	71.3	68.9	-2.3	0.9	2.6	--
SB-8	MFR	84.4	83.2	-1.3	0.0	0.5	--
SB-9	MFR	63.9	63.4	-0.6	1.5	3.9	--
SB-11	MFR	68.0	67.4	-0.5	1.2	3.1	--
SB-12	MFR	70.2	67.9	-2.2	1.0	2.7	--
SB-13	MFR	76.3	74.4	-1.9	0.3	2.1	--
SB-14	MFR	86.2	85.4	-0.9	0.0	0.3	--
SB-15	MFR	88.9	Property take	--	0.0	0.2	--
SB-16	MFR	88.9	89.7	0.8	0.0	0.2	Severe
SB-17	MFR	88.6	87.9	-0.6	0.0	0.2	--
SB-18	MFR	88.6	Property take	--	0.0	0.2	--
SB-19	MFR	87.0	Property take	--	0.0	0.3	--
SB-20	MFR	74.5	74.0	-0.5	0.5	2.2	--
SB-21	MFR	79.1	80.2	1.1	0.2	1.4	Moderate
SB-22	MFR	87.0	Property take	--	0.0	0.3	--
SB-23	MFR	61.7	61.7	0.0	1.8	4.5	--
SB-24	MFR	68.7	58.4	-10.3	1.1	3.0	--
SB-25	MFR	87.0	75.7	-11.4	0.0	0.3	--
SB-26	MFR	70.1	58.7	-11.4	1.0	2.8	--
SB-27	MFR	82.6	71.3	-11.4	0.1	0.7	--

No.	Receiver Description	Existing Noise Level	Predicted Build	Increase	FTA Allowable Noise Increase		Impact?
		(L_{dn} in dBA)	(L_{dn} in dBA)	(dB)	Moderate Impact (dB)	Severe Impact (dB)	
Category 3 (Institutional) Land Uses[1]							
NB-10	School	80.6	71.8	-8.8	0.4	2.7	--
SB-10	Church	64.1	64.1	0.1	3.6	7.4	--

dB = decibels; dBA = A-weighted decibels; L_{dn} = day-night average sound level; MFR = multifamily residence

[1]Existing and predicted noise levels for Category 3 land uses (schools and churches) are the L_{eq} of the peak hour.

Note: Sensitive receiver clusters that would experience a reduction in noise compared to existing conditions are provided in bold, red text.

6.2.2.2 Operational Vibration

Changes in vibration levels with the Build Alternative would result from a change in the track structure, the construction of the bypass structure closer to some receivers, and an increase in train speeds. The Build Alternative assumes a closed-deck aerial structure with direct fixation track.

Special trackwork can increase vibration levels by up to 10 decibels. At some sensitive receivers, the bypass structure would be relocated closer to some residences; however, special trackwork on the mainline structure would result in higher vibration levels from the mainline tracks. Vibration predictions are presented for both the mainline tracks and the bypass track. The highest predicted vibration level is then compared to the impact threshold.

Table 6-4 presents the estimated distance to the closest future column, estimated existing vibration level, the FTA impact threshold, and predicted future vibration level for each cluster of sensitive receivers. The far right column indicates the clusters of sensitive receivers where impact is predicted. The mainline track predictions are based on trains operating on the track closest to the sensitive receivers. Vibration impacts before mitigation are shown graphically in **Figure 6-3**.

Impacts before mitigation are predicted at five clusters of residential receivers (NB-11, SB-03, SB-04, SB-05, and SB-06) and at one institutional sensitive receiver (NB-10, the Truman College Lakeview Learning Center). The high predicted vibration levels at these sensitive receivers are due to special trackwork and higher train speeds.

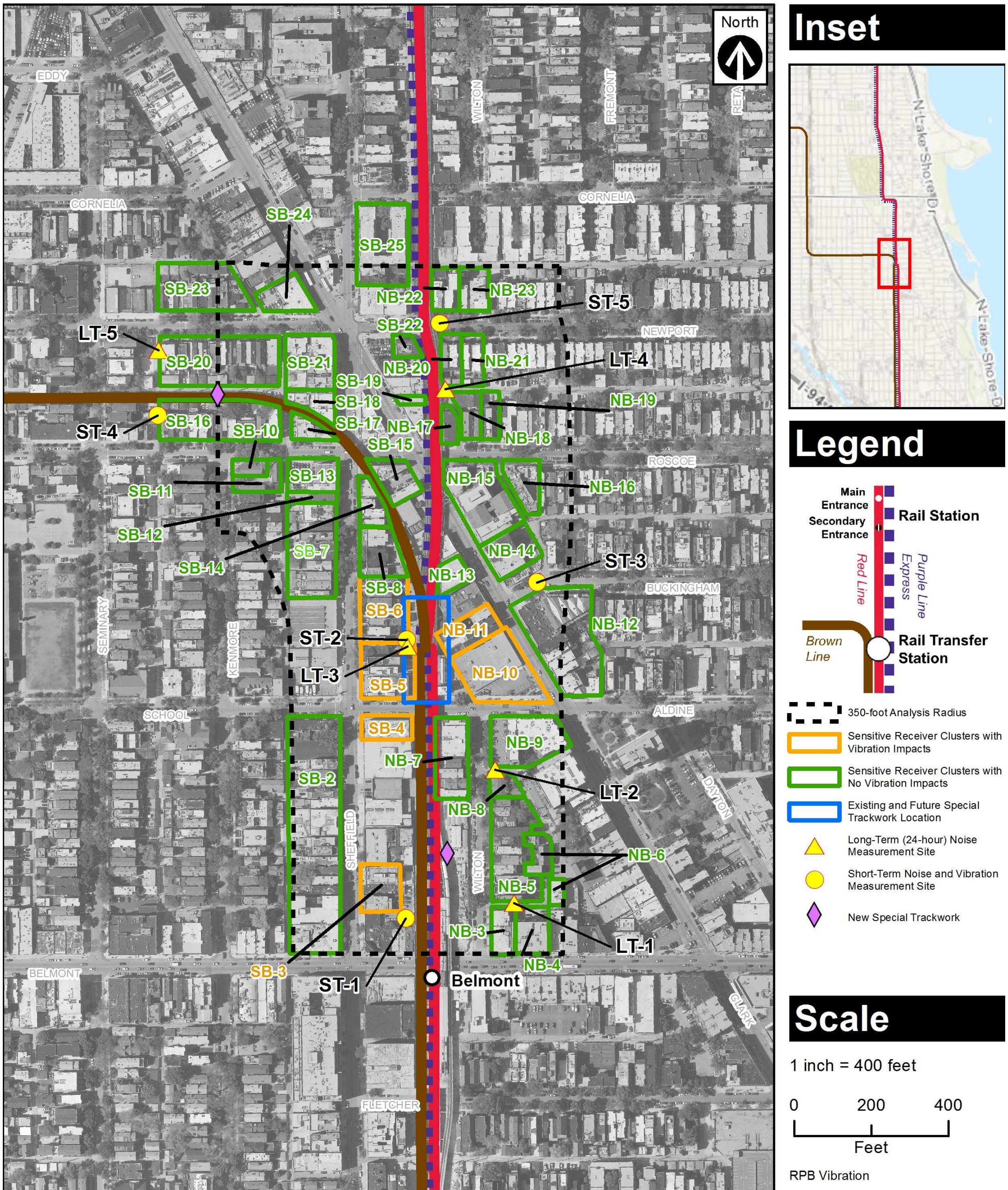


Figure 6-3: Vibration Impacts Before Mitigation

Table 6-4: Predicted Vibration Levels at Sensitive Receivers

No.	Receiver Description	Distance to Near Mainline Column (feet)	Existing L_v (VdB) (Band Max.)[1]	Predicted L_v (VdB) (Band Max.) Mainline	Predicted L_v (VdB) (Band Max.) Bypass	Impact Threshold (VdB)	Impact	Amount Exceeds (VdB)
Category 2 (residential) sensitive receivers								
NB-01	MFR	32	71	71	66	72	--	--
NB-02	MFR	114	65	65	60	72	--	--
NB-03	MFR	120	66	67	66	72	--	--
NB-04	MFR	160	65	65	64	72	--	--
NB-05a	MFR	130	67	70	66	72	--	--
NB-05b	MFR	143	66	67	65	72	--	--
NB-06	MFR	225	65	65	61	72	--	--
NB-07	MFR	10	79	Property take	Property take	82	--	--
NB-08	MFR	157	66	67	60	72	--	--
NB-09	MFR	202	63	66	59	72	--	--
NB-11	MFR	70	68	75	66	72	Yes	3
NB-12	MFR	231	62	63	58	72	--	--
NB-13	MFR	10	77	Property take	Property take	80	--	--
NB-14	MFR	117	65	69	60	72	--	--
NB-15	MFR	10	77	78	--	80	--	--
NB-16	MFR	184	64	62	--	72	--	--
NB-17	MFR	22	77	72	--	80	--	--
NB-18	MFR	52	71	68	--	72	--	--
NB-19	MFR	118	66	64	--	72	--	--
NB-20	MFR	25	77	71	--	80	--	--
NB-21	MFR	75	69	66	--	72	--	--
NB-22	MFR	10	79	73	--	82	--	--
NB-23	MFR	78	69	65	--	72	--	--
NB-24	MFR	10	79	73	--	82	--	--
NB-25	MFR	75	70	65	--	72	--	--
NB-26	MFR	10	79	73	--	82	--	--
NB-27	MFR	158	66	62	--	72	--	--
SB-01	MFR	190	62	62	57	72	--	--
SB-02a	MFR	188	66	66	57	72	--	--

No.	Receiver Description	Distance to Near Mainline Column (feet)	Existing L_v (VdB) (Band Max.)[1]	Predicted L_v (VdB) (Band Max.) Mainline	Predicted L_v (VdB) (Band Max.) Bypass	Impact Threshold (VdB)	Impact	Amount Exceeds (VdB)
SB-02b	MFR	188	65	63	57		--	--
SB-03	MFR	47	71	73	61	72	Yes	1
SB-04	MFR	37	71	81	61	72	Yes	9
SB-05	MFR	12	76	85	63	79	Yes	6
SB-06	MFR	31	72	82	62	75	Yes	7
SB-07	MFR	110	66	66	59	72	--	--
SB-08	MFR	21	74	74	63	77	--	--
SB-09	MFR	172	64	64	62	72	--	--
SB-11	MFR	138	65	65	63	72	--	--
SB-12	MFR	106	66	66	60	72	--	--
SB-13	MFR	50	70	70	63	72	--	--
SB-14	MFR	14	76	76	65	79	--	--
SB-15	MFR	10	77	Property take	Property take	80	--	--
SB-16	MFR	10	77	77	76	80	--	--
SB-17	MFR	10	77	77	66	80	--	--
SB-18	MFR	80	77	Property take	Property take	80	--	--
SB-19	MFR	10	77	Property take	Property take	80	--	--
SB-20	MFR	75	69	68	76	72	--	--
SB-21	MFR	48	71	70	71	72	--	--
SB-22	MFR	10	77	Property take	Property take	80	--	--
SB-23	MFR	247	62	62	60	72	--	--
SB-24	MFR	213	64	60	--	72	--	--
SB-25	MFR	17	77	72	--	80	--	--
SB-26	MFR	205	65	60	--	72	--	--
SB-27	MFR	36	73	69	--	76	--	--
Category 3 (institutional sensitive receivers)								
NB-10	School	46	70	79	70	78	Yes	1
SB-10	Church	159	64	64	32	78	--	--

L_v = vibration velocity level; MFR = multifamily residence; VdB = root mean squared vibration velocity in decibels relative to 1 microinch per second

[1]The band maximum is the vibration level from the maximum 1/3 octave band of the L_{max} spectra.

Section 7
Potential Mitigation Measures

7.1 Construction Mitigation Measures

7.1.1 Construction Noise

Construction of the project is exempt from the City's noise limits; however, predicted construction noise levels do exceed the limits provided in the FTA Guidance Manual. Construction noise impacts can be reduced with operational methods, scheduling, equipment choice, and acoustical treatments. The following best-practice noise mitigation measures should be implemented to minimize annoyance from construction noise:

- Whenever possible, conduct all construction activities during the daytime and on weekdays.
- Require contractors to use best available control technologies to limit excessive noise when working near residences.
- Where practical, erect temporary noise barriers between noisy activities and the noise-sensitive receivers.
- Use cast-in-place drilled holes, caissons, or drilled piers rather than impact-driven piles to reduce excessive noise.
- Adequately notify the public of construction operations and schedules. Methods such as construction-alert publications and postings to the CTA website should be used.
- During nighttime work, use spotters and smart backup alarms that automatically adjust (lower) the alarm level or tone based on the background noise level.
- When possible, avoid the use of air horns when crews are on the tracks.
- Implement noise-deadening measures for truck loading and operations.
- Use lined or covered storage bins, conveyors, and chutes with sound-deadening material.
- Use acoustic enclosures, shields, or shrouds for equipment and facilities.
- Install high-grade engine exhaust silencers and engine-casing sound insulation.
- Prohibit aboveground jack hammering and impact pile driving during nighttime hours.
- Minimize the use of generators or use whisper-quiet generators to power equipment.
- Limit use of public address systems.

- Use movable noise barriers at the source of the construction activity, if possible.
- Locate construction traffic and haul routes through non-sensitive areas, where possible.

7.1.2 Construction Vibration

Construction vibration levels may exceed the construction vibration damage criteria at some of the closest receivers. The following precautionary vibration mitigation strategies are recommended to minimize the potential for damage to any structures in the project area:

- A vibration-monitoring plan should be developed during final design to ensure appropriate measures would be taken to avoid any damage to buildings during construction.
- Pre-construction survey: Before beginning construction, undertake a survey of any buildings where the predicted construction vibration level exceeds the damage risk criteria. The survey should include inspection of building foundations and photographs of existing conditions. The survey should be used to establish baseline, pre-construction conditions.
- Less vibration-intensive construction equipment or techniques should be used to the extent possible near vibration-sensitive buildings.

If pile driving is required near a vibration-sensitive building, then vibration levels should be monitored during pile driving to ensure that vibration levels remain below the FTA damage criteria.

7.2 Operational Mitigation Measures

7.2.1 Noise

Noise impacts at sensitive receivers where predicted noise levels exceed the FTA impact thresholds are identified in **Section 6**. FTA defines two levels of impact: moderate impact and severe impact. FTA's policy is that noise mitigation should be considered when there is moderate impact, and when there is severe impact, noise mitigation should be implemented unless there are compelling reasons why mitigation is not feasible.

A closed-deck structure, sound wall along the edges of the structure, and welded rail north of Belmont station are assumed to be part of the project. Lower noise levels associated with these features are taken into account in the predicted noise levels presented in **Section 6**; therefore they are not considered as potential mitigation measures. Increasing the height of the sound wall on the structure is also not considered a potential mitigation measure because the majority of the noise impacts are at upper story sensitive receivers, where a higher sound wall would not be effective in lowering noise levels.

The following mitigation measures could be incorporated into the project to reduce noise levels at sensitive receivers:

- Use monoblock frogs or another low-impact frog. A monoblock frog is designed without bolted joints and rails which results in a smoother running surface compared with traditional frogs.
- Removal or relocations of some proposed special trackwork.
- Replace jointed rail with welded rail. At Belmont station and along the open-deck Brown Line structure, the existing jointed rail would not be replaced as part of the project. Jointed rail may be replaced with welded rail to reduce noise levels at sensitive receivers near these locations.
- Install rail dampers. Rail dampers are tuned to absorb specific vibration frequencies which reduce the amount of noise radiated by the rail. The dampers are attached directly to the rail between the ties.
- Install high resilience (soft) fasteners on the remaining open-deck steel structure. Softer fasteners would reduce the noise radiated from the structure.
- Install residential sound insulation for upper story receivers or receivers without outdoor land uses. Assessment of the existing sound insulation at sensitive receivers may show that additional sound insulation is not warranted and no further mitigation measure is necessary.

Table 7-1 presents the sensitive receivers where severe impact is predicted. At sensitive receivers with severe impacts, noise mitigation measures should be implemented unless there are compelling reasons why this is not feasible. The table presents a monoblock frog as a potential noise mitigation measure that would reduce predicted noise levels to below the moderate impact threshold at each receiver with severe impact. All clusters where severe noise impact is predicted are located close to a turnout.

Alternative mitigation options for the sensitive receivers where severe noise impact is predicted include installing residential sound insulation or relocating special trackwork. Replacing jointed rail with welded rail or installing rail dampers is not an effective mitigation measure for sensitive receivers located near turnouts because installing welded rail does not eliminate the gap in the special trackwork that increases noise levels. At upper story receivers near Belmont station, installing sound barriers around the gaps in the track deck or increasing the height of the sound barrier on the edge of the structure would reduce noise levels at ground floor receivers, but would not reduce noise levels at upper story residences. All of the sensitive receivers near Belmont station have upper story residences.

Table 7-1: Potential Mitigation Measures for Severe Noise Impacts

No.	Receiver Description	#Units[2]	Level[3]	Mitigation Measure	Amount Exceeds Moderate Impact Level (dB)	Change in Level with Mitigation (dB)	Residual Impact
NB-5a	MFR	37	Upper	Monoblock frog	2.2	2.2	No
NB-9	MFR	23	Upper	Monoblock frog	2.6	3.0	No
NB-14	MFR	12	Upper	Monoblock frog	2.2	3.0	No
SB-16	MFR	34	Upper	Monoblock frog	0.8	1.4	No

[1] MFR = multifamily residence

[2] # Units is an estimate of the number of residential units in a cluster. For institutional land uses, such as schools, the number of units is 1.

[3] Level indicates if the sensitive receiver is at the ground floor or on an upper story. If a cluster has both ground floor and upper story receivers, upper story is assumed as a worst-case noise condition.

Table 7-2 presents the sensitive receivers where moderate impact is predicted. At sensitive receivers with moderate impact, noise mitigation measures should be considered; however, final mitigation recommendations should take into account cost, number of receivers affected, amount of noise reduction provided to receivers, existing ambient noise levels, and other factors as described in Section 3.2.5 of the FTA Guidance Manual.

Table 7-2 also presents a potential mitigation measure for each receiver that would reduce predicted noise levels to below the moderate impact threshold. Five of the clusters are located near special trackwork, and installing a monoblock frog would decrease predicted noise levels to below the impact threshold. Alternative mitigation measures for sensitive receivers near special trackwork include installing residential sound insulation or removing or relocating the special trackwork. As discussed for severe impacts, replacing jointed rail with welded rail or installing rail dampers are not effective mitigation measures for sensitive receivers near special trackwork.

One cluster of sensitive receivers (SB-21) is not located near special trackwork, but noise impact is predicted as a result of removing an intervening building. Potential mitigation measures for this cluster of sensitive receivers include installing high resilience fasteners on the open-deck Brown Line structure, installing rail dampers, or installing residential sound insulation. Alternatively, further study of the noise increase at SB-21 as a result of the removal of the building may show no mitigation measures are warranted.

It is common and appropriate to perform more detailed, site specific studies during Preliminary Engineering to refine noise and vibration mitigation measures. Typical examples include adjusting sound wall heights and lengths, and fine tuning or changing vibration mitigation measures based on detailed studies. An example relevant to this project would be refining the noise impact assessment based on detailed studies of how removing buildings would increase noise levels at the buildings farther back from the tracks.

Table 7-2: Potential Mitigation Measures for Moderate Noise Impacts

No.	Receiver Description	#Units[2]	Level[3]	Mitigation Measure	Amount Exceeds Moderate Impact level (dB)	Change in Level with Mitigation (dB)	Residual Impact
NB-3	MFR	18	Upper	Monoblock frog	0.8	2.6	No
NB-4	MFR	24	Upper	Monoblock frog	1.2	2.4	No
NB-6	MFR	17	Upper	Monoblock frog	1.2	2.2	No
NB-8	MFR	3	Upper	Monoblock frog	1.0	5.6	No
SB-2a	MFR	57	Upper	Monoblock frog	1.0	2.1	No
SB-21	MFR	27	Upper	Welded Rail	0.9	3.1	No

[1]MFR = multifamily residence

[2]# Units is an estimate of the number of residential units in a cluster. For institutional land uses, such as schools, the number of units is 1.

[3]Level indicates if the sensitive receiver is at the ground floor or on an upper story. If a cluster has both ground floor and upper story receivers, upper story is assumed as a worst-case noise condition.

7.2.2 Vibration

Vibration impacts at sensitive receivers where predicted vibration levels exceed the FTA impact thresholds are identified in **Section 6**. A closed-deck aerial structure with concrete columns and welded rail is assumed to be part of the project.

All of the sensitive receivers where vibration impact is predicted are located near special trackwork. The gaps associated with special trackwork can cause vibration levels to increase by 10 decibels. The following mitigation measures could be incorporated into the project to reduce vibration levels at sensitive receivers:

- Use monoblock frogs or other low-impact frog. A monoblock frog is a low-impact frog that would reduce vibration levels from special trackwork. A monoblock frog is designed without bolted joints and rails which results in a smoother running surface compared with traditional frogs. Alternative designs for low-impact frogs, such as flange-bearing frogs, may also be used to reduce vibration levels from special trackwork.

- Install rubber bearing pads on the top of the columns to reduce the vibration transmitted through the columns into the ground. Specific details of this approach would be investigated during the preliminary engineering phase. Based on experience with floating slab track systems to reduce levels of ground-borne vibration, this appears to be a practical approach for eliminating the vibration impacts.

Table 7-3 presents the sensitive receivers where vibration impact is predicted, and the reduction expected from installing a monoblock frog. Further study during preliminary engineering is required to predict the vibration reduction that would result from installing rubber bearing pads on top of the columns. At some of the sensitive receivers, a monoblock frog does not reduce the predicted vibration level to below the impact threshold (denoted as a residual impact in **Table 7-3**). At these receivers, an alternative mitigation measure to reduce vibration levels, such as installation of rubber bearing pads on top of the columns, should be considered as a mitigation measure in addition to or in place of monoblock frogs to reduce predicted vibration levels to below the FTA impact threshold at all sensitive receivers. Preliminary studies show that rubber bearing pads on top of the columns would reduce vibration levels. However, the magnitude of the vibration reduction would depend on details determined during Preliminary Engineering or Final Design. After the necessary design information is available, it would be determined if rubber bearing pads provide sufficient vibration reduction on their own, or if they would be used together with monoblock frogs to reduce vibration to below the applicable FTA impact threshold.

Table 7-3: Potential Mitigation Measures for Predicted Vibration Impact

No.	Receiver Description[1]	# Units[2]	Amount Exceeds Threshold	Reduction from Monoblock Frog	Residual Impact
NB-10	School	1	1	5	No
NB-11	MFR	11	3	4	No
SB-3	MFR	10	1	1	No
SB-4	MFR	12	9	5	Yes
SB-5	MFR	18	6	5	Yes
SB-6	MFR	24	7	5	Yes

[1]MFR = multifamily residence

[2]# Units is an estimate of the number of residential units in a cluster. For institutional land uses, such as schools, the number of units is 1.

[3]Residual impact indicates a flange-bearing frog would not reduce predicted vibration levels to below the impact threshold, and additional or alternative measures should be investigated.

Section 8 Conclusions

8.1 No Build Alternative

No change is predicted in noise and vibration levels for the No Build Alternative. The noise levels for the No Build Alternative do not exceed the FTA impact thresholds and no noise impact is predicted. The existing vibration levels exceed the FTA impact thresholds for Category 2 land uses that are within 30 feet of the existing open-deck structure and within 35 feet of the existing closed-deck structure for trains traveling 25 mph, and the condition would remain in the No Build Alternative.

8.2 Build Alternative

Noise impacts are predicted to exceed FTA criteria where special trackwork would be installed (i.e., where crossovers would be installed to allow trains to move from one track to another) and where existing buildings would be removed as a result of the project. Removing buildings would cause noise levels to increase because acoustic shielding is removed. Wheel impacts at special trackwork are predicted to increase noise levels by up to 6 dB. Impacts are also predicted at sensitive receivers located near turnouts that would be installed as part of the project. New turnouts are proposed where the bypass track would tie in with the existing mainline tracks on the existing Belmont station structure at the south end of the project area and on the Brown Line at the north end of the project area.

There were 56 clusters of sensitive receivers identified within 350 feet of the alignment. Six of these are predicted to have a moderate permanent impact and four are predicted to have a severe permanent impact before mitigation. Noise mitigation measures would be feasible and would reduce the noise levels to below the FTA impact criteria, and impacts would not be adverse after mitigation is applied. The specific mitigation measures to be applied and their locations would be determined in coordination with FTA.

Changes in permanent vibration levels with the Build Alternative would result from a change in the track structure, the construction of the bypass structure closer to some receivers, and an increase in train speeds. Special trackwork can increase vibration levels by up to 10 decibels. Of the 56 clusters of sensitive receivers identified with 350 feet of the alignment, six are predicted to have vibration impacts which exceed the FTA impact threshold before mitigation. Mitigation measures may be applied that would reduce vibratory impacts at three affected receivers to below the FTA impact thresholds. Additional mitigation options may be added to reduce levels at the remaining three affected receivers, and the application of mitigation measures for all locations would be determined in coordination with FTA.

Section 9
References

Federal Transit Administration. 2006. Transit Noise and Vibration Impact Assessment, Department of Transportation, Federal Transit Administration, Report No. FTA-VA-90-1003-06, May 2006.

Appendix A: Noise Measurements

A.1 Summary of Noise Measurements Completed

Noise measurements were completed to (1) document the existing noise conditions at sensitive receivers throughout the project area and (2) determine reference train noise levels to use in the prediction model. Existing conditions measurements were conducted at representative sensitive receivers throughout the project area. Reference level measurements were conducted at structures similar to what may be built as part of the project.

Existing Conditions Measurements:

Two types of noise measurements were completed to document existing conditions in the project area: long-term (24-hour) unattended measurements and short term (1-hour) attended measurements. The 24-hour long-term measurements were conducted at five representative sensitive receivers throughout the project area. Short-term measurements were conducted at an additional five sites in the project area to help estimate existing noise levels at sensitive receivers where long-term measurements were not conducted. The short-term measurements were attended and the time, direction, track, and speed of each train event was logged. The logged information was used to better understand how existing train noise varies throughout the project area.

The location, date, and time of the existing conditions noise measurements are shown in **Table 1**.

Table 1: Summary of Existing Conditions Measurements

Site Label	Measurement Locations	Distance from Nearest Track	Start Date	Start Time	Duration
Long-term Noise Measurements					
LT1	3213 Wilton Avenue	150 ft	20 May 2014	11:50 am	24 hrs
LT2	3245 Wilton Avenue	150 ft	20 May 2014	12:10 pm	24 hrs
LT3	3319 N Sheffield Avenue	20 ft	20 May 2014	10:30 am	24 hrs
LT4	937 W Newport Avenue	25 ft	20 May 2014	11:45 am	24 hrs
LT5	1043 W Newport Avenue	100 ft	16 July 2014	12:00 pm	22 hrs
Short-term Noise Measurements					
ST1	Belmont Station	30 ft	15 July 2014	6:00 pm	1 hr
ST2	School Street	25 ft	20 May 2014	11:00 am	1 hr
ST3	Buckingham and Clark	200 ft	16 July 2014	10:50 am	1 hr
ST4	Roscoe Avenue	30 ft	16 July 2014	12:00 pm	1 hr
ST5	Newport Avenue	25 ft, 50 ft, 100 ft, 200 ft, and 300 ft	16 July 2014	5:35 pm	1 hr

Reference Noise Level Measurements

Reference noise level measurements were conducted at CTA structures similar to what may be built for the project. Reference noise levels were conducted north of Fullerton Station on the existing Red, Purple, and Brown lines. The measurement was attended and the time, direction, track, and speed of each train event was logged. The reference noise level measurement locations and start date and time are shown in Table 2.

Table 2: Summary of Reference Noise Level Measurement

Site Label	Measurement Locations	Distance from Nearest Track	Start Date	Start Time	Duration
NA	100 feet North of Fullerton Station Platform	50 feet	16 July 2014	10:00 a.m.	2 hours

A.2 Existing Conditions: Long Term Noise Measurements

Site LT1: 3213 Wilton Avenue

The microphone was located 150 feet east of the closed deck structure at Belmont Station, in the alley adjacent to 3213 Wilton Avenue. The microphone had a direct line-of-sight to the closed deck, concrete structure at Belmont Station. The microphone was 5 feet above ground level. The dominant noise source was the noise from the existing Red, Purple, and Brown Line trains entering and existing Belmont Station. The train noise levels often exceeded 70 dBA. Figure 1 is an aerial photograph showing the location of the microphone. Figure 2 shows the measured noise levels over the 24-hour measurement duration. The measurement showed unusual noise levels between 10:00 pm and 1:00 am and between 5:00 am and 6:00 am. The 24-hr Ldn at site LT1 with the unusually high noise levels excluded is 66.9 dBA; this level was used in the analysis. The 24-hr Ldn with the unusually high noise levels included is 71.5 dBA.

Figure 1: Aerial Photograph of Measurement Site LT1

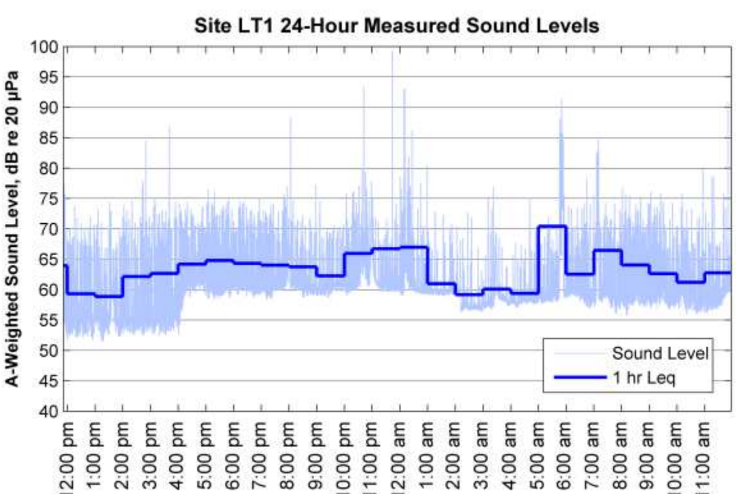


Figure 2: Measured Sound Levels at Site LT1

Site LT2: 3245 Wilton Avenue

The microphone was located 150 feet east of the existing track structure in the alley adjacent to 3245 Wilton Avenue and 150 ft south of School Street. The microphone was 5 feet above ground level. The microphone had a line-of-sight to the closed deck structure at Belmont Station; however, a row of intervening buildings blocked the line-of-sight to the open deck, steel structure which was located closer to the measurement position. The dominant noise source was the noise from the existing Red, Purple, and Brown Line trains. The train noise levels often exceeded 75 dBA. Figure 3 is an aerial photograph showing the location of the microphone. Figure 4 shows the measured noise levels over the 24-hour measurement duration. The unusually high noise level recorded at 13:00 was excluded from the analysis. The noise levels between 00:00 and 02:00, although not shown in Figure 4, were recovered and included in the analysis. The 24-hr Ldn at site LT2 is 69.9 dBA.

Figure 3: Aerial Photograph of Measurement Site LT2

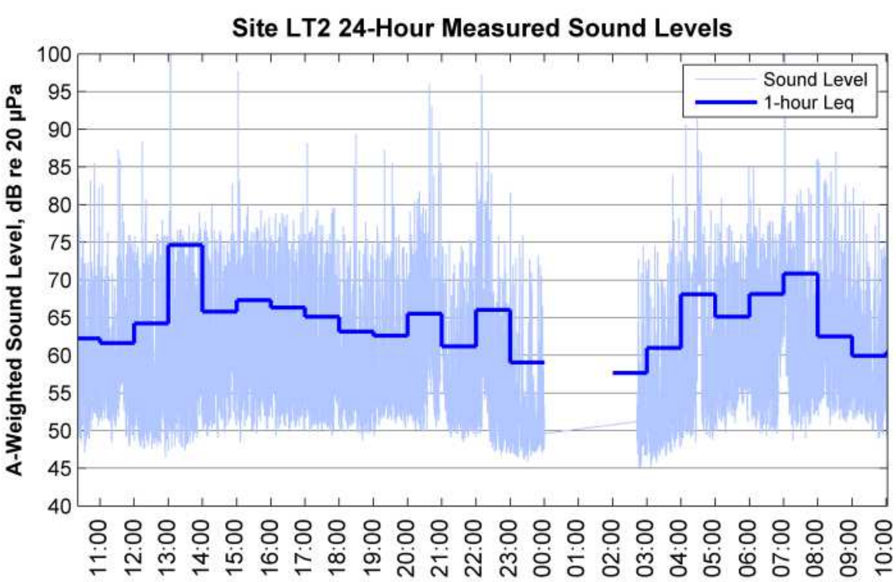


Figure 4: Measured Sound Levels at Site LT2

Site LT3: 3319 N Sheffield Avenue

The microphone was located 20 feet west of the existing open deck, steel structure in the alley behind 3319 N Sheffield Avenue, about 150 ft north of School Street. The microphone was 5 feet above ground level. The dominant noise source was the noise from the existing Red, Purple, and Brown Line trains. The measurement position was located next to several crossovers. The train noise levels often exceeded 95 dBA. Figure 5 is an aerial photograph showing the location of the microphone. Figure 6 shows the measured noise levels over the 24-hour measurement duration. The 24-hr Ldn at site LT3 is 87.5 dBA.

Figure 5: Aerial Photograph of Measurement Site LT3

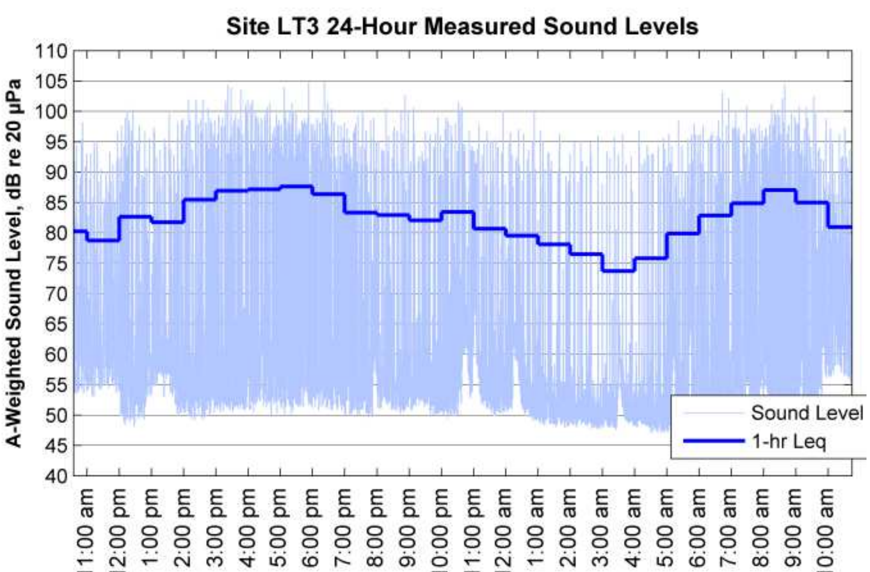


Figure 6: Measured Sound Levels at Site LT3

Site LT4: 937 W Newport Avenue

The microphone was located 25 feet east of the existing open deck, steel structure in the alley behind 937 W Newport Avenue. The microphone was 5 feet above ground level. The dominant noise source was the noise from the existing Red and Purple Line trains. The train noise levels often exceeded 90 dBA. Figure 7 is an aerial photograph showing the location of the microphone. Figure 8 shows the measured noise levels over the 24-hour measurement duration. The 24-hr Ldn at site LT4 is 81.9 dBA.

Figure 7: Aerial Photograph at Measurement Site LT4

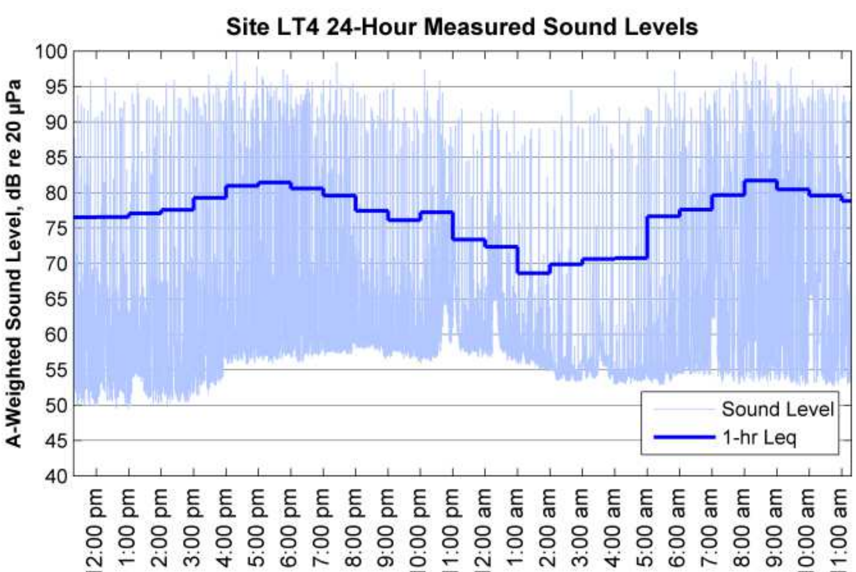


Figure 8: Measured Sound Levels at Site LT4

Site LT5: 1043 W Newport Avenue

The microphone was located 100 feet north of the existing open deck, steel structure in the alley behind 1043 W Newport Avenue. The microphone was 5 feet above ground level. The dominant noise source was the noise from the existing Brown Line trains. The train noise levels often exceeded 85 dBA. Figure 9 is an aerial photograph showing the location of the microphone. Figure 10 shows the measured noise levels over the 24-hour measurement duration. The noise levels significantly decrease during the 03:00 to 04:00 hour, when Brown Line trains were not operating. The 24-hr Ldn at site LT5 is 71.3 dBA.

Figure 9: Aerial Photograph of Measurement Site LT5

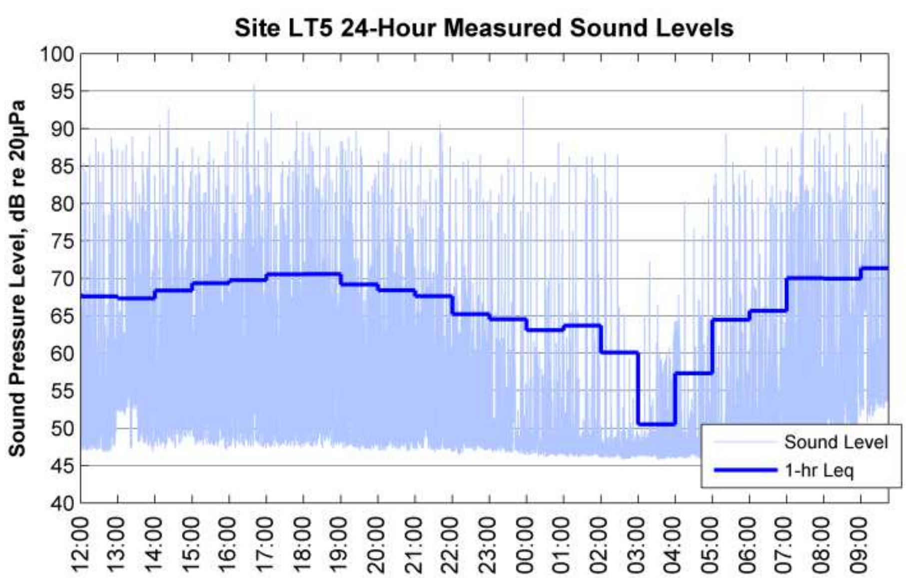


Figure 10: Measured Sound Levels at Site LT5

A.3 Existing Conditions: Short Term Noise Measurements

ST1: Belmont Station

The microphone was located 30 feet west of the existing Belmont Station structure, in the alley adjacent to the tracks about 150 ft north of Belmont Avenue. The microphone was 5 feet above ground level. An aerial photograph of the measurement location is shown in Figure 11. Red Line trains were operating on tracks 2 and 3. Brown Line trains and Purple Line trains were operating on tracks 1 and 4.

Figure 12 and Figure 13 show the spectra of the SEL of the train events for the northbound and southbound direction. The average of the train events is plotted with a dashed black line. The train events that were not included in the analysis plotted in gray. Although the measurement was attended, it was not possible to determine the track the trains were on due to limited visibility. The direction of the train was estimated based on the noise level. The trains were traveling approximately 25 mph.

Figure 11: Aerial Photograph of Measurement Site ST1

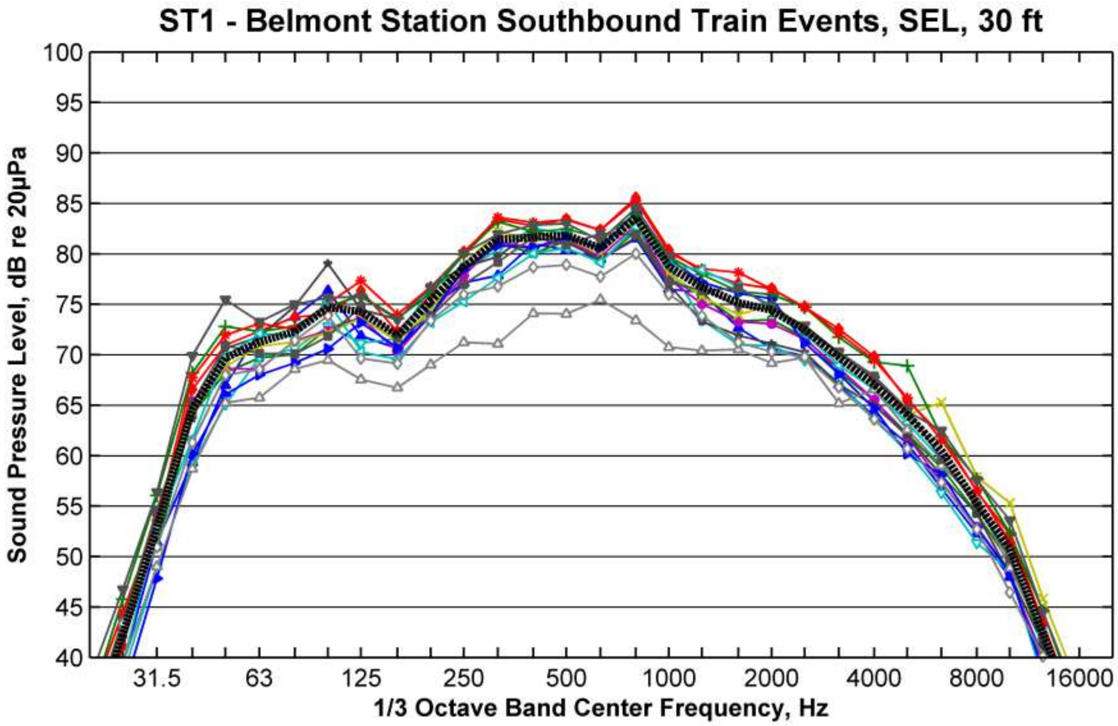


Figure 12: Spectra of Measured SEL for Southbound Train Events at Site ST1, 30 ft

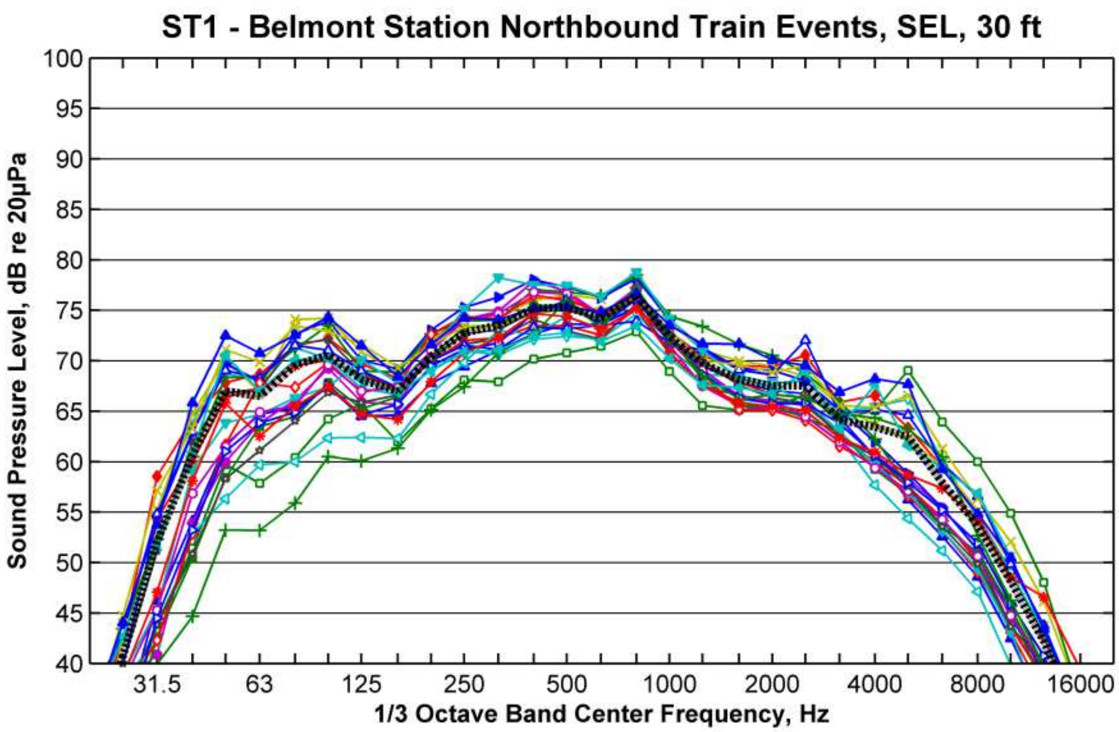


Figure 13: Spectra of Measured SEL for Northbound Train Events at Site ST1, SEL, 30 ft

ST2: School Street

The microphone was located 25 feet west of the open deck, steel structure, adjacent to measurement site LT3. The microphone was 5 feet above ground level. An aerial photograph of the measurement location is shown in Figure 14. Red Line trains were operating on tracks 2 and 3. Southbound Brown Line trains were operating on tracks 1. Northbound Brown Line trains were completing a diverting movement from track 4 to track 2. Purple Line trains were not operating during the measurement.

Figure 15 through Figure 18 show the spectra of the SEL of the train events on each track. The average of the train events is plotted with a dashed black line. The train events that were not included in the analysis are plotted in gray. During the measurement, there was a work crew on tracks 3 and 4 so train speeds did not exceed 15 mph. The train speeds on tracks 1 and 2 were about 25 mph.

Figure 14: Aerial Photograph of Measurement Site ST2

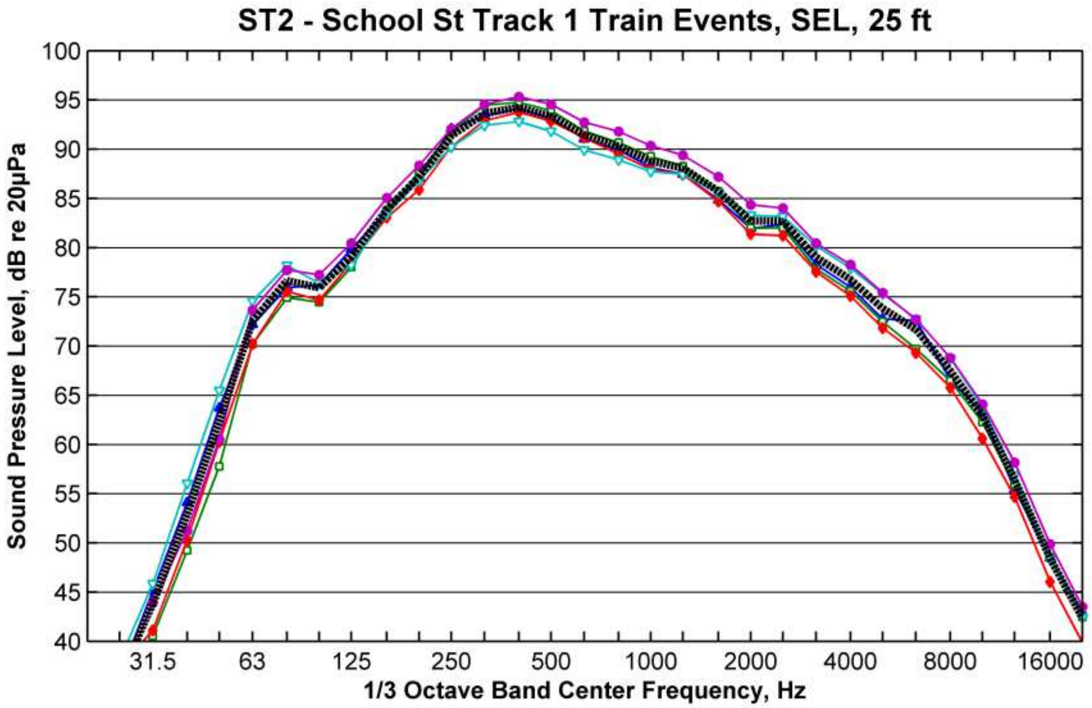


Figure 15: Spectra of Measured SEL for Track 1 Train Events at Site ST2, 25 ft

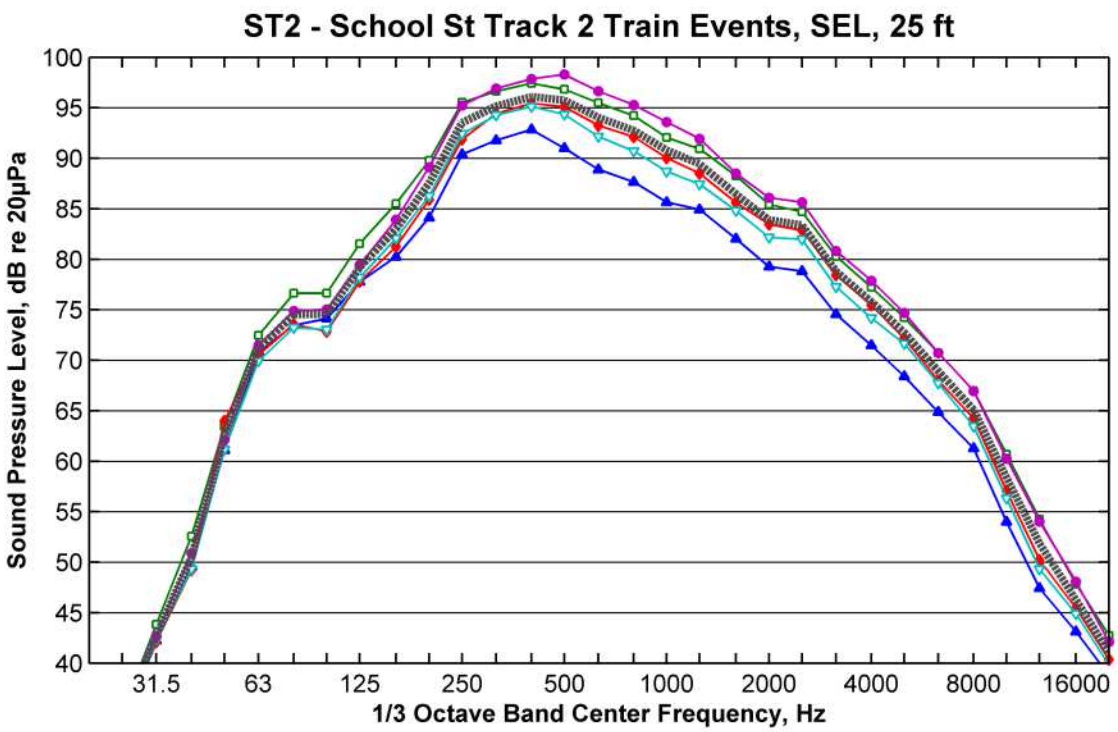


Figure 16: Spectra of Measured SEL for Track 2 Train Events at Site ST2, 25 ft

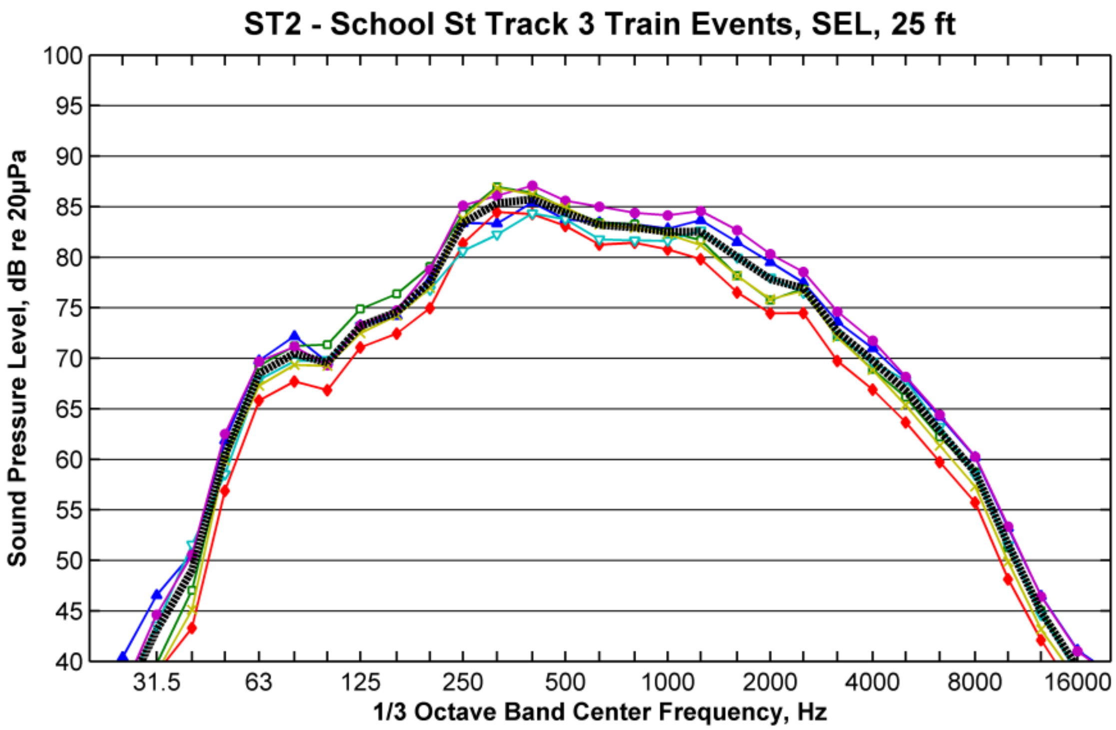


Figure 17: Spectra of Measured SEL for Track 3 Train Events at Site ST2, 25 ft

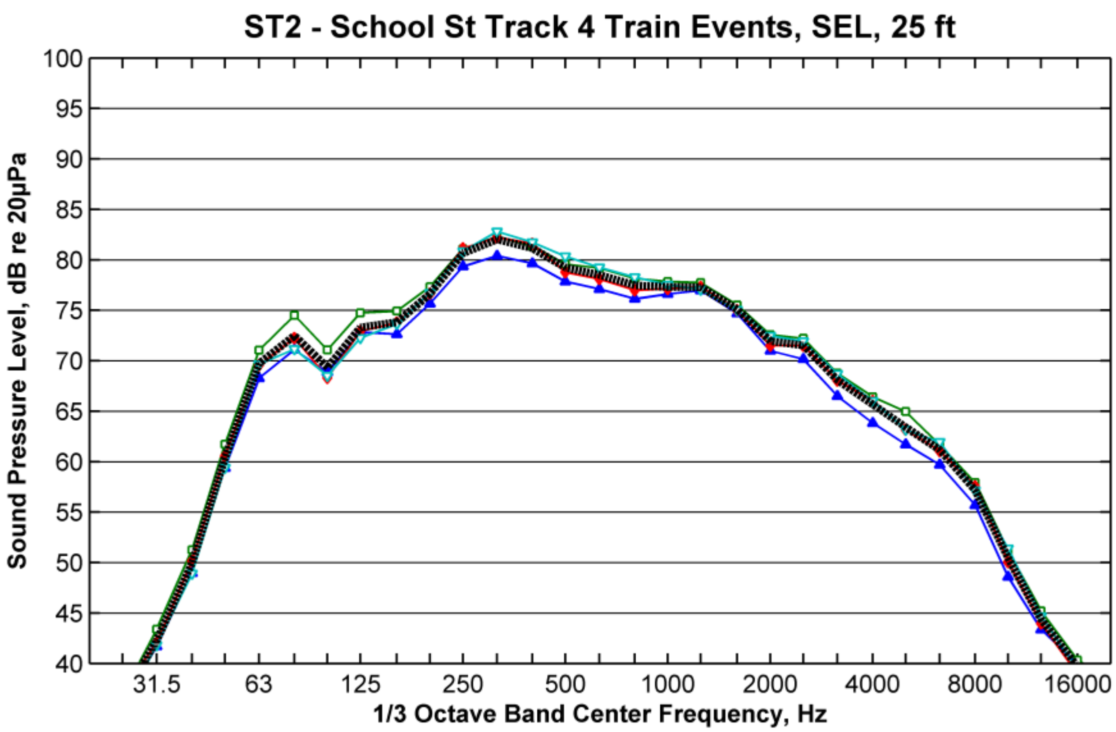


Figure 18: Spectra of Measured SEL for Track 4 Train Events at Site ST2, 25 ft

ST3: Buckingham and Clark

The microphone was located 200 ft east of the open deck, steel structure at the corner of Buckingham Place and Clark Street. The microphone was located 5 feet above ground level. An aerial photograph of the measurement location is shown in Figure 19. Note that the building between the measurement position and the track structure had burned down, so the microphone had a direct line-of-sight to the tracks. Red Line trains were operating on tracks 2 and 3. Southbound Brown Line trains were operating on track 1. Northbound Brown Line trains were completing a diverting movement from track 4 to track 2; those events are included with the track 3 events because the Brown Line trains were on track 3 as they passed the measurement site. There was a single Purple Line train event on track 4 during the measurement. The measurement site was adjacent to crossovers. The diverting trains were traveling about 15 mph. The trains on the other tracks were traveling 20-25 mph.

Figure 20 through Figure 23 show the spectra of the SEL of the train events for the different tracks. The average of the train events is plotted with a heavy, dashed black line. The train events that are not included in the analysis are plotted in gray.

Figure 19: Aerial Photograph of Measurement Site ST3

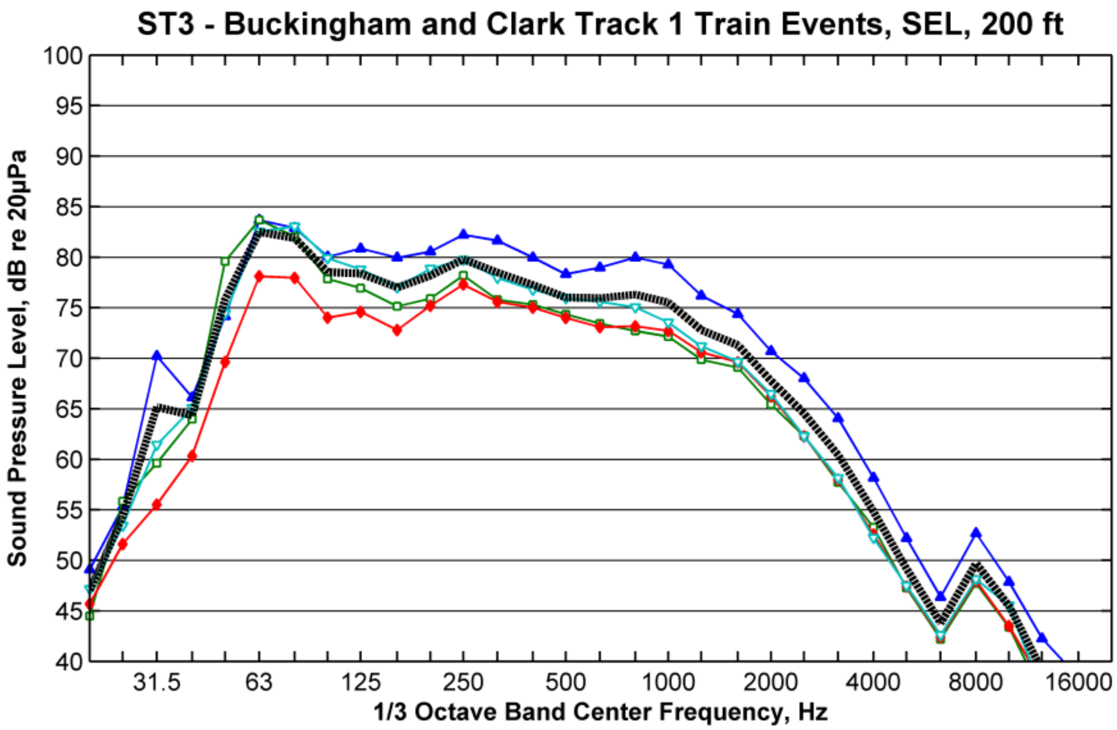


Figure 20: Spectra of Measured SEL for Track 1 Train Events at Site ST23 200 ft

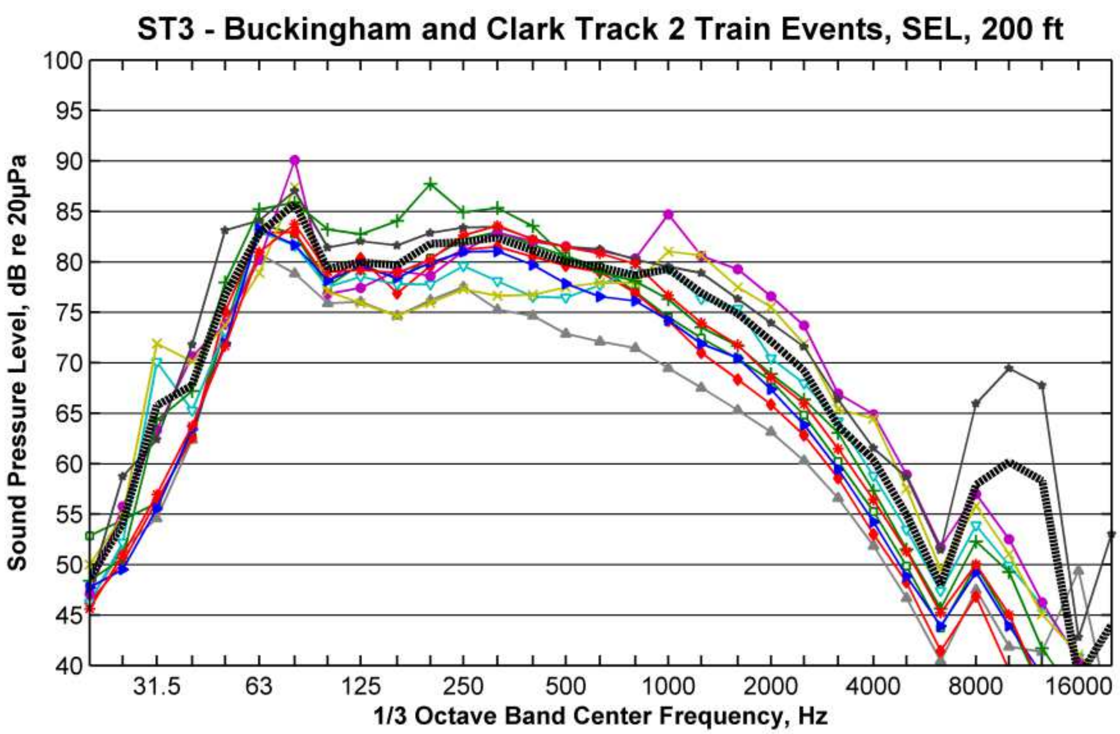


Figure 21: Spectra of Measured SEL for Track 2 Train Events at Site ST3, 200 ft

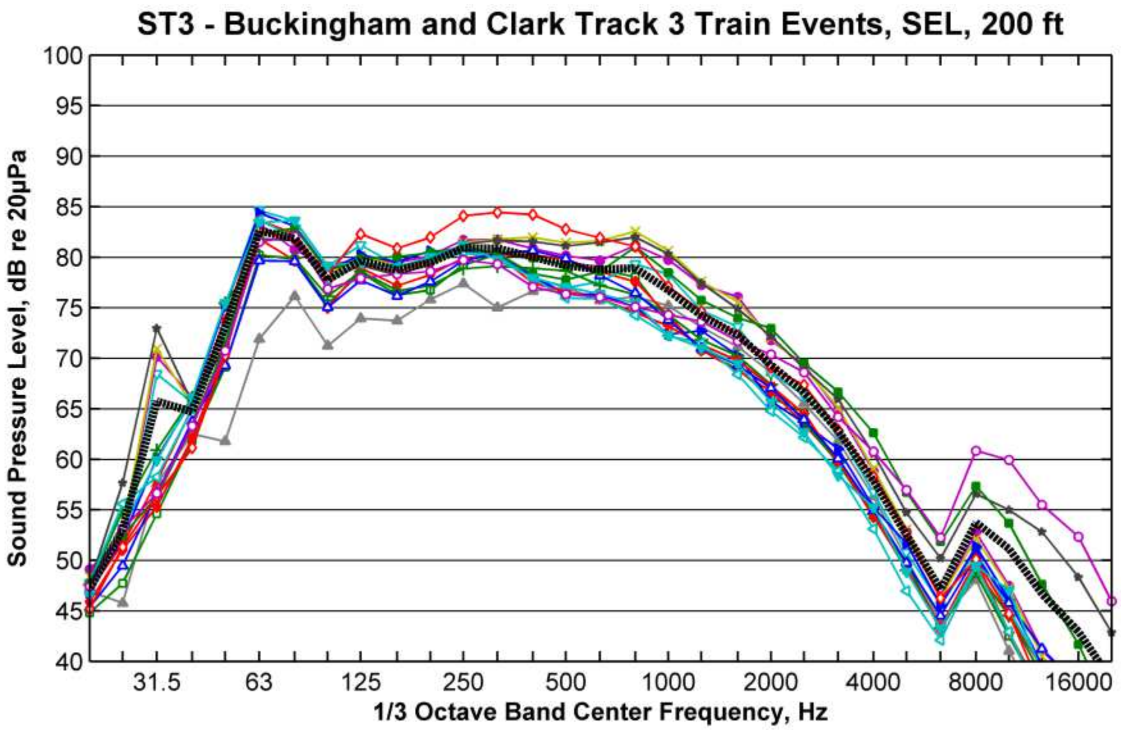


Figure 22: Spectra of Measured SEL for Track 3 Train Events at Site ST3, 200 ft

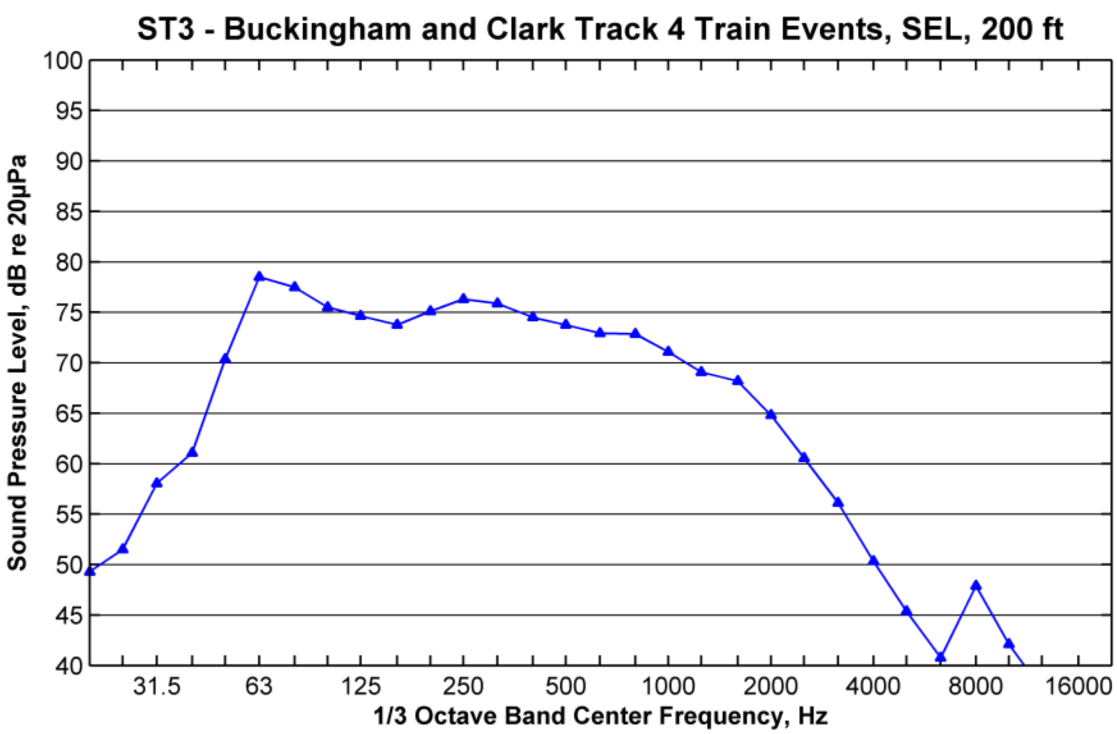


Figure 23: Spectra of Measured SEL for Track 4 Train Events at Site ST3, 200 ft

ST4: Roscoe Avenue

The microphone was located 30 feet south of the open deck, steel structure about 150 ft east of Seminary Avenue. The microphone was 5 feet above ground level. An aerial photograph of the measurement location is shown in Figure 24. Brown Line trains were running adjacent to the measurement location. There are only two tracks at this site; eastbound trains were running on track 1 and westbound trains were running on track 4.

Figure 25 and Figure 26 show the spectra of the SEL of the train events for the two tracks. The average of the train events is plotted with a heavy, dashed black line.

Figure 24: Aerial Photograph of Measurement Site ST4

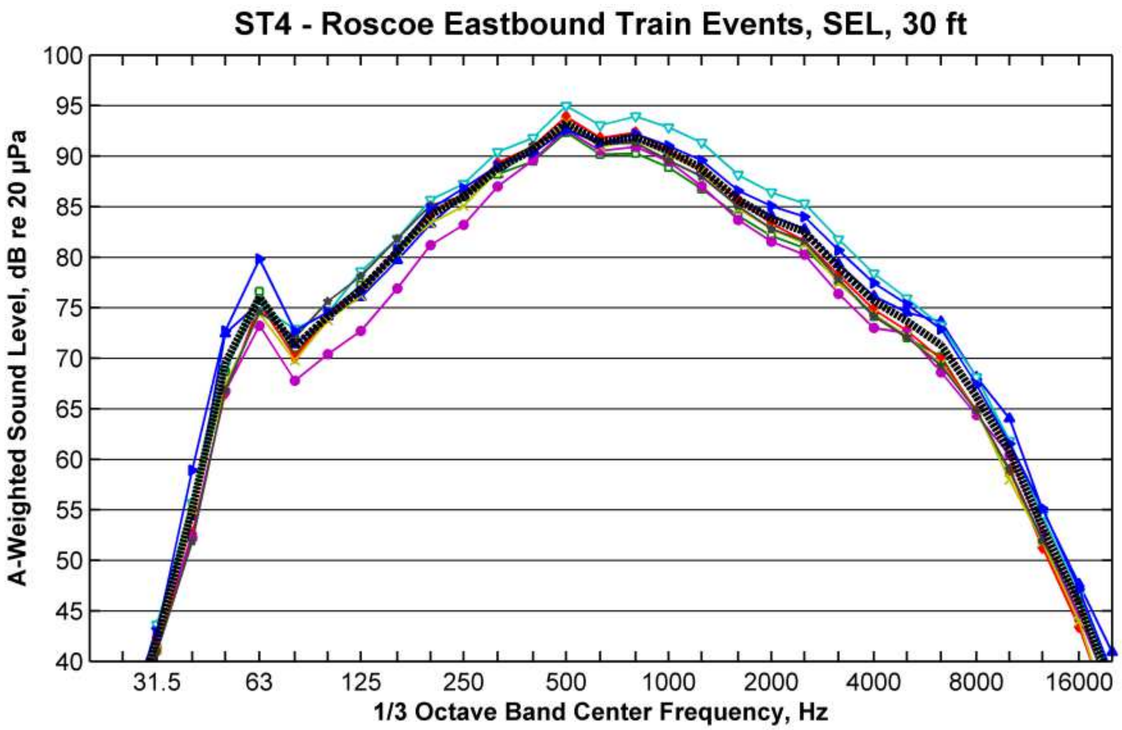


Figure 25: Spectra of Measured SEL for Eastbound Train Events at Site ST4, 30 ft

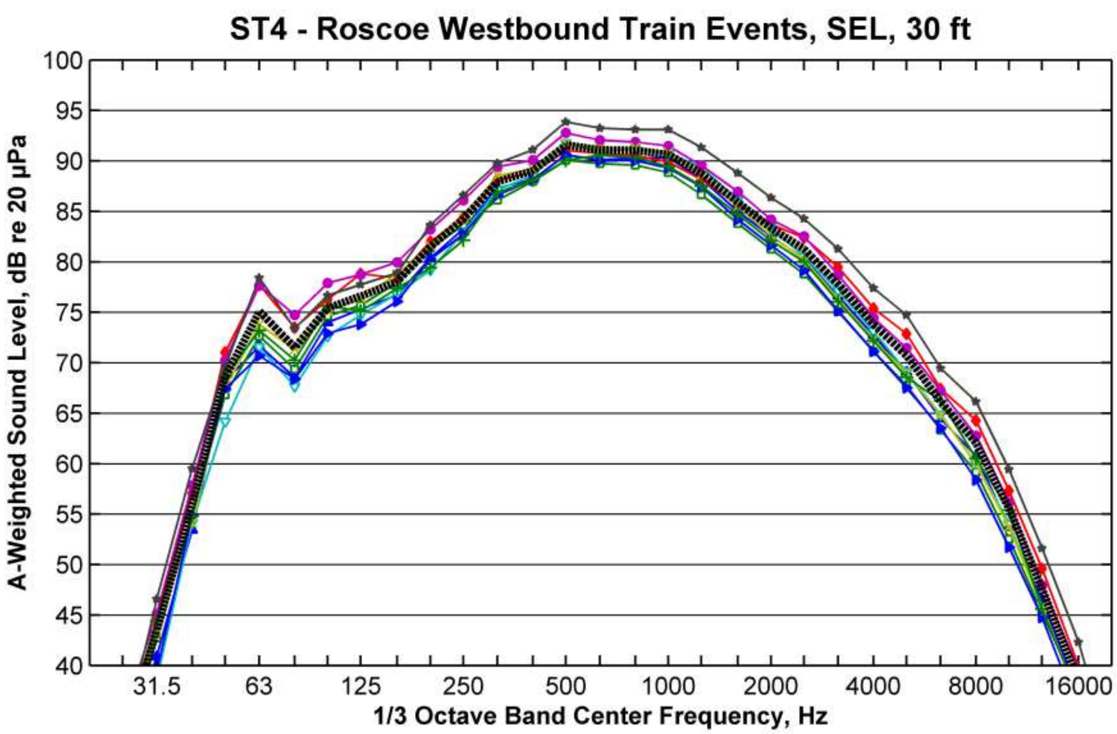


Figure 26: Spectra of Measured SEL for Westbound Train Events at Site ST4, 30 ft

ST5: Newport Avenue

Microphones were located 25 feet, 50 feet, 100 feet, 200 feet, and 300 feet east of the open deck, steel structure on the south sidewalk of Newport Avenue. At the 25 ft and 50 ft measurement positions there were two microphones: one 5 feet above ground level and a second 30 feet above ground level. The microphones at 100 ft, 200 ft, and 300 ft were 5 feet above ground level. An aerial photograph of the measurement location is shown in Figure 27. Red Line trains were running on tracks 2 and 3. Purple Line trains were running on tracks 1 and 4.

Figure 28 through Figure 34 show the spectra of the SEL of the train events for the different tracks and measurement locations. The average of the train events is plotted with a dashed black line.

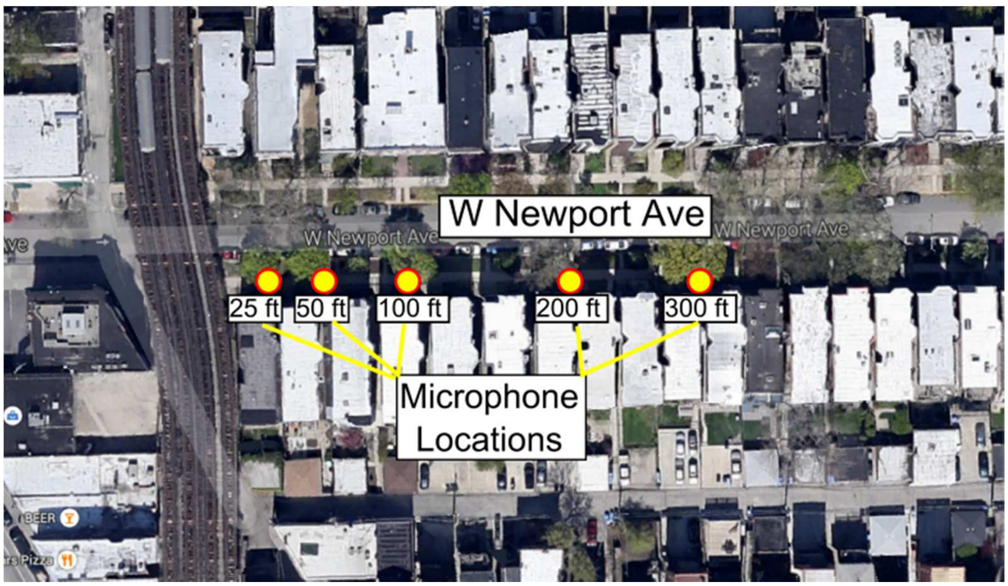


Figure 27: Aerial Photograph of Measurement Site ST5

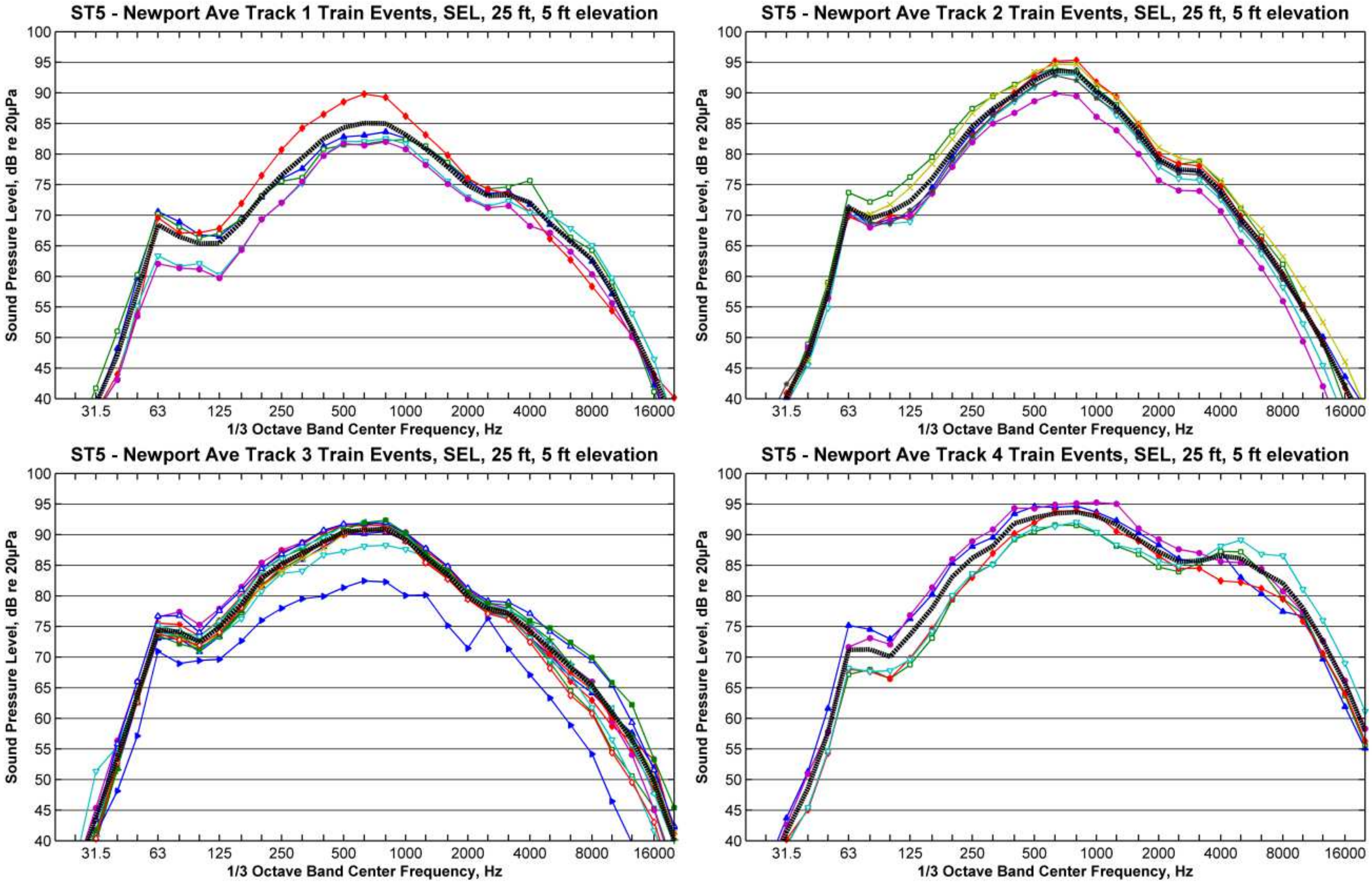


Figure 28: Spectra of Measured SEL for Train Events at Site ST5, 25 feet, 5 feet Elevation

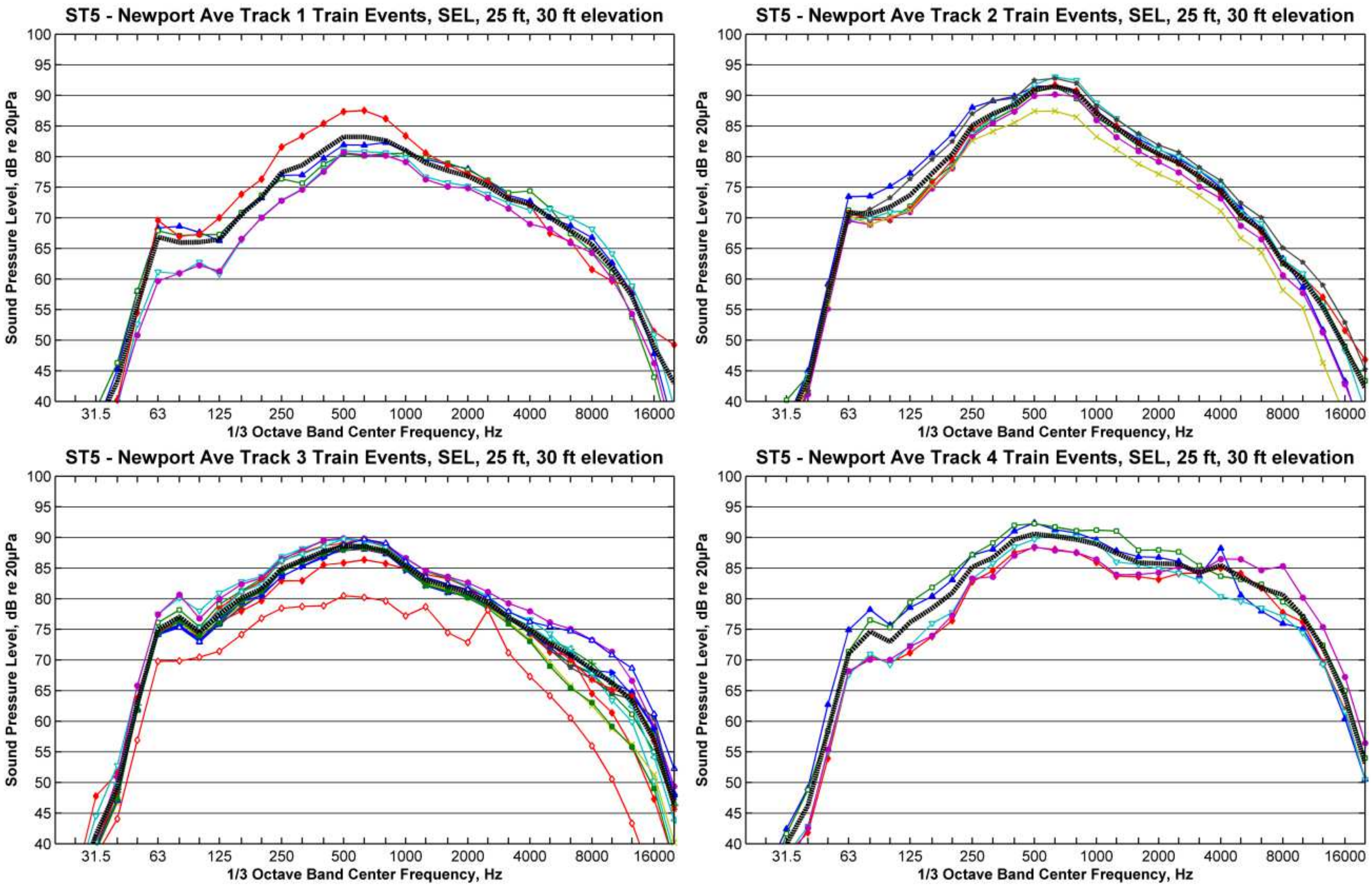


Figure 29: Spectra of Measured SEL for Train Events at Site ST5, 25 feet, 30 foot Elevation

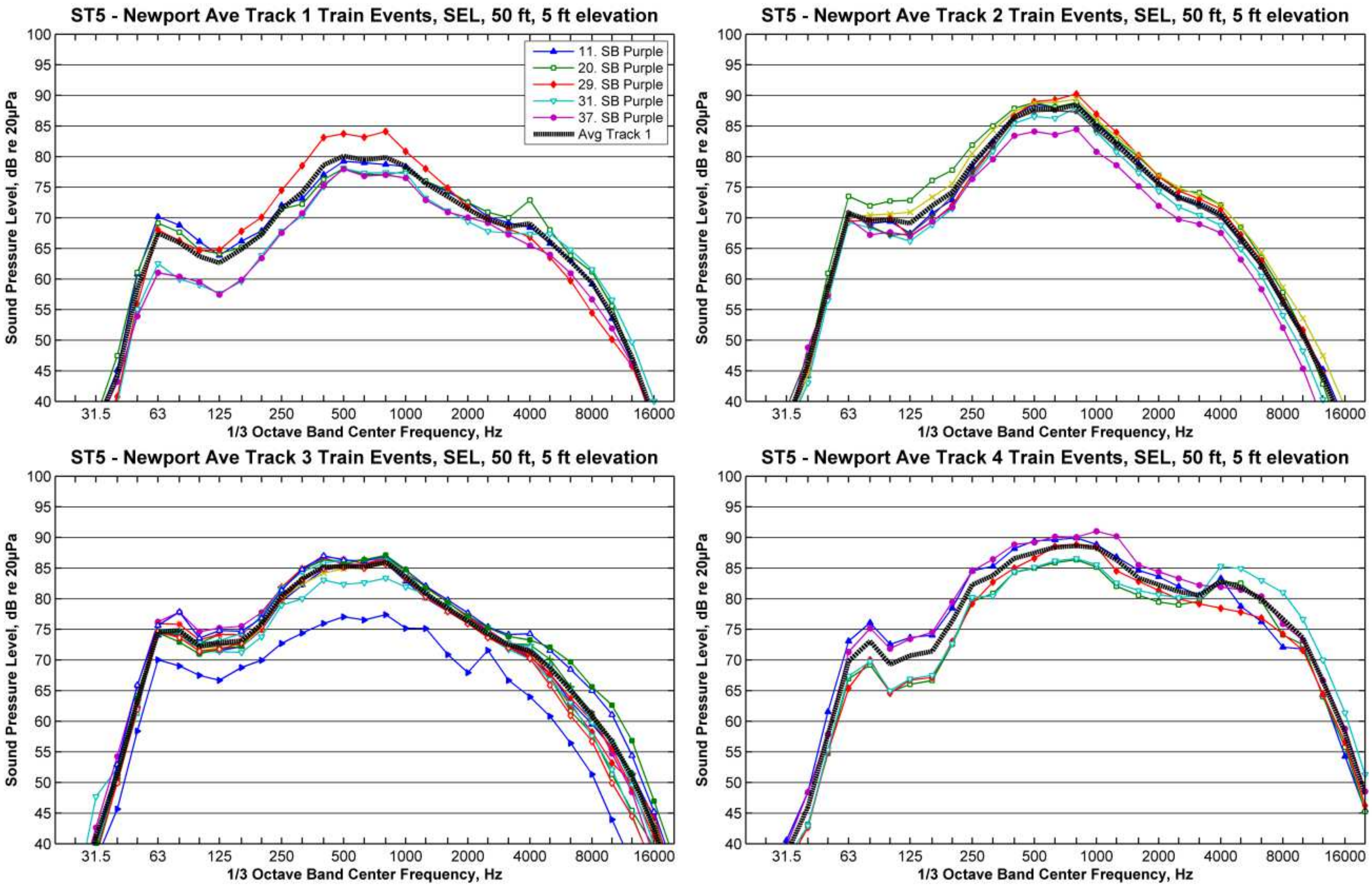


Figure 30: Spectra of Measured SEL for Train Events at Site ST5, 50 feet, 5 foot Elevation

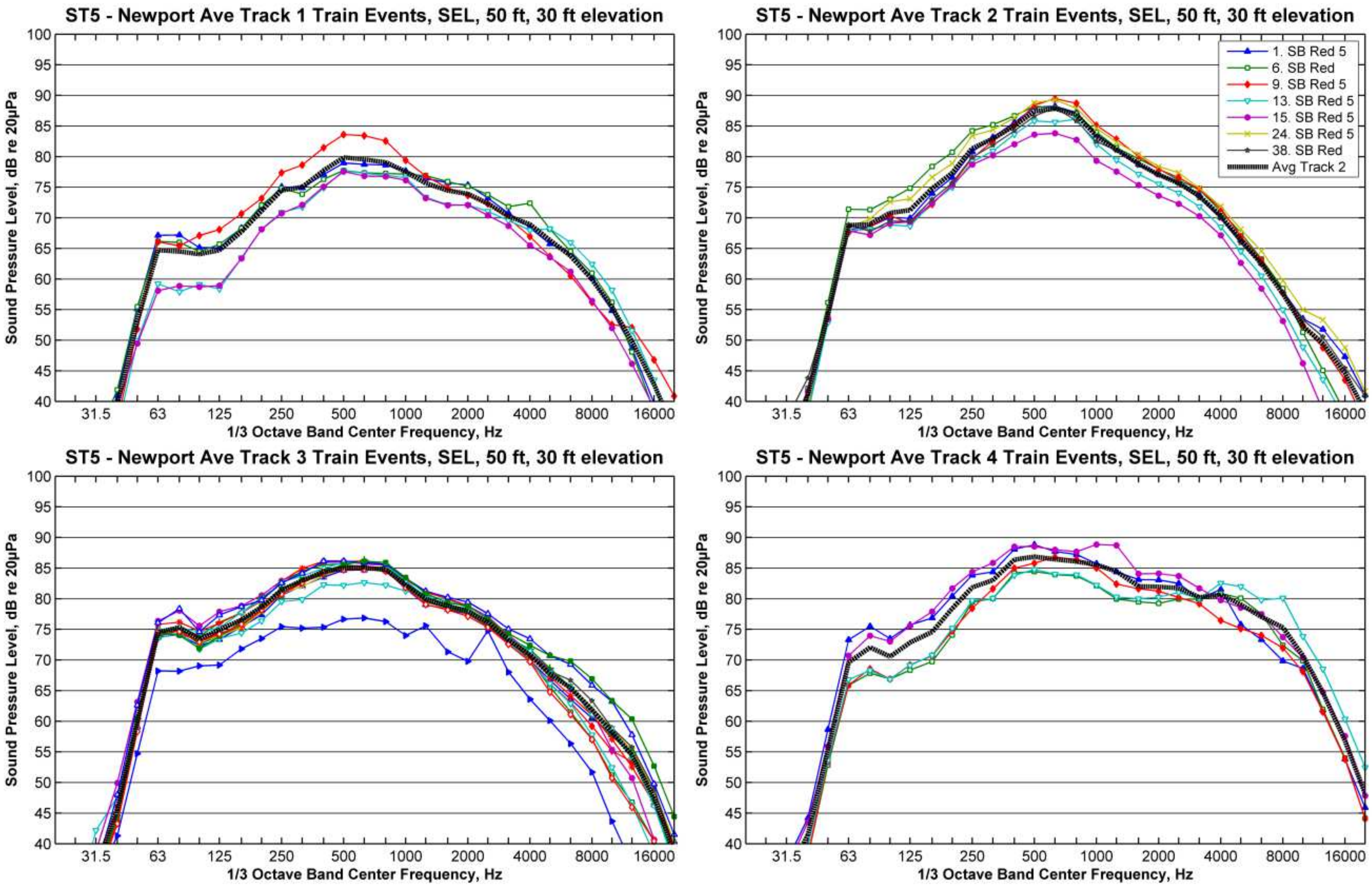


Figure 31: Spectra of Measured SEL for Train Events at Site ST5, 50 feet, 30 foot Elevation

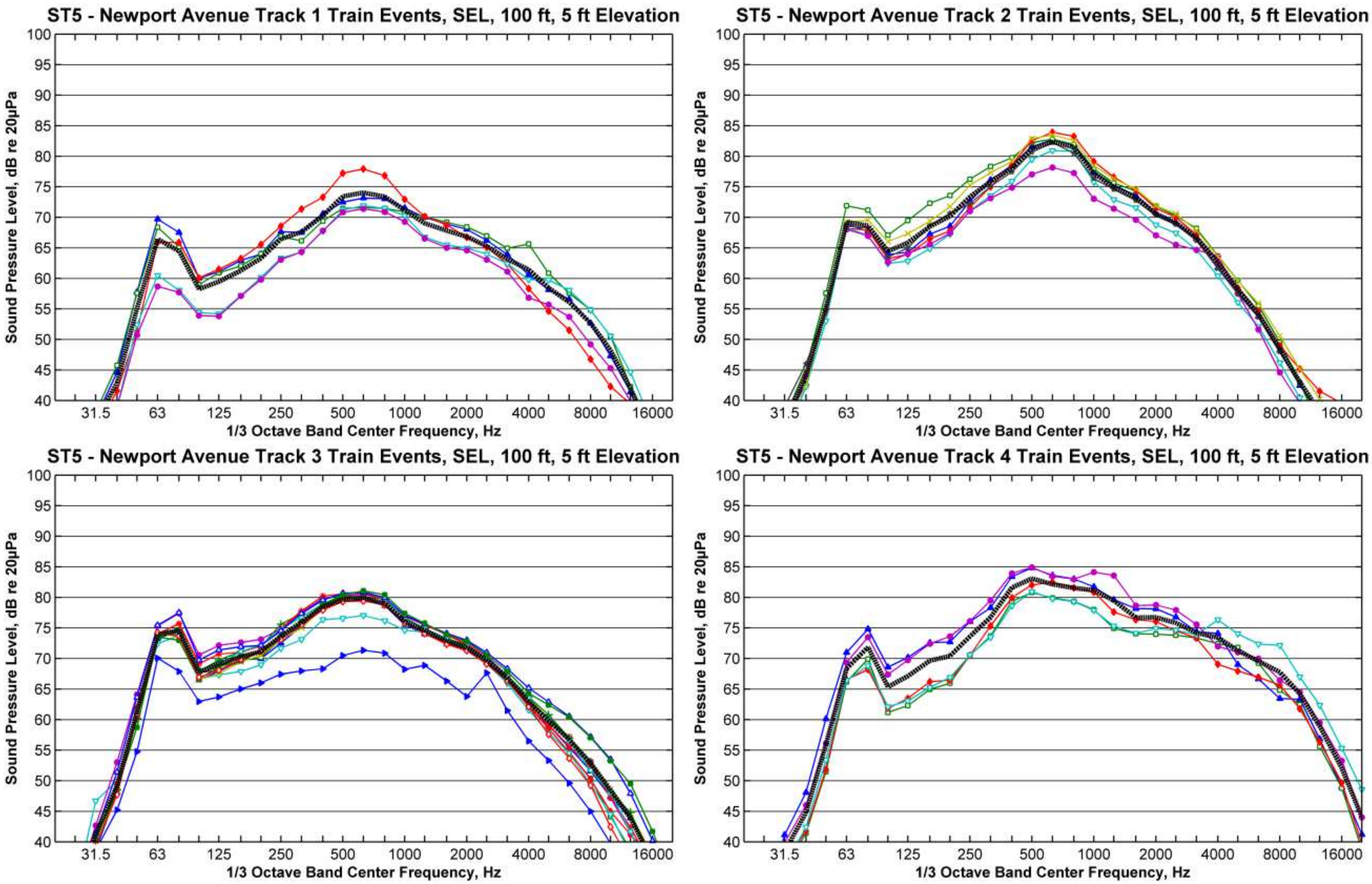


Figure 32: Spectra of Measured SEL for Train Events at ST5, 100 feet, 5 foot Elevation

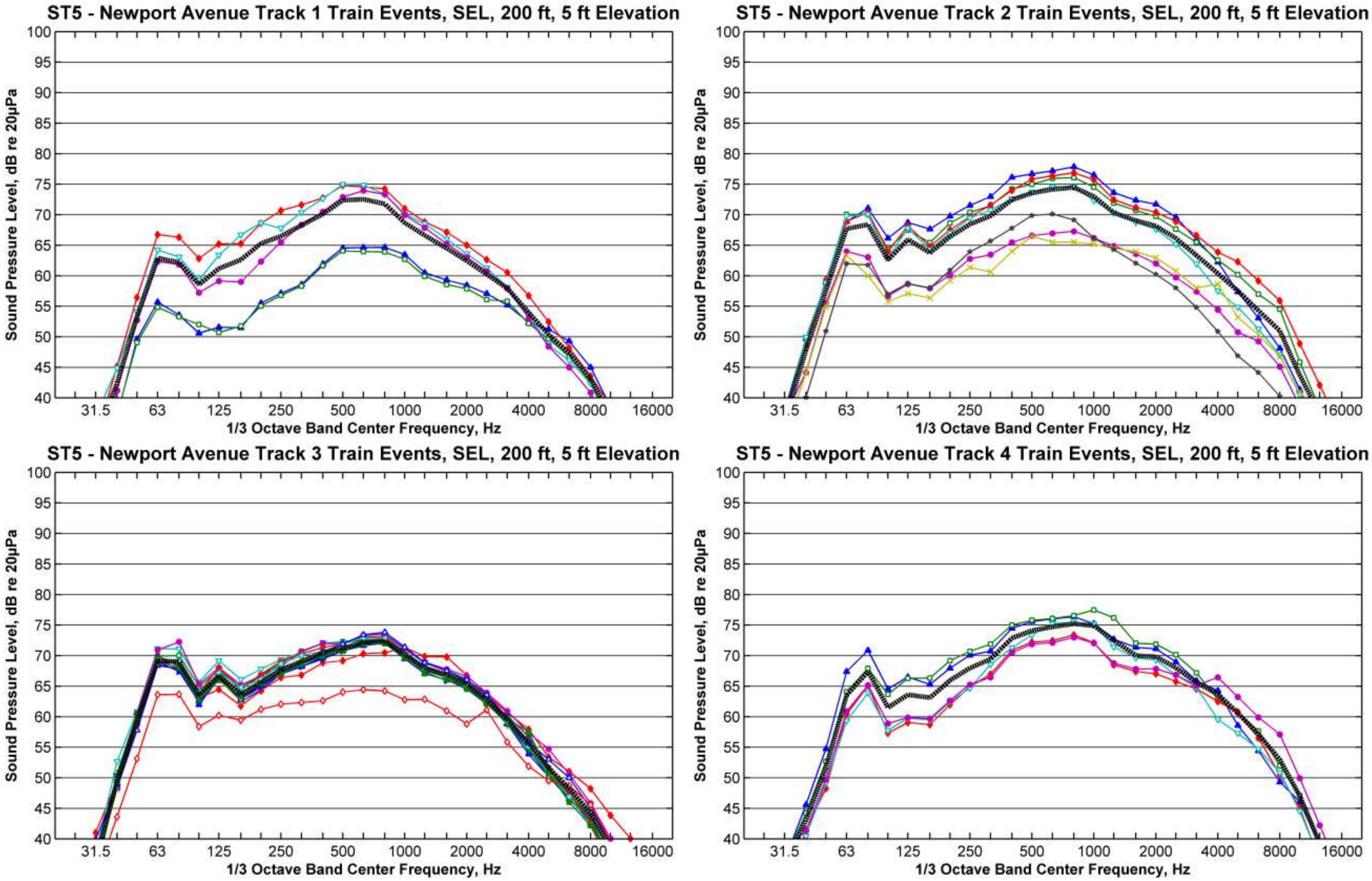


Figure 33: Spectra of Measured SEL for Train Events at ST5, 200 feet, 5 foot Elevation

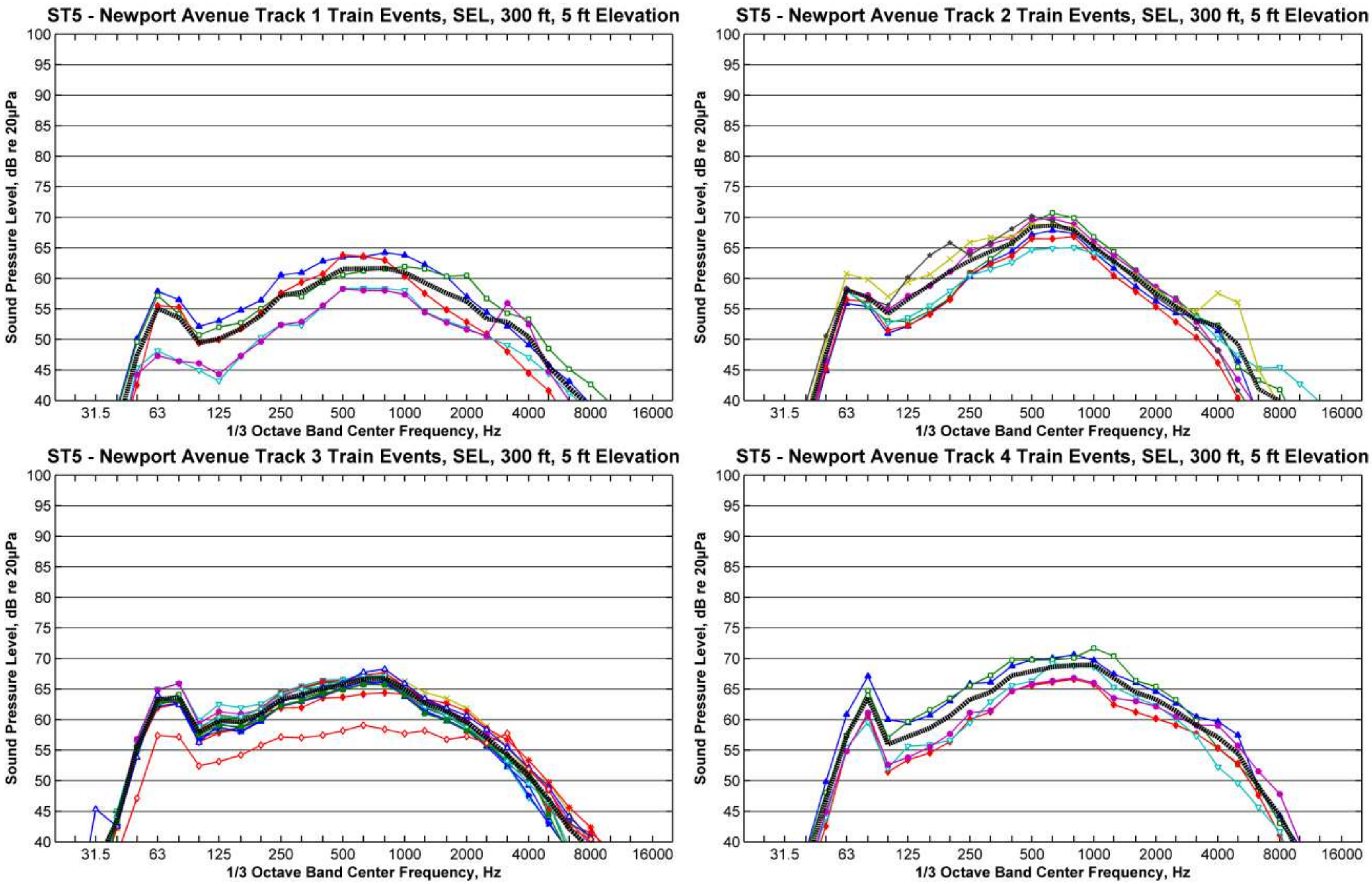


Figure 34: Spectra of Measured SEL for Train Events at ST5, 300 feet, 5 foot Elevation

A.4 Reference Level Measurements: Fullerton Station

A train noise measurement was conducted at the existing Fullerton Station structure to determine a reference noise level for CTA trains operating on a closed deck structure with direct fixation track. Details about the measurement location are presented in **Section 5.1.1**. The train noise was measured 50 feet east of the structure at two microphone positions: 5 feet above ground level and 30 feet above ground level.

Figure 35 and **Figure 36** show the SEL of the train events measured on all four tracks at Fullerton Station. Six-car Purple Line trains and four-car Brown Line trains were operating on tracks 1 and 4 and eight-car Red Line trains were operating on tracks 2 and 3. The average of the train events in each figure is plotted with a dashed black line. The train events that were excluded from the average are plotted in gray. Key observations from the measurement results are:

- The train events with generally low levels and a peak in the 1000 Hz 1/3 octave band are trains that were traveling very slowly and sounded their horn as they exited the station. These trains were excluded from the averages used in the noise impact analysis.
- Averages from tracks 2 and 3 include only 5000 series trains. In general, 5000-series trains have lower noise levels which is likely due to better wheel condition. Averages from tracks 1 and 4 include all train series because there were very few 5000 series trains operating on those tracks.
- Averages include trains traveling at similar speeds. Trains traveling on tracks 2, 3, and 4 were traveling about 25mph. Trains traveling on track 1 were traveling about 40 mph. The trains on all tracks were accelerating and decelerating as they entered and exited Fullerton Station.
- The track at Fullerton Station has jointed rail. The noise from the joints was particularly audible from track 3.

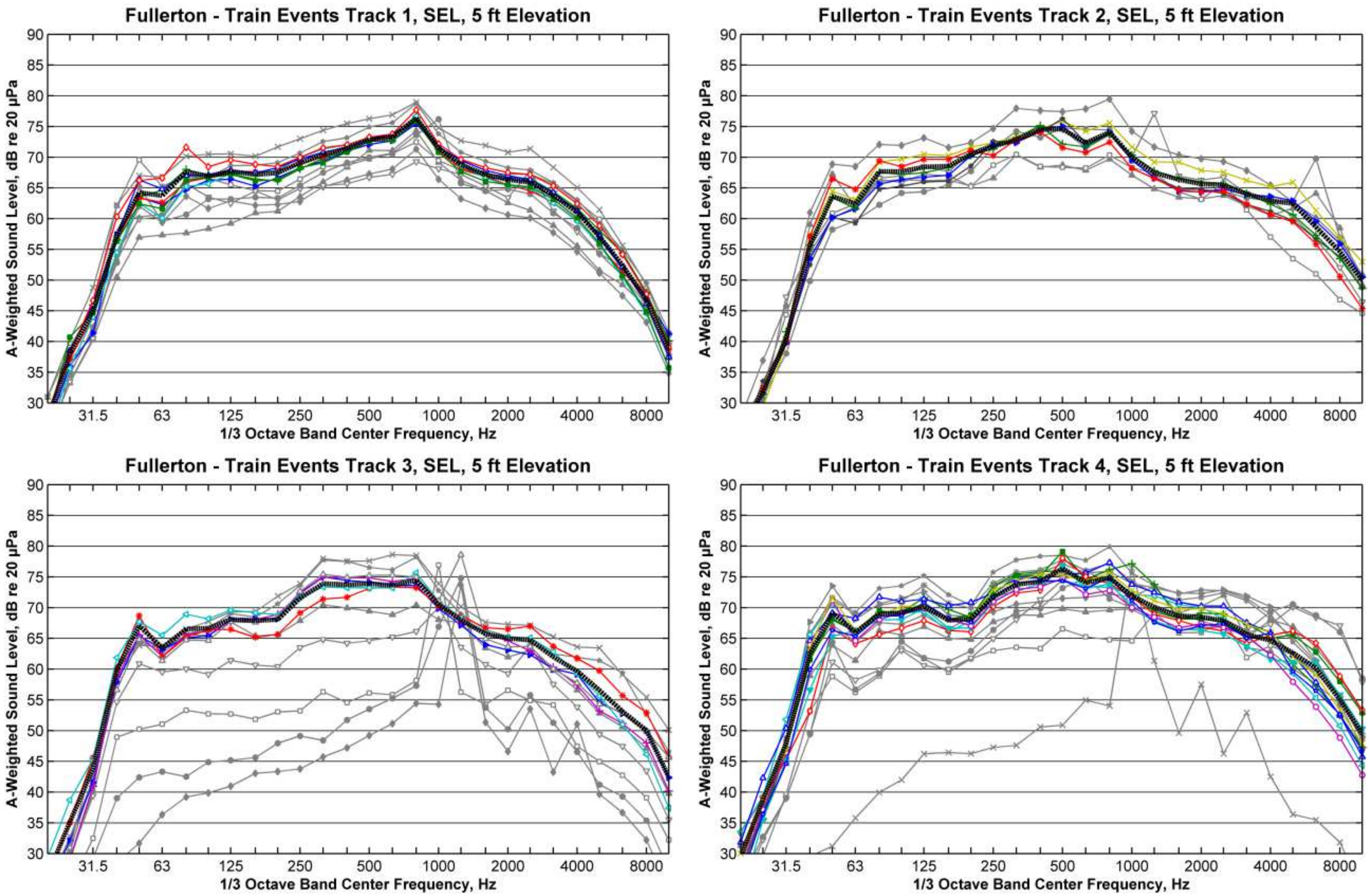


Figure 35: Spectra of Measured SEL for Train Events at Fullerton Station, Microphone at 5 feet Above Ground Level

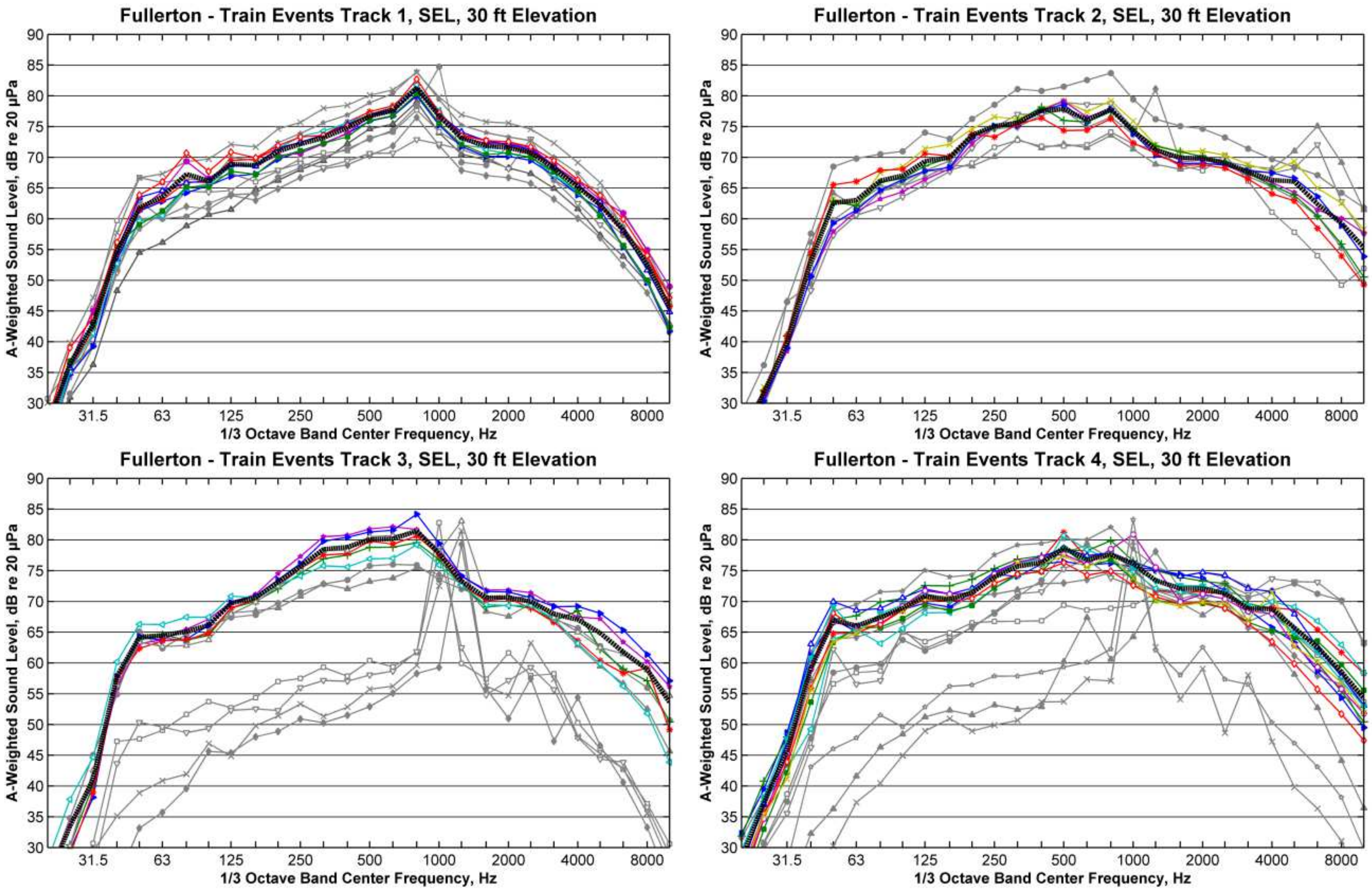


Figure 36: Spectra of Measured SEL for Train Events at Fullerton Station, Microphone at 30 feet Above Ground Level

Appendix B: Vibration Measurements

ST1: Belmont Station

The accelerometer was located 30 feet east of the closed deck structure at Belmont Station, in the alley adjacent to the tracks. The train speeds were approximately 20 to 25 mph. An aerial photograph of the measurement site is shown in Figure 37.

Figure 38 and Figure 39 show the spectra of the L_{max} of the train events for the northbound and southbound directions. The average of the train events is plotted with a dashed black line. Although the measurement was attended, it was not possible to determine the track the trains were on due to limited visibility. The direction of the train was estimated based on noise level.

Figure 37: Aerial Photograph of Measurement Site ST1

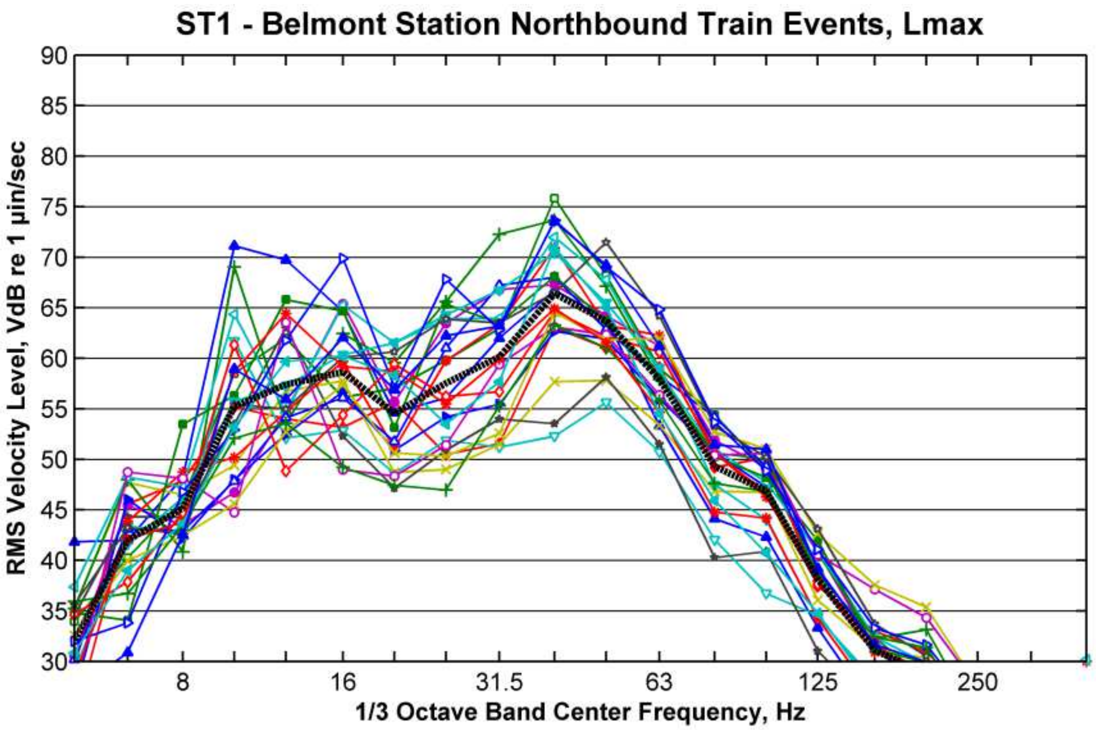


Figure 38: Spectra of Measured L_{max} for Northbound Train Events at Site ST1

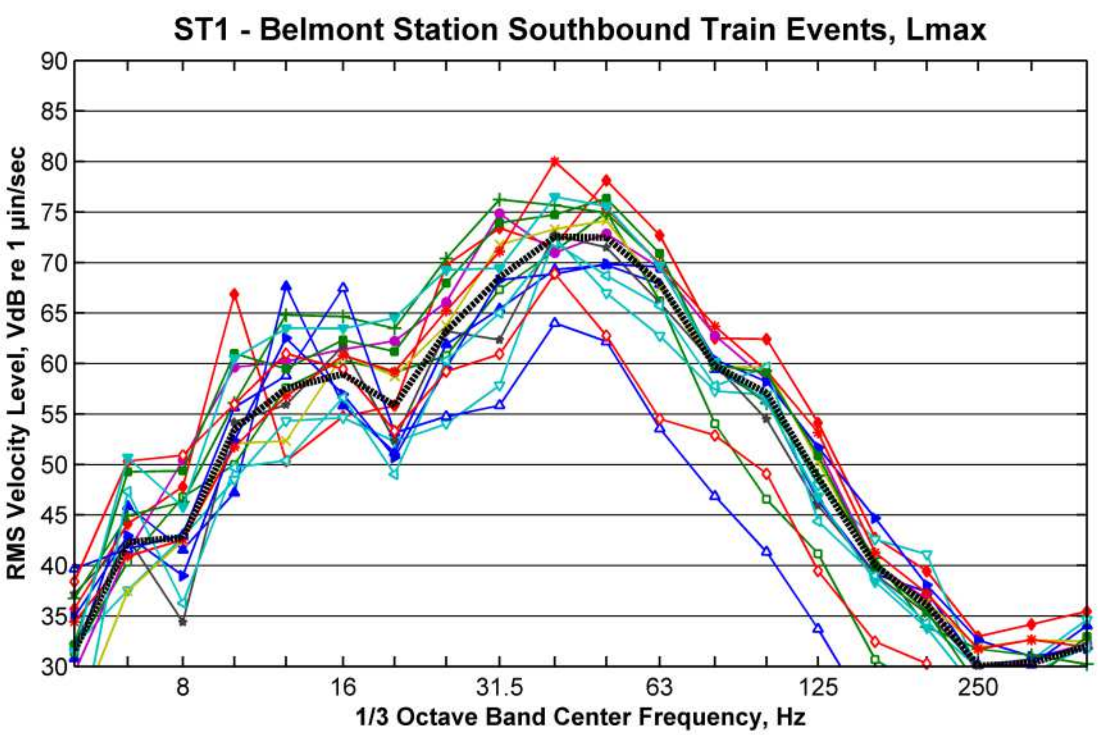


Figure 39: Spectra of Measured L_{max} for Southbound Train Events at Site ST1

ST2: School Street

The accelerometer was located 25 feet west of the open deck, steel structure in the alley north of School Street. During the measurement, there was a work crew on tracks 3 and 4 so train speeds did not exceed 15 mph on those tracks. The train speed on tracks 1 and 2 was about 25 mph. Red Line trains were operating on tracks 2 and 3. Southbound Brown Line trains were operating on track 1. Northbound Brown Line trains were completing a diverting movement from track 4 to track 2. Purple Line trains were not operating during the measurement. An aerial figure of the measurement site is shown in Figure 40.

Figure 41 through Figure 44 show the spectra of the L_{max} of the train events on each track. The average of the train events is plotted with a dashed black line.

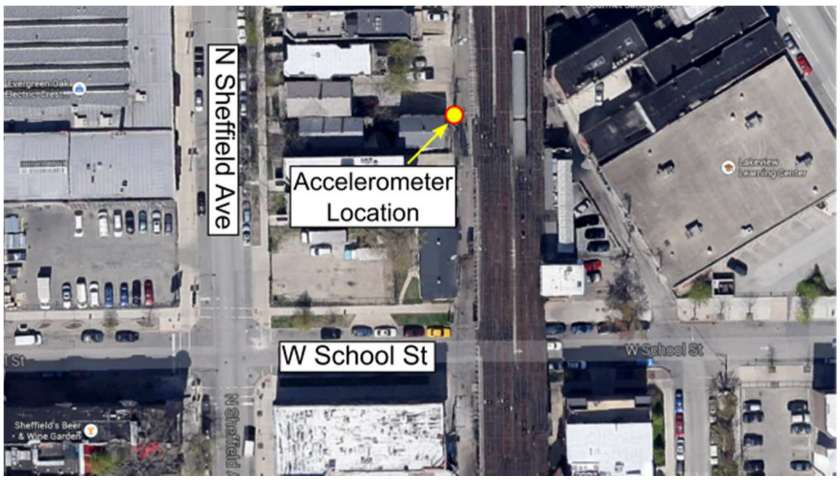


Figure 40: Aerial Photograph of Measurement Site ST2

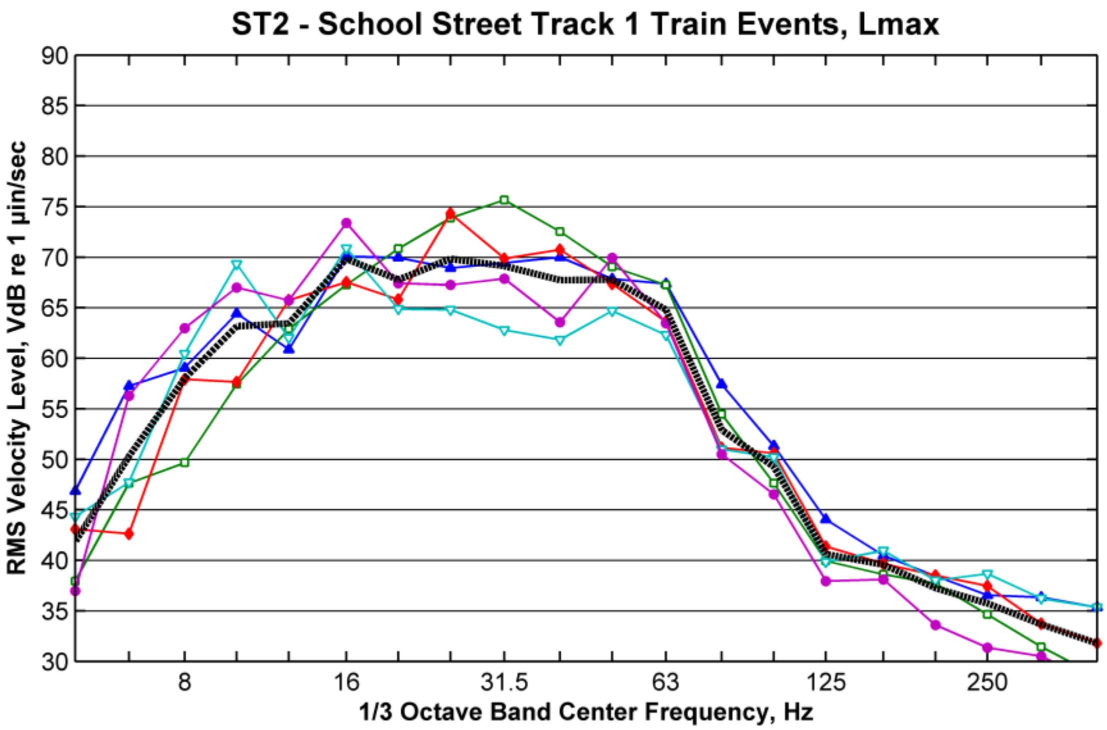


Figure 41: Spectra of Measured L_{max} for Track 1 Train Events at Site ST2

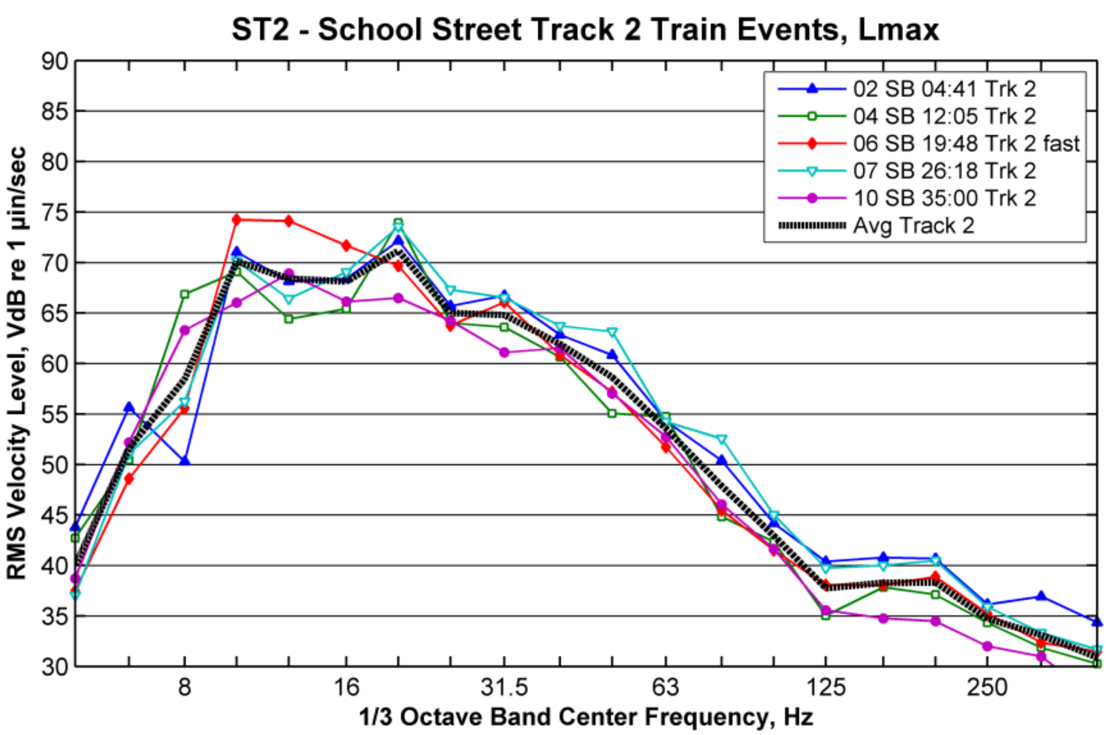


Figure 42: Spectra of Measured L_{max} for Track 2 Train Events at Site ST2

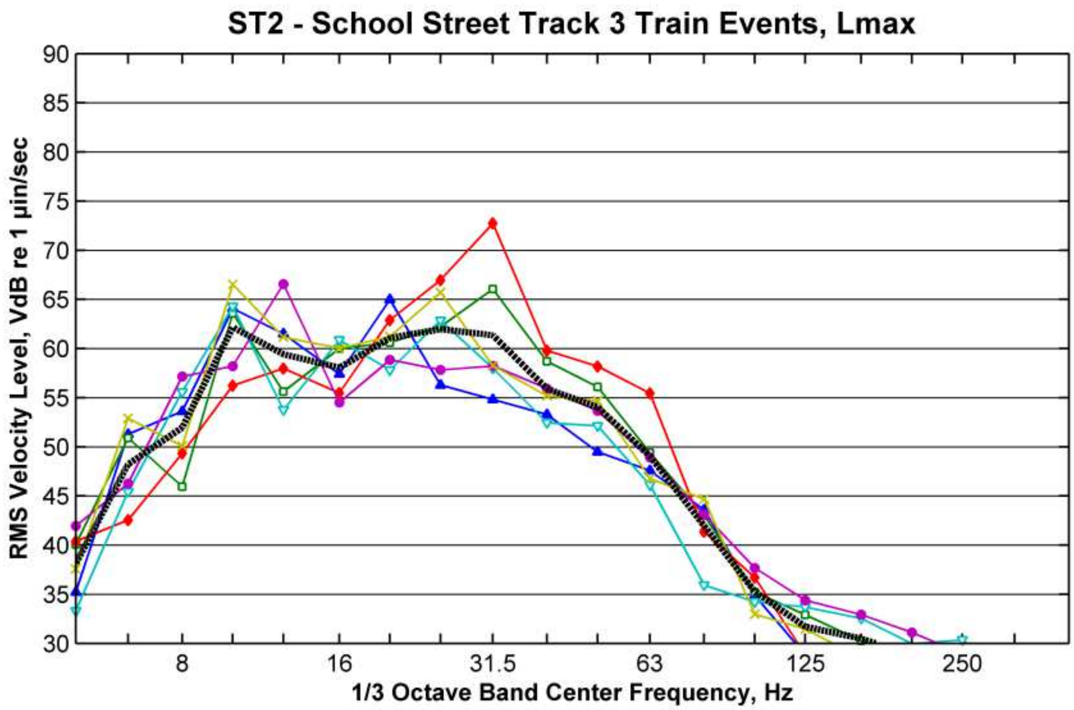


Figure 43: Spectra of Measured L_{max} for Track 3 Train Events at Site ST2

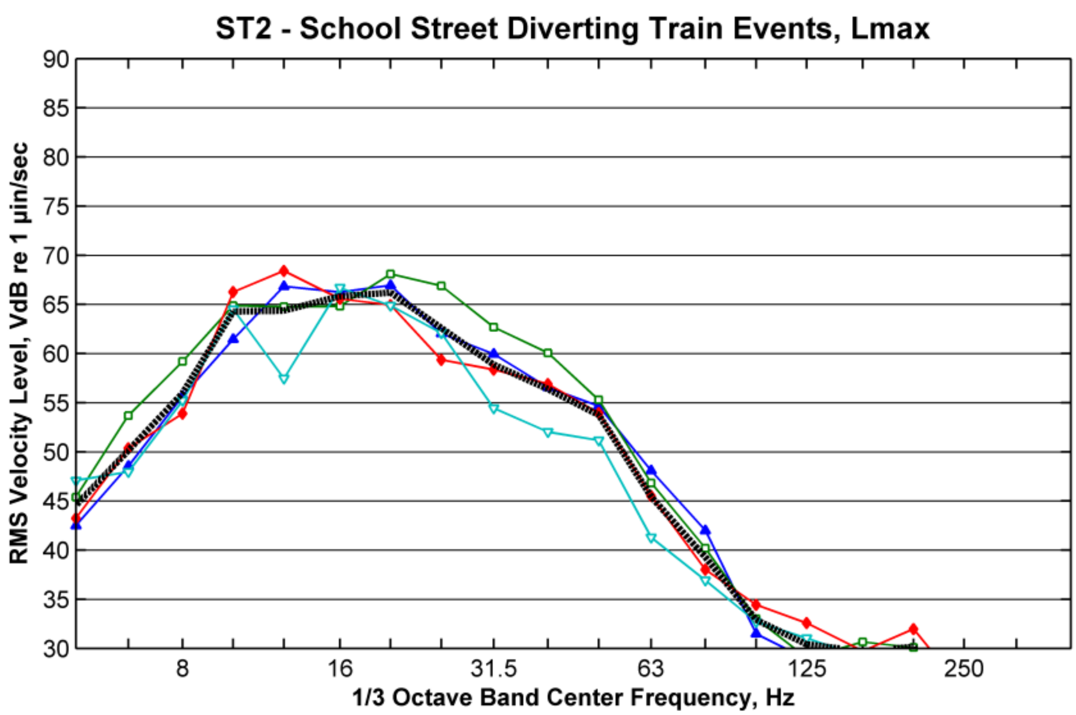


Figure 44: Spectra of Measured L_{max} for Diverting Train Events at Site ST2

ST3: Buckingham and Clark

The accelerometer was located 200 ft east of the open deck, steel structure at the corner of Buckingham Place and Clark Street. During the measurement, Red Line rains were operating on tracks 2 and 3, Brown Line trains were operating on track 1, and northbound Brown Line trains were completing a diverting movement from track 4 to track 2. The diverting trains were traveling about 15 mph. The trains on the other tracks were traveling 20-25 mph. An aerial photograph showing the measurement location is shown in Figure 45.

Figure 46 through Figure 49 show the spectra of the L_{max} of the train events for the different tracks. The average of the train events is plotted with a heavy, dashed black line.

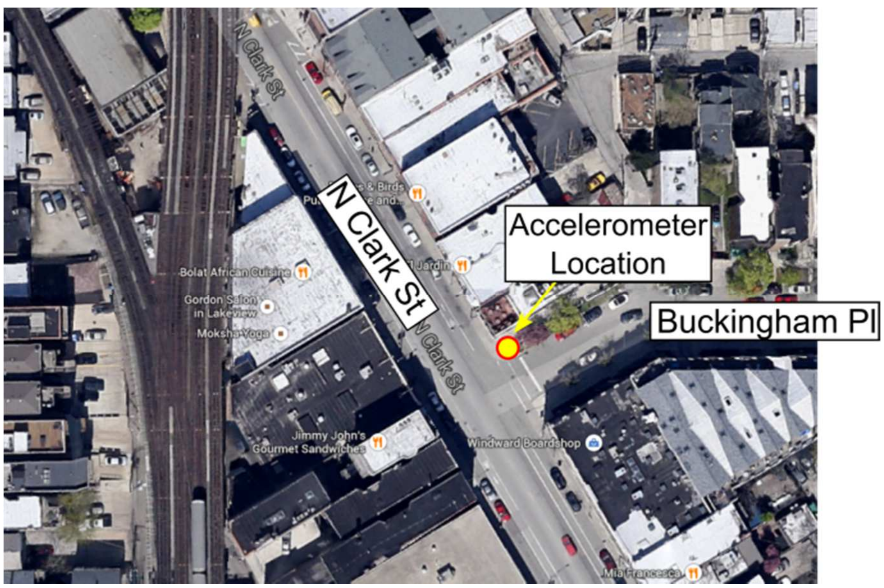


Figure 45: Aerial Photograph of Site ST3

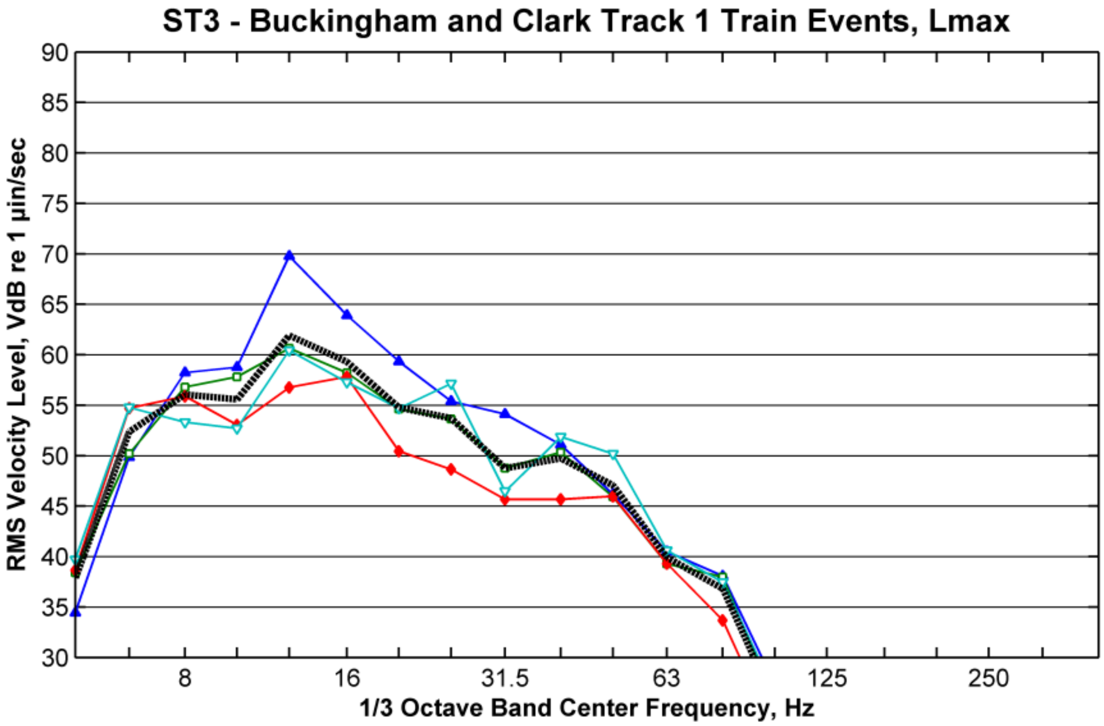


Figure 46: Spectra of Measured L_{max} for Track 1 Train Events at Site ST3

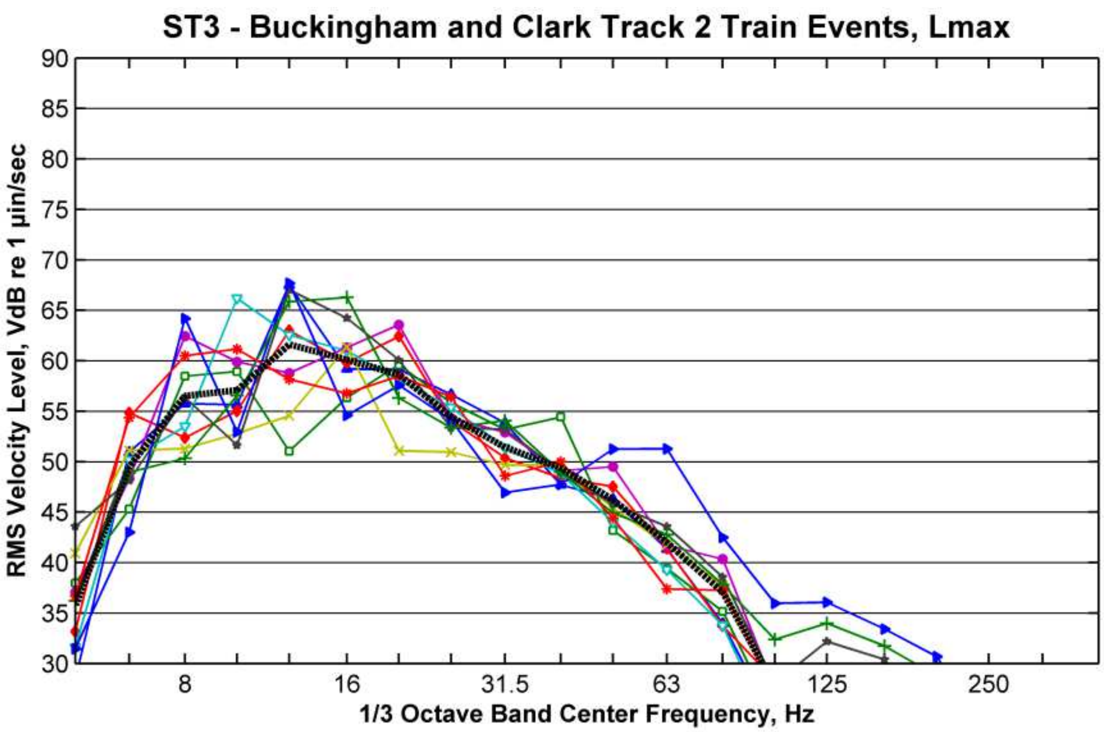


Figure 47: Spectra of Measured L_{max} for Track 2 Train Events at Site ST3

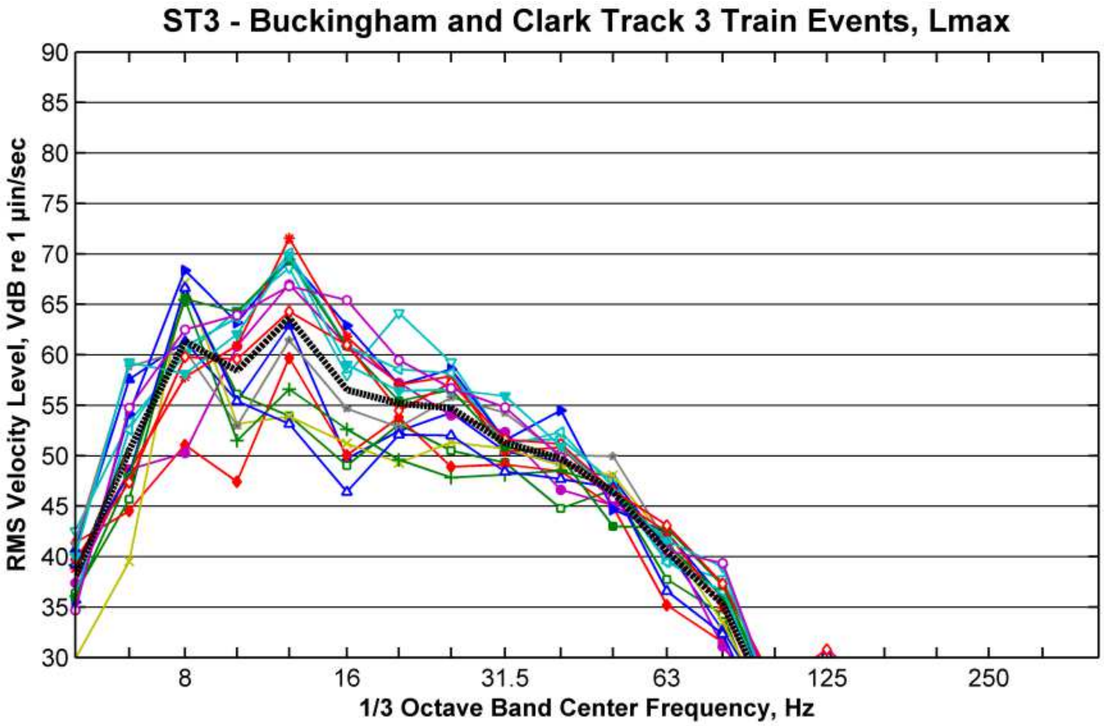


Figure 48: Spectra of Measured L_{max} for Track 3 Train Events at Site ST3

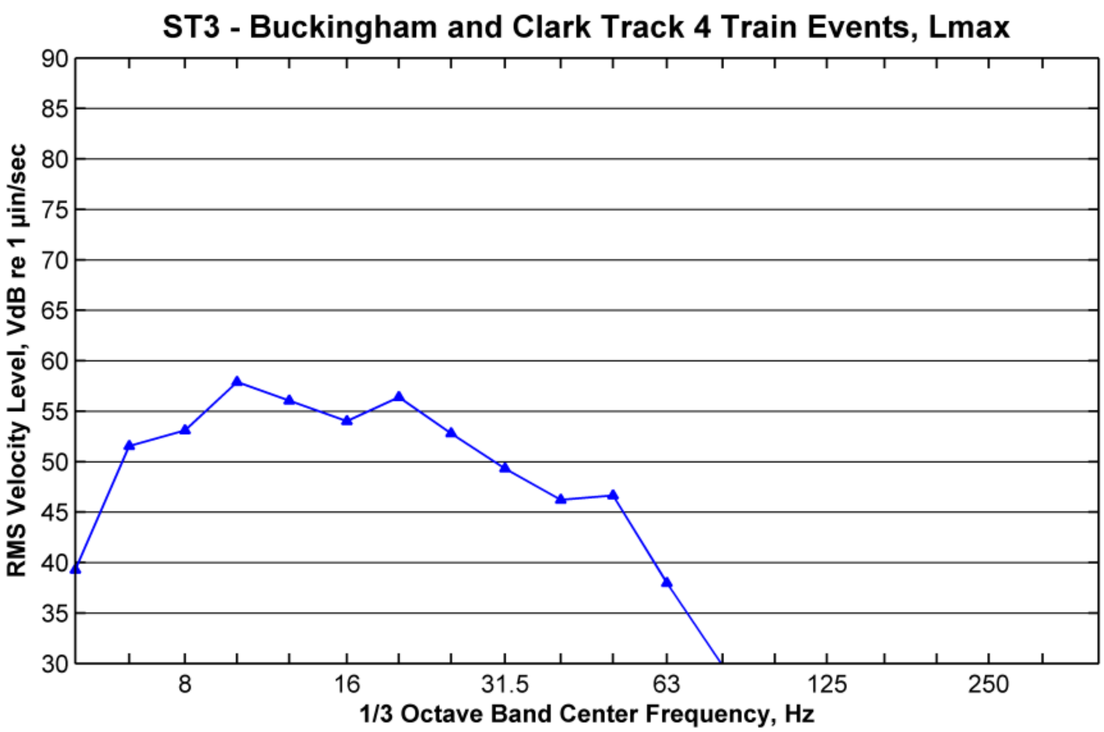


Figure 49: Spectra of Measured L_{max} for Track 4 Train Events at Site ST3

ST4: Roscoe Avenue

The accelerometer was located 30 feet south of the open deck, steel structure about 150 ft east of Seminary Avenue. Brown Line trains were running adjacent to the measurement location. There are only two tracks at this site; eastbound trains were running on track 1 and westbound trains were running on track 4. An aerial photograph of the measurement location is shown in Figure 50.

Figure 51 and Figure 52 show the spectra of the L_{max} of the train events for the two tracks. The average of the train events is plotted with a heavy, dashed black line.

Figure 50: Aerial Photograph of Measurement Site ST4

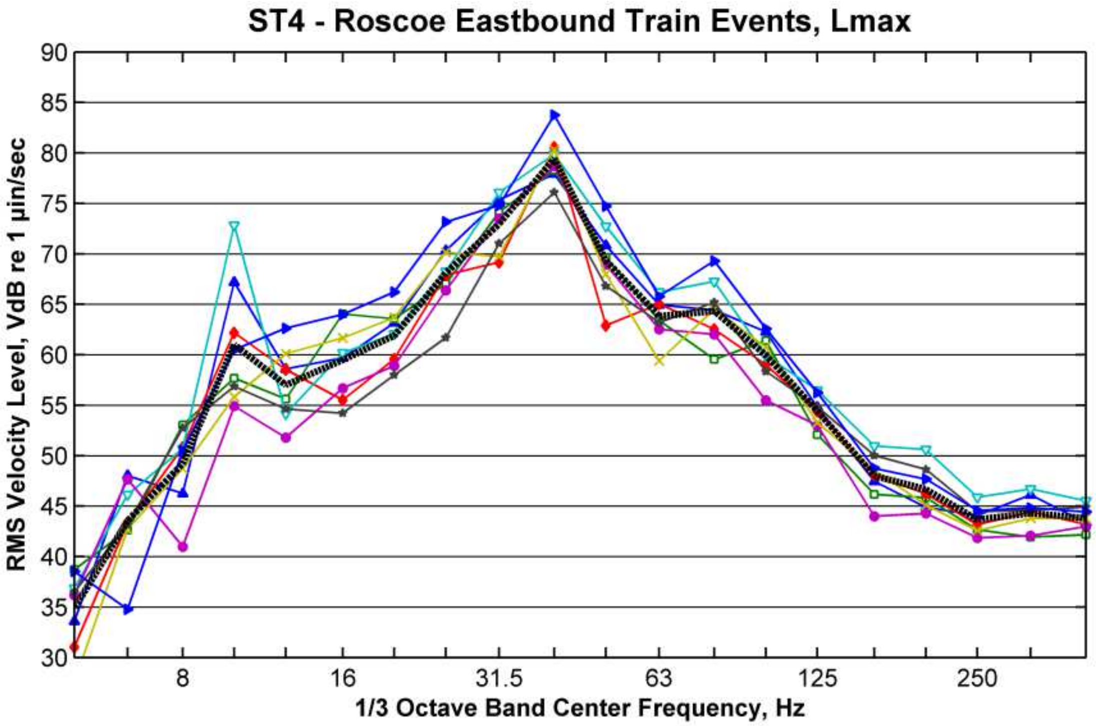


Figure 51: Spectra of Measured L_{max} for Eastbound Train Events at Site ST4

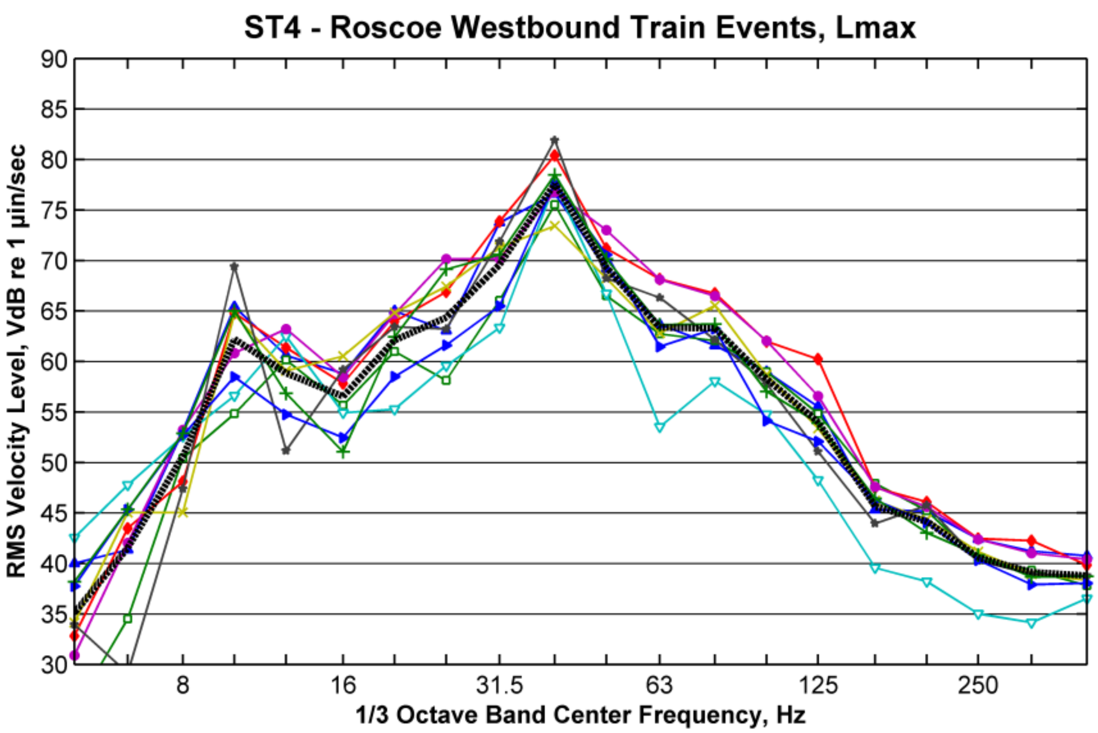


Figure 52: Spectra of Measured L_{max} for Westbound Train Events at Site ST4

ST5: Newport Avenue

Accelerometers were located 25 feet, 50 feet, 100 feet, 200 feet, and 300 feet east of the open deck, steel structure on the south sidewalk of Newport Avenue. Red Line trains were running on tracks 2 and 3. Purple Line trains were running on tracks 1 and 4. An aerial photograph of the measurement location is shown in Figure 53.

Figure 54 through **Figure 58** show the spectra of the L_{max} of the train events for the different tracks and measurement locations. The average of the train events is plotted with a dashed black line.

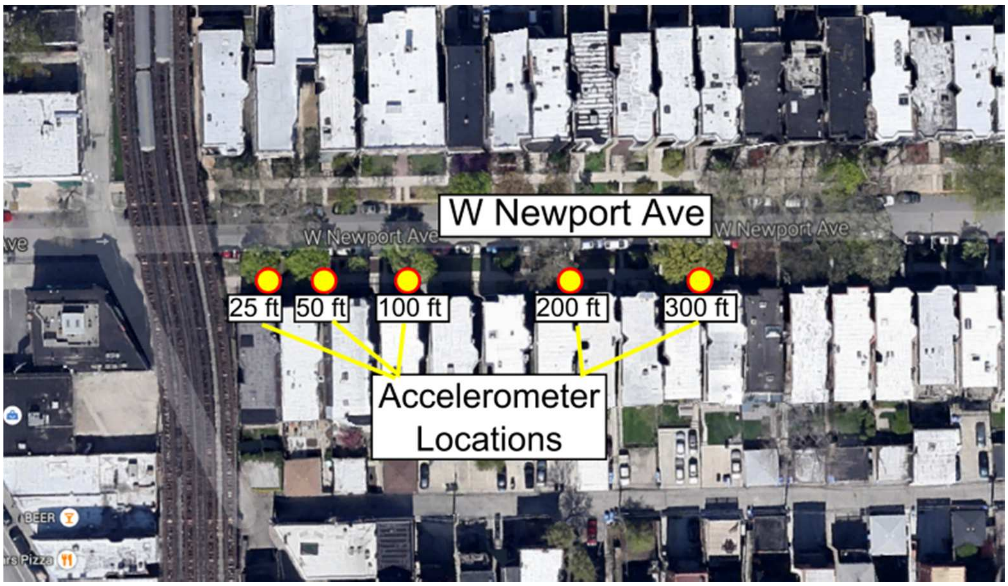


Figure 53: Aerial Photograph of Measurement Site ST5

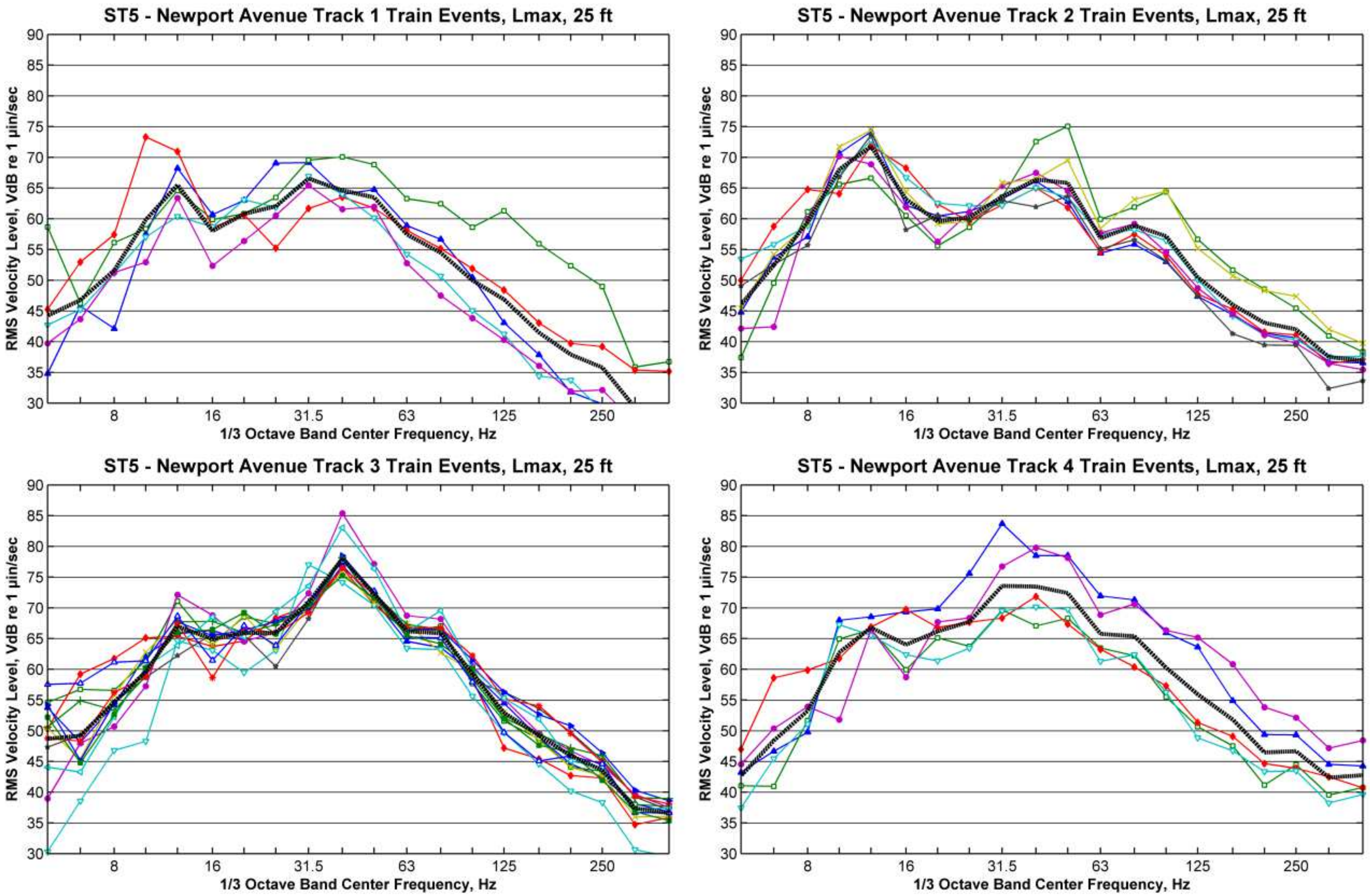


Figure 54: Spectra of Measured L_{max} for Train Events at ST5, 25 ft

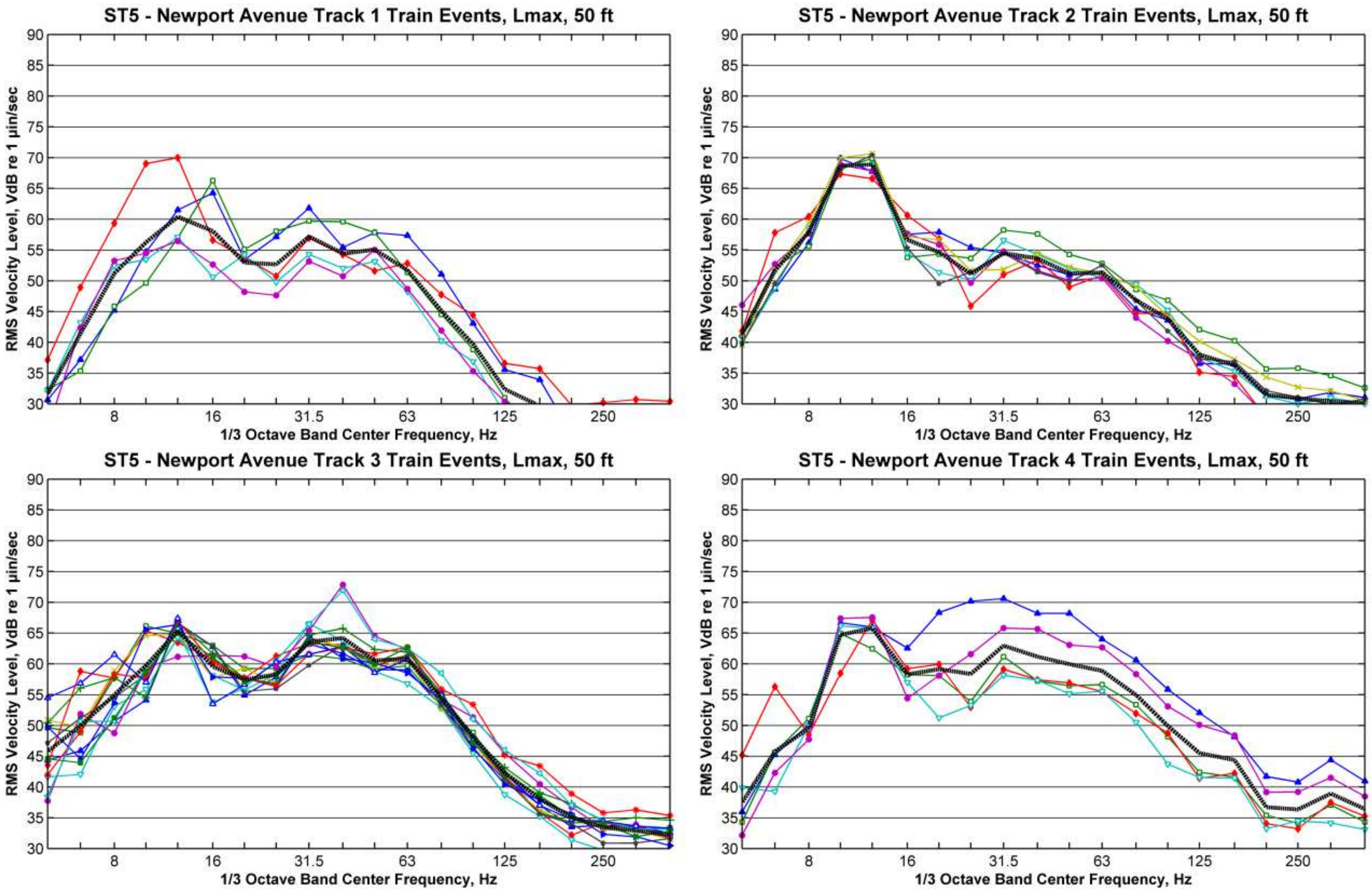


Figure 55: Spectra of Measured L_{max} for Train Events at ST5, 50 ft

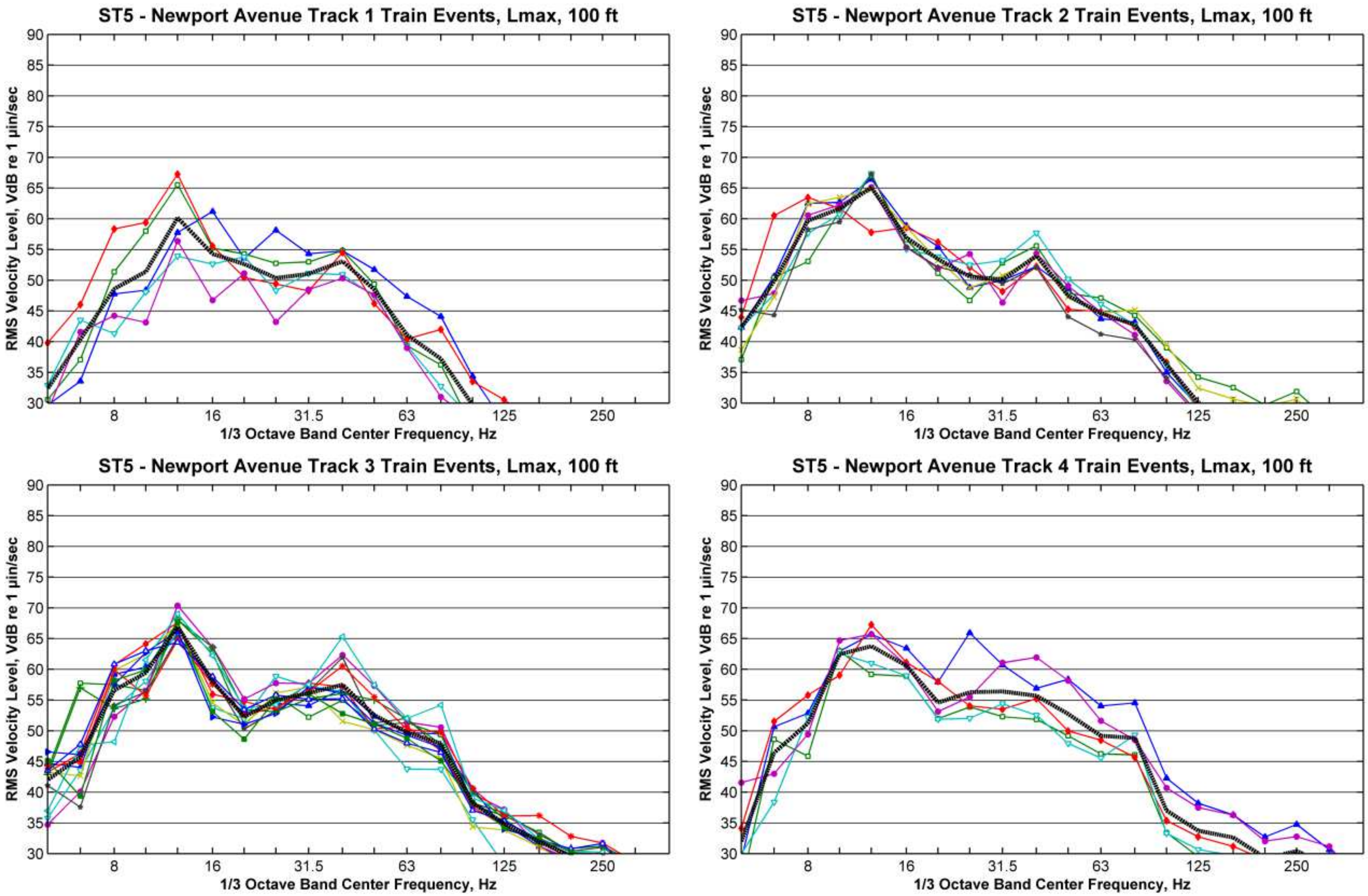


Figure 56: Spectra of Measured L_{max} for Train Events at ST5, 100 ft

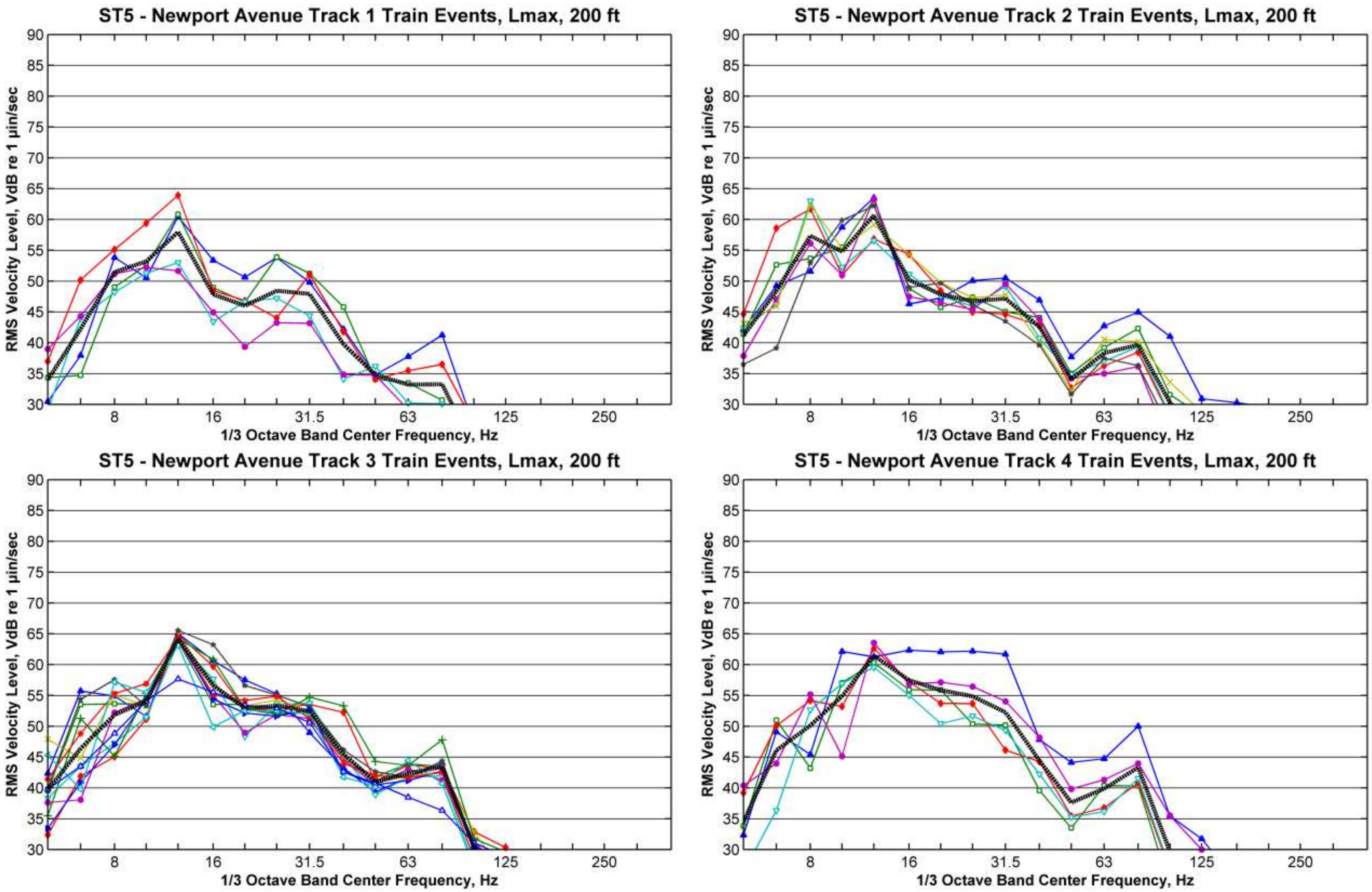


Figure 57: Spectra of Measured L_{max} for Train Events at ST5, 200 ft

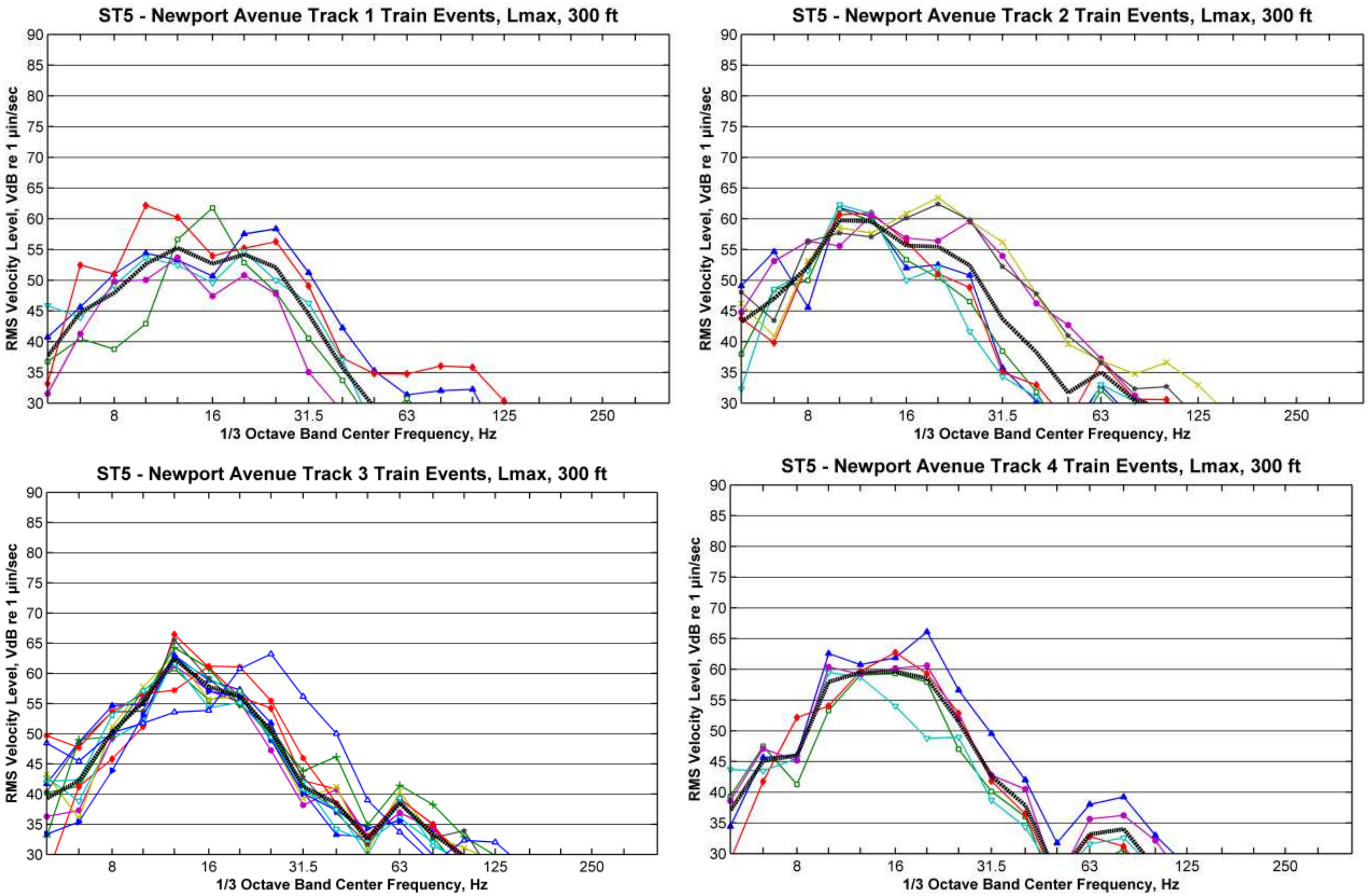


Figure 58: Spectra of Measured L_{max} for Train Events at ST5, 300 ft

B.1 Reference Level Measurements: Fullerton Station

Train vibration measurements were conducted at the existing Fullerton Station structure to determine a reference vibration level for CTA trains operating on a closed deck structure with direct fixation track. Details about the measurement location are presented in **Section 5.4.1**. The train vibration was measured on the both sides of the structure with distances relative to the closest column.

Figure 111 through **Figure 119** show the L_{max} of the train events measured at all measurement sites on all tracks. Key observations from the measurement results are:

- The train events measured 25 feet east of Track 4 were excluded from the vibration prediction model due to abnormally high levels. Other sites at a comparable distance from the tracks did not show these same high levels.
- Train events measured 50 feet west of Track 1 were excluded from the vibration prediction model due to abnormally low levels. The low levels may be due to attenuation from an adjacent building.
- During the measurement, some of the trains were traveling at slow speeds due to a work crew on the tracks. The spectra from these train events are not plotted.
- The track at Fullerton Station has jointed rail. Vibration levels from a similar structure with welded rail would be lower.
- The maximum vibration levels were measured from trains traveling over the column closest to the measurement position. For example, the maximum vibration levels at the accelerometer 30 feet west of Track 1 was from train events traveling on Track 1 and maximum vibration levels at the accelerometer 31 feet east of Track 4 was from train events traveling on Track 4.

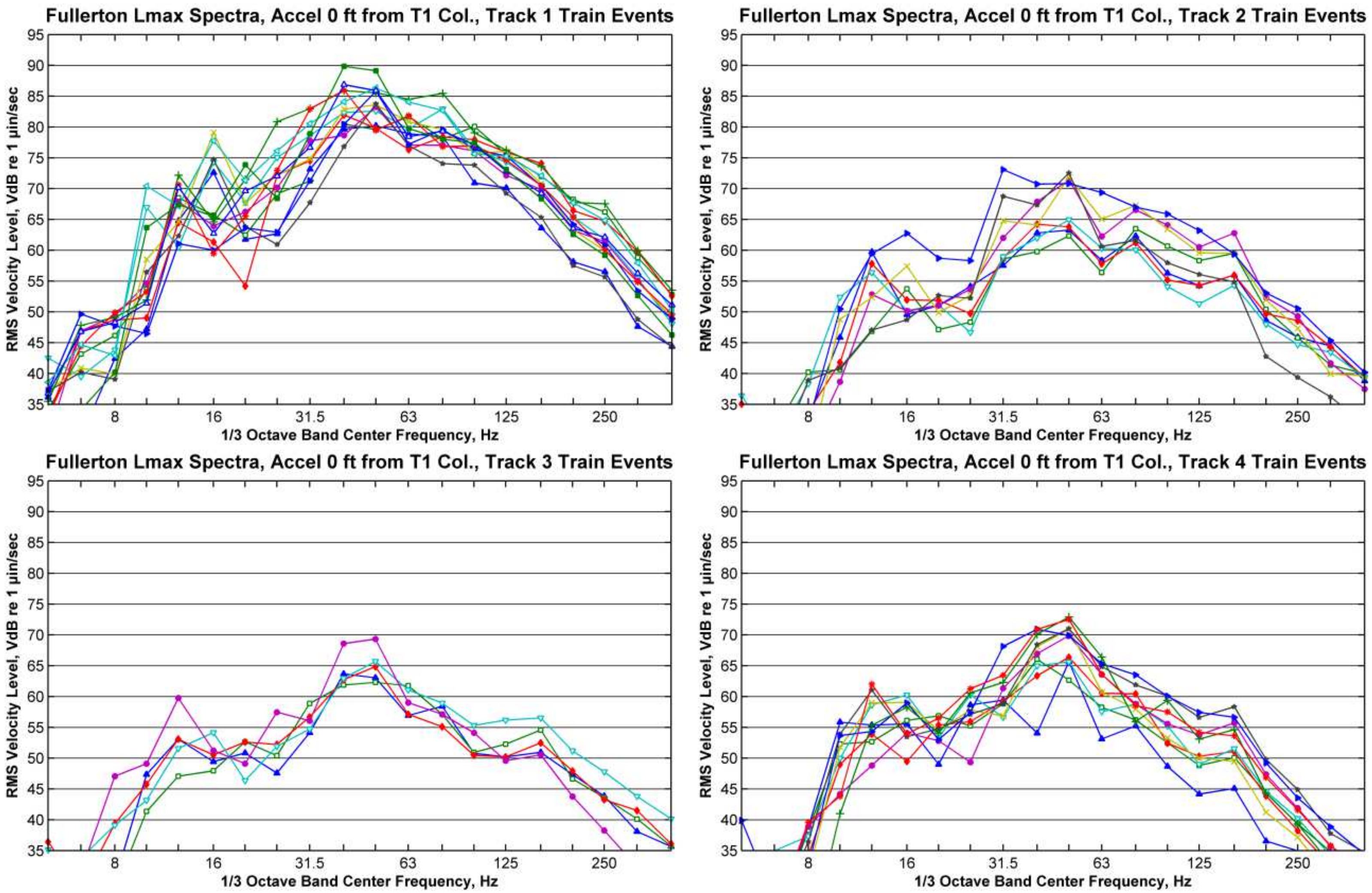


Figure 59: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer Adjacent to Column under Track 1

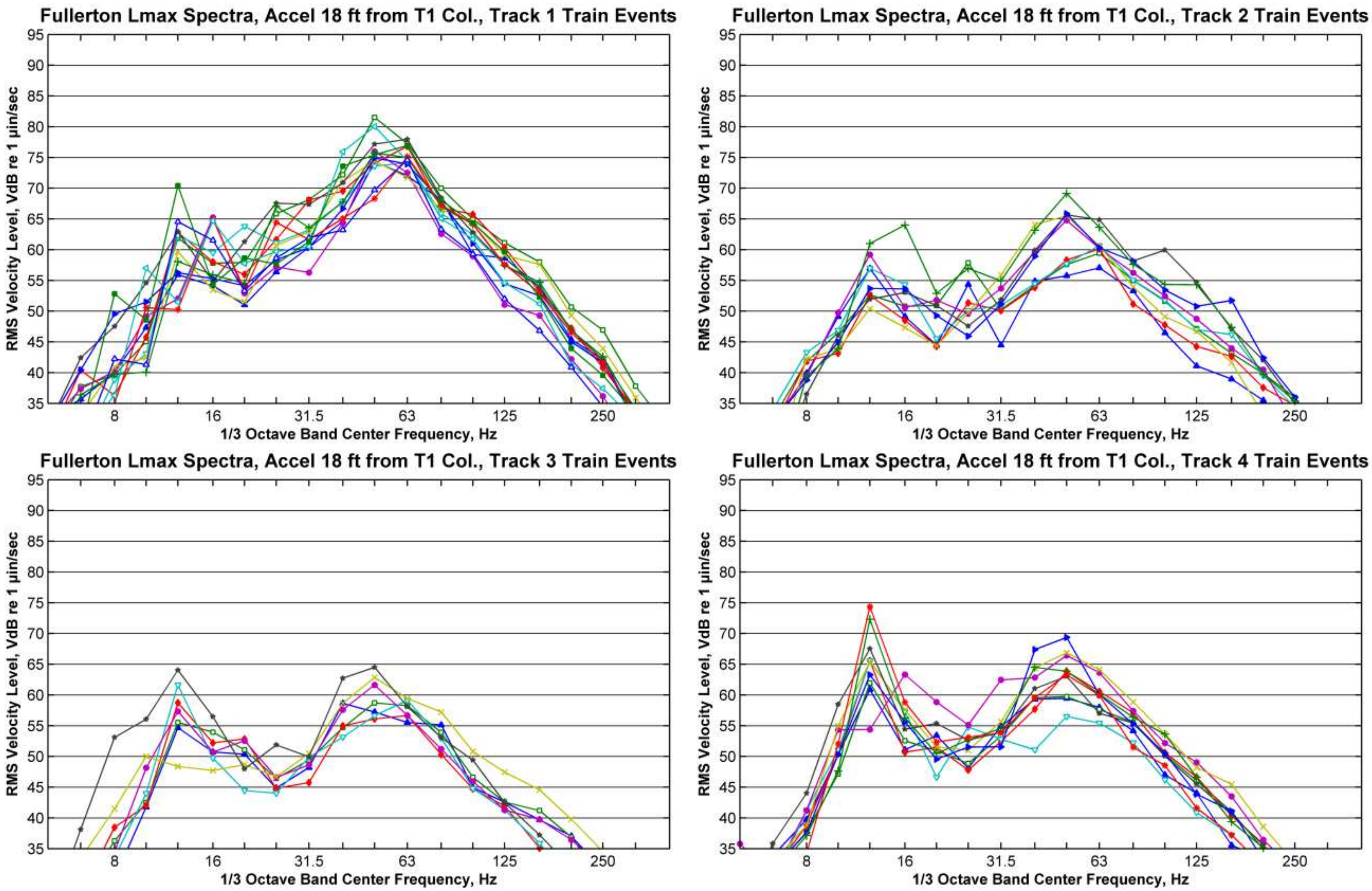


Figure 60: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer Between Two Columns Under Track 1

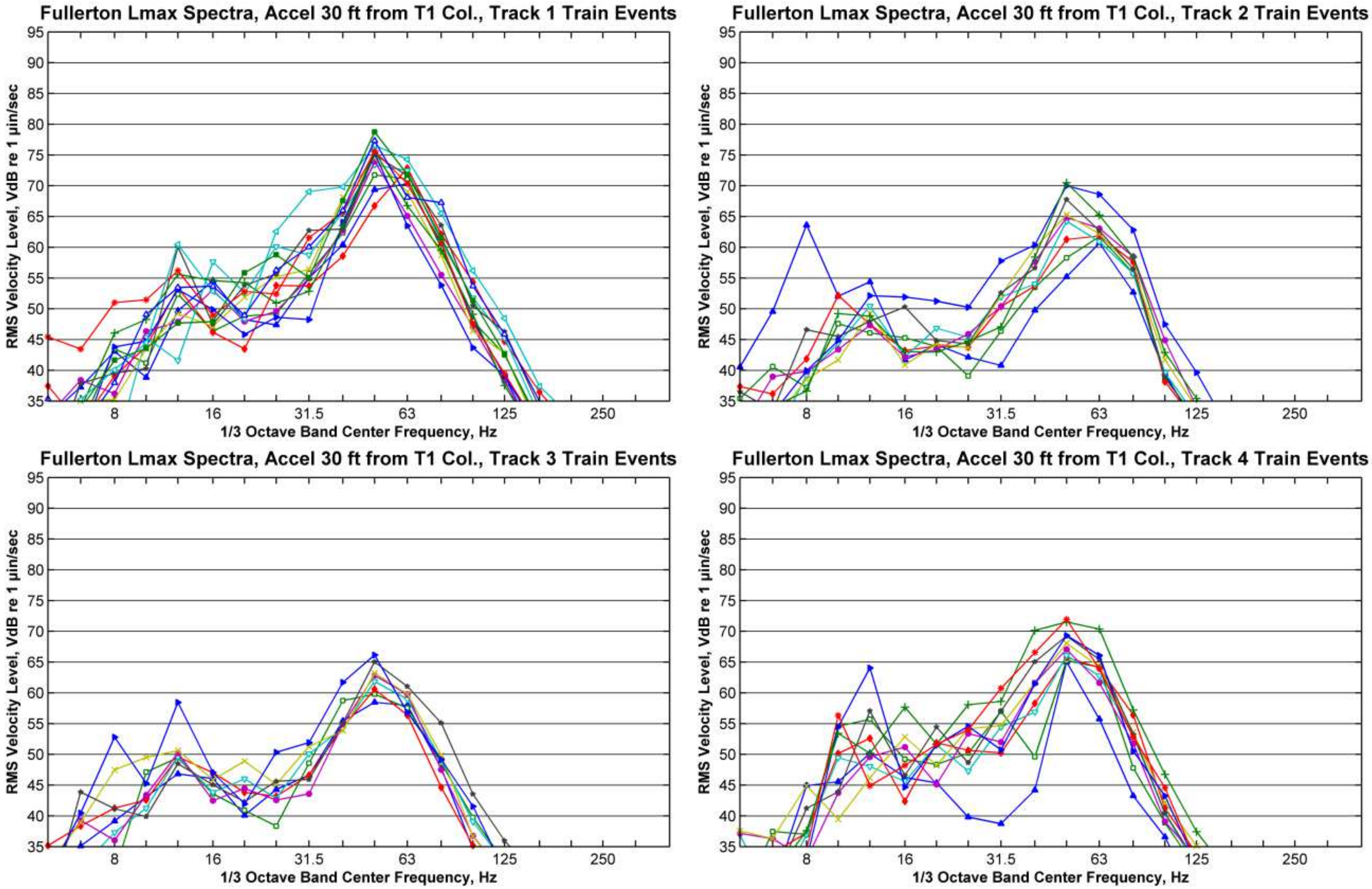


Figure 61: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 30 feet West of Column Under Track 1

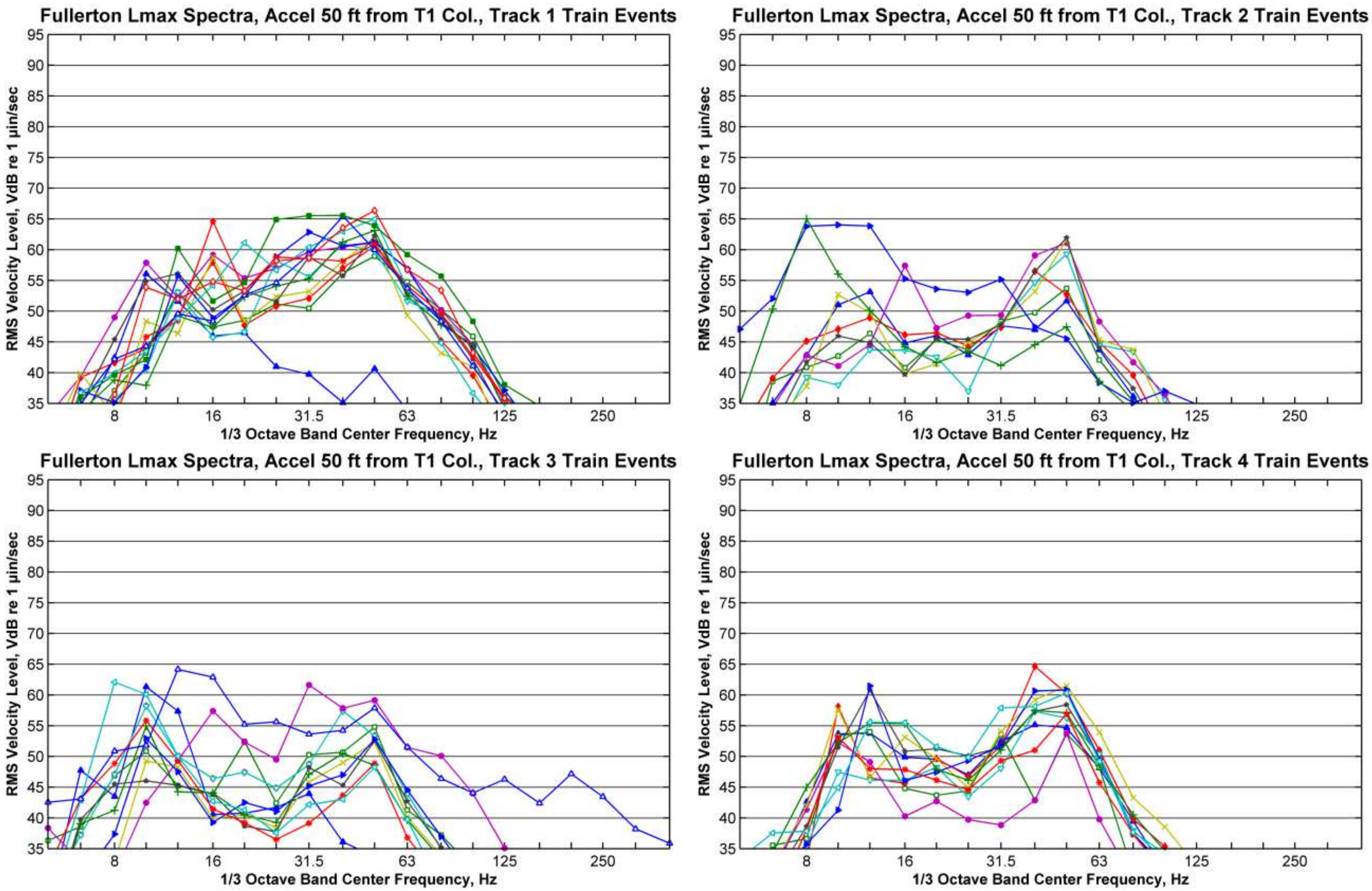


Figure 62: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 50 feet West of Column Under Track 1

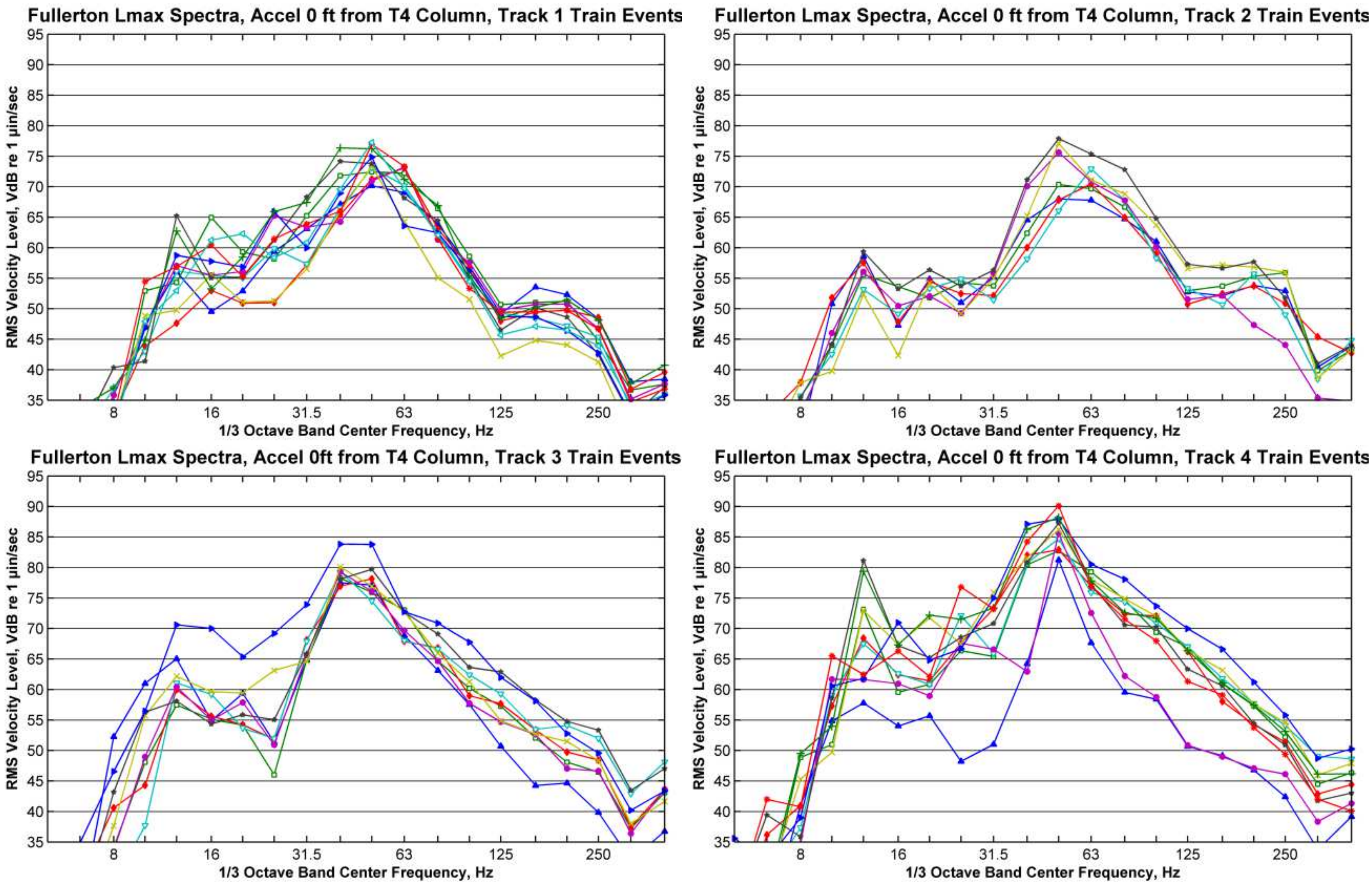


Figure 63: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 0 feet from Column Under Track 4

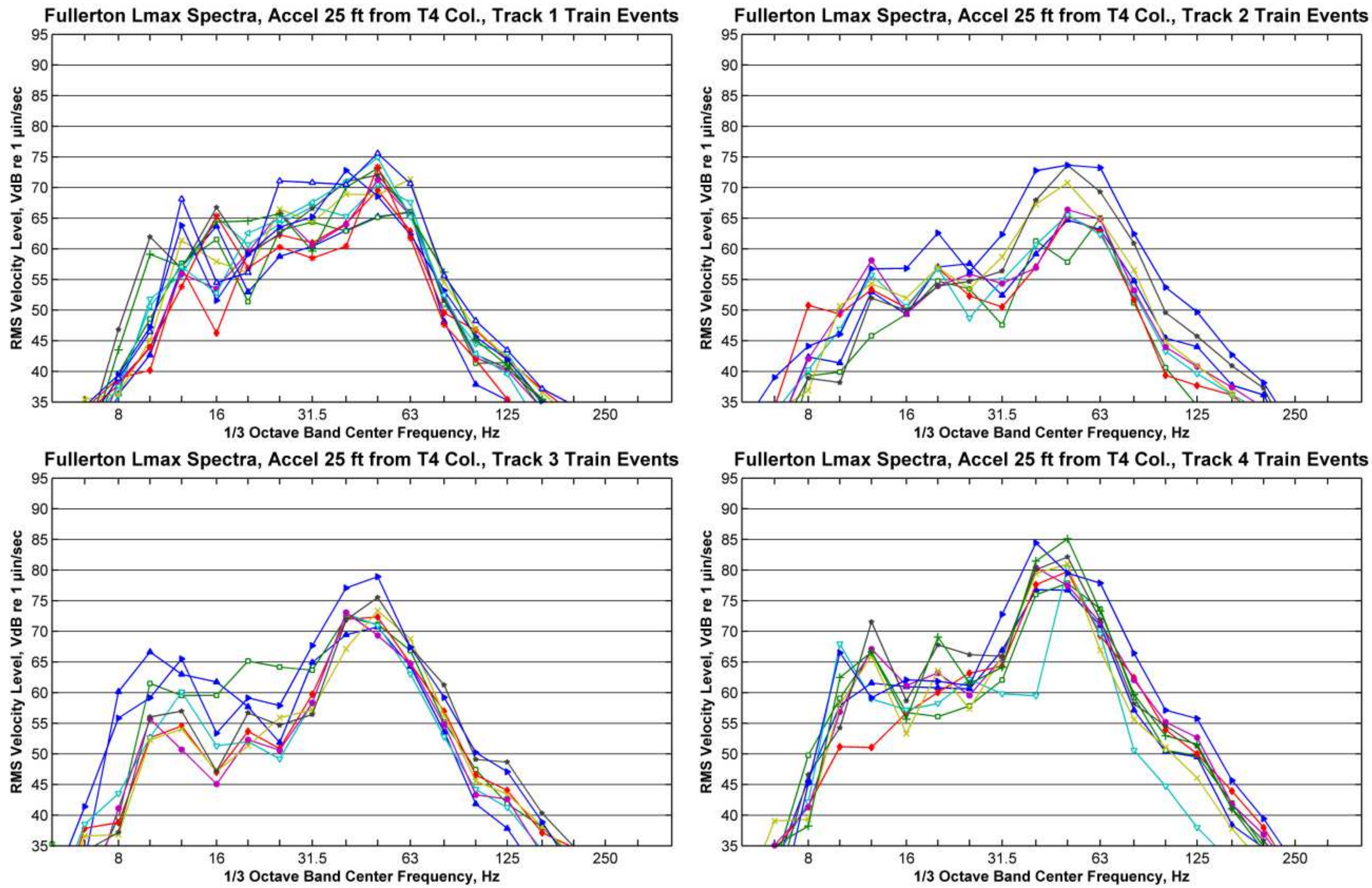


Figure 64: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 25 feet West of Column Under Track 4

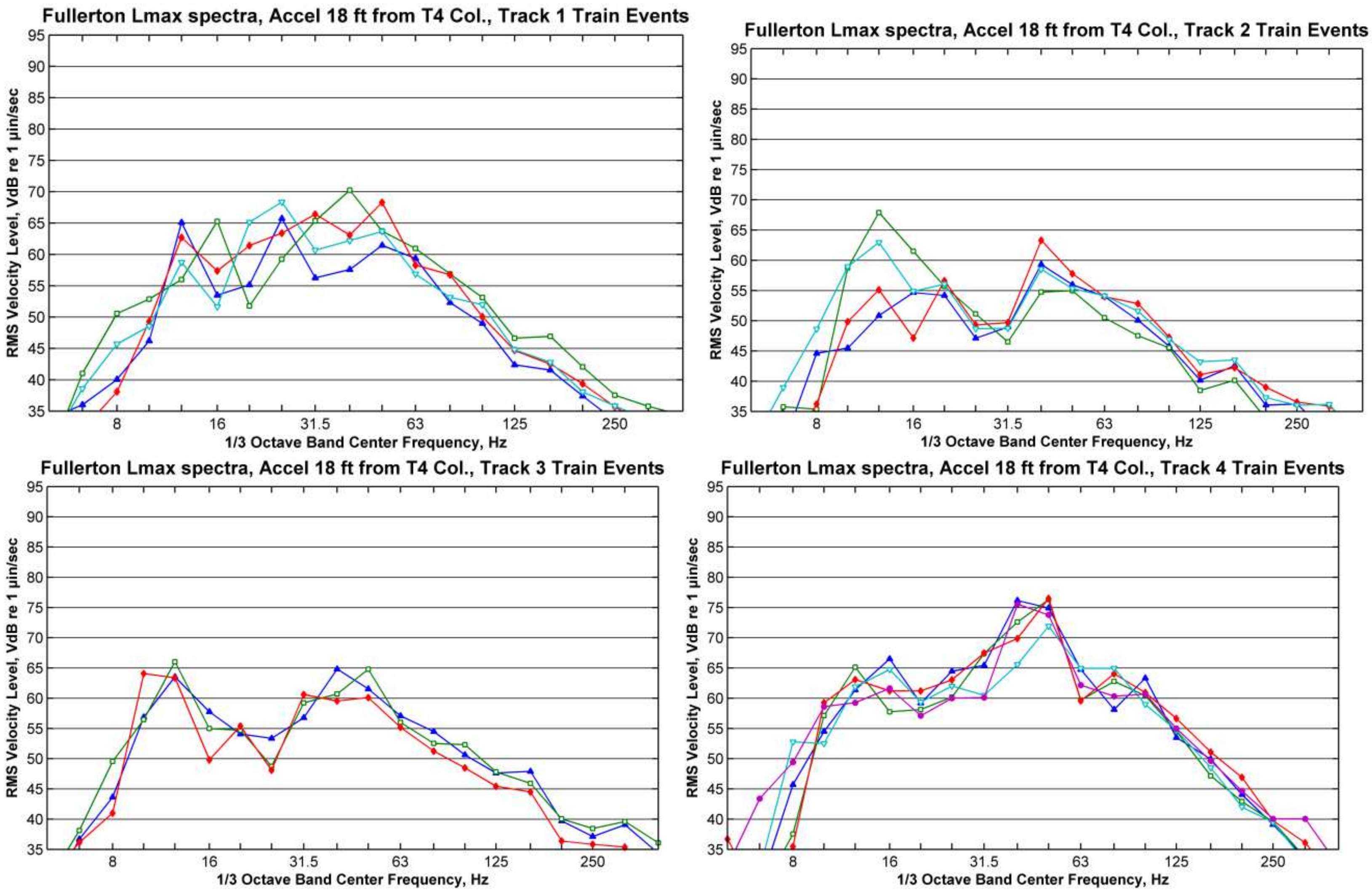


Figure 65: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 18 feet North of Column Under Track 4

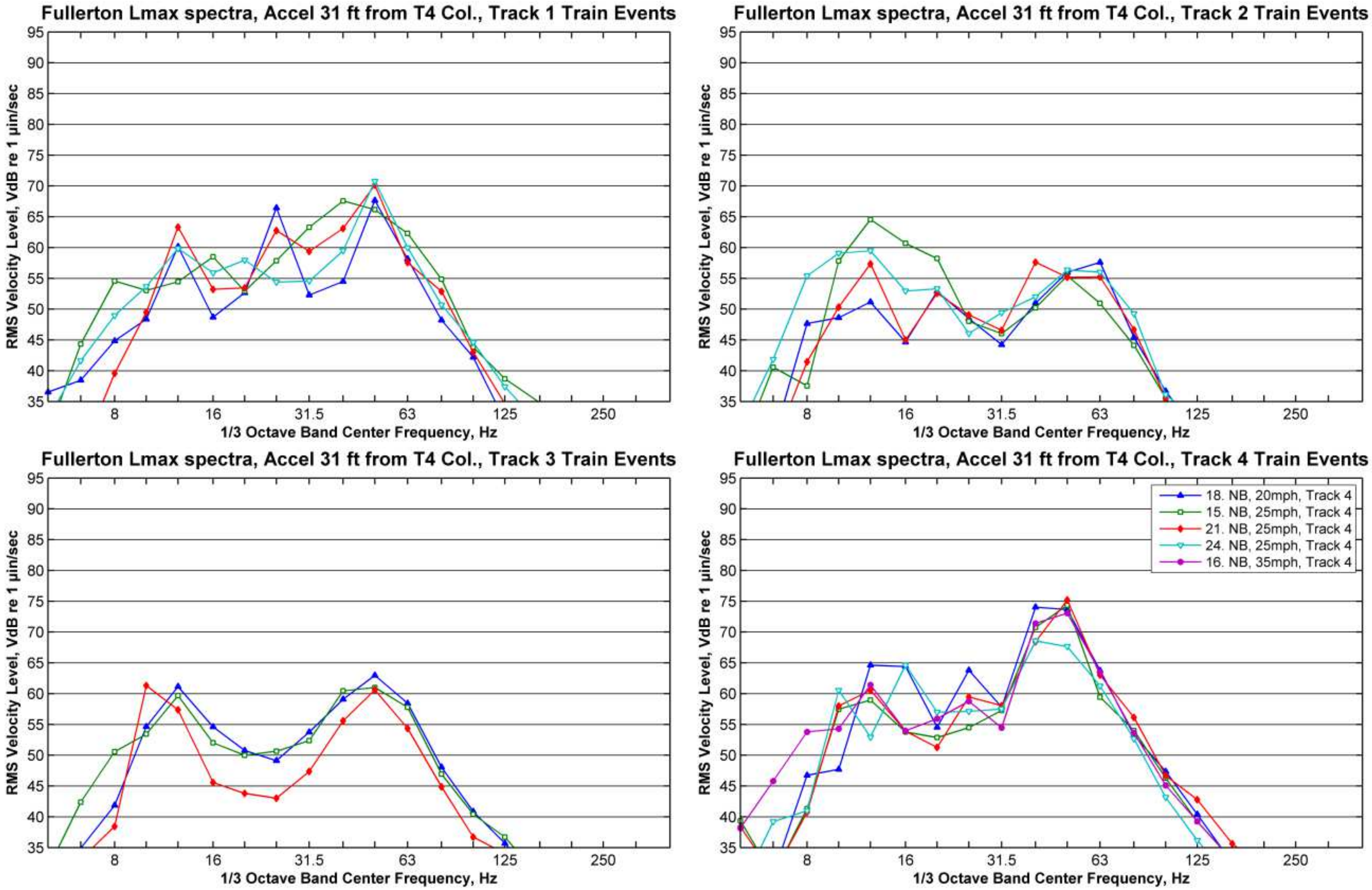


Figure 66: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 31 feet West of Column Under Track 4

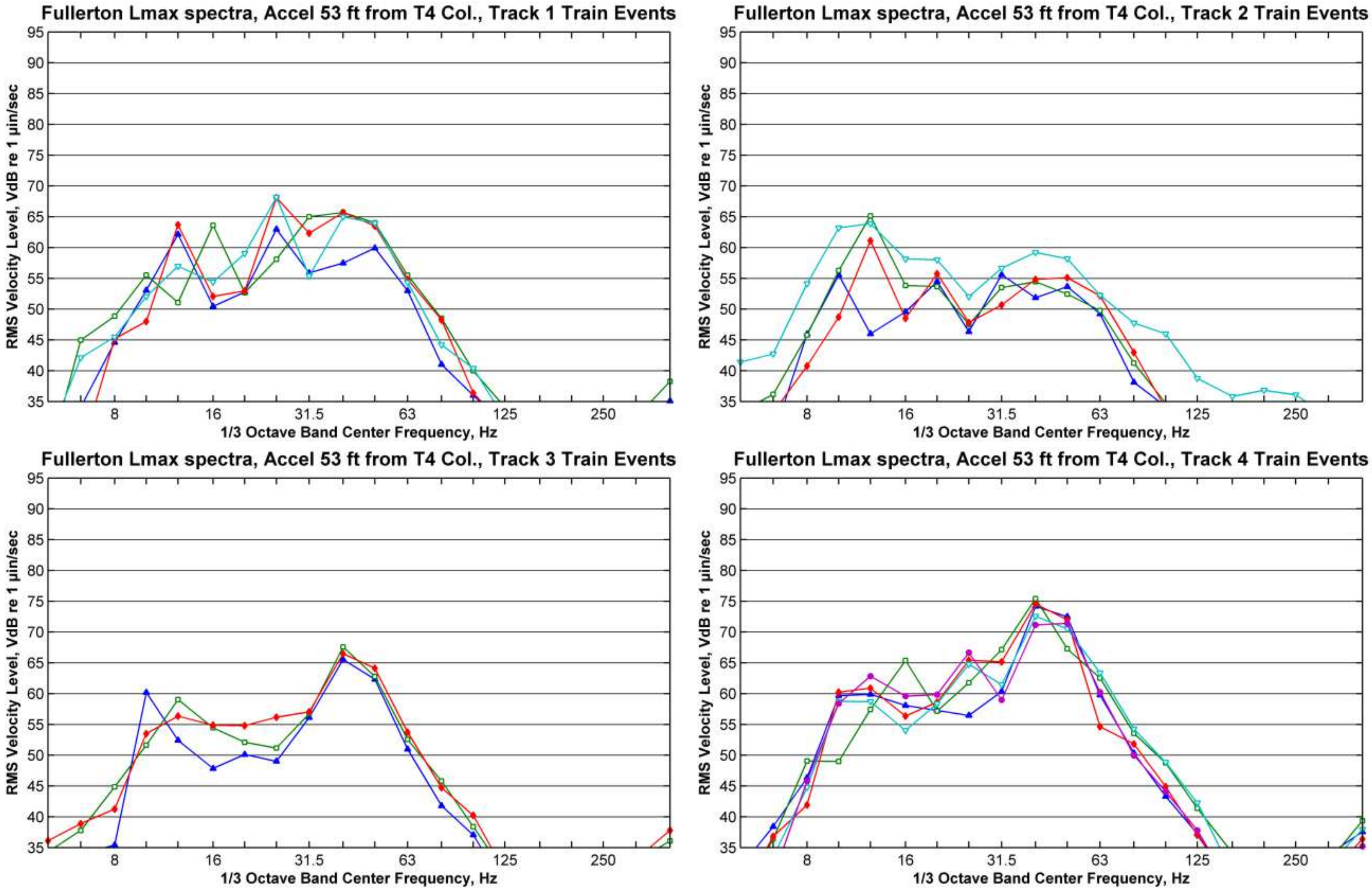


Figure 67: Spectra of L_{max} for Train Events on all Tracks at Fullerton Station, Accelerometer 53 feet West of Column Under Track 4

Appendix C: Background on Noise and Vibration

Noise

Sound is mechanical energy transmitted by pressure waves in a compressible medium such as air. Noise is generally 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. To better approximate the sensitivity of human hearing, the A-weighted decibel scale has been developed. A-weighted decibels are abbreviated as "dBA." On this scale, the human range of hearing extends from approximately 3 dBA to around 140 dBA. As a point of reference, **Figure 68** includes examples of A-weighted sound levels from common indoor and outdoor sounds.

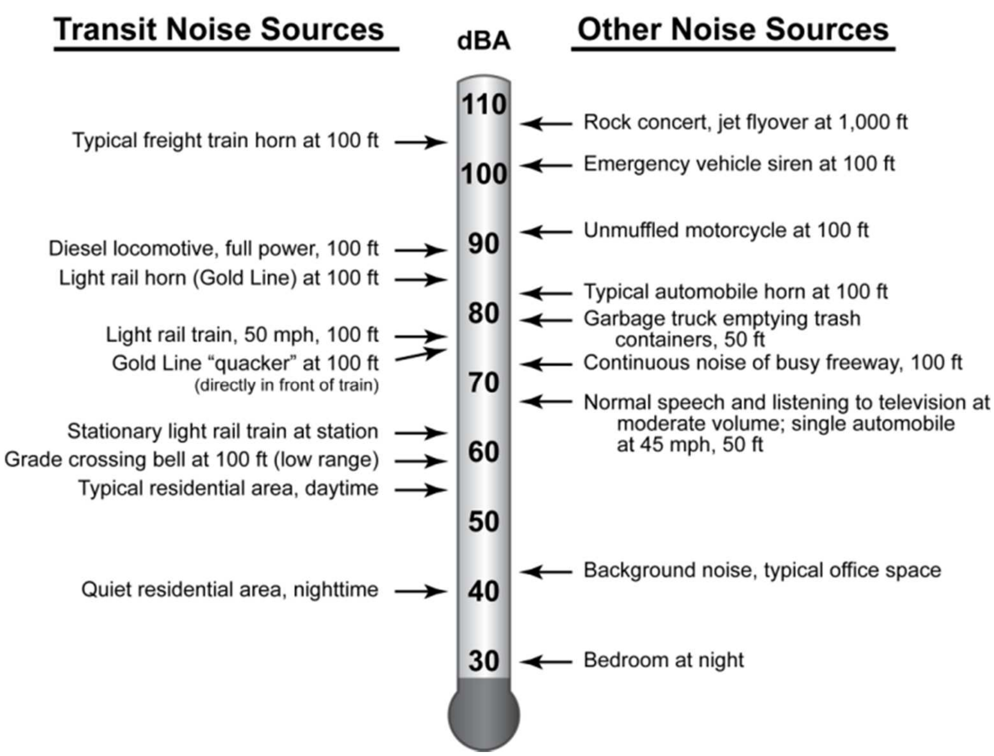


Figure 68. Typical Indoor and Outdoor Noise Levels

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 generally considered 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 increasing the distance between the sound source and the receiver and 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.

Following are brief definitions of the measures of environmental noise used in this study:

- *Maximum Sound Level (L_{max}):* L_{max} is the maximum sound level that occurs during an event such as a train passing. For this analysis L_{max} is defined as the maximum sound level using the slow setting on a standard sound level meter.

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

- *Day-Night Sound Level (L_{dn}):* L_{dn} is basically a 24-hour L_{eq} 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 p.m. to 7:00 a.m. The effect of the penalty is that, when calculating L_{dn}, any event that occurs during the nighttime is equivalent to ten occurrences of the same event during the daytime. L_{dn} is the most common measure of total community noise over a 24-hour period and is used by the FTA to evaluate residential noise effects from proposed transit projects.

- *L_{XX}:* This is the percent of time a sound level is exceeded during the measurement period. For example, the L_{99} is the sound level exceeded during 99 percent of the measurement period. For a 1-hour period, L_{99} is the sound level exceeded for all except 36 seconds of the hour. L_1 represents typical maximum sound levels, L_{33} is approximately equal to L_{eq} when free-flowing traffic is the dominant noise source, L_{50} is the median sound level, and L_{99} 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 1-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 L_{eq} and L_{dn}.

- *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.

Vibration

One potential community effect from the proposed project is vibration that is transmitted from the tracks through the ground to adjacent houses. This is referred to as *ground-borne vibration*. When evaluating human response, ground-borne vibration is usually 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.).[1] The potential adverse effects of rail transit ground-borne vibration are as follows:

- **Perceptible Building Vibration:** This is when building occupants feel the vibration of the floor or other building surfaces. Experience has shown that the threshold of human perception is around 65 VdB and that vibration that exceeds 75 to 80 VdB may be intrusive and annoying to building occupants.

- **Rattle:** The building vibration can cause rattling of items on shelves and hanging on walls, and various different rattle and buzzing noises from windows and doors.

- **Reradiated Noise:** The vibration of room surfaces radiates sound waves that may be audible to humans. This is referred to as *ground-borne noise*. When audible ground-borne noise occurs, it sounds like a low-frequency rumble. When the tracks are at-grade, the ground-borne noise is usually 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 rail transit system could cause damage to fragile buildings, the vibration from rail transit systems is usually one to two orders of magnitude below the most restrictive thresholds for preventing building damage. Hence the vibration effect criteria focus on human annoyance, which occurs at much lower amplitudes than does building damage.

Vibration is an oscillatory motion that can be 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 passenger trains, human response is best approximated by the vibration velocity level. Therefore, vibration velocity has been used in this study to describe train-generated vibration levels.

When evaluating human response, ground-borne vibration is usually expressed in terms of decibels using the root mean square (RMS) vibration velocity. RMS is defined as the average of

[1] One μin/sec= 10^{-6} in/sec.

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 µin/sec.

Figure 69 shows typical vibration levels from rail and non-rail sources as well as the human and structure response to such levels.

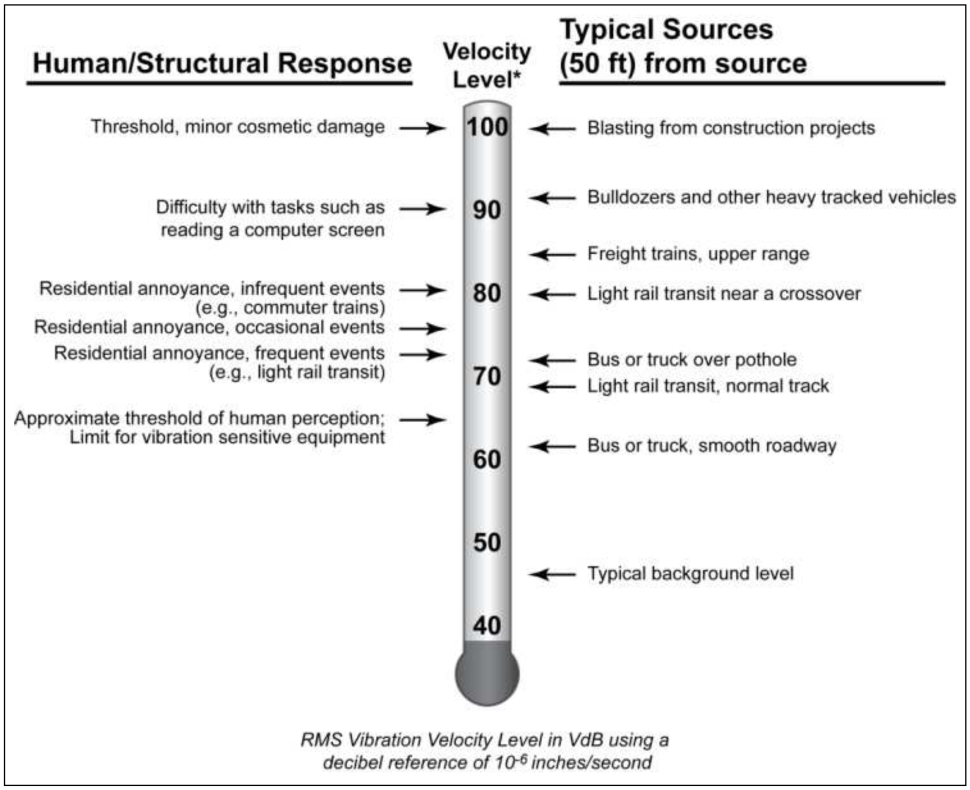


Figure 69: Typical Vibration Levels

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

- It is rare that ground-borne vibration from transit systems results in building damage, even minor cosmetic damage. The primary consideration therefore is whether vibration will be intrusive to building occupants or will interfere with interior activities or machinery.

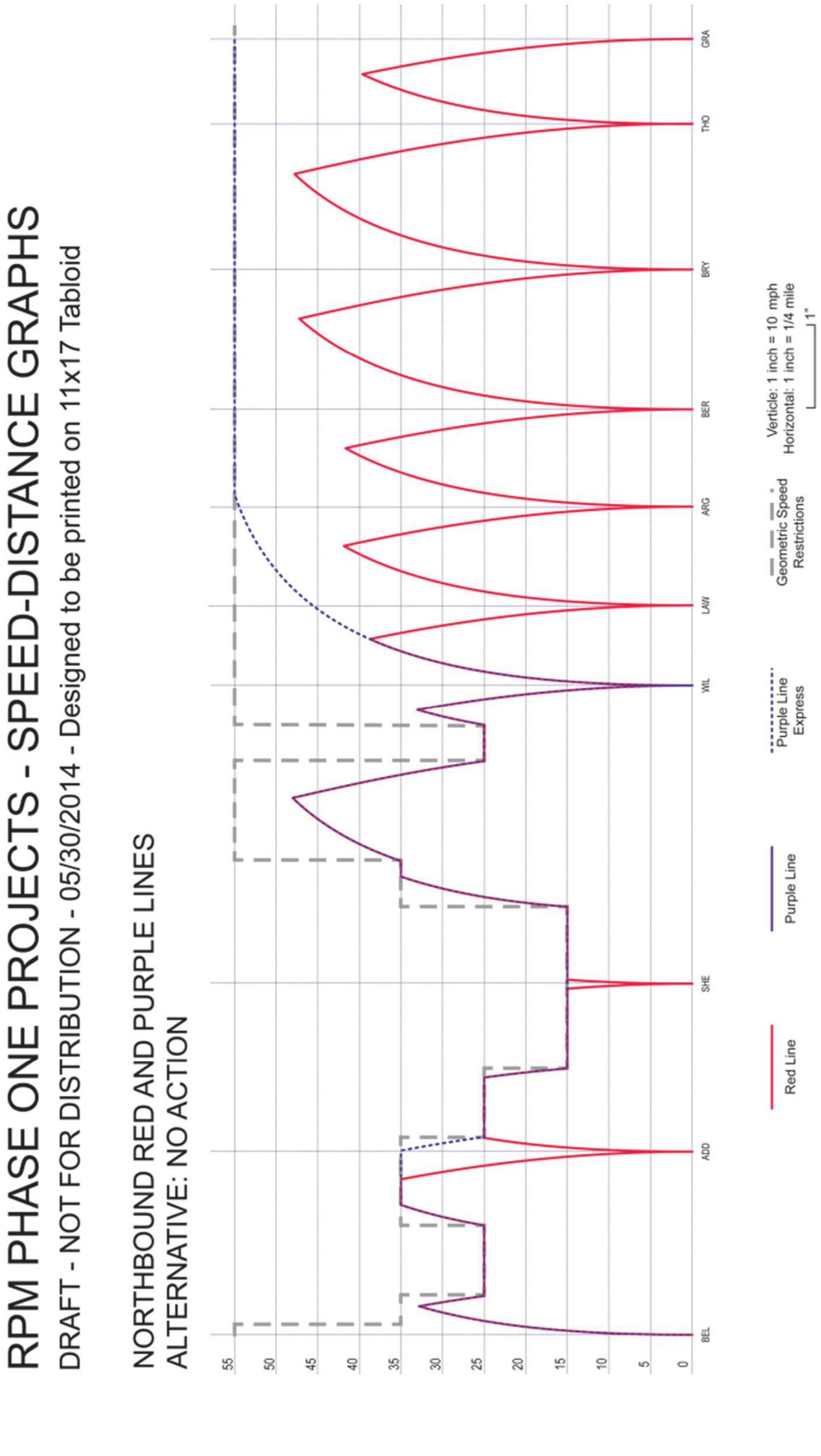
- The threshold for human perception is approximately 65 VdB. Vibration levels in the range of 70 to 75 VdB are often noticeable but acceptable. Beyond 80 VdB, vibration levels are often considered unacceptable.

- For human annoyance, there is a relationship between the number of daily events and the degree of annoyance caused by ground-borne 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.

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” has been 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. The FTA Guidance Manual is a good reference for additional information on transit noise and vibration and the technical terms used in this section.

Appendix D: Existing and Future Train Speeds


RPM PHASE ONE PROJECTS - SPEED-DISTANCE GRAPHS
DRAFT - NOT FOR DISTRIBUTION - 05/30/2014 - Designed to be printed on 11x17 Tabloid
NORTHBOUND RED AND PURPLE LINES
ALTERNATIVE: NO ACTION
55
50
45
40
35
30
25
20
15
10
5
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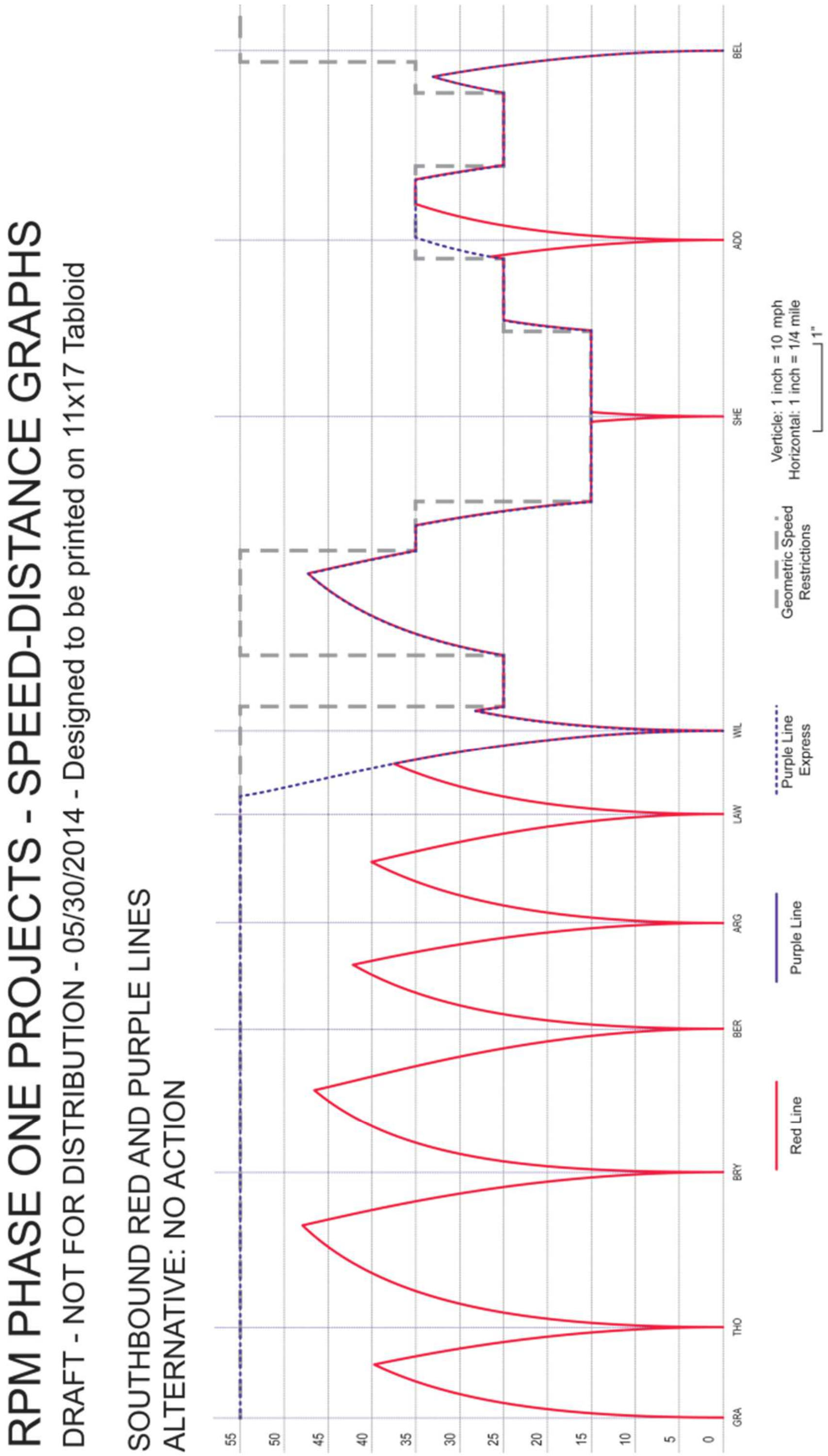
BEL
ADD
SHE
WIL
LAW
ARG
BER
BRY
THO
GRA
Red Line
Purple Line
Purple Line Express
Geometric Speed Restrictions
Verticle: 1 inch = 10 mph
Horizontal: 1 inch = 1/4 mile
1"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DRAFT - NOT FOR DISTRIBUTION - 05/30/2014 - Designed to be printed on 11x17 Tabloid
SOUTHBOUND RED AND PURPLE LINES
ALTERNATIVE: NO ACTION
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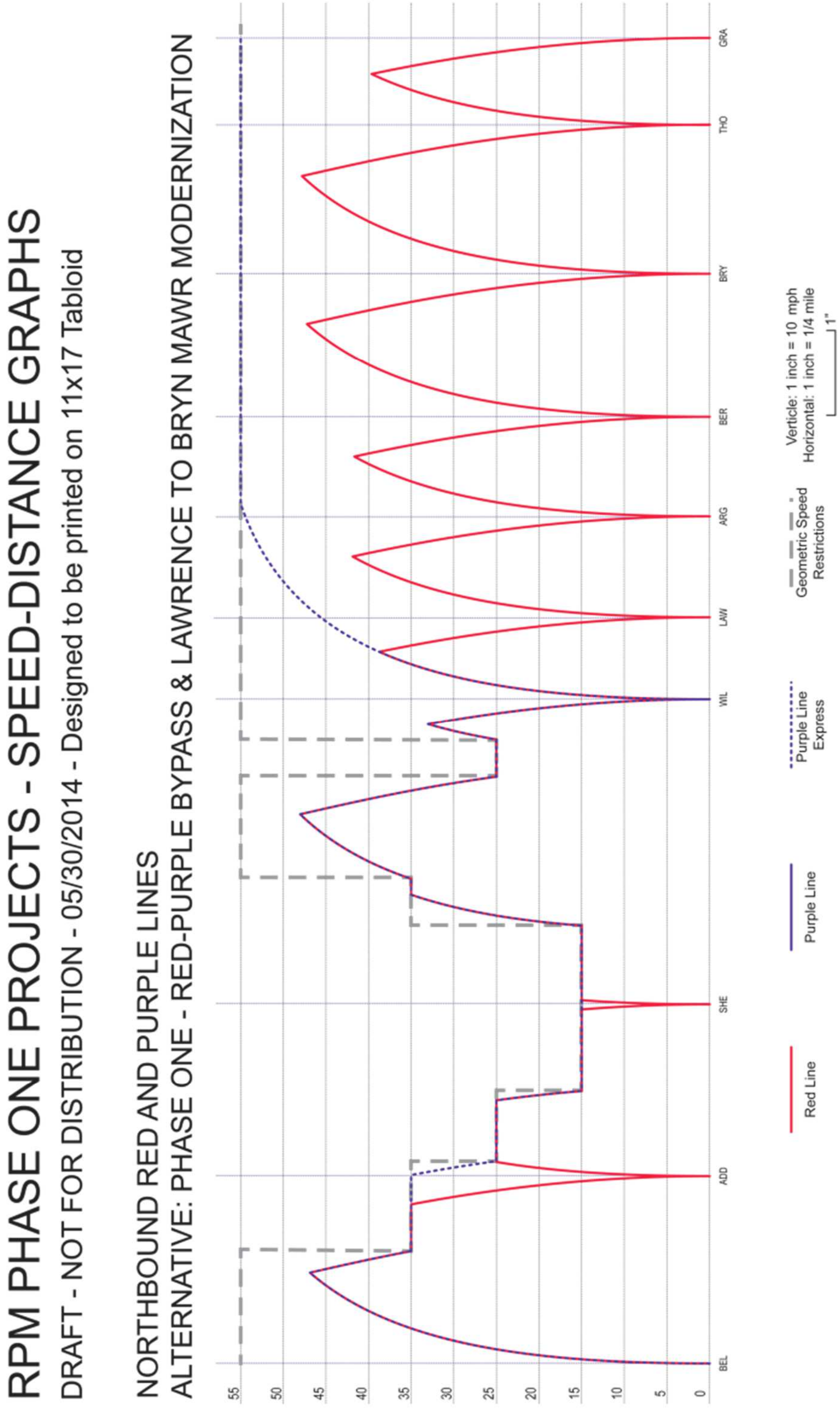
Red Line
Purple Line
Purple Line Express
Geometric Speed Restrictions
Verticle: 1 inch = 10 mph
Horizontal: 1 inch = 1/4 mile
1"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DRAFT - NOT FOR DISTRIBUTION - 05/30/2014 - Designed to be printed on 11x17 Tabloid
NORTHBOUND RED AND PURPLE LINES
ALTERNATIVE: PHASE ONE - RED-PURPLE BYPASS & LAWRENCE TO BRYN MAWR MODERNIZATION
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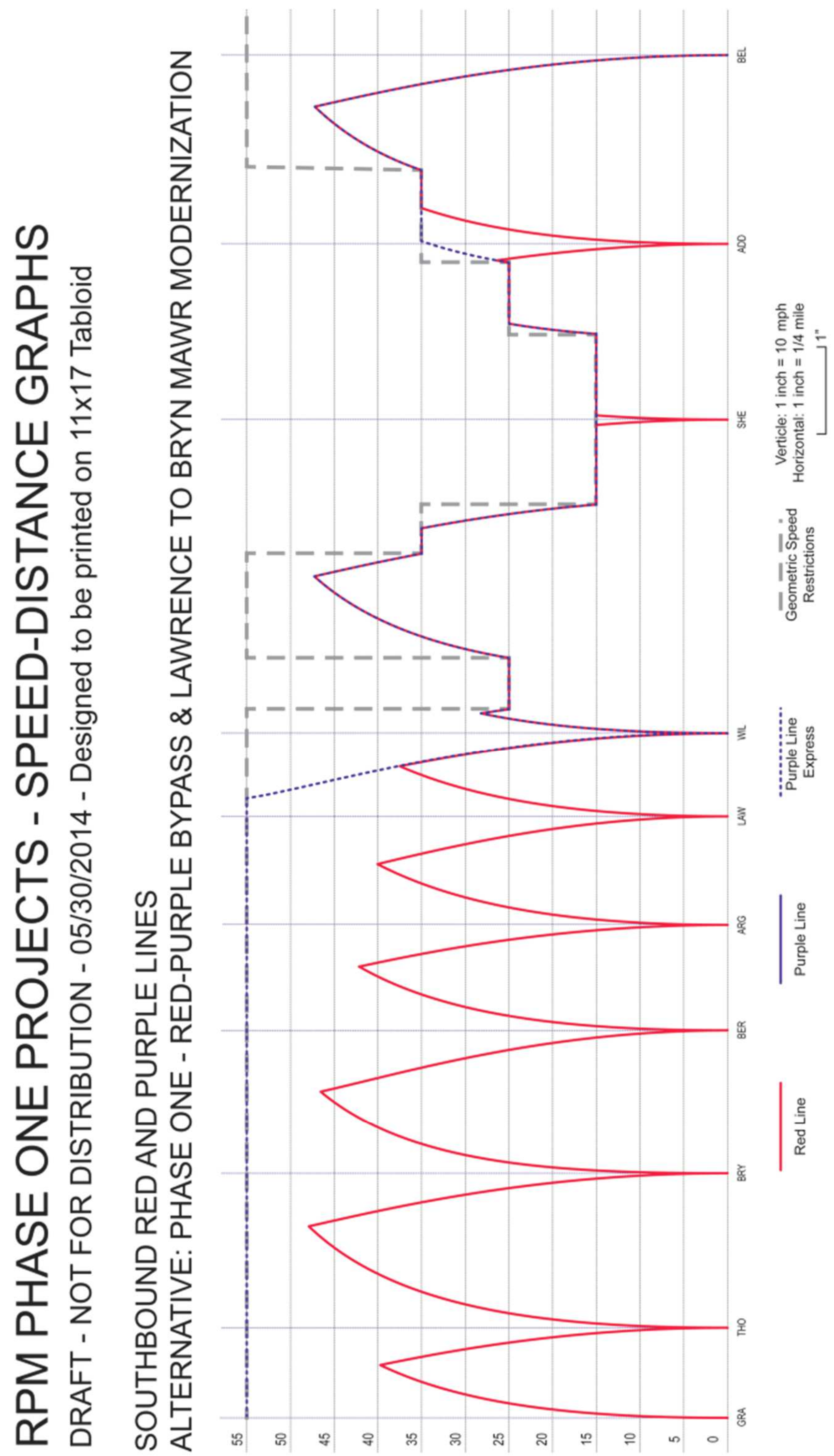
Purple Line
Purple Line Express
Geometric Speed Restrictions
Verticle: 1 inch = 10 mph
Horizontal: 1 inch = 1/4 mile
1"


RPM PHASE ONE PROJECTS - SPEED-DISTANCE GRAPHS
DRAFT - NOT FOR DISTRIBUTION - 05/30/2014 - Designed to be printed on 11x17 Tabloid
SOUTHBOUND RED AND PURPLE LINES
ALTERNATIVE: PHASE ONE - RED-PURPLE BYPASS & LAWRENCE TO BRYN MAWR MODERNIZATION
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Red Line
Purple Line
Purple Line Express
Geometric Speed Restrictions
Verticle: 1 inch = 10 mph
Horizontal: 1 inch = 1/4 mile
1"

Appendix E: List of Sensitive Receivers

No.	Receiver Description	Location	Story	Distance to Existing NT (feet)[1]	Distance to Bypass Track (feet)[1]	Special Trackwork
Category 2 (Residential) Land Uses:						
NB-01	MFR	Belmont Ave; Tracks to Wilton Ave. South side	upper	32	32	--
NB-02	MFR	Belmont Ave; Wilton Ave to alley. South side	upper	114	114	--
NB-03	MFR	Wilton and Belmont. NE corner	upper	120	120	Future
NB-04	MFR	Belmont Ave; Wilton Ave to alley. North side	upper	160	160	Future
NB-05a	MFR	3215-39 Wilton Ave South Side, near closed deck	upper	130	125	Future
NB-05b	MFR	3215-39 Wilton Ave South Side, near open deck	upper	143	125	Future
NB-06	MFR	Wilton back roads	upper	225	220	Future
NB-07	MFR	Wilton between Belmont and School. West side	upper	10	Property take	Existing
NB-08	MFR	Wilton and School. SE corner	upper	157	127	Existing and future
NB-09	MFR	Wilton and N alley. SE corner	upper	202	172	Existing and Future
NB-11	MFR	Clark and Buckingham. SW corner	upper	70	40	Existing and Future
NB-12	MFR	Clark between Aldine and Buckingham	upper	231	215	Existing and Future
NB-13	MFR	3330s Clark St. West Side	upper	10	Property take	Existing
NB-14	MFR	Clark and Buckingham. N Corner to 3341 N Clark	upper	117	129	Existing and Future
NB-15	MFR	Clark and Roscoe. SE corner to 3345 N Clark	upper	10	45	--
NB-16	MFR	865-891 W Roscoe. South Side	upper	172	207	--
NB-17	MFR	936 W Roscoe St	upper	10	--	--
NB-18	MFR	928-30 W Roscoe St. North Side	upper	40	--	--
NB-19	MFR	922-24 W Roscoe St. North Side	upper	106	--	--
NB-20	MFR	933-37 W Newport Ave. South Side	upper	10	--	--

No.	Receiver Description	Location	Story	Distance to Existing NT (feet)[1]	Distance to Bypass Track (feet)[1]	Special Trackwork
NB-21	MFR	925-31 W Newport Ave. South Side	upper	60	--	--
NB-22	MFR	932-34 W Newport Ave. North Side	upper	10	--	--
NB-23	MFR	924-30 W Newport Ave. North Side	upper	78	--	--
NB-24	MFR	937 W Cornelia Ave. South side	upper	10	--	--
NB-25	MFR	925 W Cornelia Ave. South side	upper	75	--	--
NB-26	MFR	N Wilton Ave. Cornelia Ave-3524 Wilton. West Side	upper	10	--	--
NB-27	MFR	N Wilton Ave. Cornelia Ave-3525 Wilton. East Side	upper	158	--	--
SB-01	MFR	1001 W Belmont Ave	upper	190	257	--
SB-02a	MFR	Sheffield Ave between Belmont Ave and School St, near closed deck	upper	188	257	Future
SB-02b	MFR	Sheffield Ave between Belmont Ave and School St, near open deck	upper	188	257	Future
SB-03	MFR	3211-21 N Sheffield Ave. East Side	upper	47	116	Future
SB-04	MFR	3255 N Sheffield Ave	upper	37	106	Existing and Future
SB-05	MFR	N Sheffield Ave. School-3311. East side	upper	10	83	Existing and Future
SB-06	MFR	3315-31 N Sheffield Ave. East side	upper	31	86	Existing and Future
SB-07	MFR	3324-46 N Sheffield Ave. West side	upper	110	165	Existing and Future
SB-08	MFR	3331-41 N Sheffield Ave. East side	upper	21	76	Existing and Future
SB-09	MFR	Roscoe St and Kenmore Ave. SW corner	upper	172	201	Future
SB-11	MFR	Roscoe St and Kenmore Ave. SE corner	upper	138	167	Future
SB-12	MFR	3350 N Sheffield Ave	upper	106	135	--
SB-13	MFR	N Sheffield Ave. Roscoe-3352. West side	upper	50	79	--
SB-14	MFR	N Sheffield Ave. Roscoe-3343. East side	upper	14	47	--

No.	Receiver Description	Location	Story	Distance to Existing NT (feet)[1]	Distance to Bypass Track (feet)[1]	Special Trackwork
SB-15	MFR	3354 N Clark St	upper	10	Property take	--
SB-16	MFR	1014-42 W Roscoe St. North side	upper	10	39	Future
SB-17	MFR	1000 W Roscoe St	upper	10	39	--
SB-18	MFR	3406 N Sheffield Ave	upper	10	Property take	--
SB-19	MFR	3413 N Clark St	upper	10	Property take	--
SB-20	MFR	1015-41 W Newport Ave	upper	62	46	Future
SB-21	MFR	Newport Ave and Sheffield Ave. SW corner	upper	35	19	--
SB-22	MFR	947-49 W Newport Ave.	upper	10	Property take	--
SB-23	MFR	1022-42 W Newport Ave	upper	225	225	Future
SB-24	MFR	Clark St and Newport Ave. NW Corner	upper	229	--	--
SB-25	MFR	3441-55 N Sheffield Ave	upper	17	--	--
SB-26	MFR	3462-3516 N Sheffield Ave	upper	205	--	--
SB-27	MFR	3501-27 N Sheffield Ave	upper	36	--	--
Category 3 (Institutional) Land Uses:						
NB-10	School	Lakeview Learning Center	ground	46	12	Existing and Future
SB-10	Church	Northside Mosque of Chicago	upper	159	188	Future

[1]Distance to the track nearest to the sensitive receiver.

[2]Inidicates if a sensitive receiver is within 350 feet of existing special trackwork (crossover or turnout) or of special trackwork proposed as part of the project. (future).

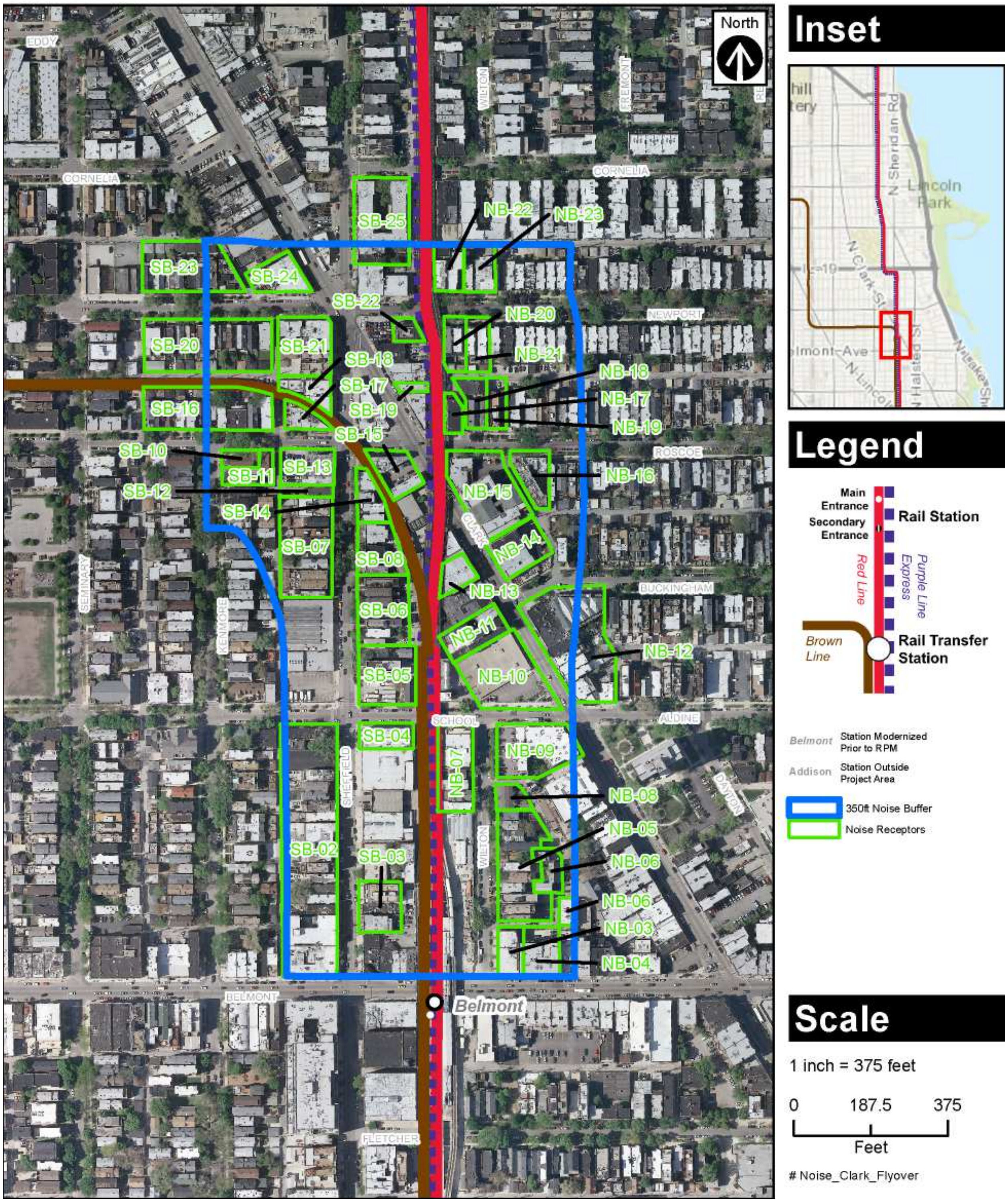

Figure 70: Aerial Photograph of Sensitive Receiver Locations